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OCCUPATIONAL EXPOSURE to TALC CONTAINING ASBESTOS

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health

OCCUPATIONAL EXPOSURE TO TALC CONTAINING ASBESTOS

Morbidity, Mortality, and Environmental Studies of Miners and Millers

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ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) conducted studies of mortality and morbidity patterns and occupational exposures among talc miners and millers in upper New York. The mortality study was based on 398 white male workers who began employment between January 1, 1947 and December 31, 1959, and whose vital status was determined as of June 30, 1975. Observed cause specific mortality for the cohort as compared with that expected based on U.S. white male mortality rates indicated a significant increase in mortality due to bronchogenic cancer, nonmalignant respiratory disease (excluding influenza and pneumonia) and respiratory tuberculosis. The average latency period for bronchogenic cancer was 20 years.

In the morbidity study current workers (156 male miners and millers) from the same New York talc company were examined. One hundred twenty-one (121) workers were administered the MRC respiratory questionnaire (including smoking and work histories), lung function tests (FEV_1, FVC, expired flow rates), and chest X-rays (PA and lateral). The results are similar for all 121 workers, and for a subset of 93 workers having talc exposure only at the facility under study. Lung function is expressed as percent predicted, with 9,347 coal miners and 1,095 potash miners matched on age, height, and smoking habits providing expected values for the prevalence of symptoms, X-ray findings, and lung function. Cumulative exposure is calculated by estimating the mean exposure level in a current job, times the time spent in that job summated for all jobs.

Findings from the morbidity study included the following: Talc workers with less than 15 years work have a higher prevalence of cough and phlegm than coal and potash miners. Talc workers with more than 15 years work have a higher prevalence of cough, dyspnea, and irregular opacities than potash miners, but less phlegm and dyspnea than coal miners. Pleural thickening and calcification is significantly higher in talc workers than in coal and potash miners, and pleural thickening is significantly higher than in chrysotile asbestos workers in Canada. Mean pulmonary function of the talc workers is reduced compared to coal and potash workers: Reductions in FEV_1 and FVC are associated with the highly correlated variables of years worked, particulate, and fiber exposure. Talc workers with pleural thickening have reduced lung function compared to those workers without pleural thickening.

The industrial hygiene study demonstrated that the major components of the talcs mined and milled are talc, tremolite, anthophyllite, and serpentines with traces of dolomite, calcite, and quartz. These trace metals were found to be present only in very small quantities. Time-weighted average (TWA) exposures to asbestiform amphiboles (anthophyllite and tremolite) were found to be in excess of present U.S. Occupational Safety and Health (OSHA) and Mine Safety and Health Administration (MSHA) occupational exposure standards in many mine and mill operations with more than 90 percent of the total airborne fibers being less than 5-μm in length.

Results of the present study are compared with those of other studies of workers exposed to the same or similar minerals, and it is concluded that exposures to such talcs are associated with an increased risk of developing not only pleural thickening and pleural calcification, but also both bronchogenic cancer and nonmalignant respiratory disease.

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DEFINITIONS

COUGH	YES to the question, "Do you cough like this on most days for as much as three months each year?"
DYSPNEA	YES to the question, "Do you get short of breath walking with other people your own age on level ground?"
FEF_{25}, FEF_{50}, FEF_{75}	Forced Expiratory Flow (liters/second) at 25 percent, 50 percent and 75 percent of expired FVC.
FEV_1	Forced Expiratory Volume in one second (liters).
FEV percent	FEV_1/FVC x 100.
FVC	Forced Vital Capacity (liters).
HEMOPTYSIS	YES to the question, "Have you ever coughed up blood?"
PHLEGM	YES to the question, "Do you bring up phlegm like this on most days for as much as three months each year?"
SMR	Observed deaths/Expected deaths x 100.
TWA	Eight-hour time weighted average.

INTRODUCTION

The term "talc" in the mineralogical sense denotes a specific rockforming mineral of the sheet silicate category; however, when "talc" is referenced in the industrial or commercial setting, it may represent a varied mixture of minerals with physical properties similar to the mineral talc (1). Minerals commonly found associated with talc include calcite, quartz, diopside, magnesite, serpentines (chrysotile, antigorite, and lizardite), and fibrous and nonfibrous amphiboles (tremolite, anthophyllite, actinolite) (1, 2). The United States produces about 30 percent of the world's talc with New York, California, Vermont, Texas, and Montana accounting for three-fourths of the U.S. production. The work force for both talc mining and milling has been estimated to be about 1,200 in over sixty-five facilities (3).

Largely due to the great variety of minerals commonly associated with talc, few studies have been undertaken which adequately characterize the various minerals to which talc workers are exposed and simultaneously delineate the latent disease manifestations associated with those work environments.

Recognizing the need for additional research with regard to health hazards from industrial talc exposure, the National Institute for Occupational Safety and Health (NIOSH) undertook an industrywide program to study talc mining and milling in two geographic areas, New York and Vermont. This program includes detailed industrial hygiene studies to characterize the various agents to which workers have been exposed, cross-sectional medical surveys to evaluate respiratory impairment, and retrospective cohort studies to evaluate latent disease patterns among workers who have been exposed to talc in the work environment.

The present report restricts itself to that part of the industrywide study concerning an investigation of talcs containing fibrous amphibole minerals as mined and milled in the Gouverneur Talc District in upper New York. This talc mining district located in St. Lawrence County represents a complex association of amphiboles (anthophyllite, tremolite, etc.), talc, quartz, and serpentines (2, 4). Previous studies by Kleinfeld et al. (5, 6) of asbestiform talc miners and millers in this district have demonstrated significantly increased proportional mortality due to both malignant and nonmalignant respiratory diseases. Morbidity studies also have indicated increased symptoms and X-ray and lung function changes consistent with pneumoconiosis (7, 8, 9, 10, 11, 12). More recently a talc mining company in this district maintained that these studies were not applicable to all talcs in the Gouverneur Talc District. The company stated that talcs extracted from its original mine in the Gouverneur Talc District do not contain asbestiform minerals and that the talcs have been so certified (13). One study, however, at the same operations concluded that asbestiform minerals were contained in the talcs (11). To address this contradiction, the present study restricts itself to that one mine and mill reported by the company to be producing nonasbestiform talc.

DESCRIPTION OF FACILITIES STUDIED

The company under study began talc mining and milling operations in the Gouverneur Talc District of upper New York in 1947. Talcs extracted from this mine are used for a variety of applications including ceramics, pottery, artware, electrical insulators, ceramic tile glaze and flux, paint fillers, in putties, and in spackling compounds.

MINING

In the study mine, underground hard rock mining methods are employed using jackleg drills to make holes for blasting the ore in open stopes. The mine consists of one main shaft 1,250 feet in depth with three main working levels. In 1975, ore was being mined from approximately 6 of the 26 active stopes. Mining follows a typical cycle including: (1) blasting, which is done with gelatin dynamite and ammonium nitrate; (2) dissipation of dusts and gases; (3) removal of ore with some secondary blasting; and (4) drilling of blasting holes for the next shift.

Ore (muck) from the stoping areas is loaded into 2-ton rail cars using either gravity drawpoint or scraper (slusher) loading. Ore from these cars is discharged into a central jaw crusher located at the 700-ft. level although some crushing is also done on the 1,110-ft. level. The crushed ore is loaded into a skip and carried to the mine headframe where a gyratory crusher reduces the ore to approximately 3/4-in. screen size. The ore is then transported by conveyor belt to one of the four wet ore storage bins in the mill. Approximately 40,000 cubic feet per minute (cfm) of mining ventilation is provided. The ore may be inherently moist, and wet drilling is employed. Water sprays are also used for dust suppression at the 700-ft. level crusher. According to company personnel, wet drilling has been practiced since the beginning of these operations.

MILLING

Mill operations include cone crushing first, followed by moisture removal in rotary dryers. The dry ore is further reduced in particle size using a gyratory disc crusher followed by vibratory screening and transportation to one of six dry ore silos. Finely ground products are made from these ores, using either Hardinge pebble mills in closed circuit with Raymond separators or impact crushers in closed circuit with fluid energy mills. The finely ground products are stored in one of several concrete silos and are withdrawn by air slides and pumped to the packaging and shipping areas. Talcs are either sold in bulk or packaged in 50-lb. valve-type Kraft paper bags. Bag filling is done using pneumatic packing machines.

In the mill, most material transfer points are provided with local exhaust ventilation, and bucket elevators and conveyors are maintained under negative pressure. At the bagging machines, local exhaust ventilation is provided at the filling spout and downdraft ventilation at the bag hopper. For bulk car loading, the telescopic loading spout is provided with a local exhaust ventilation collar.

INDUSTRIAL HYGIENE STUDY

METHODS

In order to evaluate occupational exposure characteristics and levels among workers in this mine and mill and to compare them with those pf previous studies of New York talc operations, a detailed environmental study was undertaken. This study included determinations of time-weighted average (TWA) exposures to respirable dust, free silica, and asbestiform minerals in addition to detailed mineralogical assays of talcs produced at the mine and mill under study. Talc product samples were collected during the study (samples A-F), and additional product samples from the mine and mill being studied were submitted by the company (samples 1-7).

Analyses of collected bulk talc samples were performed by both NIOSH and independent research laboratories. These analyses included X-ray diffraction, optical petrographic microscopy, and electron microscopy. For X-ray diffraction studies, step scanning of diagnostic reflections for the asbestiform minerals and quartz was used (1). Electron diffraction and microchemical analyses of individual fibers were performed by electron microscopy (14, 15). Bulk talc samples were also analyzed for major oxide composition and trace metal contamination. These analyses were performed using spectrophotometry, atomic absorption, and flame photometry (1).

Personal air samples were collected from the breathing zone of miners and millers to determine TWA exposures to respirable dust, free silica, and mineral fibers. Personal samples for respirable dust and free silica were collected at a flow rate of 1.7 liters per minute (lpm) using 37-mm diameter polyvinyl chloride filters (preweighed) preceded by 10-mm nylon cyclone separators. Samples for fiber analysis were collected on open-faced 37-mm diameter Millipore Type AA filters (0.8-μm pore size) at a flow rate of 1.7 lpm. Respirable dust samples were collected for the full work shift periods while fiber samples were changed periodically during the work shift as needed to prevent overloading of filters.

Free silica concentrations were determined using X-ray diffraction as specified in the NIOSH Criteria Document (16). All fiber samples were analyzed using the NIOSH phase contrast counting technique (17). In addition, a representative number of the individual fiber samples was randomly chosen and the samples were analyzed by electron microscopy using selected area electron diffraction and energy dispersive X-ray analysis for fiber identification. Electron microscopy was also used to determine airborne fiber concentrations and size (diameter and length) distributions (14). Samples for electron microscopic analysis were prepared using methods previous described (15).

In order to compare results of the present industrial hygiene study with historic data for the facility studied, midget impinger samples were also collected for selected jobs in a manner similar to past sampling techniques. Breathing zone impinger samples were collected in ethyl alcohol at a flow rate of 0.1 cubic feet per minute with sampling periods ranging from 15 to 30 minutes. These samples were counted at the end of each work shift using Dunn counting cells and bright field optical microscopy (100x). Two preparations were made for each sample and allowed to stand for 30 minutes prior to counting. Particle counts were made by two experienced counters, and new preparations were made and samples recounted, if counts differed by more than 10 percent.

RESULTS

Product Samples

Results of the X-ray diffraction and petrochemical microscopic analyses of bulk talc product samples collected during the study are shown in Table 1. Talc product samples were found to contain 14 to 48 percent mineral talc, 37 to 59 percent tremolite and 4.5 to 15 percent anthophyllite. All samples were found to contain 10-15 percent serpentines (lizardite and antigorite) and less than 2.6 percent free silica. Calcite and dolomite were also present in trace quantities. Trace metal analyses of talc product samples are shown in Table 2 and major components analyses are shown in Table 3. All trace metals except iron and manganese were essentially absent. Iron and manganese levels were also very low (<0.02 percent). As seen in Table 3, all talcs were found to have a high CaO content which correlates with the observed high tremolite content. Except for traces of calcite, other carbonates were absent or negligible in these talcs as demonstrated by low CO_2 values (18). The Fe and Mn analyses in Table 3 are consistent with the results shown in Table 2, and all major element analyses are in basic agreement with results obtained by Ross et al. (19) and by Dreessen (20) for talcs in the Gouverneur, New York area. Ross et al. (19) also suggested that an additional manganese-rich amphibole, tirodite, may be found in trace quantities in these deposits. While the major element analyses shown in Tables 1, 2, and 3 show 0.12 to 0.22 percent MnO, no manganese-rich amphiboles were detected by the electron microscopy analyses using selected area electron diffraction and microchemical analysis. Typical electron micrographs of fibers observed in the bulk samples are shown in Figures 1 and 2. Examples of typical electron diffraction patterns and X-ray spectra for the tremolite and anthophyllite fibers observed in these products are also shown in these figures. These analyses have shown that most of the long, thin fibers in these talcs are low iron anthophyllite while tremolite fibers tend to be shorter and have smaller aspect ratios (length/width).

Air Samples

Tabular summaries of TWA exposures by job category for the mine and mill under study are given in Tables 4 and 5, respectively, and more detailed summary statistics concerning these data are given in Appendix I. As shown in Tables 4 and 5, free silica exposures were found to be very low. The highest TWA free silica exposure observed was 0.040-mg/m^3, which is below the 8-hour TWA exposure value of 0.05-mg/m^3 recommended by NIOSH for this material (16). Respirable dust exposures ranged from 0.25 to 2.96-mg/m^3. No respirable dust standard has been determined for the mineral talc or talc containing fibrous tremolite or anthophyllite; however, these concentrations are well below the OSHA limits for nuisance dusts (21).

TWA breathing zone impinger concentrations ranged from 0.5 to 15.8 million particles per cubic foot of air (mppcf) with highest concentrations being observed in the mine. The present OSHA and MSHA standard for "talc" containing less than 1 percent free silica and no asbestos fibers is 20 mppcf (21). Only one of the 32 impinger samples exceeded 20 mppcf. However, since this talc contains asbestiform material this standard is not relevant to these exposures.

TWA exposures to asbestos fibers greater than 5-μm in length exceeded 5 fibers per cc for three of six job categories sampled in the mine and for 6 of 18 job categories sampled in the mill. In addition, 17 of the 24 job categories sampled had TWA exposures exceeding the current OSHA standard of 2.0 fibers less than 5-μm in length/cc. Exposures in excess of the MSHA and OSHA allowable ceiling value of 10 fibers less than 5-μm in length/cc were observed in 9 of 24 job categories sampled.

A summary of TWA airborne fiber concentrations as determined by analytical electron microscopy is given in Table 6. In the mine, concentrations of positively identified fibrous amphiboles (all lengths) ranged from 9.5 to 17.5 fibers/cc whereas concentrations in the mill were somewhat higher ranging from 9.9

to 70.6 fibers/cc. These concentrations represent minimum estimates of true amphibole fiber exposures since many true amphibole fibers may not give identifiable electron diffraction patterns. The concentrations found using electron microscopy are far in excess of those obtained by the optical microscopy as fibers less than 5-μm in length are included in the electron microscopy results, but not in those from optical microscopy.

A summary of airborne fiber types as determined by electron microscopy is shown in Table 7. In the mine, 38 percent of all airborne fibers were anthophyllite, 19 percent were tremolite, and 39 percent were unidentified. In the mill, 45 percent of all fibers were anthophyllite, 12 percent were tremolite, and 38 percent were unidentified. Three percent of the fibers in the mine and 2 percent in the mill gave chrysotile electron diffraction patterns. Approximately 65 percent of the airborne fibers longer than 5-μm in length were identified as anthophyllite while only 7 percent were tremolite. The presence of chrysotile in the air samples is consistent with the results of the NIOSH bulk sample analyses where trace quantities of chrysotile were noted in some samples. All of the chrysotile fibers observed in the air samples were less than 1-μm in length. Nearly all of the serpentine minerals identified in the bulk samples are lizardite.

Results of airborne fiber size determinations (diameter and length) for tremolite and anthophyllite fibers are shown in Tables 8 and 9 with appropriate summary statistics. As expected, tremolite fibers tended to be larger in diameter and shorter in length than anthophyllite fibers. The size distributions for these minerals were similar for the mine and mill. Median fiber diameters of 0.19 and 0.13-μm were observed for tremolite and anthophyllite, respectively. In the mine, median fiber lengths of 1.6-μm for tremolite and 1.5-μm for anthophyllite were observed. Similar lengths were seen in the mill. In the mine and mill, only 3 percent of the tremolite fibers were longer than 5-μm whereas 8-10 percent of the anthophyllite fibers were longer than this length. Median aspect ratios (length to width) of 9.5 and 7.5 were observed for anthophyllite and tremolite, respectively, as shown in Table 10. Only 30 percent of the tremolite fibers had aspect ratios greater than 10 to 1 whereas 48 percent of the anthophyllite fibers had aspect ratios greater than this value. These fiber size characteristics are similar to those observed in other industrial operations processing asbestos fibers (22).

Typical electron photomicrographs of airborne particulates from the mine and mill are shown in Figures 3, 4, and 5. The asbestiform nature of these fibers may be further demonstrated by observations of their fibril structures.

COMPARISON OF PAST AND PRESENT EXPOSURES

The present studies demonstrate elevated exposures to asbestiform minerals in nearly all mine and mill process operations. Comparisons between present dust (mppcf) and fiber (fibers > 5-μm in length/cc) exposures and historic exposure measurements are shown in Tables 11 and 12, respectively. These data are gathered from a number of sources (11, 23-33).

Trends in dust concentrations as a function of calendar time are difficult to interpret for several reasons. Of primary importance is the relative paucity of data on some operations prior to 1970. Secondly, very few samples were taken in any given year, therefore the representative of these samples is unknown.

