

**THE MORBIDITY AND MORTALITY OF VERMICULITE
MINERS AND MILLERS EXPOSED TO
TREMOLITE-ACTINOLITE**

BY

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SUMMARY

In 1978, 12 cases of benign pleural effusion were reported among workers employed at an Ohio fertilizer plant which had processed Montana and South African vermiculite concentrates. This led to a cross-sectional study of the radiographic and clinical findings in the Ohio workers, an environmental study of the Montana raw ore and concentrate by the Environmental Protection Agency (EPA), and finally to this study of the mortality and morbidity of employees at the Montana vermiculite mine and mill.

The results of analyses of the raw ore from the Montana mine, and airborne dust from the Montana mill, indicate that the vermiculite ore is contaminated with an asbestiform fiber of the tremolite-actinolite series. Approximately 96% of 599 fibers (length >5 μ m) counted by optical microscopy in 8 membrane filter air samples had an aspect ratio greater than 10, and 17% had an aspect ratio greater than 50.

Environmental air samples were collected periodically in the mill since 1942, and in the mine since 1968, by the State of Montana, the Mine Enforcement and Safety Administration, the Mine Safety and Health Administration, the National Institute for Occupational Safety and Health, and the company. From these data, individual cumulative fiber exposure was estimated.

Estimates of exposure before 1964 in the dry mill were 168 f/cc for working areas, 182 f/cc for sweepers, 88 f/cc for skipping, and 13 f/cc for the quality control laboratory. In 1964-71 exposure estimates for these areas were 33, 36, 17, and 3 f/cc respectively. Estimates of exposures in the mine before 1971 ranged from 9-23 f/cc for drillers and were less than 2 f/cc for non-drilling jobs. All 8-hour TWA job exposure estimates decreased from 1972-76, and from 1977-1982 were less than 1 f/cc.

A retrospective follow-up study of mortality, and a cross-sectional morbidity study, were conducted. The mortality experience was evaluated for a cohort of 581 workers (569 men and 12 women) hired prior to 1970 and employed at least 1 year at the Montana site. Radiographic findings and respiratory symptoms were evaluated for 184 men employed from 1975-1982 and who had worked at least 5 years at the Montana site.

Conclusions from the epidemiological studies are that past exposures were associated with increased prevalence of dyspnea, prevalence of parenchymal and pleural radiographic findings, and mortality from non-malignant respiratory disease and lung cancer.

If (1) smoking is not a confounder, (2) the models employed are appropriate, and (3) the health risk associated with a certain level of f-y is similar whether accumulated in a 'high' or 'low' average exposure environment, then 5 f-y is associated with at least a 1% increased risk of lung cancer and the prevalence of radiographic small opacities. NIOSH presently recommends that the 8-hour TWA concentration of asbestiform fibers greater than 5 μm . in length should be less than 0.1 f/cc. Because 5 f-y could be considered an average exposure of 0.1 f/cc over a working lifetime of 50 years, results from this study suggest that 0.1 f/cc is not a conservative limit for tremolite-actinolite fibers contaminating the Montana vermiculite ore.

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I. INTRODUCTION

This report covers an investigation of the morbidity and mortality of workers who were employed at a vermiculite mine and mill near the town of Libby, Montana. The Montana mine and mill produces the majority of the vermiculite concentrate used in the United States.

Vermiculite is a micaceous mineral with a ferromagnesium-aluminum silicate composition. It exfoliates when heated and has properties of high bulk, good thermal insulation, inert composition, fire-proof nature, and high absorption (U.S. Bureau of Mines, 1970). Expanded vermiculite is used in construction materials (aggregates in plaster and concrete), agricultural products (potting soil, soil conditioner, nursery stock packing material, fertilizer, and a carrier for chemicals), and other industrial uses.

Vermiculite has not been associated with significant health effects; however, vermiculite deposits in Montana and South Carolina are contaminated with fibrous tremolite-actinolite (Atkinson et al., 1980). Concern for the health effects of exposure to the tremolite contaminating the Montana vermiculite concentrate has led to (1) Lockey et al.'s (1984) cross-sectional study of radiographic and pulmonary function findings in workers at an Ohio fertilizer plant which had processed concentrate from South Africa and from the Libby mine and mill, (2) The Environmental Protection Agency's (EPA) study of the asbestos content of the bulk and airborne dust in the Libby facility (Atkinson et al., 1982), and (3) our study of the mortality and morbidity of the Libby miners and millers (Amandus et al., 1985a,b). In addition to our study, McDonald et al. (1985a,b) have conducted a parallel but separate study of the Libby workers.