To illustrate trends in dust concentrations, average yearly values for mine and mill operations were calculated and are shown in Figures 6 and 7, respectively. Figure 6 shows no consistent trends in dust concentrations when all mine operations are considered. On the other hand, the mine exposures for such operations as drilling, dragline loading, tramming, and mucking show relatively consistent exposure levels over time with only slight deviations. This might be expected since wet drilling has been a routine practice. In addition, ores being mined are relatively wet. Primary crushing and hoist loading operations show a slightly decreasing trend. Controls such as water sprays for dust suppresion at the primary crusher are the most probable explanation for this trend.

A greater trend of decreasing dust concentrations in mill operations is demonstrated in Figure 7 for all mill operations combined. Figure 7 also shows a more pronounced decreasing trend in exposure when the uncontrolled operation of loading bagged talc into box cars is excluded form the calculated yearly averages. Engineering controls for talc milling operations have improved with time.

As shown in Table 12, fiber exposure measurements have only been made since 1970. Results of the 1975 NIOSH survey tend to show a recent reduction in fiber exposure when contrasted with earlier data for most operations.

Radon daughter measurements have been made in the mine under study by the Mining Enforcement and Safety Administration

(MESA). Measurements taken in 1973 and 1976 showed only nil to trace levels (34, 35).

COMPARISON OF EXPOSURE CHARACTERISTICS WITH OTHER TALC MINES AND MILLS IN THE GOUVERNEUR, N.Y. AREA

Throughout the years, a number of different companies have operated talc mining and milling operations in the Gouverneur Talc District. In addition, past health effects studies of workers in these mills have generally considered exposure characteristics between the various operations in this area to be substantially the same. The company under study, however, maintains that ores from various mines in the area are not the same, with some containing asbestos while others do not. The company further maintains that ores from another nearby operation do contain anthophyllite asbestos while ores from the mine and mill which is the subject of the present study do not contain asbestos fibers.

In order to compare airborne exposure characteristics between these two operations, 10 airborne dust samples collected by MESA in the mine and mill acknowledged as containing asbestos were obtained. These samples were analyzed for airborne fiber characteristics using analytical electron microscopy (analytical methods previously described). Results of these studies and comparisons with data from the mine and mill studied by NIOSH and maintained, to be asbestos free by the company, are shown in Table 13.

The data shown in Table 13 demonstrate that exposure characteristics between the two operations are substantially the same. In fact, the airborne dust samples from the mine and mill studied by NIOSH and maintained by the company to be asbestos free were found to contain a higher proportion of positively identified asbestiform amphiboles largely due to a higher tremolite content. All other fiber characteristics, such a median length, diameter, aspect ratio, and proportion < 5-μm in length, were not statistically different at the 0.05 level (36).

REVIEW OF HEALTH EFFECTS FROM EXPOSURE TO TALCS

CONTAINING ASBESTIFORM AND ASSOCIATED MINERALS

What are the known health effects of talc? Inhalation by children of large doses of talc have resulted in an inflammatory pulmonary response leading to death in some cases (37, 38). The acute symptoms are initial slight respiratory distress increasing after four to six hours and accompanied by cough, tachycardia, and cyanosis. Autopsy revealed bronchitis and acute bronchiolitis with pulmonary edema, focal atelectasis, and emphysema. Alivisator reported the rapid development of talcosis in eight workers between 16 and 60 months after first exposure in an industrial setting (39). The rapid development and progression was attributed to the high concentration of talc particles less than 50-μm in size as well as the high silicate content. Most of these anecdotal reports have included little characterization of the talcs involved.

RESPIRATORY MORBIDITY STUDIES

Three patterns of infiltration on chest X-ray among those exposed to talc have been described: (1) nodular -- discrete opacities 3-5 mm, similar to silicosis and favoring the mid-lung fields; (2) diffuse -- interstitial fibrosis similar to asbestosis and favoring the lower lung zone; (3) mixed -- both types present (40). This varied type of X-ray pattern has been attributed to the heterogenicity of talc (40). Although changes suggestive of silicosis were observed in some instances, in general X-ray changes were similar to those seen in asbestosis (9, 10, 41).

More than four decades have elapsed since the first epidemiological data were published demonstrating adverse health effects of tremolite talc exposure. In 1933, Dreessen (20) published the results of a chest X-ray study of 57 workers engaged in the mining and milling of talcs containing up to 45 percent tremolite and little free silica. This study showed that all workers with greater than 10 years exposure had increased lung markings ranging from increased fibrosis to what was termed "second stage" pneumoconiosis. Among these 17 workers, no cases of active tuberculosis were observed. Dreessen stated that the observed pneumoconiosis had not led to disability.

The respiratory effects of exposure to talc containing 10 percent "bladed" tremolite in two Georgia talc mines and mills were reported by Dreessen and Dalla Valle in 1935 (42). A total of 66 workers were given physical examinations and chest X-rays of which 19 were exposed for more than 10 years with only 2 having 20 or more years of exposure. Twenty-two of these workers demonstrated pneumoconiosis with varying severity. Approximately half of the mill workers exposed to an average dust concentration of 300 mppcf were diagnosed as having pneumoconiosis with eight having frank symptoms such as dyspnea, cough, chest pain, rales, and finger clubbing. Examination of nine former talc workers who had been separated from exposure more than 3 years demonstrated pneumoconiosis in all cases with four cases in advanced stages causing these authors to conclude that the lung changes were permanent.

Many of the health effects studies on individuals exposed to talc have been done in New York in the same areas as this study (Table 14). The exposures were generally quite high. These studies indicate that exposed talc workers report increased subjective complaints of dyspnea and cough. Physical findings include diminished breath sounds, rales, rhonchi, wheezing, crepitations, and clubbing. Pulmonary function measures suggest a restrictive disease with reduced transfer capacity (DI_{CO}).

In addition to these findings, radiographic changes in the chest have also been noted, although the findings have not been reported in ILO/UC nomenclature. These include fibrosis and pneumoconiosis, primarily reported as pulmonary infiltrates of grade 0, 1, 2, and 3. The grading of pulmonary infiltrates involves a reticulated appearance in the lower lung fields (grade 1), reticulonodular infiltration involving approximately 50 percent of the total lung area (grade 2), and a more diffuse reticulonodular infiltration involving more than 50 percent of the total lung (grade 3) (10).

Case studies of New York tremolite talc workers were first reported by Porro et al. (43). Fifteen pneumoconiosis deaths in talc workers were studied in addition to five autopsy studies. Thirteen of these deaths were considered to be directly attributable to the pneumoconiosis thus confirming the disabling character of this exposure. These authors concluded that the disabling tissue changes were due to tremolite talc exposure. Some classifications were noted.

Siegal et al. (44, 45) reported a study of roentgenological findings among New York talc workers in addition to an assessment of their exposures. These talcs were described as containing fibrous tremolite and anthophyllite and less than 1 percent free SiO_2. A total of 221 talc workers in three mines and five mills were given chest X-ray examinations. Of the 221 men examined, 32 showed marked fibrosis. Those workers with 10 or more years employment demonstrated an incidence of fibrosis of 29.9 percent whereas those employed for more than 30 years had a fibrosis incidence of 74 percent. This fibrosis was described as disabling and often accompanied by dyspnea, cough, and fatigue. "Talc plaques" were identified in 6.3 percent of the workers examined. These authors described the fibrosis observed as resembling that seen among asbestos workers.

The 32 cases of pneumoconiosis identified by Siegal et al. (44, 45) were followed prospectively by Kleinfeld et al. (46). In the 14 year period after the Siegal study, 19 of the 32 workers died with the ages of death ranging from 48 to 84 years. Four of these 19 deaths were believed to be directly attributable to talc pneumoconiosis. One death due to pleural mesothelioma was reported. Medical examinations of the 13 living workers were performed including a physical examination, chest X-ray, EMG, and peripheral blood studies (Hgb, RBC, WBC, diffferential count). Dyspnea of such severity as to limit ordinary physical activity was found in all workers. Moderate to severe progression of lung X-ray findings were seen in 10 of these workers and "talc plaques" were seen in all but one worker. Six out of 11 demonstrated an abnormal electrocardiogram. Peripheral blood findings were not considered to be of significance. These authors also reported the presence of "asbestos bodies" histologically. Similar findings were reported in a latter study of six pneumoconiosis cases with autopsy studies (41).

A comparative clinical and environmental study of workers exposed to fibrous and nonfibrous talcs in New York was reported by Messite et al. (7). Three talc operations in St. Lawrence County (fibrous ore formations) and one operation in Lewis County (nonfibrous ore formations) were selected for study and a total of 229 workers were given physical examinations and chest X-rays. Among miners, the incidence of pulmonary fibrosis was low for both the St. Lawrence and Lewis County cohorts; however, the mean duration of exposure was only 12.7 and 10.3 years, respectively. Among millers, the incidence of fibrosis was 12.2 percent and 4.3 percent, respectively, for the St. Lawrence and Lewis cohorts. Exposure levels in the plant were described as being similar with all talcs having a low free silica content. These authors concluded that both types of talc were capable of producing pulmonary fibrosis although the tremolite (fibrosis) variety was more pathogenic. In addition, these investigators stated that no cases of fibrosis were found in millers of either talc variety whose average exposure was less than 20 mppcf or whose duration of exposure was less than 10 years.

In a follow-up study, Kleinfeld et al. (8) made additional comparisons, including lung function, between the St. Lawrence and Lewis County, New York, cohorts described above. Thirty workers exposed to fibrous talcs and 13 exposed to nonfibrous talcs were given chest X-ray and pulmonary function tests. Dyspnea was present in 16 of 30 workers in the fibrous talc exposed group and in 6 of 13 in the nonfibrous talc exposed group. Abnormal auscultatory findings (rales, rhonchi, wheezing) were found in 8 of the 30 workers and 6 of the 13 workers exposed to fibrous and nonfibrous talc, respectively. The incidence of pulmonary infiltration as seen in chest films was 13 of 30 for the fibrous group and 3 of 13 for the nonfibrous group. Both groups showed pulmonary function changes with 4 of 13 workers in the group exposed to nonfibrous talc and 14 of 30 workers in the group exposed to fibrous talc showing significantly reduced vital capacity. Exposures to both groups were reported to be considerably in excess of 20 mppcf.

Kleinfeld et al. (12) studied the lung function of 16 tremolite talc workers who ranged from 39 to 69 years of age (mean age 54.8 years). All had been exposed to talc dust in milling operations for 10 or more years and had no previous occupational dust exposures. Clinical examinations of the 16 workers showed 14 had dyspnea on exertion; 10 rales or wheezing; and 6 clubbing of the fingers. Increased pulmonary infiltration was noted in 5 of the 16 workers. The lung function studies showed 7 of the 16 to have reduced vital capacities and one worker was found to have a lung function consistent with restrictive lung disease. The mean duration of exposure for the 16 workers was 20.4 years and the mean weighted average exposure was reported to be 68.9 mppcf. Thirteen of the 16 workers studied gave a positive smoking history (30 cigarettes per day for a minimum of 5 years).

In a subsequent study, Kleinfeld (10) performed similar studies as those described above among a group of 43 tremolite talc workers and 41 unexposed controls of similar age and smoking history. In the talc cohort, 29 had dyspnea versus only 2 in the control population. Eleven talc workers gave a history of chronic cough and 8 talc workers showed finger clubbing whereas no clubbing or cough was noted among controls. Sixteen of 43 talc workers had positive X-ray findings of pulmonary infiltration versus none in controls, and reduced vital capacity was also found in 13 talc workers and one control. These talc workers were reported to have a mean exposure duration of 19 years and weighted average exposure of 62.3 mppcf.

A study of chest X-ray findings and clinical symptoms among miners and millers at the talc mine and mill under study was reported by Kleinfeld et al. (11). Thirty-nine workers with a mean exposure of 16.2 years (range 11-22 years) were examined in addition to 41 controls who lived in the same geographic area and who were of the same sex and mean age but had no occupational dust exposure. Dyspnea was present in 23.1 percent of the talc workers versus 7.3 percent of the controls, a finding similar to that seen in anthophyllite asbestos workers (47). One worker studied was said to have radiologic findings compatible with pneumoconiosis, whereas no cases were found among controls. The authors suggested that talc containing tremolite and anthophyllite may be less fibrogenic than chrysotile and amosite asbestos at similar exposure levels and exposure duration; however, these authors did not preclude the possible existence of pneumoconiosis among these workers since no lung function studies were conducted.

The importance of sublight microscopic asbestos fibers in asbestosis has recently been reported (48, 49, 50) and brings into question the concept that only fibers greater than 5 microns in length are pathogenic in talcosis (51). In a patient with talc pneumoconiosis, Miller et al., (48) were unable to detect talc by histological techniques using light microscopy. The presence of talc was established by X-ray diffraction and electron microscopy. Most particles were less than 0.5 micron in length, and therefore, below the limit of resolution of the light microscope. The question of the site of early changes in the human lung after exposure to talc has not been very well investigated. Seeler et al. (52), claimed that the earliest change involving the lung parenchyma in two cases of talc pneumoconiosis was a fibrous thickening of the alveolar walls. Kleinfeld et al. (41), noted deposition of ferruginous bodies in the respiratory bronchioles.

The earlier studies of talc workers in the New York area variably reported the presence of pleural plaques and pleural densities (41, 44, 45, 46). The pleura of men exposed to talc are often found on autopsy to have dense fibrosis thickening (41, 48, 52, 53). Pericardial calcification has also been observed (54). Pleural thickening is associated with symptoms and a decreased pulmonary function; pleural plaques are not (55). Pleural thickening may also have a poorer prognosis (56). Pleural thickening and calcifications are a very common radiographic finding in asbestosis and individuals exposed to asbestos, and may be more common than fibrosis (56, 57, 58, 59, 60, 61). The prevalence of pleural changes is higher where there is exposure to anthophyllite (55, 62). Not all pleural changes, however, are necessarily related to asbestos exposure (63).

MORTALITY STUDIES

Although a number of the studies described above have demonstrated the presence of pneumoconiosis among tremolite talc miners in New York, these study designs were insensitive to detection of carcinogenic risks. However, two retrospective proportional mortality studies have demonstrated an increased risk of mortality due to cancer of the lung and pleura among these workers (5, 6). An initial study by Kleinfeld et al. (6) included 220 talc miners and millers employed in 1940 who had 15 or more years exposure between 1940 and 1965. Among this cohort there were 91 deaths of which 10 (11 percent) were due to malignancies of the lung or pleura, whereas only 2.9 (3.2 percent) were expected. In addition, 28 deaths were due to pneumoconiosis or its complications. One of the respiratory cancers was a fibrosarcoma of the pleura.

In a subsequent follow-up study, Kleinfeld et al. (5) extended the period of observation of the previously studied cohort from 1965 to 1969. This updated cohort consisted of 260 workers among which there were 108 deaths. Thirteen of these deaths (12 percent) were due to respiratory cancer, whereas only 4 (3.7 percent) were expected. Twenty-nine deaths were due to pneumoconiosis or its complications. These authors analyzed mortality patterns by 5 year intervals between 1940 and 1969 and concluded that the respiratory cancer risk approached expected values after the period 1960-1964. The validity of this conclusion must be questioned since an analysis of mortality in relation to cancer latency was not undertaken. Indeed, during the additional 9 years of observation, 17 deaths were observed of which 2 (12 percent) were respiratory cancers, observations similar to previous findings. In addition, the limitations of proportional mortality studies in the presence of an elevated pneumoconiosis risk are now well known.

An excess cancer risk has been demonstrated among workers exposed to anthophyllite asbestos (47, 64, 65). Nurminen (65) reported on the mortality experience of anthophyllite asbestos workers in Finland. This study included 1,030 workers who had been employed for 3 months or more from 1936 to 1966 and followed until 1968. Expected cause specific deaths were calculated using Finland national rates for 1951-1964. There were 224 deaths in this cohort whereas 204 were expected. The mean age at death for the cohort was 53.4 years. Twenty-five deaths (12 percent) had asbestosis as an underlying cause, and there was also a highly significant excess risk of respiratory cancer (13 obs. versus 6 exp.; $p<0.01$). No mesotheliomas were detected. The mean latency between first exposure and death due to asbestosis was 19 years.

One of the most comprehensive studies of mortality and morbidity among anthophyllite asbestos workers was reported by Meurman et al. (47) and Kaviluto et al. (64). A cohort of 1,092 workers who had worked at least 3 months between January 1936 and June 1967 was obtained from two mining operations; one of which produced mainly tremolite talc. For calculation of expected age and cause specific deaths, proportional rates for Finland were used for 1958 which was the median year of death for these workers. In addition, a control group matched for date of birth and sex was chosen from a local population registry. Of the 1,092 employees, 248 deaths were observed. Thirteen deaths due to asbestosis were observed for the cohort and none in the controls. Twenty-one lung cancers were observed in the worker cohort versus 13 in the control group. The most significant cancer risk was observed in those with 10 or more years of exposure. These authors adjusted lung cancer rates for smoking habits and concluded that a nonsmoking asbestos worker has a relative risk of 1.4 whereas the smoking asbestos worker had a relative risk of 17.0. No cases of mesothelioma were reported.

All of the above studies of workers exposed to talc containing fibrous tremolite, fibrous anthophyllite or anthophyllite asbestos have demonstrated an excess risk of both pneumoconiosis and respiratory cancer. Little evidence of an excessive risk of mesothelioma among such exposed workers has yet been demonstrated; however, an excessive incidence of pleural changes including pleural thickening and calcifications has been observed in chest films.

CROSS-SECTIONAL MORBIDITY STUDY

A cross-sectional morbidity study was initiated to examine all presently employed workers in this talc mine and mill. The study was designed to answer the following questions regarding chronic effects of exposure:

1) Is there an increased prevalence of abnormal health effects (e.g., symptoms, decreased pulmonary function) in workers exposed to talc when compared to other industrial populations?

2) If there are detrimental effects of exposure, what are the dose-response relations?

DESCRIPTION OF WORK FORCE

The present work force consists of approximately 156 male millers and miners, 35 of whom had worked at other talc mines. One hundred and twenty-one (78 percent) participated in the study. The average for years of talc exposure is 10.2 years for the study population, and 10.5 years for the nonparticipants. The participation rate among the different work areas is similar.

MATERIALS AND METHODS

A modified Medical Research Council respiratory questionnaire containing questions on total work and smoking history was administered by trained interviewers. Standard PA and lateral chest X-rays were taken and read by three readers using ILO/UC scheme. Flow volume curves from a minimum of five forced respiratory maneuvers were obtained and recorded on magnetic tape using an Ohio 800 rolling seal spirometer. The maximum values from the curves were used for analysis.

Lung function, the prevalence of symptoms and radiographic findings in this population were compared with those from 9,347 coal miners from the second round of the National Coal Study, and 1,095 potash miners examined by NIOSH in the Study of the Effects of Diesel Exhaust in Non-Coal Miners. Individuals in each control population were grouped into similar age (10 year intervals), height (10 cm intervals), smoking (nonsmoker, ex-smoker, and smoker), and years in mining (<15 years, ≤15 years) categories. The expected prevalence of symptoms and radiographic findings in coal and potash workers were calculated by using the rates in each category of the comparison populations and multiplying them by the number of individuals in the same categories of the talc population. Predictive equations reflecting the effects of age and height were calculated for each smoking/years worked category of coal and potash miners. Each talc worker's lung function was then compared to predicted values obtained from the appropriate category in the comparison population. All comparison of talc worker's lung function with expected lung function was summated and multiplied by 100 to give the mean percent predicted lung function. For FEV_1 percent, the difference between observed and expected +100 was used.

Dose was calculated in three ways: (1) Years of exposure is simply the number of years worked at the plant under study; (2) Cumulative exposure was calculated by multiplying (a) present exposure in each job as determined by personal sampling (fibers/cc, mg/m^3) times (b) the time spent in that job (years), and then by summing all the exposure scores. The results for each individual are expressed as fiber-years/cc for cumulative fiber exposure and mg-years/m^3 for respirable particulate exposures. As past environmental exposures are not well defined, and in some jobs exposures were greater in the past than at present (especially in the mill) these estimates of cumulative exposure are lower than actual exposures; (3) The relation of average time spent in each job was examined in workers with and without pleural thickening over the total work history omitting the most recent 10 years.

RESULTS

The age-smoking distribution of the 93 talc workers whose talc exposure was only at the mine and mill being studied is shown in Table 15. Almost half are cigarette smokers with slightly more ex-smokers than nonsmokers. Almost 2/3 of the nonsmokers are less than 30, and over 3/4 of the ex-smokers are 40 years of age or more. Smokers are more evenly distributed in all age groups, although the percentage of smokers is highest in the 30-39 year age group. The distribution is very similar for all 121 workers (Table 15A).

Table 16 shows the distribution of years worked in talc, and cumulative particulate and fiber exposures by age. Except for the group over 60 years old where there are only two individuals, there is a consistent and approximately equal increase in all three exposure parameters with increasing age. A similar relationship of exposure with age is observed for all 121 workers (Table 16).

Tables 17 and 17A summarize the distribution of symptoms and radiographic findings by smoking habits. Smokers have a higher prevalence of cough, phlegm, hemoptysis and shortness of breath, with symptoms markedly lower among nonsmokers. The differences are also statistically significant for cough and phlegm. Cigarette smoking shows no apparent association with pleural thickening. There are two cases of calcification and four of irregular opacities, but the numbers are too small to analyze for dose-response relations.

Tables 18 and 18A summarize the association of age with symptoms and radiographic findings. Age (and therefore, long-term exposure) shows no discernible association with symptoms. The higher prevalence of cough and phlegm in the 30-39 year age group is probably a reflection of the high proportion of smokers in the category. Likewise, the slightly higher prevalence of dyspnea in the 30-39 and 50+ year age group is also probably due to the relative proportion of smokers and ex-smokers in those ages. Pleural thickening, on the other hand, is not found in the age groups less than 40 (mean of 14 years exposure), and is highest in the 50-59 (mean of 20 years exposure) and greater than 60 year (mean of 28 years exposure) age groups.

In Tables 19 and 19A the prevalence of symptoms and radiographic findings are compared with coal and potash workers controlling for age, height, smoking habits, and years worked. Among the talc workers employed only at the mine and mill under study for less than 15 years, the reported symptom prevalences of cough and phlegm are not significantly higher than those of coal and potash workers.

In the group of workers with more than 15 years experience, there is no statistically significant difference in the prevalence of (a) hemoptysis in talc workers compared to coal and potash workers; (b) cough in talc workers compared to coal workers; and (c) phlegm in talc workers compared to potash workers.

Coal miners with more than 15 years experience have higher prevalence of phlegm and dyspnea than do talc workers, while cough and dyspnea is higher in these talc workers than in the potash workers. These differences are not statistically different.

The prevalence of radiographic abnormalities is less than two percent in all groups with less than 15 years worked. The rates are higher in the greater than 15 year groups, but there are no significant differences in the prevalence of regular opacities between the talc and comparison groups. In the talc workers with no previous talc exposure, pleural calcification is 0 percent in those with less than 15 years worked and 3.4 percent in those with more than 15 years worked (one case), while pleural thickening is 1.6 percent and 31.0 percent respectively. This compares to a rate for pleural thickening of 0.3 percent to 1.6 percent in coal miners and 0.5 percent to 4.4 percent in potash miners. There is no pleural calcification in the potash population, while in coal miners the prevalence is 0 percent for those working less than 15 years and 0.1 percent for those working more than 15 years. In those with more than 15 years experience, the prevalence of irregular opacities is 3.4 percent, 5.3 percent and 0.7 percent in talc, coal, and potash workers respectively (Table 19).

Reported symptom rates increase slightly when all 121 talc workers are considered (Table 19A). In the 82 talc workers with less than 15 years worked, cough and phlegm are higher than potash and coal workers. There is little difference in the prevalence of dyspnea. In the 39 talc workers with more than 15 years experience, reported cough is still higher than in potash workers, but is essentially the same as in coal miners. Phlegm is about the same in talc and potash workers, however, the 26 percent phlegm reported by these talc workers is significantly less than the 46 percent prevalence among coal workers. Dyspnea in these talc workers is 23 percent which is significantly less than the 39 percent in coal workers and greater than the 13 percent in potash workers. Among these talc workers, there is no unusual prevalence of hemoptysis in either category of years worked. There are no differences in the prevalence of radiographic abnormalities in the group who have worked less than 15 years. In those with more than 15 years experience, pleural thickening and pleural calcification are higher in the talc workers than in coal and potash workers; the increased prevalence of pleural thickening is highly statistically significant. Irregular opacities among talc workers are higher than those in coal and potash workers, but the increase is statistically significant only when compared with that in potash workers. The prevalence of rounded opacities is 3 and 2 percent in talc and potash workers respectively, but 15 percent in coal workers.

Table 20 summarizes the relationship between cumulative exposure and pulmonary function among both groups of talc workers employed only at the mine and mill under study. Using predicted values based on coal and potash workers, mean percent-of-predicted FEV_1 and FVC ranged from 92-95 percent. Predicted FEV percent is near 100, and peak flow is above predicted compared to coal workers, but this is not true when compared to potash workers. Mean flow rates are significantly reduced compared to both coal and potash workers.

Exposure among these talc workers to particulates and to fibers shows a significant association with reduced FEV_1 and FVC. For example, a talc worker in a job with 2 mg/m^3 exposure to respirable particulate will, on the average, experience about a 1 - 1.4 percentage point reduction/year in observed to predicted ratio for FEV_1 and FVC. For an average exposure of 5 fibers/cc, the reduction is about 0.5 - 0.7 percentage points per year. FEV percent and flow rates are not significantly related to exposure, although the percentage point reduction is large for flows at lower lung volumes. The reductions are larger when the comparison group is potash miners. Similar reductions occur if age or years of employment are substituted for fiber or particulate exposure because of their high correlations. These talc workers empirically "age" faster (experience a faster reduction in the FEV_1 and FVC) compared to coal and potash miners.

Table 21 and 21A compare age, smoking habits, and exposure history of talc workers with and without pleural thickening. As previously noted, smoking is not related to pleural thickening. For example, the 50-59 year group with pleural thickening has the lowest mean pack years, and the 40-49 year old group with pleural thickening has fewer average pack years than the 40-49 year old group without pleural thickening. Particulate exposure is slightly lower in the groups with pleural thickening, the average fiber exposure on a yearly basis is the same in the groups with and without pleural thickening. In the 50-59 year age group, those with pleural thickening started working at an earlier age than those without pleural thickening. In the 40-60 year age group, those with pleural thickening have reduced lung function.

Past environmental exposures in each job are not necessarily reflected by present exposure estimates. Exposure information is not available for all jobs and past environmental data were largely collected using impingers rather than filters. For these reasons time worked in different jobs by workers with and without pleural thickening were compared. These data on the 93 talc workers employed only at the mine and mill in this study are summarized in Table 22. There are 9 individuals with pleural thickening and 20 without pleural thickening among those with greater than 15 years employment. Among those with pleural thickening, about 71 percent of their years worked were spent in seven particular jobs, compared to about 17 percent of these same jobs for those without pleural thickening.

To assess the significance of pleural thickening on the health of the individual, symptoms and pulmonary function of all those with pleural thickening in this study are summarized in Table 23.

Controlling for years employment, those with pleural thickening are slightly older than those without pleural thickening. Those with Grade 2 pleural thickening have significantly elevated rates of cough and phlegm, but those with Grade 1 pleural thickening have rates lower than the comparable age group without pleural thickening. The prevalence of hemoptysis and dyspnea increases with increasing grade of pleural thickening, but the increases are not large. Mean ratios of observed to predicted FEV_1 and FVC in Grade 1 pleural thickening is about 10 percentage points below the group without pleural thickening; there is about a 4 percentage point difference between Grade 1 and Grade 2 pleural thickening. Mean FEV_1 percent is reduced only in Grade 2 pleural thickening. Predicted peak flow and FEF_{25} are not related to pleural thickening. Predicted FEF_{50} and FEF_{75} are reduced by about the same proportion as FEV_1 and FVC for those with Grade 1 pleural thickening compared to those with Grade 2.

DISCUSSION

Any cross-sectional epidemiologic study of chronic effects is beset by the problem of selective survival. This study population consists only of workers presently employed. Nonrespondents present a similar problem. For example, if all 35 of the workers who did not participate had had no cough or phlegm, and had participated, the prevalence of cough would have been reduced from 32 percent to 24 percent. Similarly, if all 35 had reported cough and phlegm, the rate would have increased from 32 percent to 49 percent.

Several methodological issues are important in interpreting the data. Even if there had been 100 percent participation instead of 78 percent, the size of the population would still be relatively small to disentangle the effects of age, years worked, and particulate and fiber exposure. In order to evaluate the significance of the health findings, and to adjust for confounding variables of age, height, and smoking habits in estimating dose-response relations, comparison groups of coal miners and potash miners were selected. Although coal mining is a known health hazard, and potash mines using equipment may also present a hazard, using these mine workers as comparison populations can be justified in several ways.

1) The measurement of lung function is not a completely standardized procedure with respect to equipment, training and proficiency of technicians, number of trials, and calculation of the lung measurement. These potential measurement errors are reduced in this study as these procedures were virtually the same in the control and study populations. Comparison with previously published predictive equations (e.g., Kory, Morris) may be misleading. For example, the NIOSH measurement of coal worker lung function tends to be higher than Kory's measurement of healthy, nonexposed populations, and is at least equivalent to Morris's measurements of nonsmoking exposed populations -- two commonly used prediction equations. In addition, prediction equations for different smoking categories are either nonexistent or based on small numbers, thereby making smoking adjustments impossible or of questionable validity. Since one of our primary interests is the effects of exposure to talc on pulmonary function, it is necessary to adjust for age and smoking habits. This is because pulmonary function generally decreases more rapidly in smokers than in ex-smokers and nonsmokers. Comparing smokers with nonsmokers may produce an apparent association of exposure with age, which in fact may be a smoking/age interaction (66). By comparing observed pulmonary function of smokers (ex-smokers, nonsmokers), the analysis of exposure effects is not confounded by the effects of smoking.

2) Talc, coal and potash workers are from mining populations and are likely to be similar with respect to many potentially confounding variables (e.g., physique, socio-economic characteristics, education) that could affect the conclusions, but are not related to the effect of work exposure. Using these mining comparison groups is therefore preferable to comparisons with salaried workers in the same company or even local nonmining populations, for in the comparisons with salaried or other workers there are problems of major discrepancies in physique, pay, education, nutrition and other factors that by themselves could result in differences in health status.

3) Comparing effects of talc exposure with effects from exposure to other substances will not conclusively indicate the nature of the effects of the talc exposure but it will provide relative comparisons; for example, if the health of talc workers is worse than coal miners the differences indicate the toxicity of talc as compared to coal and pinpoint specific health hazards associated with talc. Conversely, effects of talc less toxic than coal do not

necessarily mean there is no risk associated with talc exposure, but only that talc workers are "better off" (e.g., have fewer symptoms, fewer radiographic abnormalities, etc.) than coal workers. If talc workers are healthier than coal miners, they may still be less healthy than if they were not exposed to talc at all. Although less studied than coal, a mortality study of potash miners suggest that exposure to potash does not increase respiratory disease (67). Thus, the medical findings in these talc workers are compared with those in two mining comparison groups -- one that is thought to have little effects on the respiratory system, and one that is known to have a detrimental effect on the respiratory system.

The reported respiratory symptoms in this study group seem high for any healthy population. Most of those with symptoms are either smokers or ex-smokers, and many populations in the dusty trades also report similarily high symptom rates. Specifically, the prevalence of symptoms (except for dyspnea) when contrasted with coal workers is higher in talc workers if length of time worked is less than 15 years, but lower if years worked is greater than 15 years. When compared to potash workers, however, talc workers have higher symptom rates in both groups (except for phlegm and hemoptysis in the greater than 15 years group).

Table 24 compares the prevalence of respiratory symptoms from the talc workers in this study with chrysotile asbestos workers in Canada. Except for the nonsmoking category where asbestos workers report a higher prevalence of symptoms, the results are remarkably similar. When compared to synthetic textile workers, both the asbestos and talc workers generally have a considerably higher prevalence of phlegm and shortness of breath. Anthophyllite asbestos workers cannot be compared directly with talc workers in this study but are included in the table for completeness.

The greatest difference between the coal and potash miners and the talc workers is the highly significant increased prevalence of pleural thickening in the talc workers with greater than 15 years of exposure. In this group, nearly one out of every three talc worker has pleural thickening. Since smoking is not associated with radiographic changes and the same criteria are used, it is possible to compare the prevalence of irregular small opacities, pleural thickening and pleural calcification in chrysotile asbestos workers and the talc workers (Table 25). Grade 1 pneumoconiosis and pleural calcification show no striking dissimilarity between the asbestos and talc workers.

Pleural thickening, on the other hand, is four times higher in the talc workers than in the asbestos workers.

Pleural thickening is a common finding in workers exposed to asbestos. It should be regarded as a significant indicator of exposure and may occur in the presence or absence of fibrosis (57, 58) (Table 26). Pleural calcification occurs later, as it probably develops from the uncalcified pleural plaque (57, 60). In insulation workers it rarely occurred in less than 20 years from onset of exposure (68). Calcification, particularly if bilateral, is very useful in the diagnosis of asbestosis (57, 68), although there are other causes of pleural calcification (e.g., pleurisy, injury following hemothorax, inflammatory conditions that produce pleural effusion and empyema).

Pleural thickening is accompanied by a decrease in lung function, either with or without fibrosis. This was true when measuring FEV_1, FVC, or flow rates as in this and other studies, and for diffusing capacity, total lung capacity, and residual volume in other studies (61, 69, 70).

Except for peak flow and FEV percent, mean percent predicted pulmonary function is significantly reduced in the talc workers when compared to both coal and potash miners. This reduction is thought to be the result of occupational exposure, since adjustments are made for years worked and the known effects of age, height, and smoking habits on pulmonary function.

Despite the association of reduced FEV_1, FVC and flow rates with fiber and particulate exposure and years worked, interpretation of these data are difficult. The cumulative exposure is only an index, not an actual measure of exposure. There is a suggestion from past environmental measurements that exposures in certain jobs, particularly in the mill, have declined over the years. Exposure in the mine appears to be more constant. Analysis of time spent in different jobs by those with and without pleural thickening shows that for the jobs of mine foreman, hoistman, crusher operator, packer, packer serviceman, quality control technician, and shipping and inventory coordinator, those with pleural thickening spent more time in these particular jobs than those without pleural thickening. The time spent in these jobs by those with pleural thickening is 2-5 times greater than the average time spent in all other jobs, and contributes to a majority of the time spent in all jobs. There is, however, no way to adequately determine actual or relative past exposure levels in these jobs.

RETROSPECTIVE COHORT STUDY OF MORTALITY

METHODS

A retrospective cohort study was initiated to determine whether workers who have been employed at this mine and mill have experienced any unusual mortality patterns. This study cohort was defined as all white (those cohort members where racial status was unknown were considered white for purpose of the study, since the majority of this work force is known to be white) males initially employed sometime between January 1, 1947, and December 31, 1959. This cutoff date was selected to allow for a sufficient latent period for any development of chronic disease. An effort was made to determine the vital status of each individual in the cohort as of June 30, 1975, and person-years at risk and duration of employment for the cohort were accumulated until this date.

Vital status was determined through records maintained by Federal and State agencies, including the Social Security Administration, state vital statistics offices, and state motor vehicle registration. For those individuals who could not be located through these sources, U.S. Postal Mail Correction Services and other follow-up searches were used.