Subsequently, in 1978, 12 cases of benign pleural effusion were reported among employees of an Ohio fertilizer plant which had processed Montana and South African concentrates. Lockey et al examined 512 workers employed at the Ohio expander plant, and found an increased prevalence of pleuritic chest pain

and radiographic pleural abnormalities which they attributed to tremolite fiber exposure. However, only 1 worker had evidence of small opacities, and neither small opacities or abnormal pulmonary function were found to be associated with fiber exposure. The authors concluded that the findings for chest pain and pleural abnormalities suggest that the cluster of 12 cases of benign pleural effusions was likely due to the tremolite exposure.

As a result of Lockey et al.'s conclusion, Atkinson et al. (1982) evaluated the raw ore and vermiculite concentrates from mine and mill facilities in Libby, Montana; Patterson, South Carolina; and Enoree, South Carolina (Atkinson et al., 1982). Their results for the Montana mill and screening plant showed that the raw ore and finished product contained fibrous tremolite-actinolite, non-fibrous tremolite-actinolite, and non-fibrous anthophyllite. Their results also showed that the percentage of fibrous tremolite-actinolite by weight was approximately 21-26% in the raw ore sampled at the head feed of the mill, and 2-6% in the finished product.

Results from mineralogical analyses conducted by the company indicated that the percentage of tremolite by weight in 1984 samples varied from 3.5% to 6.4% in the raw ore at the head feed, and from 0.4% to 1.0% in the concentrate (Wolter, 1985).

There is very little published information regarding the health effects in humans from exposure to tremolite-actinolite fibers. Baris et al. (1978) and Yazicioglu et al. (1978, 1980) reported on Turkish populations which had an exposure to tremolite from the soil and stucco of their homes. Although a high prevalence of radiographic pleural abnormalities and mesothelioma was reported in the Turkish studies, information isn't available concerning the exposure-response curve. Moreover, the pleural findings in the population studied by Baris et al. may have been due partly to a fibrous zeolite called erionite.

Baris et al.(1978) reported on the morbidity and mortality of residents in the village of Karain. From 1970-1974, 55 deaths occurred in the area, and 24 were due to pleural mesothelioma, 3 to lung cancer, and 7 to gastro-intestinal cancers. Mesothelioma and lung cancer mortality was greater in Karain than in neighboring villages. Results of radiographic surveys of 564 people in 1971, and 452 people in 1975, showed that 21 in 1971 and 24 in 1975 had fibrosis, 2 in 1971 and 2 in 1975 had pleural calcification, and 0 in 1971 and 3 in 1975 had pleural thickening.

Rohl et al.(1982) analyzed the mineral content of the soil, house stucco, settled dust, and building stone. They found evidence of a fibrous zeolite (erionite), fibrous chrysotile, and fibrous tremolite in samples from Karain, but not in samples from surrounding areas.

Yazicioglu et al.(1980) reported on examinations of approximately 7000 people living in a town called Cermik in southeast Turkey. They found 461 cases (6.5%) with pleural calcification and 103 cases (1.5%) with pulmonary fibrosis. Of 41 hospital admissions with mesothelioma or lung cancer at the Diyarbakir hospital, 33 were from districts where asbestos was used in residential whitewash and stucco, and 8 were from districts where asbestos had not been found in the soil or homes. Of 33 neoplasms from the asbestos districts, 22 cases of mesothelioma were reported.

Pooley et al.(1979) found chlorite talc, antigorite/lizardite, and asbestiform tremolite in the whitewash and stucco in homes in Cermik. Analysis of a biopsy specimen showed that 98% of the fibers were tremolite and 2% were chrysotile.

Other worker populations with exposure to tremolite include New York talc miners and millers, and Quebec chrysotile miners and millers. Results for talc workers do not indicate an increased prevalence of small opacities (Gamble et al., 1979), and the carcinogenicity of tremolitic talc is still unclear. Brown and Wagoner (1980) reported that lung cancer mortality risk

increased with latency among New York talc workers. However, Lamm et al. (1985) in a re-analysis of an extended follow-up of Brown and Wagoner's cohort, reported that the lung cancer risk was inversely related to exposure indices, and was likely due to occupational exposures other than in the talc industry. Because the exposure classification in both studies was imprecise, the carcinogenicity of tremolite in New York talc has not yet been substantiated epidemiologically.

With regard to Quebec miners and millers, tremolite appears as a contaminant of Canadian chrysotile (McDonald et al., 1980). Thus, the effects of tremolite asbestos among Canadian miners and millers cannot be separated from that due to chrysotile.

The purpose of this study is to evaluate the health effects of exposure to fibrous tremolite-actinolite. Results from the review of the literature indicate that there has never been a report on the health effects from exposure to tremolite-actinolite without other confounding exposures. Thus, the Montana vermiculite population is appropriate to investigate the effects of exposure to tremolite-actinolite without confounding from other fiber types.

The primary objective of this study is to estimate the exposure-response relationship between fiber exposure, radiographic small opacities, respiratory symptoms, and mortality. Questions to be addressed are as follows:

1. What were the past airborne fiber concentrations? What types of fibers were workers exposed? What are the dimensions of the fibers? What is an estimate of each worker's cumulative fiber exposure?
2. Is there an excess mortality from lung cancer, mesothelioma, non-malignant respiratory disease, and other diseases among vermiculite miners and millers exposed to tremolite-actinolite asbestos? What is the exposure-response curve for fiber exposure and mortality from lung cancer and non-malignant respiratory disease?
3. What is the exposure-response relationship between cumulative fiber exposure, respiratory symptoms, and radiographic evidence of parenchymal and pleural findings controlled for age and cigarette smoking?

II. EVALUATION OF ENVIRONMENTAL EXPOSURES

METHODS

Description and history of the vermiculite facility

Production of the Montana vermiculite concentrate begins at the mine where the ore is drilled, loaded, and hauled to a transfer point. Coarse fractions greater than 5/8 inch are separated while the fine fraction is transferred by belt to the mill. The milling operation is a wet beneficiation process comprised of several circuits. From the mill, the processed concentrate is transferred by skip to a loading site, placed into enclosed trucks, and hauled to a screening plant. Screened concentrate is either stored or transferred across the Kootenai river for shipment, while a smaller quantity of concentrate is hauled to a bagging plant located in Libby. The mine and mill are located approximately 12 miles from Libby, and the screening and loading dock are approximately 7 miles from town.

Prior to 1974, both milling and screening facilities were located in the same building at the mine site. From 1935 to 1954 milling was a totally dry process, and a wet mill was added in 1954. In 1973, a new wet mill was constructed adjacent to the old mill facility, and the old and new mills operated alternately from 1973 to 1974, after which time the old mill was closed. A new screening plant was also constructed in 1973 at the river loading area, and a ventilation system and bag-house was installed in this plant to reduce dust exposure.

Prior to 1950, the ore was loaded into railroad boxcars at a loading site in Libby by the bagging plant. In 1950, the bulk loading operation was moved from the facility in Libby, to the river loading site. Railroad box cars continued to be used from 1950-1960, at which time tank cars, and subsequently, enclosed hopper cars were placed in service. In 1961, cyclones and an exhaust system were incorporated. In 1979, the loading operator's control room was destroyed by a railroad derailment, and was subsequently

reconstructed away from the loading area.

Several other changes were made which likely reduced airborne dust exposures. A ventilation fan was installed in the mill in 1964; however, the exhaust from the fan contaminated the surrounding area where the maintenance shops were located, and in 1968 the exhaust stack was moved to route the exhaust away from the shop area. A new drill with a dust control bagging system was purchased in 1970, the skipper's control room was pressurized and ventilated in 1972, and an automatic bagging machine replaced hand filling and sewing of bags in 1972.

The history of plant changes, and employment of workers over the years in the various areas, are summarized in Appendix I. The largest number of workers was employed in construction and dry mill jobs.

Environmental samples

Samples of airborne dust have been taken in the mill since 1942, and in the mine since 1968. Prior to 1969, the state of Montana collected midget impinger samples of airborne dust, and measured the dust concentrations in million particles per cubic foot of air (mppcf). After 1967, federal agencies (NIOSH, MESA, MSHA) and the company collected membrane filter samples of airborne dust, and measured the number of fibers per cubic centimeter of air (f/cc). Table 2.1 describes the samples available for analysis.

Exposure estimates

Job exposure estimates in each year of operation were derived, and an index of cumulative exposure (fiber-years) was calculated for each worker in the epidemiological studies. The individual cumulative exposure estimate was derived in 8 steps:

Step 1: Abstract and code environmental data

Data on fiber concentrations from samples taken after 1968 were abstracted from sample reports, and the jobs of the workers who were sampled were coded

for statistical analysis.