For all those who were known to be deceased, death certificates were requested and causes of death were interpreted by a qualified nosologist according to the International Classification of Diseases (ICD Codes) in effect at the time of death and then converted to the 7th Revision of the ICD Codes. A modified life table technique was used to obtain person-years at risk of dying by five-year calendar time periods, by five-year age groups, by duration of employment, and by number of years since initial employment at the talc company. Comparison was made between the observed number of deaths among the study cohort and the number expected for this population using age, calendar time, and cause specific mortality rates of the U.S. white male population. The vital status of 96 percent of the cohort was confirmed (Table 27). Those with an unknown vital status are assumed to be alive as of June 30, 1975 so that the true risk of mortality associated with exposure to talc is not overestimated.

RESULTS

A total of 398 workers meeting the study cohort definition generated 8,733 person-years at risk of dying. Fifty percent of the workers were employed less than one year, while less than 25 percent were employed for 10 years or more. Tables 28 and 29 illustrate the distribution of the study population by duration of employment and by date of initial employment.

Tables 30 and 30A summarize the deaths observed from the study cohort and those expected based on death rates for the U.S. white male population. Although the overall observed mortality is higher than expected, this difference is not statistically significant ($p<0.05$). However, several specific causes of death exhibit increased mortality. The standardized mortality ratio (SMR) (SMR = observed deaths/expected deaths x 100) is significantly elevated for the cause of death category, "all malignant neoplasms", which is partly due to the statistically significant increase in bronchogenic cancer (9 obs. vs. 3.3 exp.; $p<0.05$). Other statistically significant increases for specific causes of death occurred in the categories: "nonmalignant respiratory disease other than influenza, pneumonia, bronchitis, and acute upper respiratory infection" (5 obs. vs. 1.3 exp.; $p<0.05$) and "respiratory T.B." (3.0 obs. vs. 0.49 exp.; $p<0.05$). One death due to mesothelioma was observed.

Table 31 demonstrates the association between bronchogenic cancer and the time interval between the initial date of employment and the date of death (latency). As seen, there is an increasing risk of bronchogenic cancer with increasing latency, a trend consistent with an occupational etiology. In addition, the deaths due to bronchogenic cancer have an average latency of 20 years (Table 32); a period previously observed for a population occupationally exposed to anthophyllite and other minerals (47, 64, 65).

Three additional deaths due to bronchogenic cancer are known to have occurred among study members. However, these deaths occurred shortly after the cutoff date (6/30/75) for analysis and therefore were not included as observed deaths. One individual worked for 17 continuous years at the talc company under study and died at the age of 50. The latency period was 24 years. Another individual who worked for 2 months at the talc company died at the age of 54. The latency period was 27 years. The third lung cancer death was that of a worker employed for 12 years at the company under study and 12 years previously at another New York talc company. He died at the age of 59 and had a latency period of 23 years.

At least three cases of nonmalignant respiratory disease among study cohort members are known to have been reported to the New York State Workmen's Compensation Board. These individuals filed workmen's compensation claims for: (1) pneumoconiosis, chronic bronchitis; (2) talcosis, pulmonary emphysema, chronic bronchitis; and (3) talcosis, pulmonary fibrosis. These individuals worked at the talc company under study for 18 years, 18 years, and 25 years, respectively.

DISCUSSION

The results of the present study demonstrate an excessive risk of 273 percent due to lung cancer mortality and 385 percent due to nonmalignant respiratory disease among a cohort of talc workers occupationally exposed to both asbestiform tremolite and anthophyllite, but to little free silica. However, several possible confounding factors must be taken into consideration before one can attribute this observed mortality pattern to occupational exposures received at this talc mine and mill.

One such factor that has been shown to be correlated with the causation of lung cancer is cigarette smoking. The smoking patterns are largely unknown for this cohort as is the case with most retrospective studies. However, it has been estimated that in heavy smoking worker population, smoking alone would increase the expected lung cancer mortality risk by no more than 49 percent (71). Thus, cigarette smoking per se is unlikely to account for the increased bronchogenic cancer risk of 273 percent observed among these talc miners and millers.

Another factor to be considered is occupational exposure among cohort members resulting from prior employment. Known prior employment among those in the study who died from malignant and nonmalignant respiratory disease are given in Table 32. Several of these individuals as well as other members of the study cohort worked at other New York State talc companies located in the Gouverneur Talc District. Due to this consideration industrial hygiene analyses were carried out to compare the make-up of talcs in a neighboring mine acknowledged as having asbestiform talc. These comparisons are presented in Table 13.

The analysis of amphibole fiber characteristics between these talc operations showed them to be substantially the same. Thus, while exposure levels in other talc companies may have been higher, all operations involved exposures to asbestiform amphiboles with similar airborne fiber characteristics. All these operations have been shown to have fiber exposures far in excess of established OSHA asbestos standards. Thus, exposures to asbestiform tremolite and anthophyllite stand out as the prime suspected etiologic factors associated with the observed increase in bronchogenic cancer and nonmalignant respiratory disease among this study cohort.

Of interest is the fact that four of nine deaths due to bronchogenic cancer in this cohort were workers employed less than 1 year in the operations under study and only one of these cases is known to have previous exposures to talcs containing asbestiform minerals. Although this cohort is relatively small, it appears plausible that even brief periods of exposure to elevated concentrations of asbestiform minerals may be associated with an increased bronchogenic cancer risk. Such an observation has previously been reported (72).

One death due to mesothelioma is known to have occurred in the study population. This individual worked for 16 years in the talc operation and had 11 years previous employment in construction work. Without full knowledge of this individual's exposure as a construction worker, it is difficult to arrive at any conclusions regarding the etiologic role of talc exposure from this mine and mill for this case. Although previous studies (5, 6, 47, 64, 65) have not shown an association between exposure to asbestiform anthophyllite or tremolite and subsequent development of mesothelioma, a study in Turkey by Baris (73) has demonstrated an increased risk of developing mesothelioma among residents of a particular community exposed to asbestiform tremolite, probably from their drinking water. Therefore, the possible association between exposure to asbestiform tremolite and the risk of developing mesothelioma should be further studied by continued follow-up of these talc workers.

CONCLUSIONS AND RECOMMENDATIONS

An industrial hygiene study, a cross-sectional morbidity study, and a retrospective mortality study were conducted among miners and millers of industrial talcs in upper New York. These talcs were shown to contain fibrous tremolite and anthophyllite as major contaminants. In addition, both present and past worker exposures to these fibers were shown to be far in excess of occupational exposure standards established by the Occupational Safety and Health Administration (OSHA) and the Mining Enforcement and Safety Administration (MESA) (now called Mine Safety and Health Administration MSHA).

The most striking finding of the morbidity study was an increased prevalence of pleural thickening in talc workers with greater than 15 years of exposure, occurring in nearly one out of every three talc workers. Reduced FEV_1, FVC, and flow rates were also observed after adjusting for smoking habits.

The study of mortality among the workers who began employment between 1947 and 1960 demonstrated an increased number of deaths due to bronchogenic cancer. The average latency period for bronchogenic cancer was 20 years.

A thorough review of the available literature demonstrated that findings of the present studies are in agreement with those of other studies of occupational groups exposed to the same or similar minerals or mineral mixtures. This is especially true for occupational exposures to anthophyllite asbestos. These findings make it imperative that workers from the mine and mill studied, herein, be routinely observed using medical surveillance criteria established in the OSHA and MSHA asbestos standard. Furthermore, all provisions of these standards should be followed during the production and subsequent use of these talcs.

Table 1

Results of X-Ray Diffraction and Petrographic Microscopic Analyses of Bulk Talc Samples Collected During Study

Mineral Component	Sample Analysis, % By Weight					
	Product A	Product B	Product C	Product D	Product E	Product F
Talc	31-36	43-48	30-35	33-38	35-40	14
Tremolite	∿40	∿37	∿49	∿43	∿38	∿59
Anthophyllite	∿10	∿4.5	∿5	∿8	10	15
Quartz	2.6	<0.25	<0.25	0.7	0.8	1.1
Calcite	1	<0.5	0	0	<0.5	<1
Dolomite	1	<0.5	<0.5	<0.5	<0.5	<0.5
Serpentines*	10-15	10-15	10-15	10-15	10-15	10

* Includes lizardite and antigorite.

Table 2

Results of Trace Metal Analyses of Bulk Talc Samples Collected During Study*

Product	Date Collected	Trace Metal, PPM**						
		Cr	Co	Fe	Mn	Ni	Zn	Cd
A	11/4/75	3	1	1100	1700	7	20	<1
B	11/4/75	3	<1	1000	840	5	19	<1
C	11/4/75	2	2	880	1000	6	17	<1
D	11/4/75	3	2	970	1300	7	20	<1
E	11/3/75	2	3	1000	1700	5	23	<1
F	11/3/75	3	2	900	1400	5	22	<1

* Trace metals determined by atomic absorption spectroscopy.

** PPM-Parts per million by weight.

Table 3

Results of Major Components Analyses
of Product Talc Samples

Major Components	Sample Analyses, % By Weight*							
	1	2	3	4	5	6	7	Talc Stds**
SiO_2	54.85	54.52	56.11	56.14	52.81	52.47	55.47	61.49
TiO_2	0.04	0.15	0.07	0.03	0.08	0.04	0.07	0.01
Al_2O_3	0.38	0.32	0.13	0.13	0.16	0.11	0.13	1.20
Fe_2O_3	0.10	0.13	0.08	0.11	0.08	0.06	0.11	0.38
FeO	0.04	0.03	0.05	0.03	0.03	0.01	0.03	1.07
MnO	0.21	0.20	0.22	0.15	0.12	0.10	0.12	0.00
MgO	28.40	28.78	29.40	29.56	30.20	30.56	29.10	30.54
CaO	9.02	8.53	7.50	7.40	8.15	8.30	8.25	0.46
Na_2O	0.28	0.44	0.18	0.25	0.38	0.16	0.18	--
K_2O	0.10	0.17	0.10	0.10	0.10	0.10	0.13	--
P_2O_5	0.03	0.03	0.03	0.03	0.03	0.03	0.03	--
H_2O	5.37	5.07	5.00	5.56	6.07	6.67	5.24	5.00
CO_2	1.35	1.15	1.03	0.96	1.30	0.98	0.84	5.00
Total	100.17	99.52	99.90	100.45	99.51	99.59	99.59	

* Samples submitted to NIOSH by Company Analyses performed by Dr. Q.R. Bowes, University of Glasgow.

** From talc standard analyses in reference 1.

Table 4

Summary of TWA Exposures
By Job, Mining Operations

Job Title	Fibers fibers >5 µm in length/cc (Optical Microscopy)	Resp.Mass. mg/m^3	Impinger mppcf	Free SiO_2 mg/m^3
Crusher Operator	9.8 (4)	--	--	--
Trammer	5.6 (25)	0.64 (3)	10.1 (3)	0.020 (3)
Scrapper Man	--	1.29 (3)	11.8 (5)	0.012 (3)
Underground Laborer	--	0.58 (1)	--	0.006 (2)
Driller	3.0 (5)	0.98 (3)	0.7 (1)	0.014 (2)
Mucker	--	--	15.8 (1)	--
Cageman	9.5 (5)	0.23 (1)	2.0 (1)	--
Repairman	--	1.14 (1)	--	--
Repairman's Helper	--	0.86 (1)	3.6 (1)	0.000 (1)
Blacksmith	2.6 (3)	--	--	--
Maintenance Mechanic	1.7 (12)	0.42 (1)	1.5 (1)	0.000 (1)

( ) = Number of samples used for calculation of TWA values for each job category. Samples for respirable mass and free SiO_2 were full shift samples.

-- indicates no samples

Table 5

Summary of TWA Exposures
By Job Title

Job Title	Fibers fibers >5 μm in length/cc (Optical Microscopy)	Resp. Mass mg/m^3	Impinger mppcf	Free SiO_2 mg/m^3
Mill Foreman	5.3 (9)	0.58 (2)	2.9 (2)	0.013 (2)
General Laborer	5.6 (5)	1.14 (1)	0.5 (1)	0.014 (1)
Crusher Operator	5.1 (16)	0.85 (2)	2.6 (4)	0.020 (2)
Hardinge Operator	7.9 (14)	1.09 (2)	3.4 (2)	0.012 (1)
Wheeler Operator	8.4 (14)	1.56 (2)	3.1 (2)	0.012 (1)
Packer	5.1 (48)	0.59 (9)	3.6 (6)	0.010 (7)
Packer Serviceman	3.6 (11)	0.42 (2)	2.1 (1)	0.007 (2)
Packhouse Foreman	1.5 (5)	0.25 (2)	--	0.014 (2)
Fork Lift Operator	4.0 (15)	0.35 (3)	1.6 (1)	0.000 (1)
Car Liner	3.4 (4)	0.31 (1)	--	0.000 (1)
Bulk Car Loader	2.0 (3)	0.25 (1)	--	0.016 (1)
Millwright	1.9 (3)	2.37 (2)	--	0.040 (2)
Instrument Repairman	2.8 (6)	0.59 (2)	--	0.000 (1)
Machinist	1.8 (3)	0.40 (1)	--	0.016 (1)
Millwright Helper	4.0 (2)	2.96 (1)	--	0.000 (1)
Sheet Metal Worker	1.7 (3)	0.50 (1)	--	0.013 (1)
Oiler	4.0 (4)	0.72 (1)	--	0.016 (1)
Welder	1.9 (3)	0.75 (1)	--	

( ) = Number of samples used for calculation of TWA values for each job category. Samples for respirable mass and free SiO_2 were full shift samples.

Table 6

Summary of TWA Amphibole Fiber Exposures (All Fiber Lengths) in Mining and Milling Operations As Determined by Analytical Electron Microscopy

Job Title	Asbestos Fiber Conc. fibers/cc*
<u>Mine</u>	
Trammer	17.5 (4)
Driller	9.5 (1)
Cageman	17.5 (1)
Mechanic	16.7 (1)
<u>Mill</u>	
Mill Foreman	25.0 (2)
General Laborer	23.6 (2)
Crusher Operator	12.0 (2)
Hardinge Operator	70.6 (2)
Wheeler Operator	22.9 (2)
Packer	36.0 (2)
Packer Serviceman	11.1 (2)
Packhouse Foreman	14.6 (2)
Fork Lift Operator	36.0 (1)
Machinist	24.9 (1)
Welder	9.9 (1)

*Concentrations shown are only for those giving identifiable electron diffraction patterns and include tremolite and anthophyllite.

( ) Number of samples analyzed by electron microscopy.

Table 7

Summary of Airborne Fiber Types Determined By Analytical Electron Microscopy

Operation	Percent of Airborne Fibers (All Lengths)				
	Positive Amphiboles*		Positive Chrysotile	Non-Asbestos	Not Identified***
	Tremolite**	Anthophyllite**			
All Fibers					
Mine	19	38	3	1	39
Mill	12	45	2	2	38
Fibers > 5 µm in Length (Mine & Mill)	7	65	0	3	25

* Airborne fibers were identified as positive amphiboles by selected area electron diffraction.

** Amphiboles differentiated by energy dispersive microchemical analysis.

*** Electron diffraction patterns are not sufficient for identification; however, many had X-ray spectra identical to tremolite.

Table 8

Summary of Airborne Fiber Diameters for Positive Amphiboles

Operation and Fiber Type	Median Diameter µm	Geo. Std. Deviation	95% Conf. Interval For Median Diameter µm	% ≤ 0.5 µm in Diameter
Mine*				
Tremolite (N=83)	0.19	2.3	0.16-0.23	88
Anthophyllite (N=164)	0.13	2.4	0.12-0.15	93
Mill				
Tremolite (N=160)	0.19	2.4	0.17-0.22	87
Anthophyllite (N=687)	0.13	2.9	0.12-0.14	90

* Results of all samples combined for distribution analysis.

N = Number of individual fibers identified and sized using electron microscopy.

Table 9

Summary of Airborne Fiber Lengths for Positive Amphiboles

Operation and Fiber Type	Median Diameter µm	Geo. Std. Deviation	95% Conf. Interval For Median Diameter µm	% ≤ 0.5 µm in Length
Mine*				
Tremolite (N=83)	1.6	1.8	1.4-1.8	97
Anthophyllite (N=164)	1.5	2.6	1.3-1.7	90-92
Mill*				
Tremolite (N=160)	1.5	1.9	1.4-1.7	97
Anthophyllite (N=687)	1.4	2.9	1.3-1.5	90

* Results of all samples combined for distribution analysis.

N = Number of individual fibers identified and sized by electron microscopy.

Table 10

Aspect Ratios for Positive Amphiboles Determined by Electron Microscopy (All Fiber Lengths)

Aspect Ratio Measurement	Tremolite*		Anthophyllite*	
	Mine	Mill	Mine	Mill
Median Aspect Ratio	7.5	7.5	9.5	9.5
Aspect Ratio				
≤ 5/1	23%	24%	17%	15%
≤ 10/1	70%	70%	52%	52%
≤ 20/1	96%	96%	85%	88%
≤ 50/1	>99%	99%	99%	>99%

* Data shown are for all fiber lengths.

Table 11

Summary of Historic Impinger Dust Measurements in Mine and Mill Operations

Job or Operation	Mean Dust Concentration (mppcf)										Median Yearly Average
	1954	1958	1963	1964	1969	(1) 1970	(2) 1972	(2) 1973	(2) 1975	NIOSH 1975	
<u>Mine</u>											
Drilling	5		5		13	7	4	5	3	12	5
Dragline & Mucking			7			10	8	3	5	12	8
Tramming & Mucking					29	11	10	3	5	10-15	10
Primary Crushing	2	26	23	18	13	48	11	5	18		18
Hoist Loading				70	140	14	18	10	15	2	14
<u>Mill</u>											
Secondary Crushing	12	23	8	10	12	13	3	8	3	3	9
Wheeler Grinding	15	13	5	3	11	19		4	10	3	10
Hardinge Grinding	18	14	4	7		8			10	3	8
Bagging	25	15	5	9	4	8		8	9	4	8
Palletizing	40			25	10	6		8	15	2	10
Bulk Loading						10					35
Loading Bags		109	39	31		62					50
<u>Other</u>											
Millwright								4		4	
Maintenance								12		2	

(1) Values for 1954 - 1970 taken from reference 16.