Step 2: Selection of "Location-Operations"

The facility was divided into major locations of common activity (mine, mill, bagging, loading, and concentrate hauling), and these areas were further sub-divided when necessary by operation based on exposure. This scheme was derived by McDonald et al (1985) who have conducted parallel but separate studies of the health of the Libby workers. In this study, we selected 25 "Location-Operations" (LO) based on the estimated average exposure from membrane filter samples collected from 1967-1974 (table 2.2). In the mill, the average fiber concentration differed markedly among dry mill sweepers, quality control lab workers, skippers, millwrights, other dry mill workers, and wet mill workers. In the mine, the average f/cc differed among drillers, non-drilling equipment operators, and other miscellaneous mine jobs. At the loading dock, the average f/cc differed between dock hands and ore loaders.

Step 3: Selection of the arithmetic procedure

Several estimates of the mean have been recommended when a population is log-normally distributed (Aitchinson and Brown, 1969; Oldham, 1965). However, Attfield et al.(1985) and Sieber et al.(1985) found these approximations to be more variable and biased than the arithmetic average when the population is not log-normally distributed.

The distribution of f/cc is presented in figures 2.1a-k for some LO, and was not likely log-normal except in the dry mill. For this reason the arithmetic mean was chosen as the method to compute the average f/cc, rather than an approximation to the mean.

Step 4: Conversion Ratio (mppcf:f/cc)

A conversion ratio was needed (mppcf:f/cc) to convert measurements from impinger samples collected before 1967. The conversion ratio should be derived ideally from impinger and membrane filter samples collected in the same area and at the same time. Because such data were unavailable, the ratio

Table 2.1

Description of Environmental Samples

<u>Source</u>	<u>Units of measurement</u>	<u>Year sample collected</u>	<u>Number of samples</u>
State of Montana*	mppcf	1956-1969	336
NIOSH	f/cc	1967-68	48
MESA/MSHA+	f/cc	1971-1981	789
COMPANY	f/cc	1970-1982	3279

* One sample report is available in 1942.

+ From 1969 to 1977, membrane filter samples were collected by MESA; MSHA took over MESA's activities in 1977.

Table 2.2

The average fiber/cc-years calculated from membrane filter samples collected in 1967-1974 by "Location-Operation" and year

"Location-Operation"	Year	fiber/cc-years		
		Average	Standard Deviation	Number Samples
Bus ride	67-71	1.7	--	1
	72-74	1.0	--	3
<u>Mine</u>				
Mine office	67-71	1.2	0.9	2
	72-74	1.0	0.3	6
Mine miscellaneous	67-71	1.5	1.3	8
	72-74	1.6	2.2	20
Drilling	67-71	5.9	4.2	9
	72-74	10.3	21.2	11
Mine-non-drilling	72-74	2.6	3.7	57
	74	2.6	3.4	83
Transfer point	67-71	1.9	0.6	4
	72-74	2.6	2.0	17
Tails belt	67-71	11.2	6.9	12
	72-74	4.3	5.0	16
<u>Mill</u>				
Dry mill sweeping	67-71	35.9	23.1	28
	72-74	19.0	19.8	42
Dry mill	67-71	33.2	34.7	81
	72-74	16.6	10.9	155
Old wet mill-non-millwright	67-71	3.4	2.2	9
	72-74	3.8	3.7	39
Old and new wet mill-millwright	67-71	20.2	11.6	4
	72-74	2.6	2.6	12
New wet mill-non-millwright	67-71	--	--	--
	72-74	4.6	3.6	59
Quality control lab	67-71	4.5	3.2	13
	72-74	1.7	1.5	26
Skip area	67-71	17.4	15.2	11
	72-74	4.8	14.3	31
Service area by mill	67-71	4.5	10.0	8
	72-74	1.6	5.0	75
Concentrate hauling	67-71	6.1	5.7	5
	72-74	5.3	5.3	16
<u>Loading</u>				
River station-binside	67-71	10.9	17.4	6
	72-74	26.3	43.2	12
River conveyor tunnel	67-71	48.5	19.1	2
	72-74	119.6	160.4	18
River office-binside	67-71	10.6	--	2
	72-74	10.6	0	2
Ore loading	67-71	5.6	3.3	9
	72-74	0.7	0.5	10
River dock and car cleaning	67-71	7.3	--	1
	72-74	4.9	6.1	10
Verxite plant	67-71	2.8	0.8	3
	72-74	2.8	0.8	3
Bagging plant	67-71	4.6	1.5	3
	72-74	6.0	8.2	5
Screen plant	72-74	5.0	4.1	27

Figure 2.1

Distribution of log exposures ($\ln f/cc$) by "Location-Operation"

Fig. a: All areas

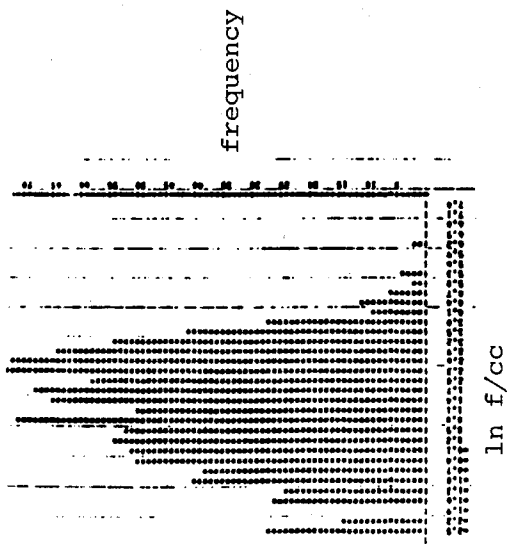


Fig. b: Quality Control

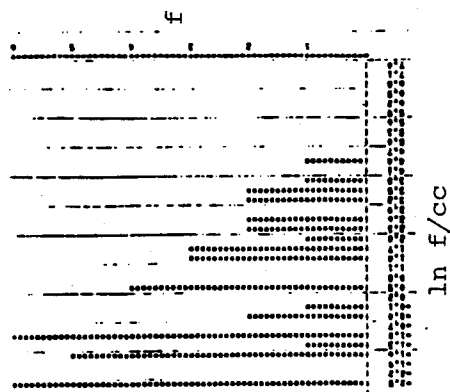


Fig. c: Service

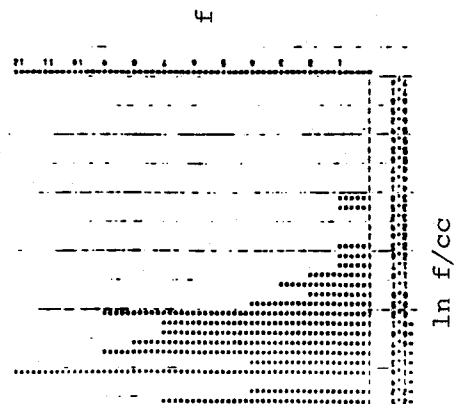


Fig. d: Skipping

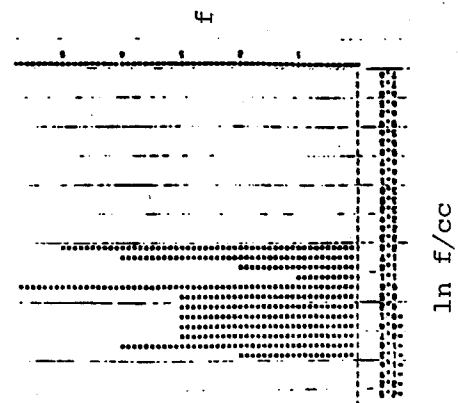


Fig. e: Tails-belt

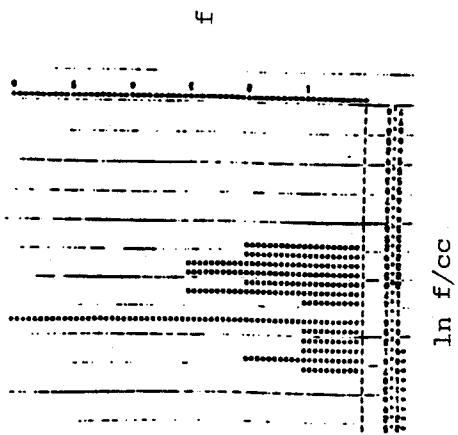
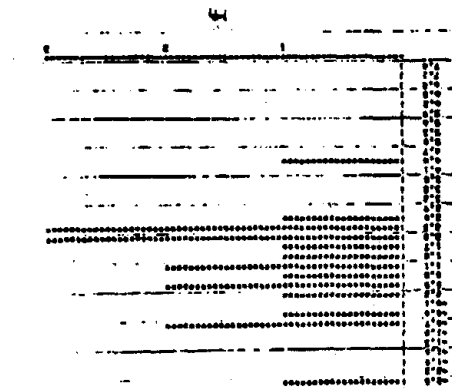