(2) Calculated from MESA reports, references 33-42.

Table 12

Summary of Historic Fiber Exposure Measurements in Mine and Mill Operations

Job or Operation	Mean Fiber Concentration (fiber > 5μm/cc						
	(1) 1970	(2) 1972	(2) 1973	(2) 1974	(2) 1975	NIOSH 1975	(2) 1976
<u>Mine</u>							
Drilling	8	4	1	1	1	3	24
Dragline & Mucking	16	6	1	2		6	
Tramming & Mucking	22	6	1		3	6	8
Primary Crushing	260	22	5	9	20	10	25
Hoist Loading	29	5	10	13	3	10	12
<u>Mill</u>							
Secondary Crushing	13	5	14	6	9	5	18
Wheeler Grinding	30		14	13	17	8	14
Hardinge Grinding	33			13	10	8	14
Bagging	30		11	15	6	5	14
Palletizing	27		8	15		4	
Bulk Loading	8					2	
Loading Bags						3	
<u>Other</u>							
Millwright			9			2	
Maintenance			14			2-4	38

(1) Taken from reference 16
(2) Calculated from MESA reports, references 33-43

Table 13

Comparison of Airborne Fiber Characteristics in
Study of Mine and Mill
Operations with New York Talc
Operations Acknowledged as Containing
Asbestiform Minerals

Airborne Fiber Characteristic	Asbestiform Mine and Mill	Study Mine and Mill	Statistical Significance
Proportion Positive Amphiboles	0.50	0.58	$p < 0.05$
Proportion Anthophyllite	0.47	0.45	NS
Proportion Tremolite	0.03	0.13	$p < 0.001$
Median Fiber Length			
Anthophyllite	1.61 μm	1.45 μm	NS
Tremolite	•	1.55 μm	--
Median Fiber Diameter			
Anthophyllite	0.16 μm	0.13 μm	NS
Tremolite	*	0.19 μm	--
Median Fiber Aspect Ratio			
Anthophyllite	9.9	9.5	NS
Tremolite	•	7.5	--
% of Fiber ≤ 5 μm in length			
Anthophyllite	92	90-92	NS
Tremolite	•	97	--

• Insufficient number of fibers observed for calculation of size distribution parameters.

NS - Not significantly different at 0.05 level.

TABLE 14

Summary of morbidity studies of workers exposed to tremolite and/or anthophyllite fibers

Reference	Mineral Characteristics	Sample	Exposure	Medical Findings
20	Talc containing 45% tremolite and no free silica St. Lawrence CO., New York	57 talc miners & millers, 93% sample of one mine & mill	Miners=4 mppcf Millers=52 mppcf	Bronchitis=5% Dyspnea=0% Normal X-ray=5% Fibrosis=67% Early pneumoconiosis =26% Pneumoconiosis II=2%
42	Steatite talc (70% talc, 10% tremolite, no quartz) Murray County, Georgia	66 talc miners & millers, 30 working at time of survey. 8/11 females working	33 millers=300 mppcf 13 miners=135 mppcf 20 workers=17 mppcf	Pneumoconiosis (Grade) 0 1 2 3 High Exposure 52% 24% 15% 9% Medium Exposure 54% 46% - - Low Exposure 100% - - -
44	Fibrous talc containing tremolite, anthophyllite, 1% free silica St. Lawrence County, N.Y.	221 men at 3 talc mines and 5 talc mills	Mill:crushing milling=46-61 mppcf Mine:drilling= 1350 mppcf Stoping=1290 mppcf Mucking=35 mppcf	Fibrosis Total population= 14.5% 10 years exposure= 29.9% 30 years exposure= 74.% Visceral plaques=6.3% for those 35-75 years old, 4-52 years exposure.

TABIE 14 (continued)

Reference	Mineral Characteristics	Sample	Exposure	Medical Findings
74	Tremolite talc of upper New York. Composition of airborne dust from two mines and 4 mills: (Median) Talc 15-25% 24% Tremolite 15-60% 52.5% Anthophyllite 2-40% 8% Serpentine 1-10% 3% Calcite 2-50% 6% Quartz 0.1-9% 2%	Autopsy specimens of 7 miners and 1 miller.	miners=drilling for 10 months to 27 years. Miller=employed for 6 years.	Lung Ash: Appreciable quantities of talc, tremolite, anthophyllite, quartz only in men engaged in non-talc mining. Characteristic "talc lesion" of multiple irregularity shaped foci of fibrocytic proliferation and macrophages accumulation around medium-sized and smaller blood vessels; bronchioles and smaller bronchi distended and distorted with hypertrophic epithelium.
7	Talc from St. Lawrence County, New York (same location as Siegal, et al.) containing tremolite	82 miners and 156 millers in 2 talc plants, all without previous significant occupational exposure to other dusts.	Pre'46 '46-58 (mppcf) Mine: Drilling 818 3 Mucking 120 4 Mill: Crushing 180 52 Screening 69 37 Milling 92 20 Bagging 151 24	PREVALENCE OF FIBROSIS Miners = 3.6% Millers = 12.2% 20-50 mppcf 10-20 years 18.8% > 20 years 22.2% >50 mppcf 10-20 years 33.3% > 20 years 80.0% NO PLAQUES WERE FOUND

TABLE 14 (continued)

Reference	Mineral Characteristics	Sample	Exposure	Medical Findings
41	Talc admixed with tremolite and anthophyllite and a small amount of free silica.	Case histories of six talc miners and millers with pneumoconiosis.	24 years (20-23) talc exposure. Exposure in early years estimated as 150-470 mppcf; in later years as 0-53 mppcf.	Major Findings Clinical: Chronic productive cough, dyspnea, diminished breath sounds, limited chest expansion, diffuse rales, clubbing. X ray: Interstitial infiltration, opaque plate-like densities in region of diaphram; less frequent emphysema and observation of left cardiac border.
8	Fibrous talc, St. Lawrence County, New York	30 talc millers >10 years exposure and no previous occupational dust exposure; 59% smoked >20 cigarettes per day for ≥5 years	Mean duration of exposure= 19.5 years (13-26). Average exposure= 63.1 mppcf, 15 exposed 20-60 mppcf 15 exposed 60-100 mppcf	Dyspnea=53.3%. Abnormal findings (rales, rhonchi, wheezing=26.7%. Pulmonary infiltration (X-ray)=43.3% (4 is grade 1; 7 grade 2; 2 grade 3). Mean % predicted FVC=76.6%, Mean FVC%=.71% Mean % predicted RV/TLC=120.8; Mean % predicted RV=105.2; Mean % predicted TLV=82.1; Mean DL_{CO} = 23.7 cc/mm Hg/min.

TABLE 14 (continued)

Reference	Mineral Characteristics	Sample	Exposure	Medical Findings
9	Predominantly talc admixed with tremolite, anthophyllite, serpentine and <5% free silica.	16 Talc millers with >10 years talc exposure and no previous occupational dust exposure. 81% smoked >30 cigarettes/day ≥ 5 years.	7 avg exp= 20-60 mppcf 7 avg exp= 60-120 mppcf 2 avg exp> 120 mppcf	Cough=44%. Exertional dyspnea=88%. Dyspnea at rest= 6%. Lung findings (rales, rhonchi, wheezing) = 63%. Clubbing=38%. Pulmonary Infiltration (x-ray) Grade 1 = 25% Grade 2 = 63% Grade 3 = 12% No platelike densities. % predicted FVC = 72.5% (48-91) 44% were <75%. FEV% = 70% (53-84) 6% were <60%. % predicted RV = 100% (72-153) 6% were >133%. % predicted TLV = 81% (54-103) 31% were <73%. % predicted RV/TLC=121.3% (96-143) 50% were >124%. DL_{CO} 19.2 cc/mm Hg/min (10-38) 38% were <17.7%.

TABLE 14 (continued)

Reference	Mineral Characteristics	Sample	Exposure	Medical Findings
10	Talc admixed with tremolite anthophyllite, serpentine, and <5% free silica.	43 talc millers with >10 years exposure and no previous occupational dust exposure; 26 had smoked >30 cigarettes/day for >5 years.	2% avg exp=19 mppcf 49% avg exp= 20-60 mppcf 42% avg exp= 60-120 mppcf 7% avg exp= >120 mppcf	Cough = 33%. Dyspnea = 65%. Lung Crepitations = 28%. Clubbing = 19%. Pulmonary Infiltration (x-ray) Grade 1 = 9% Grade 2 = 23% Grade 3 = 5% % predicted FVC = 80% (30% <75% of pred.) FEV% = 70% (12% had < .60) % predicted RV = 101% (14% >133%) % predicted TLC = 84% (16% <73%) % predicted RV/TLC = 116% (37% >124%) DL_{CO} 24.2 cc/mm Hg/min (19% <17.7)
47	Anthophyllite asbestos, Finland	707 living asbestos workers (including office & forestry workers with no occupational exposure); 110 of these 787 had been engaged in asbestos work for more than 10 years.	 Nonsmoker <15 cigs/day >15 cigs/day Total Adjusted for Smoking	Cough (%): All / Mod. Exp. / Hvy. Exp.; Dyspnea(%) 17% / 14% / 59%; 20% 32% / 27% / 57%; 23% 35% / 30% / 57%; 13% 27% / 23% / 58%; 20%

TABLE 14 (continued)

Reference	Mineral Characteristics	Sample	Exposure	Medical Findings
12	Talc admixed with other silicates (tremolite and anthophyllite) and <5% free silica.	20 workers with >10 years in talc mining and milling, & presence of clinical & x-ray findings compatible with talc pneumoconiosis.	Mean years exposure = 23.1 (11-40) 11 avg. exp=50-100 mppcf 9 avg. exp.>100 mppcf	70% cough. 100% exertional dyspnea. 25% dyspnea at rest. 90% diffuse rales, wheezing, and/or prolonged expiratory phase. 50% minimal to severe clubbing. X-rays 90% interstitial infiltration predominantly in mid-lower lung fields. 25% fine nodulations. 55% obliteration of costophrenic sinus. 70% obliteration of cardiac borders. 25% platelike densities in region of diaphragm. 25% diffuse type of emphysema. 10% bullous emphysema. % Predicted Mean FVC=67% (50% <60% predicted) Mean FEV%=.67 (45% < .70) Mean Peak Flow=76% Mean % Pred. RV=99% (25% >120% pred., 30% < 80% pred.) Mean % Pred. TLC=75% (75% < 80% pred.)

TABLE 14 (continued)

Reference	Mineral Characteristics	Sample	Exposure	Medical Findings
64	Anthophyllite, asbestos Finland	252 living workers who had worked between 1936-1967.		Respiratory disease = 44% Normal chest X-ray = 44% Changes in lung parenchyma (X-ray) = 39% Pleural pathology only (X-ray) = 17% Pulmonary and/or pleural pathology =58% Lung pathology excluding pleural lesions (X-ray) = Slight (7%); Moderate (15%); Severe (6%)
75	Anthophyllite asbestos, Finland	116 employed (103 men) & 24 retired (18 men) miners & millers.	TLV for asbestos fibers/cc, > 5μm in length: 33%= 2 yrs exp. 27%= 5-15 yrs exp. 30%=15-25 yrs exp. 7%= 25 yrs exp.	Asbestosis (X-ray) = 27% Mild (49%); Moderate (32%); Marked (19%)
11	Talc with tremolite & anthophyllite as major fibrous components.	39 talc workers exposed >10 years 49% has smoked >20 cigarettes/ day for >5 years.	Avg. yrs. exp. 16.2 (11-22) + ++ Mine: Drilling 6 8 Mucking 20 22 Mill: Crushing 15 13 Milling 13 31.5 Bagging 16 30	Cough = 26%; Dyspnea =23%; Grade 1 = 67%; Grade 2 = 11%; Grade 4 = 22%; Lung Crepitations = 5%; Clubbing = 0%. Radiographic findings compatible with pneumoconiosis = 3%.

TABLE 14 (continued)

Reference	Mineral Characteristics	Sample	Exposure	Medical Findings
11			+ mean dust counts (mppcf) over 20 year period ++ fiber count 75 µm/ml in 1970 only	

Table 15

Age-Smoking Composition of Morbidity Study Population Who Had No Previous Occupational Exposure to Talc

	Age					
	20-29	30-39	40-49	50-59	60+	Total
Smoking Status	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Nonsmoker	12 (41)	2 (11)	3 (11)	2 (12)	0 (0)	19 (20)
Ex-smoker	3 (10)	3 (17)	13 (48)	8 (47)	1 (50)	28 (30)
Smoker	14 (48)	13 (72)	11 (41)	7 (41)	1 (50)	46 (49)
Total	29 (31)	18 (19)	27 (29)	17 (18)	2 (2)	93

Cells are column percentages; marginals are percentages of the total.

Table 15A

Age-Smoking Composition of Total Morbidity Study Population
Regardless of Previous Employment

	Age											
	20-29		30-39		40-49		50-59		60+		Total	
Smoking Status	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)
Nonsmoker	16	(46)	3	(13)	4	(11)	3	(13)	0	(0)	26	(21)
Ex-smoker	3	(9)	3	(13)	16	(46)	13	(54)	2	(67)	37	(31)
Smoker	16	(46)	18	(75)	15	(43)	8	(33)	1	(33)	58	(48)
Total	35	(29)	24	(20)	35	(29)	24	(20)	3	(2)	121	

Cells are column percentages; marginals are percentages of the total.

Table 16

Age-Exposure Composition of Morbidity Study Population Who Had No Previous Occupational Exposure to Talc

Exposure	Age				
	20-29	30-39	40-49	50-59	60+
	n=29	n=18	n=27	n=17	n=2
Employment (years)	2.7 (0.3)	5.9 (0.8)	13.9 (1.4)	19.5 (2.0)	28.0 (0)
Particulate Exposure (mg-years/m^3)	2.0 (0.3)	4.6 (1.0)	8.6 (1.3)	11.3 (2.0)	13.7 (11.7)
Fiber Exposure (fiber-years/cc)	10.4 (1.6)	16.7 (3.3)	52.7 (7.6)	68.8 (13.1)	47.4 (41.4)

Standard Error in Parentheses

Table 16A

Age-Exposure Composition of Total Morbidity Study Population Regardless of Previous Employment

Exposure	Age				
	20-29	30-39	40-49	50-59	60+
	n=35	n=24	n=35	n=24	n=3
Employment (years)	3.0 (0.3)	5.8 (0.7)	14.0 (1.2)	19.5 (1.8)	28.3 (0.3)
Particulate Exposure (mg-years/m^3)	2.3 (0.3)	4.3 (0.8)	9.3 (1.3)	12.1 (1.7)	18.0 (8.0)
Fiber Exposure (fiber-years/cc)	12.5 (1.6)	18.3 (2.8)	55.7 (7.7)	72.2 (11.2)	47.2 (23.9)

Standard Error in Parentheses

Table 17

Prevalence (%) of Symptoms and Radiographic Findings by Smoking Habits Among Morbidity Study Population Who Had No Previous Occupational Exposure to Talc

Symptoms/ Radiographic Findings	Nonsmoker n = 19	Ex-smoker n = 28	Smoker n = 46	Total n = 93	p Value
Cough	0	21.4	52.2	32.3	0.0001
Phlegm	10.5	14.3	50.0	31.2	0.0005
Hemoptysis	0	3.6	13.0	7.5	0.12
Dyspnea (≥Grade 2)	0	14.3	19.6	14.0	0.12
Pleural Thickening (≥Grade 1)	10.5	14.3	8.7	10.8	0.76
Pleural Calcification	5.3	0	0	1.1	0.14
Irregular Opacities	0	0	2.2	1.1	0.60

H_o: There is no difference in rates among the three smoking categories.

Table 17A

Prevalence (%) of Symptoms and Radiographic Findings By Smoking Habits Among The Total Morbidity Study Population Regardless of Previous Employment

Symptoms/ Radiographic Findings	Nonsmoker n = 26	Ex-smoker n = 37	Smoker n = 58	Total n = 121	p Value
Cough	3.9	24.3	53.5	33.9	.0001
Phlegm	19.2	16.2	51.7	33.9	.0004
Hemoptysis	0	8.1	13.8	9.1	.12
Dyspnea ($\geq$Grade 2)	7.7	18.9	19.0	16.5	.40
Pleural Thickening ($\geq$Grade 1)	7.7	18.9	8.6	11.6	.24
Pleural Calcification	3.9	2.7	0	1.7	.37
Irregular Opacities ($\geq$Grade 1)	0	8.1	1.7	3.3	.13

H_o: There is no difference in rates among the three smoking categories.

Table 18

Prevalence (%) of Symptoms and Radiographic Findings by Age Among Morbidity Study Population Who Had No Previous Occupational Exposure to Talc

Symptoms/ Radiographic Findings	Age						
	20-29 n = 29	30-39 n = 18	40-49 n = 27	50-59 n = 17	60+ n = 2	n = 93	p Value
Cough	17.2	55.6	22.2	41.2	100.0	32.3	0.009
Phlegm	20.7	44.4	29.6	29.4	100.0	31.2	0.11
Hemoptysis	6.9	11.1	11.1	0	0	7.5	0.66
Dyspnea (≥ Grade 2)	10.3	16.7	11.1	17.7	50.0	14.0	0.56
Pleural Thickening (≥ Grade 1)	0	0	7.4	41.2	50.0	10.8	0.0001
Pleural Calcification	0	0	0	5.9	0	1.1	0.34
Irregular Opacities (≥ Grade 1)	0	0	0	5.9	0	1.1	0.34

H_O: There is no difference in rates among the five age groups.