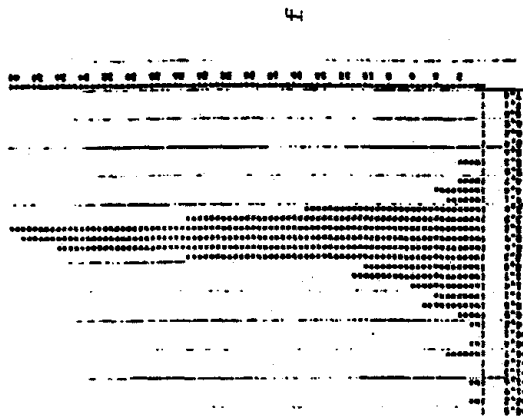
Figure 2.1 continued

Fig. g: Drilling



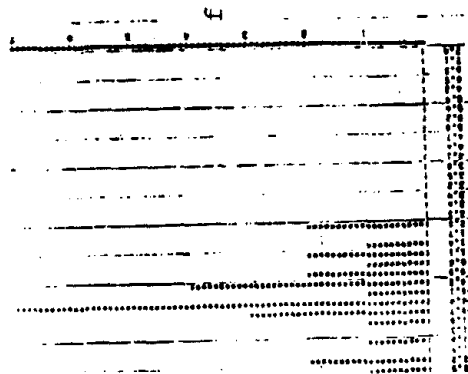
ln f/cc

Fig. j: Dry mill other



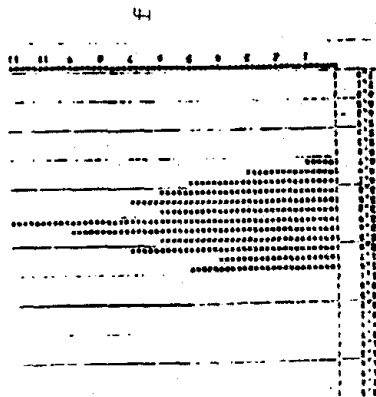
ln f/cc

Fig f: mine-miscellaneous



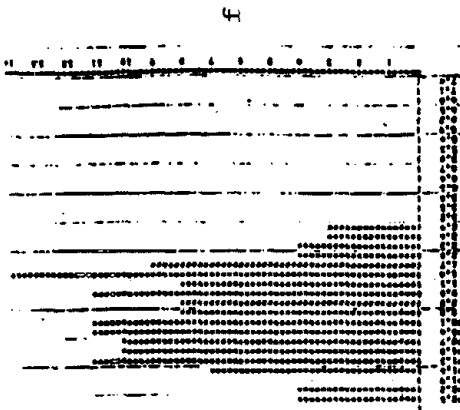
ln f/cc

Fig i: dry mill sweeping



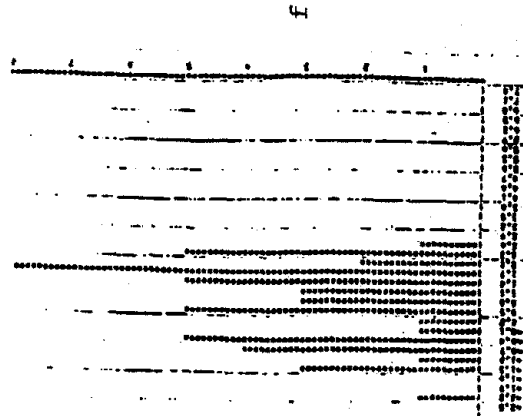
ln f/cc

Fig, h: mine-non-drilling



ln f/cc

Fig. k: old wet mill



ln f/cc

was derived from comparison of the average mppcf and average f/cc from samples taken in working areas of the dry mill during adjacent time periods when the production processes and exposures were similar. This was assumed to be the case during 1965-1971. Conversion ratios could not be derived for other LO, because prior to 1968 samples were primarily collected in the dry mill.

For the computation of the conversation ratio, only impinger and filter samples taken between 1965 and 1971 were used. Results in table 2.3 indicate that the average dust exposure in the mill was 42.1 mppcf in 1950-1964, 9.5 mppcf in 1965, and 5.7 mppcf in 1969. The average fiber exposure was 65.3 f/cc in 1967-1968, 31.0 f/cc in 1971, and 15.2-21.0 f/cc in 1972-1974. Exposures before 1964 were significantly higher, and exposures after 1971 were significantly lower than exposures during 1965-71. This is not surprising due to installation of exhaust system in the drymill in 1964, and to construction of the new mill and an emphasis on house-keeping in 1972-74.

Conversion ratios are presented in table 2.4 from comparisons of mean exposures for various combinations of adjacent time periods. The most comparable period is from 1967-1968, when both impinger and membrane filter samples were taken in the mill, and this comparison resulted in a conversion ratio of 8.0. However, only 14 filter samples were taken in 1967-68. Another possible comparison is impinger samples collected from 1967-1969 with filter samples collected in 1970. This comparison resulted in a factor of 1.9, but again a small number of filter samples were taken in this period and the average f/cc was significantly lower in 1970 than in 1967-68 and 1971.

A conversion ratio of 4.0 was selected for this study, based on the average mppcf from impinger samples in 1965-1969 and the average f/cc from filter samples in 1967-1971. These time periods were chosen to obtain enough samples for the derivation of a reasonable estimate of the average exposure, and because the production process and dust controls in the plant were assumed to be similar during this period.

Table 2.3

Average exposure by year in the dry mill

Unit of Measurement	Year of sample	Average	Standard deviation	Number of samples
mppcf**	50-64	42.1	21.0	40
	65	9.5	6.7	84
	66	9.4	4.4	70
	67	9.0	4.0	56
	68	7.5*	4.5	70
	69	5.7*	3.2	56
	67-68	8.2	4.3	126
	67-69	7.4	4.0	182
	65-69	8.4	5.0	336
	68-69	6.7	4.0	126
f/cc++	67-68	65.3	67.3	14
	70	10.9*	5.5	15
	71	31.0*	17.1	52
	72	15.2*	10.2	45
	73	15.8	11.1	79
	74	21.0*	10.7	31
	67-70	37.1	53.7	29
	67-71	33.2	34.7	81
	67-74	22.3	23.4	236

* The average exposure is significantly different from the average exposure in the previous year (p-value < 5%).

** Midget impinger samples

++ Membrane filter samples

Table 2.4

Conversion ratios (f/cc:mppcf)

Year	mppcf*						
	1967 (9.0)	1968 (7.5)	1969 (5.7)	1967-68 (8.2)	1967-69 (7.4)	1968-69 (6.7)	1965-69 (8.4)
1967-68 (65.3)	7.3	8.7	11.5	8.0	8.8	9.8	7.8
1970 (10.9)	1.2	1.5	1.9	1.3	1.5	1.6	1.3
f/cc+ 1967-70 (37.1)	4.1	4.9	6.5	4.5	5.0	5.5	4.4
1967-71 (33.2)	3.7	4.4	5.8	4.1	4.5	5.0	4.0

+Parentheses: mean f/cc

*Parentheses: mean mppcf

Step 5: Exposure estimates for "Location-Operations"

The average fiber exposure (f/cc) was estimated for each LO in several phases. In phase I, the average f/cc was calculated for each LO by combining all filter samples which were taken during years when production processes and dust control in the LO were similar. The interval estimate (table 2.5) was used to estimate the average exposure for each year of the interval. The standard error of the estimate was low, and confidence intervals were close to the mean, for all LO except the river conveyor tunnel.

In phase II, the conversion ratio was employed to convert dust exposure estimates (mppcf) prior to 1968 to fiber exposure estimates (f/cc) for the mill working area. For other operations in the mill (sweeping, quality control lab, and skipping), exposures prior to 1968 were estimated in proportion to the mill exposures after 1968 (table 2.6).

Finally, in phase III, assumptions were also made as to the exposure estimates prior to 1968 for the ore loading and river dock, bagging, and drilling areas (table 2.6, Appendix II). Exposures in these areas prior to 1968 were impossible to estimate objectively because of the lack of sample data, significant engineering changes, and the lack of a valid comparison to exposure in the dry mill. Estimates for these areas are regarded as "guesstimates" based on NIOSH and company experience concerning the effect of such changes.

However, the "guesstimates" for these LO prior to 1968 had a small effect on the average cumulative exposure estimate for the overall cohort, and on the estimate of the exposure-response curves, because a small number of workers were employed in these LO before 1968 (Appendix I). No drillers were employed from 1937-1948, and less than 3 were employed for most years during 1949-1960. No baggers were employed from 1937-1948, and only 1-2 from 1948-68. Finally, less than 5 workers were employed in the loading area for

all but 4 years before 1968. In any event, due to the subjective nature of the exposure estimates in these areas, a range of exposure was estimated based on input from the company and NIOSH's experience with the effect of dust controls (table 2.6).

Step 6: Job exposure estimates

A former plant manager estimated the number of hours that a worker in each job spent in each LO. For each year of operation, the 8-hour TWA job exposure estimate was computed as an average of the LO exposure estimates weighted by the proportion of time spent in the LO. Because a high and low exposure was estimated in some LO, a range of job exposure was also estimated for these areas. A description of job categories and the algorithms for computing the job exposure estimates are presented in Appendix III.

Step 7: Work histories

Work histories were assembled independently from personnel records by the company and by NIOSH, and the two sets of histories were then compared and edited. A final work history file was updated, and included all jobs each worker held with the company, and the dates employed in each job.