Table 18A

Prevalence (%) of Symptoms and Radiographic Findings by Age Among the Total Morbidity Study Population Regardless of Previous Employment

Symptoms/ Radiographic Findings	Age						
	20-29 n = 35	30-39 n = 24	40-49 n = 35	50-59 n = 24	60+ n = 3	Total n = 121	p Value
Cough	17.1	58.3	25.7	37.5	100.0	33.9	.001
Phlegm	22.9	50.0	37.1	25.0	66.7	33.9	.13
Hemoptysis	5.7	12.5	11.4	4.2	33.3	9.1	.42
Dyspnea (≥ Grade 2)	11.4	16.7	11.4	29.2	33.3	16.5	.32
Pleural Thickening (≥ Grade 1)	0	0	5.7	41.7	66.7	11.6	.0001
Pleural Calcification	0	0	0	8.3	0	1.7	.08
Irregular Opacities (≥ Grade 1)	0	0	2.9	12.5	0	3.3	.08

H_O: There is no difference in rates among the 5 age groups

Table 19

Prevalence (%) of Symptoms and Radiographic Findings Among Talc Workers Included in Morbidity Study With No Previous Occupational Exposure to Talc Compared to Coal and Potash Workers Adjusted for Age, Height and Smoking Habits

Symptoms/Radiographic Findings	Years Worked	Talc	Coal	Potash
Cough	< 15 years	31.3	20.9	23.2
	≥ 15 years	34.5	36.7	25.6
Phlegm	< 15 years	34.4	26.0	27.2
	≥ 15 years	24.1	44.6	23.7
Hemoptysis	< 15 years	10.9	6.4	6.4
	≥ 15 years	0.0	9.4	6.7
Dyspnea	< 15 years	12.5	13.3	5.3
	≥ 15 years	17.2	37.9	11.3
Pleural Thickening (Grade 1 and 2)	< 15 years	1.6	0.3	0.5
	≥ 15 years	31.0	1.6*	4.4*
Pleural Calcification**	< 15 years **	0.0	0.0	0.0
	≥ 15 years **	3.4	0.1	0.0
Irregular Opacities (Grade ≥1)	< 15 years**	0.0	0.5	0.0
	≥ 15 years	3.4	5.3	0.7
Regular Opacities (Grade ≥1)	< 15 years**	0.0	1.0	0.0
	≥ 15 years	3.4	13.7	1.1

* p = < 0.05 Hypothesis being tested is that there is no difference in rates between the coal and talc populations, or between the potash and talc populations.

** Expected values not large enough for chi square test.

Table 19A

Prevalence (%) of Symptoms and Radiographic Findings Among All Talc Workers Included in Morbidity Study Compared with Coal and Potash Workers Adjusted for Age, Height, and Smoking Habits

Symptoms/Radiographic Findings	Years Worked	Talc	Coal	Potash
Cough	<15	32.9	21.1**	23.3
	≥15	35.9	37.5	26.7
Phlegm	<15	37.8	26.0**	27.4
	≥15	25.6	45.7**	23.7
Hemoptysis	<15	11.0	6.5	6.2
	≥15	5.1	10.4	6.4
Dyspnea	<15	13.4	13.7	5.3
	≥15	23.1	39.2*	13.4
Pleural Thickening (Grade 1 and 2)	<15	1.2	0.3	0.5
	≥15	33.3	1.5****	3.7****
Pleural Calcification	<15 ++	0	0	0
	≥15 ++	5.1	0.1	0
Irregular Opacities (Grade ≥1)	<15++	0	0.6	0
	≥15	10.3	5.6	0.4****
Regular Opacities (Grade ≥1)	<15 ++	0	1.0	0
	≥15	2.6	14.5	1.6

* $p = < .05$
** $p = < .02$
*** $p = < .005$
**** $p = < .0005$

H_o: There is no difference in rates between the coal and talc populations, or between the potash and talc populations.

\+ N=37 for potash comparisons.
++ Expected values not large enough for chi square test.

Table 20

Dose-Response Relations Among Talc Workers Observed Pulmonary Function As Compared to Pulmonary Function of Coal and Potash Miners, Adjusted For Age, Height, Smoking Habits and Years Worked. (Standrard Error in Parenthesis)

A. Mean Percent Predicted and Pulmonary Function of Talc Workers Compared to Coal and Potash Workers

		Coal	Potash
FEV	a. n = 93	**** 94.0 (1.3)	****94.5 (1.4)
	b. n = 121	**** 93.8 (1.3)	****94.1 (1.3)
FVC	a. n = 93	**** 92.4 (1.2)	****94.7 (1.3)
	b. n = 121	**** 91.9 (1.1)	****94.0 (1.2)
FEV%	a. n = 93	101.3 (0.7)	99.8 (0.7)
	b. n = 121	*101.5 (0.7)	99.9 (0.7)
Peak Flow	c. n = 89	**108.1 (2.8)	99.4 (2.6)
	d. n = 114	***108.5 (2.5)	99.5 (2.3)
FEF_{25}	c. n = 89	* 93.6 (2.8)	****88.8 (2.7)
	d. n = 114	• 94.0 (2.7)	****88.9 (2.6)
FEF_{50}	c. n = 89	**** 85.9 (3.1)	****85.3 (3.2)
	d. n = 114	**** 86.8 (2.9)	****85.6 (2.9)
FEF_{75}	c. n = 89	**** 79.5 (3.1)	****83.7 (3.3)
	d. n = 114	**** 79.9 (2.9)	****83.6 (3.0)

H_0: Mean predicted pulmonary function is not different from 100.

\+ Percent predicted for FEV, FVC, Peak Flow, FEF_{50}, FEF_{75} =

$100 \times \frac{\text{observed}}{\text{predicted}}$; For FEV% = 100 + observed-predicted.

B1. Change in percent predicted pulmonary function per 100 fiber-years/cc

		Coal	Potash
FEV_1	a. n = 93	** - 9.4 (3.2)	**** - 13.7 (3.4)
	b. n = 121	*** - 10.3 (3.0)	**** - 14.4 (3.1)
FVC	a. n = 93	** - 9.6 (3.1)	*** - 12.7 (3.3)
	b. n = 121	**** - 11.6 (2.6)	**** - 14.7 (2.8)
FEV%	a. n = 93	+ 0.2 (1.7)	- 0.7 (1.8)
	b. n = 121	+ 0.8 (1.5)	- 0.05 (1.6)
Peak Flow	c. n = 89	+ 2.7 (7.1)	- 2.3 (6.5)
	d. n= 114	+ 0.4 (5.7)	- 4.0 (5.2)
FEF_{25}	c. n = 89	+ 4.8 (6.9)	- 0.3 (6.8)
	d. n = 114	+ 3.0 (6.2)	- 1.5 (5.9)
FEF_{50}	c. n = 89	- 2.5 (7.7)	- 7.6 (7.9)
	d. n = 114	- 5.0 (6.7)	- 9.7 (6.6)
FEF_{75}	c. n = 89	- 9.7 (7.7)	- 13.8 (8.3)
	d. n = 114	-12.0 (6.6)	* - 15.9 (6.9)

B2. Change in percent predicted pulmonary function per 10 mg-particulate-yrs/mg^3

		Coal	Potash
FEV_1	a. n = 93	* - 5.2 (1.9)	*** - 7.5 (2.2)
	b. n = 121	* - 3.8 (1.8)	** - 6.2 (1.9)
FEV	a. n = 93	** - 5.3 (1.9)	** - 6.7 (2.1)
	b. n = 121	*** - 5.5 (1.6)	**** - 7.1 (1.8)
FEV%	a. n = 93	+ 0.2 (1.0)	- 0.6 (1.1)
	b. n = 121	+ 1.2 (0.9)	+ 0.6 (0.9)
Peak Flow	c. n = 89	+ 1.2 (4.2)	+ 0.08 (4.0)
	d. n = 114	+ 1.6 (3.3)	- 0.2 (3.1)
FEF_{25}	c. n = 89	- 0.03 (4.1)	- 2.3 (4.2)
	d. n = 114	+ 2.2 (3.6)	- 0.4 (3.6)
FEF_{50}	c. n = 89	- 1.4 (4.6)	- 4.8 (4.9)
	d. n = 114	+ 1.2 (4.0)	- 2.7 (4.0)
FEF_{75}	c. n = 89	- 4.6 (4.6)	- 7.9 (5.1)
	d. n = 114	- 1.8 (3.9)	- 5.1 (4.2)

H_o: Change in pulmonary function is not different from 0.

Table 20 (continued)

* $p = \leq 0.05$

** $p = \leq 0.005$

*** $p = \leq 0.001$

**** $p = \leq 0.0001$

a. For potash comparison, n=91 for FEV, FVC, FEV%

b. For potash comparison, n=119 for FEV, FVC, FEV%

c. For potash comparison, n=87 for Peak Flow, FEF_{25}, FEF_{50}, FEF_{75}.

d. For potash comparison, n=112 for Peak Flow, FEF_{25}, FEF_{50}, FEF_{75}.

Table 21

Comparison of Talc Workers Included in Morbidity Study and Having No Previous Talc Exposure With and Without Pleural Thickening (PT)*
By Age, Exposure, and Smoking Habits.
(Standard Error in Parentheses) N=93

		Age		
		40-49	50-59	60+
N	No PT PT	25 2	10 7	1 1
Age	No PT PT	44.4 (0.5) 46.5 (0.5)	53.1 (0.6) 51.9 (0.6)	63.0 51.9
Smoking (pack years)	No PT PT	27.8 (4.7) 39.0 (23.0)	39.0 (8.6) 18.6 (5.2)	99.0 44.0
Years Worked	No PT PT	13.8 (1.4) 14.5 (6.5)	16.5 (3.1) 23.7 (0.9)	28.0 28.0
Particulate Exposure (mg-yrs/m^3)	No PT PT	8.7 (1.4) 7.9 (3.9)	11.3 (2.6) 11.2 (3.4)	25.4 2.0
Fiber Exposure (fibers-yrs/cc)	No PT PT	52.5 (7.9) 55.9 (41.0)	59.5 (16.7) 82.0 (41.0)	88.8 6.0
% Predicted FEV Coal	No PT PT	97.9 (2.6) 80.8 (3.2)	90.6 (4.7) 77.6 (5.3)	84.0 87.3
Potash	No PT PT	96.3 (2.8) 77.7 (5.3)	89.4 (5.0) 75.4 (5.4)	-- 86.7
% Predicted FVC Coal	No PT PT	95.9 (2.4) 72.9 (7.1)	86.7 (4.5) 77.6 (4.4)	79.6 82.8
Potash	No PT PT	96.7 (2.5) 72.5 (8.7)	88.3 (4.8) 77.1 (4.3)	-- 83.2

* Pleural thickening (Grades 1 and 2).

Table 21A

Comparison of All Talc Workers in Morbidity Study
With and Without Pleural Thickening (PT)* By Age
Exposure and Smoking Habits. (Standard Error in Parentheses) N=121

		Age		
		40-49	50-59	60+
N	No PT PT	33 2	14 10	1 2
Age	No PT PT	44.5 (0.4) 46.5 (0.5)	53.3 (0.5) 52.4 (0.7)	63.0 (----) 60.5 (0.5)
Smoking (packing years)	No PT PT	26.8 (4.0) 39.0 (23.0)	30.4 (7.2) 24.6 (6.8)	99.0 (----) 27.0 (17.0)
Years Worked	No PT PT	14.0 (1.3) 14.5 (6.5)	16.6 (2.6) 23.5 (1.5)	28.0 (----) 28.5 (0.5)
Particulate Exposure (mg-yrs/m3)	No PT PT	9.4 (1.3) 7.9 (3.9)	11.1 (2.2) 13.5 (2.7)	25.4 (----) 14.3 (12.4)
Fiber Exposure (fiber-yrs/cc)	No PT PT	55.6 (8.0) 55.9 (41.0)	57.8 (12.8) 92.4 (18.9)	88.0 (----) 26.4 (20.4)
% Predicted FEV Coal	No PT PT	95.5 (3.1) 80.8 (3.2)	91.9 (3.8) 77.8 (5.8)	84.0 (----) 102.9 (15.6)
Potash	No PT PT	94.2 (3.3) 77.7 (5.3)	90.0 (3.9) 75.4 (6.0)	-- 98.2 (11.5)
% Predicted FVC Coal	No PT PT	94.5 (2.6) 72.9 (7.1)	87.4 (3.4) 77.6 (4.7)	79.6 (----) 89.0 (6.2)
Potash	No PT PT	95.6 (2.8) 72.5 (8.7)	88.3 (3.6) 77.0 (4.8)	-- 88.0 (4.8)

* Pleural Thickening (Grades 1 and 2)

Table 22

Average Number of Years Worked for Each Individual in Morbidity Study Having No Previous Talc Exposure With and Without Pleural Thickening and the Number of These Individuals Working in Selected Jobs Over the Total Work History Of Those With Greater Than 15 Years Work When 0, 5 and 10 of the Most Recent Years Worked are Omitted.

Selected Jobs Are Those Where the Number of Years Worked Divided by the Number With Pleural Thickening is Equal to or Greater Than One and Greater Than Average Years Worked for Those Without Pleural Thickening.

Average Number of Years Worked/Individual	(Number of Individuals Ever on this Job)					
	All Years		Omit Most Recent Five Years		Omit Most Recent Ten Years	
	PT	No PT	PT	No PT	PT	No PT
Mine Foreman	19 (1)	7.7 (3)	14.1 (1)	7 (2)	9 (1)	2 (2)
Hoistman	26 (1)	1 (1)	21 (1)	1 (1)	16 (1)	1 (1)
Crusher Operator	24 (1)	8 (2)	20 (1)	6.5 (2)	15 (1)	4 (2)
Packer	14 (2)	14 (2)	9 (2)	12.5 (2)	11 (1)	8.5 (2)
Packer Serviceman	10 (2)	0	7.5 (2)	0	5 (2)	0
Quality Control Technician	16 (1)	4 (2)	16 (1)	1.5 (2)	12 (1)	2 (1)
Shipping & Inventory Coord.	13 (2)	0	16 (1)	0	11 (1)	0
All Other Jobs	5.1 (11)	8.1 (43)	5 (10)	7 (38)	4.6 (9)	5.4 (35)
All Jobs	10.2 (21)	8.0 (53)	9.0 (19)	6.9 (47)	7.4 (17)	5.2 (43)

Note: Numbers for "All Jobs" and All Other Jobs" will exceed number of individuals with (9) and with (20) pleural thickening, since many have held more than one job.

Table 23

Symptom Prevalence, Radiographic Findings and Pulmonary Function By Pleural Thickening (PT) and Years Employment

		PT =0 <15 Years Employment	PT = 0 ≥15 Years Employment	PT = 1* ≥15 Years Employment	PT = 2 ≥15 Years Employment
Age (Average)		n = 81 32.9 (1.1)	n = 26** 48.9 (1.0)	n = 8 50.9 (1.1)	n = 6 55.2 (2.0)
Symptom Prevalence (95% Confidence Levels in Parentheses)					
Cough		32.1 (22-44)	34.6 (18-55)	12.5 (0-50)	83.3 (40-100)
Phlegm		37.0 (26-49)	23.1 (9-43)	12.5 (0-50)	66.7 (25-95)
Hemoptysis		9.9 (4.5-19)	0 (0-13)	12.5 (0-50)	33.3 (4-75)
Dyspnea (> Grade 2)		13.6 (7-24)	19.2 (7-39)	25.0 (3-65)	33.3 (4-75)
Pleural Calcification		0 (0- 5)	0 (0-13)	25.0 (3-65)	0 (0-45)
Irregular Opacities		0 (0- 5)	3.9 (0-20)	25.0 (3-65)	16.7 (0-60)
Pulmonary Function (Standard Error in Parentheses)					
FEV_1 (% Pred)	Coal	95.5 (1.3)	95.0 (3.4)	83.8 (3.2)	79.1 (11.5)
	Potash	97.5 (1.5)	91.5 (3.5)	80.9 (3.5)	76.5 (11.1)
FVC (% Pred)	Coal	94.4 (1.2)	91.4 (3.1)	80.1 (3.6)	76.4 (7.4)
	Potash	97.9 (1.3)	90.4 (3.1)	79.5 (3.7)	75.8 (7.7)
FEV%		78.1 (0.9)	75.3 (1.3)	76.0 (1.7)	70.2 (4.1)
		n=74			
Peak Flow (% Pred)	Coal	106.1 (2.8)	113.4 (5.5)	113.2 (10.7)	110.6 (17.2)
	Potash	99.5 (2.7)	99.7 (4.5)	99.8 (9.9)	97.2 (16.3)
FEF_{25} (% Pred)	Coal	91.6 (3.0)	98.4 (6.1)	102.6 (10.1)	93.4 (21.1)
	Potash	88.6 (2.9)	89.9 (5.9)	92.9 (9.6)	83.5 (19.3)
FEF_{50} (% Pred)	Coal	86.6 (3.1)	91.1 (7.2)	82.9 (10.0)	76.0 (24.5)
	Potash	87.3 (3.3)	86.2 (7.0)	79.1 (10.7)	70.9 (20.0)
FEF_{75} (% Pred)	Coal	82.6 (3.2)	80.3 (7.0)	65.3 (6.3)	65.5 (22.3)
	Potash	87.4 (3.5)	82.2 (7.5)	65.4 (5.1)	66.7 (19.9)

* One individual has less than 15 years employment; all others with PT ≥ 1 have more than 15 Years employment.

** n=24 for the potash comparisons.

Table 24

Symptom Prevalence (%) of Talc Workers Compared to Asbestos[1] and Synthetic Textile Workers[2] By Age and Smoking Habits

	Ages	Nonsmoker	Ex-smoker	Smokers	Total
Winter Cough (3 mos/yr)					
Asbestos Workers	21-35	19	27	49	42
	36-69	35	21	65	56
Talc Workers	20-39	0	33	48	24.4
	40-65	0	21	60	38.3
Anthophyllite Asbestos Workers-heavily exposed greater than 10 years[3]		16.8	--	<15=32.0 >15=35.6	26.6
Phlegm in Winter (3 mos/yr)					
Asbestos Workers	21-35	26	27	43	38
	36-69	40	30	51	47
Synthetic Textile Workers	15-39	6	0	12	10
	40-70	9	5	22	17
Talc Workers	20-39	18	17	45	24
	40-65	20	11	60	37
Breathlessness-Grade 2 or More					
Asbestos Workers	21-25	0	0	13	9
	36-39	22	23	23	23
Synthetic Textile Workers	15-39	6	5	6	6
	40-70	4	7	9	7
Talc Workers	20-39	6	17	14	9
	40-65	0	14	20	17
Anthophyllite Asbestos[3] (dyspnea at rest)		19.8	--	<15=23.0 >15=13.3	19.9

(1) From J.C. McDonald et. al.: Respiratory Symptoms in Chrysotile Asbestos Mine and Mill Workers of Quebec. Arch Env. Health, 24:358, (1972).

(2) J. A. Merchant: Epidemiological Studies of Respiratory Disease Among Cotton Textile Workers, 1970-73. (Rates are calculated from white men working in synthetic wool mills in North Carolina, 1970-71.)

(3) L.O. Meurman, R. Kivilvoto, and M. Hakama: Mortality and Morbidity Among the Working Population of Anthophyllite Asbestos Miners in Finland, Brit. J. Ind. Med., 31:105, 1974.

Table 25

Prevalence of Radiographic Findings in Talc Workers Compared to Asbestos Workers[1] Over 35 Years of Age and After Age Adjustment

	Prevalence (%) of Radiographic Findings		
	Pleural Thickening	Pleural Calcification	Irregular Opacities
Talc Workers with no previous occupational exposure	25.0	3.8	1.9
(n=52)	p<.01	N.S.	N.S.
Asbestos Workers[1]	4.8	2.9	5.6
Talc Workers regardless of previous employment	28.6	7.1	5.7
(n=70)	p<.01	N.S.	N.S.
Asbestos Workers[1]	4.9	3.0	5.8

(1) Data from C.E. Rossiter et.al., (1972). Radiographic Changes in Chrysotile Asbestos Mine and Mill Workers of Quebec, Arch. Env. Health 24:388 (ref. 76).

This study of asbestos workers used the 1968 ILO/UICC classification for pneumoconiosis. There are no differences in the 1968 and 1976 classification for irregular opacities, pleural thickening and pleural calcification.

Table 26 -- Summary of the Prevalence of Pleural Thickening (PT) in Workers Exposed to Asbestos

Reference	Exposure		Continuous Exposure	Intermittent Exposure	Varied or Insignificant Exposure	% of Cases with 15 Yrs. Since Exposure
56 (1968)	Naval Dockyard; all types of asbesots fibers	n	42	688	684	
		Extensive PT	5%	1%	<1%	91%
		Limited Plaques of PT	24%	4%	2%	88%

Reference	Exposure	Prevalence (%) Of Diffuse PT	
62 (1969)	Former anthophyllite asbestos workers. n=410	All	35%
		No Pulmonary Fibrosis	9%
		Pulmonary Fibrosis	26%

	Grade Diffuse PT 1	2	3
No pulmonary changes	71%	14%	14%
Grade 1 pulmonary changes	50%	32%	18%
Grade 2 pulmonary changes	21%	58%	21%
Grade 3 pulmonary changes	11%	26%	63%

Reference	Exposure	Prevalence of PT
63 (1972)	Men & women >40 yrs attending chest clinic in Birmingham (UK) area. n=3868	6% had noncalcified pleural lesions. 1% had pleural calcification, and ∿1/2 of these also had noncalcified pleural lesions.
61 (1972)	10% sample of 3 naval dockyards. n=2442	Extensive noncalcified PT = 0.01% Limited noncalcified PT = 0.01% Pleural abnormalities were more frequent than parenchymal disease.

76 (1972) — 2 Chrysotile Asbestos Mines and Mills

PT by Age	36-40	41-45	46-50	51-55	56-60	61-65	TOTAL
n=	1449	1446	1066	867	656	641	11207
PT ≥ Grade 1	1.4%	2.7%	5.8%	7.2%	7.8%	12.3%	3.8%
PT ≥ Grade in Production Wkrs. at:							
Thetford Mine	2.8%	4.2%	7.1%	8.0%	7.9%	11.5%	6.4%
Asbestos	0.7%	1.7%	4.1%	3.6%	4.6%	7.6%	3.2%

Table 26 -- Summary of the Prevalence of Pleural Thickening (PT) in Workers Exposed to Asbestos (continued)

			36-40	41-45	46-50	51-55	56-60	61-65	TOTAL
		In Factory Workers:							
		n =	87	76	66	44	61	64	967
		% in PT	1.1%	2.6%	4.5%	6.8%	4.9%	-----	1.4%

			% PT by Dust Index (dust Level x yrs worked)					
			<10	10-99	100-199	200-399	400-799	800+
		Production Workers:						
		Thetford Mine	2.4%	4.6%	6.5%	5.8%	8.3%	10.5%
		Asbestos	2.9%	2.6%	3.0%	3.0%	4.7%	5.8%

			% PT by mppcf-yr					
77 (1975)	2 asbestos cement manufacturing plants; primarily chrysotile but some exposure to crocidolite, amosite, silica, talc, mica.	Average age = 45 (21-79)						
		Average dust exposure: 17 yrs (1 month-45 yrs.)	50	50-100	100-200	200-400	400+	TOTAL
		n = 233	233	92	130	245	159	859
		(%)	9%	15%	22%	16%	16%	15%

Table 27

Vital Status of Talc Workers Included in Mortality Study Who Began Employment Between 1947-1960

Known to be alive	308
Known to be deceased	74
Unknown vital status	16
Total	398

Table 28

Study Cohort of Talc Workers Included in Mortality Study According to Length of Employment

Duration of Employment	Number
< 1 month	74
1 month - 6 months	97
6 months - 12 months	31
1 year - 10 years	90
> 10 years	106
Total	398

Table 29

Study Cohort of Talc Workers Included in Mortality Study According to Date of Initial Employment

Date of Initial Employment	Number
1947 - 1949	174
1950 - 1954	156
1955 - 1959	68
Total	398

Table 30

Observed and Expected Deaths According to Major Causes Among Talc Miners and Millers Included in Mortality Study

Cause of Death	Number	Observed	Expected	SMR
Respiratory T.B.	001-008	3.0	0.49	610*
Malignant Neoplasms	140-205	19.0	10.6	180*
Diseases of the Heart	400-443	27.0	26.5	102
All Non-malignant Respiratory Disease	470-527	8.0	2.9	280*
Accidents	E800-E999	10.0	6.4	156
Other Known Causes	---------	7.0	14.4	---
Total		74.0	61.3	120

* $p < 0.05$

Table 30A

Observed and Expected Deaths According to Specific Cause Among Talc Miners and Millers Included in Mortality Study

Cause of Death	Number	Observed	Expected	SMR
Malignant Neoplasms	140-205	19.0	10.6	180*
Digestive System	150-159	3.0	3.0	100
Respiratory System	160-164	10.0	3.5	290**
Bronchogenic	162-163	9.0	3.3	270*
Lymphatic and Hematopoietic	200-205	4.0	1.2	330
Other Neoplasms	-------	2.0	2.9	69
All Non-malignant Respiratory Disease	470-527	8.0	2.9	280*
Influenza, Pneumonia, Bronchitis and Acute Upper Respiratory Infection	470-502	3.0	1.5	200
Other Non-malignant Respiratory Diseases	510-527	5.0	1.3	380*

* $p < 0.05$

** $p < 0.01$

Table 31

Bronchogenic Cancer Among Talc Miners and Millers Included in Mortality Study According to Interval Since Onset of Employment (Latency)

Interval Since Onset of Employment (years)	Observed	Expected	SMR
<10	0	0.5	---
10-19	3	1.5	200
20-28	6	1.3	460**
Total	9	3.3	270*

** $p < 0.01$

* $p < 0.05$

Table 32

Case Review of Deaths Among Talc Miners and Millers Included in Mortality Study According to Cause of Death and Select Demographic Factors

Case	D.O.B.	Age at Death	App. Length of Emplymt. (Date of Initial Emplymt.)	Latency (Years)	Other previous Emplymt. (Length of Emplymt.)
A. Cancer of Respiratory System					
1	12/04/06	63	1 month (8/10/49)	21	Unknown
2	05/22/17	54	1 month (10/21/48)	23	Coal Supply (7 months) Diamond Drill Other N.Y. State Talc Co.
3	06/08/14	59	1 year (11/08/48)	25	Repairman-Other N.Y. State Talc Co. (5 months) Shaftman-Lead Mine (14 months)
4	03/19/24	46	2 months (11/22/48)	21	Rock Quarries (2 years) Aluminum Plant (4 years) Iron Ore Mine (4 months)
5	06/14/09	55	3 years (07/19/48)	18	Road Building (5 years) Mining (6 years)
6	06/28/07	53	5 years (08/04/54)	6	Foundry (10 years) Other N.Y. State Talc Co. (5-6 years)
7	05/10/20	54	2.5 years (07/12/50)	24	Mucker-Mining (7 years)
8	04/22/891	79	<1 month (12/13/48)	22	Construction (unknown length)
9	01/03/22	39	2.5 years (07/13/49)	12	Mucker-Lead Mine (" ")
10	10/10/11	62	17 years (01/25/56)	18	Unknown
B. Mesothelioma of Lung					
1	02/08/06	62	16 years (12/04/52)	16	Construction (11 years)

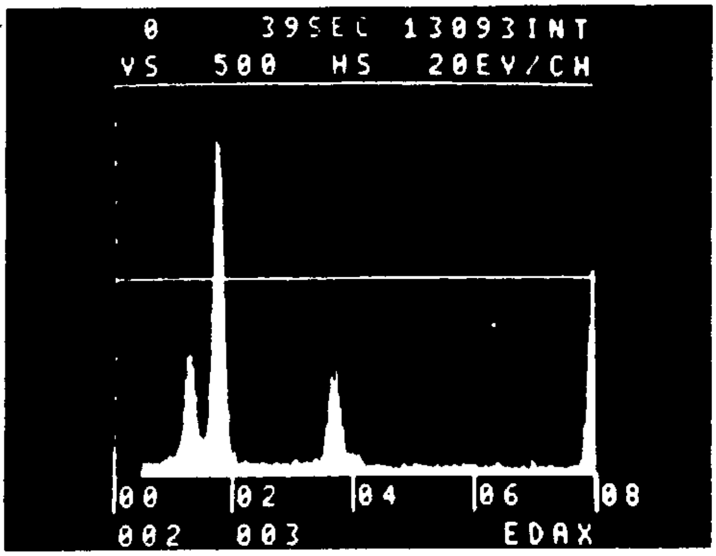
Table 32 (continued)

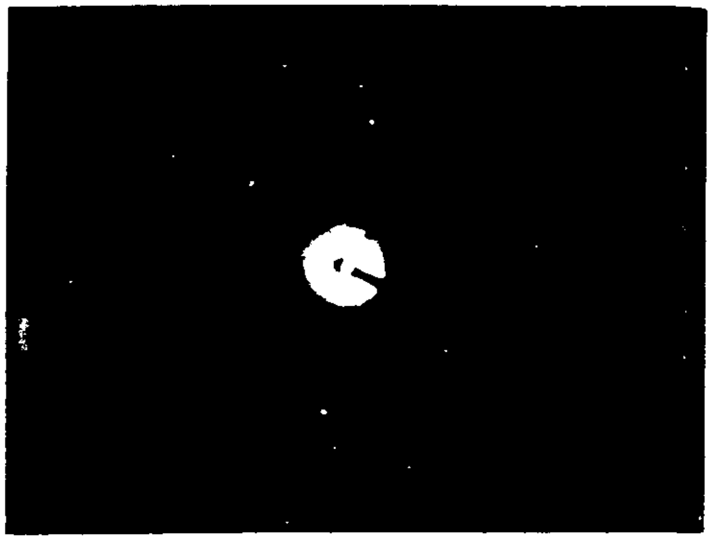
C. Non-malignant Respiratory Disease Other Than Influenza and Pneumonia					
1	08/07/885	75	10 years (11/01/48)	13	Unknown
2	01/07/16	59	<1 month (12/15/48)	27	Unknown
3	09/08/13	58	14 years (06/14/54)	17	Mucker & Driller - Limestone (9 years)
4	03/07/26	49	10 years (04/05/52)	23	Other N.Y. State Talc Co. (5 years)
5	06/20/10	58	1 year (04/17/50)	18	Unknown
D. Respiratory T.B.					
1	12/06/21	49	4 years (06/25/49)	21	Construction (4 months) Miner-Lead Miner (3 montl
2	02/11/09	53	5 months (07/11/49)	12	Miner-Other N.Y. State Talc Co. (16 years) Miner-Lead Mine (unknown length)
3	10/30/29	42	6 years (09/11/54)	17	Unknown

Figure 1. Typical Electron Diffraction Patterns and X-ray Spectra of Tremolite Fibers in Bulk Samples

X-Ray Spectrum

Diffraction Patterns





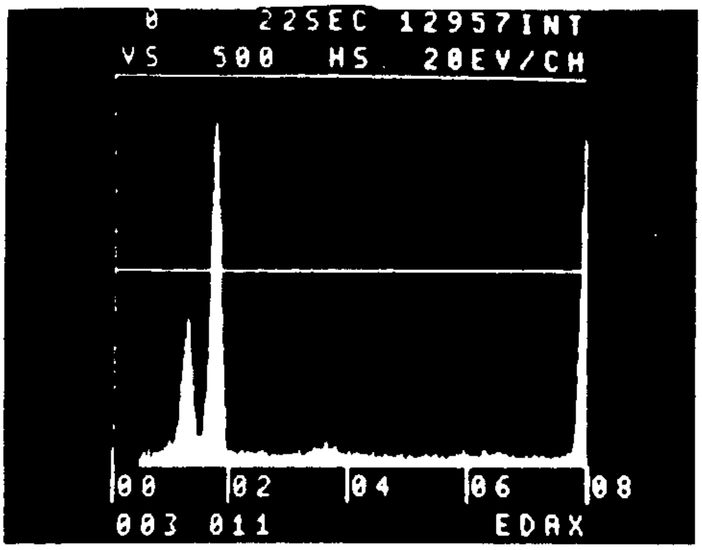
Electron Photomicrographs

Magnification
10,000 X 1 Micron

Magnification
1,700 X 10 Micron

Figure 2. Typical Electron Diffraction Patterns and X-ray Spectra of Anthophyllite Fibers in Bulk Samples

X-ray Spectrum



Diffraction Pattern

Electron Photomicrograph

Magnification 10,000 X 1 Micron

Magnification 5,000 X 1 Micron

Figure 6. Mean Yearly Impinger Dust Concentrations for Mine Operations

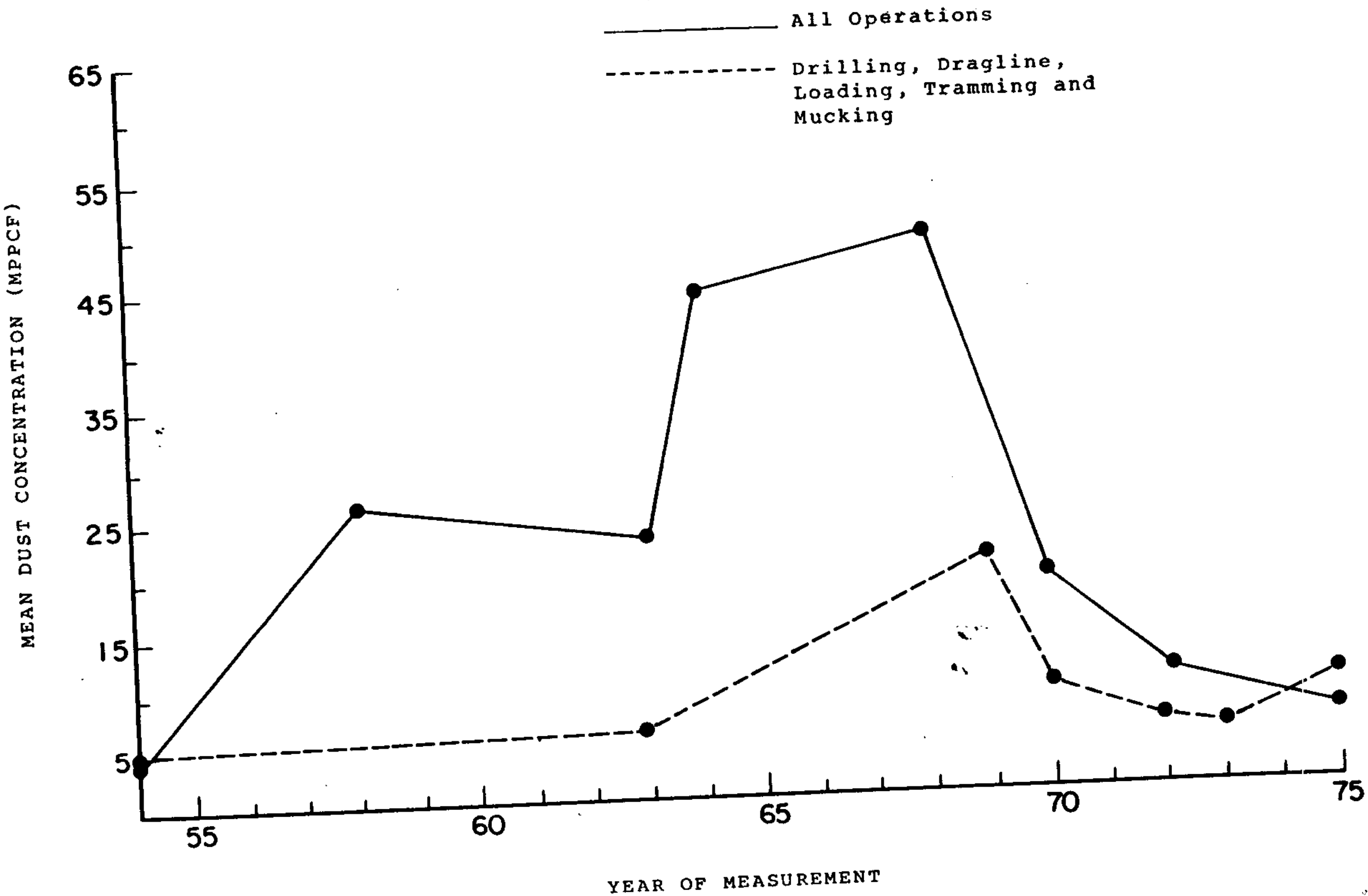
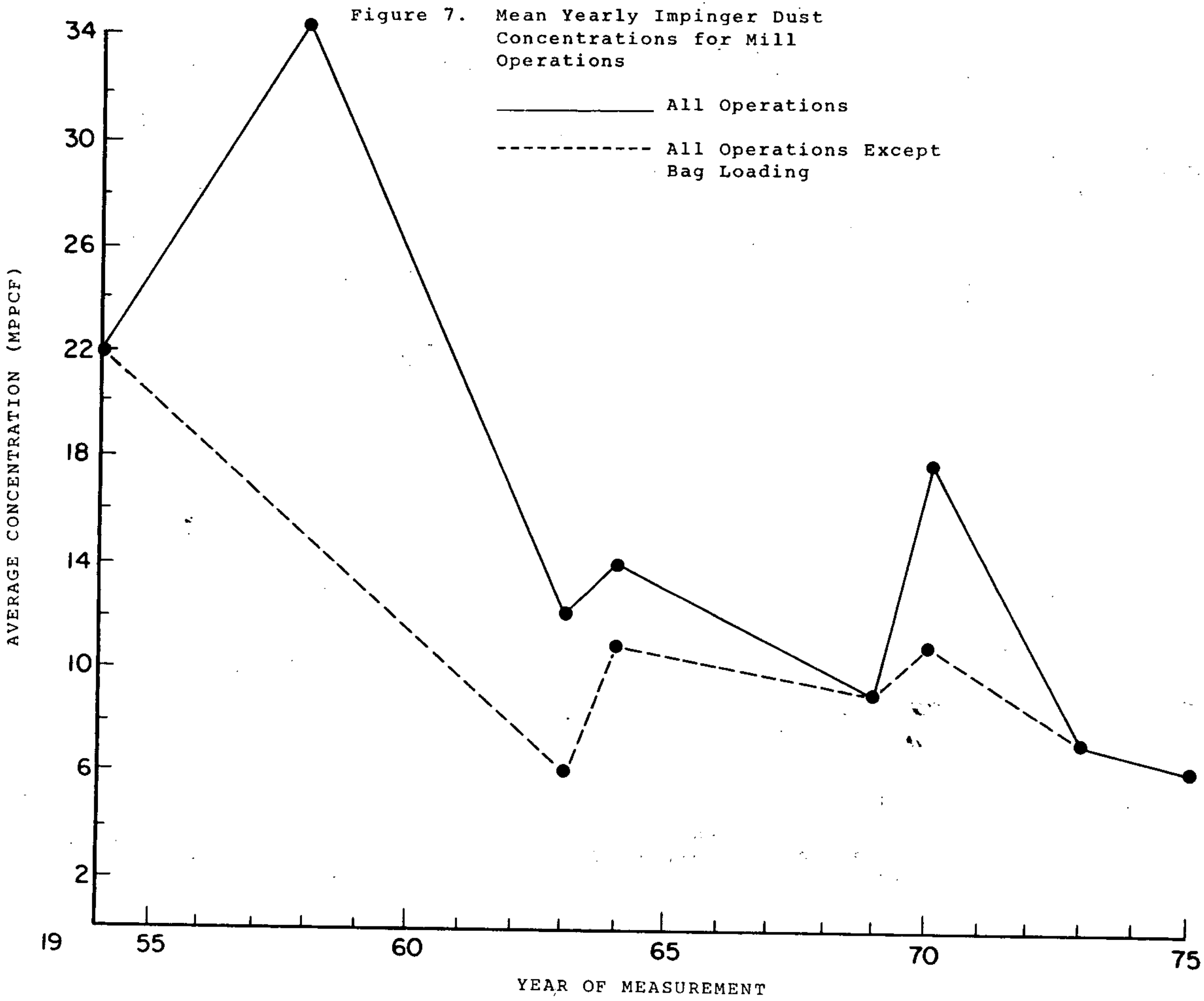


Figure 7. Mean Yearly Impinger Dust Concentrations for Mill Operations



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Appendix. Summary Statistics for NIOSH 1975 Industrial Hygiene Study (Tables A-1 through A-10).

Table A-1

Summary of Fiber Exposures in Mine Operations as Determined by Optical Microscopy

Operation or Job	Fiber >5 μm in Length per cc			
	Range of Individual Samples	Mean (± SE) of Individual Samples	Median of Individual Samples	Time-Weighted Average
Crusher Operator (4)	7.7 - 14.7	10.3 ± 1.5	9.3	9.8
Trammer (25)	2.3 - 14.6	6.4 ± 0.7	5.1	5.6
Driller (5)	0.9 - 6.8	3.9 ± 1.0	4.6	3.0
Cageman (5)	6.0 - 18.2	10.3 ± 2.1	8.4	9.5
Blacksmith (3)	1.2 - 4.4	3.1 ± 1.0	3.7	2.6
Mechanic (12)	0.2 - 3.9	1.9 ± 0.3	1.9	1.7

( ) Number of samples

SE Standard error

TABLE A-2

Summary of Fiber Exposures in Mill Operations as Determined by Optical Microscopy

Operation or Job	Fiber >5 μm in Length per cc			
	Range of Individual Samples	Mean (± SE) of Individual Samples	Median of Individual Samples	Time-Weighted Average
Mill Foreman (9)	2.4 - 16.0	5.8 ± 1.4	4.7	5.3
General Laborer (5)	1.5 - 13.2	5.8 ± 2.0	5.5	5.6
Crusher Operator (16)	1.7 - 11.6	5.5 ± 0.9	4.7	5.1
Hardinge Operator (14)	1.7 - 26.8	8.7 ± 1.8	6.4	7.9
Wheeler Operator (14)	2.6 - 29.1	9.9 ± 2.1	6.5	8.4
Packer (48)	0.2 - 21.0	6.9 ± 0.6	6.1	5.1
Packer Serviceman (11)	1.6 - 8.3	4.9 ± 0.7	5.5	3.6
Packhouse Foreman (5)	1.0 - 1.9	1.5 ± 0.2	1.6	1.5
Fork Lift Operator (15)	1.1 - 8.3	4.5 ± 0.5	4.6	4.0
Rail Car Liner (3)	1.3 - 5.6	3.8 ± 1.0	4.1	3.4
Bulk Car Loader (3)	1.6 - 2.4	1.9 ± 0.2	1.8	2.0
Millwright (3)	0.9 - 2.6	1.9 ± 0.5	2.3	1.9
Instrument Repairman (6)	1.2 - 4.0	2.8 ± 0.4	3.0	2.8
Machinist (3)	0.3 - 3.6	1.5 ± 1.1	0.5	1.8
Millwright Helper (2)	0.7 - 8.9	4.8 ± 4.1	4.8	4.0
Sheet Metal Worker (3)	1.2 - 2.2	1.8 ± 0.3	1.9	1.7
Oiler (4)	1.7 - 4.5	3.6 ± 0.7	4.1	4.0
Welder (3)	0.8 - 3.1	1.8 ± 0.7	1.6	1.9

( ) Number of samples

SE Standard error

TABLE A-3

Summary of Amphibole Fiber Exposures in Mine Operations as Determined by Analytical Electron Microscopy

Operation or Job	Amphibole Fiber Concentrations, fibers/cc			
	Range of Individual Samples	Mean ($\pm$ SE) of Individual Samples	Median of Individual Samples	Time-Weighted Average
Trammer (4)	8.9 - 22.6	16.2 $\pm$ 3.1	16.7	17.5
Driller (1)	9.5 - 9.5	9.5 - ---	9.5	9.5
Cageman (1)	17.5 - 17.5	17.5 - ---	17.5	17.5
Mechanic (1)	16.7 - 16.7	16.7 - ---	16.7	16.7

Concentrations are for positively identified asbestos fibers of all lengths

( ) Number of samples analyzed

SE Standard error

TABLE A-4

Summary of Amphibole Fiber Exposures in Mill Operations as Determined by Analytical Electron Microscopy

Operation or Job	Amphibole Fiber Concentrations, fiber/cc			
	Range of Individual Samples	Mean (± SE) of Individual Samples	Median of Individual Samples	Time-Weighted Average
Mill Foreman (2)	18.4 - 33.7	26.0 ± 7.7	26.0	25.0
General Laborer (2)	9.0 - 36.6	22.8 ± 13.8	22.8	23.6
Crusher Operator (2)	9.0 - 15.6	12.3 ± 3.3	12.3	12.0
Hardinge Operator (2)	33.6 - 102.7	68.1 ± 34.5	68.1	70.6
Wheeler Operator (2)	18.2 - 25.5	21.9 ± 3.6	21.9	22.9
Packer (2)	31.9 - 41.8	36.8 ± 4.9	36.8	36.0
Packer Serviceman (2)	7.3 - 26.7	17.0 ± 9.7	17.0	11.1
Packhouse Foreman (2)	13.6 - 16.2	14.9 ± 1.3	14.9	14.6
Fork Lift Operator (1)	36.0 - 36.0	36.0 - ----	36.0	36.0
Machinist (1)	24.9 - 24.9	24.9 - ----	24.9	24.9
Welder (1)	9.9 - 9.9	9.9 - ----	9.9	9.9

Concentrations are for positively identified asbestos fibers of all lengths.

( ) Number of samples analyzed

SE Standard error

TABLE A-5

Summary of Respirable Dust Exposures in Mine Operations

	Respirable Dust Concentrations - mg/m^3			
Operation or Job	Range of Individual Samples	Mean (± SE) of Individual Samples	Median of Individual Samples	Time-Weighted Average
Trammer (3)	0.13 - 0.95	0.64 ± 0.26	0.85	0.64
Scrapper Man (3)	0.58 - 1.72	1.29 ± 0.36	1.57	1.29
Laborer (1)	0.58 - 0.58	0.58 ± ---	0.58	0.58
Driller (3)	0.54 - 1.42	0.99 ± 0.26	1.00	0.98
Cageman (1)	0.23 - 0.23	0.23 ± ---	0.23	0.23
Repairman (1)	1.14 - 1.14	1.14 ± ---	1.14	1.14
Repairman Helper (1)	0.86 - 0.86	0.86 ± ---	0.86	0.86
Mechanic (1)	0.42 - 0.42	0.42 ± ---	0.42	0.42

( ) Number of full shift samples collected

SE Standard Error

TABLE A-6

Summary of Respirable Dust Exposure in Mill Operations

Operation or Job	Respirable Dust Concentrations - mg/m³			
	Range of Individual Samples	Mean (± SE) of Individual Samples	Median of Individual Samples	Time-Weighted Average
Mill Foreman (2)	0.52 - 0.64	0.58 ± 0.06	0.58	0.58
General Laborer (1)	1.14 - 1.14	1.14 ± ----	1.14	1.14
Crusher Operator (2)	0.60 - 1.13	0.87 ± 0.27	0.87	0.85
Hardinge Operator (2)	0.65 - 1.56	1.11 ± 0.46	1.11	1.09
Wheeler Operator (2)	0.45 - 2.73	1.59 ± 1.14	1.59	1.56
Packer (2)	0.39 - 0.95	0.59 ± 0.07	0.50	0.59
Packer Serviceman (2)	0.40 - 0.44	0.42 ± 0.02	0.42	0.42
Packhouse Foreman (2)	0.22 - 0.28	0.25 ± 0.03	0.25	0.25
Fork Lift Operator (3)	0.23 - 0.44	0.35 ± 0.06	0.37	0.35
Car Liner (1)	0.31 - 0.31	0.31 ± ---	0.31	0.31
Bulk Car Loader (1)	0.25 - 0.25	0.25 ± ---	0.25	0.25
Millwright (2)	0.16 - 4.64	2.41 ± 2.24	2.40	2.37
Instrument Repairman (2)	0.58 - 0.59	0.59 ± 0.01	0.59	0.59
Machinist (1)	0.40 - 0.40	0.40 ± ---	0.40	0.40
Millwright Helper (1)	2.95 - 2.95	2.95 ± ---	2.95	2.95
Sheet Metal Worker (1)	0.50 - 0.50	0.50 ± ---	0.50	0.50
Oiler (1)	0.72 - 0.72	0.72 ± ---	0.72	0.72
Welder (1)	0.75 - 0.75	0.75 ± ---	0.75	0.75

( ) Number of samples (all full shift samples)

SE Standard Error

TABLE A-7

Summary of Respirable Free Silica Exposures in Mine Operations

	Respirable Free SiO_2 Concentrations - mg/m_3			
Operation or Job	Range of Individual Samples	Mean (+ SE) of Individual Samples	Median of Individual Samples	Time-Weighted Average
Trammer (3)	0.012 - 0.025	0.020 ± 0.004	0.024	0.020
Scrapper Man (3)	0.012 - 0.012	0.012 ± 0.000	0.012	0.012
Laborer (2)	0.000 - 0.012	0.006 ± 0.006	0.006	0.006
Driller (2)	0.000 - 0.024	0.014 ± 0.007	0.014	0.014
Repairman's Helper (1)	0.000 - 0.000	0.000 - -----	0.000	0.000
Mechanic (1)	0.000 - 0.000	0.000 - -----	0.000	0.000

( ) Number of full shift samples collected

SE Standard error

TABLE A-8

Summary of Respirable Free Silica Exposures in Mill Operations

Operation or Job	Respirable Free SiO_2 Concentrations - mg/m^3			
	Range of Individual Samples	Mean (± SE) of Individual Samples	Median of Individual Samples	Time-Weighted Average
Mill Foreman (2)	0.013 - 0.014	0.014 - 0.000	0.014	0.013
General Laborer (1)	0.014 - 0.014	0.014 - -----	0.014	0.014
Crusher Operator (2)	0.012 - 0.028	0.020 ± 0.008	0.020	0.020
Hardinge Operator (1)	0.012 - 0.012	0.012 - -----	0.012	0.012
Wheeler Operator (1)	0.012 - 0.012	0.012 - -----	0.012	0.012
Packer (7)	0.000 - 0.015	0.019 ± 0.002	0.013	0.010
Packer Serviceman (2)	0.000 - 0.013	0.007 ± 0.006	0.007	0.007
Packhouse Foreman (2)	0.013 - 0.016	0.015 ± 0.001	0.015	0.014
Fork Lift Operator (1)	0.000 - 0.000	0.000 - -----	0.000	0.000
Car Liner (1)	0.000 - 0.000	0.000 - -----	0.000	0.000
Bulk Car Loader	0.016 - 0.016	0.016 - -----	0.016	0.016

( ) Number of full shift samples collected

SE Standard error

TABLE A-9

Summary of Airborne Dust Concentrations in Mine Operations as Determined by Midget Impinger/Optical Microscopy Techniques

Operation or Job	Impinger Dust Concentrations, mppcf			
	Range of Individual Samples	Mean (± SE) of Individual Samples	Median of Individual Samples	Time-Weighted Average
Trammer (3)	6.0 - 12.7	10.4 ± 2.2	12.4	10.1
Scapper Man (5)	3.8 - 24.5	14.0 ± 4.2	18.4	11.8
Driller (1)	11.7 - 11.7	11.7 - ----	11.7	11.7
Mucker (1)	15.8 - 15.8	15.8 - ----	15.8	15.8
Cageman (1)	2.0 - 2.0	2.0 - ----	2.0	2.0
Repairman Helper (1)	3.6 - 3.6	3.6 - ----	3.6	3.6
Mechanic	1.5 - 1.5	1.5 - ----	1.5	1.5

( ) Number of individual samples

SE Standard error

mppcf Millions of particles per cubic foot of air

TABLE A-10

Summary of Airborne Dust Concentrations in Mill Operations Determined by Midget Impinger/Optical Microscopy Techniques

Operation or Job	Impinger Dust Concentrations, mppcf			
	Range of Individual Samples	Mean (± SE) of Individual Samples	Median of Individual Samples	Time-Weighted Average
Mill Foreman (2)	1.8 - 3.9	2.9 ± 1.1	2.9	2.9
General Laborer (1)	0.5 - 0.5	0.5 - ---	0.5	0.5
Crusher Operator (4)	1.2 - 3.5	2.6 ± 0.5	2.8	2.6
Hardinge Operator (2)	2.9 - 3.9	3.4 + 0.5	3.4	3.4
Wheeler Operator (2)	2.5 - 3.6	3.1 ± 0.5	3.1	3.1
Packer (6)	2.0 - 6.4	3.6 ± 0.6	3.3	3.6
Packer Serviceman (1)	2.1 - 2.1	2.1 - ---	2.1	2.1
Fork Lift Operator (1)	1.6 - 1.6	1.6 - ---	1.6	1.6

( ) Number of individual samples

SE Standard error

mppcf = Millions of particles per cubic foot

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