Step 8: Cumulative exposure index

An individual's cumulative exposure estimate (fiber-years) was computed as a sum of job tenures weighted by the respective job exposure estimates. For this computation tenure was computed in days, and cumulative exposure was computed in fiber/cc-days and converted to fiber/cc-years. Because a range of exposure was estimated for some jobs, a range of fiber/cc-years (f-y) was also computed for workers employed in these jobs.

RESULTS

Analysis of bulk and airborne samples

Bulk samples from the mine were analyzed by polarized light microscopy in order to locate fibrous material and to determine various physical characteristics of the fibers. The fibrous component was estimated to be in

Table 2.5

The average f/cc calculated from membrane filter samples
collected in 1967-1982 by location-operation and year

Location-operation	Year	Average	Standard Error*	Number Samples	Confidence Interval	
					Upper	Lower
Bus ride	67-74	1.2	.3	4	2.3	1.1
	>74	--	--	0	--	--
Mine office	67-74	1.0	.1	8	1.2	.8
	>74	.5	.1	18	.7	.3
Mine miscellaneous	67-74	1.6	.4	28	2.4	.8
	>74	.8	.1	33	1.0	.6
Drilling	67-70	6.7	1.7	7	10.0	3.4
	71-74	9.2	5.4	13	19.8	0.0
	>74	.6	.9	63	2.4	0.0
Mine-non-drilling	67-74	2.6	.3	140	2.0	3.2
	>74	.6	.1	157	.7	0.5
Transfer point	67-74	2.2	.4	21	3.3	1.7
	>74	.6	.0	116	.7	.5
Tails belt	67-74	7.3	1.3	28	9.8	4.8
	>74	.7	.1	30	.9	.5
Dry mill sweeping	67-71	35.9	4.4	28	44.5	27.3
	72-74	19.0	3.1	42	25.1	12.9
Dry mill	67-71	33.2	3.9	81	40.8	25.6
	72-74	16.6	.9	155	18.4	14.8
Old wet mill-non- millwright	67-74	3.7	.5	48	4.7	2.7
Old and new wet mill- millwright	67-74	7.0	4.9	16	16.7	0.0
	>75	.6	.2	14	1.0	0.2
New wet mill- non-millwright	73-74	4.6	.5	59	5.6	3.6
	75-76	2.0	.3	71	2.6	1.4
	>76	.8	.1	1214	.9	.7
Quality control lab	67-74	2.6	.4	39	3.4	1.8
	>74	.6	0.1	205	.8	.4
Service area by mill	67-74	1.9	.6	83	3.1	0.7
	>74	.2	.0	108	.2	.2
Skip area	67-71	17.4	4.6	11	26.4	8.4
	72-74	4.8	2.6	31	9.9	0.0
	>74	.6	.1	190	.7	.5
Concentrate hauling	67-74	5.5	1.2	21	7.9	3.1
	>74	.4	0.0	97	.4	.4
River station- binside	67-74	21.2	8.7	18	38.3	4.1
	>74	.7	.1	62	.9	.5
River conveyor tunnel	67-74	112.5	34.3	20	179.7	45.7
	>74	.3	.1	12	.4	.2
River office- binside	67-74	10.6	0	2	10.6	10.6
	>74	.2	0	1	.2	.2
Ore loading	67-74	3.2	.8	18	4.8	1.6
	>74	.2	.1	8	.3	.1

River dock	70-74	5.1	1.7	11	8.4	1.8
and car cleaning	>74	.5	.1	64	.6	.4
Verxite plant	67-70	2.8	.5	3	3.8	1.8
Bagging plant	67-71	4.6	.9	3	6.4	2.8
	72-74	6.0	1.2	50	8.4	3.6
	>74	1.2	.1	118	1.4	1.0
Downtown office						
building	>75	0.0	.1	3	.2	0.0
Screen plant	>74	.5	.1	443	-.7	.3

*Standard error = standard deviation divided by the square root of the number of samples.

Table 2.6

Assumptions for estimates of fiber exposure in the
Location-Operations before 1968

Area	Assumptions
Mine	(1) Exposures for all mine jobs but drillers were the same before and after 1968. (2) A range of estimates for drillers was assumed before 1970: a) <u>High estimates</u> : Exposures were 2 1/2 times higher prior to 1970 than after 1970 due to installation of a new drill with a dust control system.*** b) <u>Low estimates</u> : Estimated from 7 samples collected in 1968-1970. c) Exposures were the same in each year before 1970.
Drymill	1) Exposures for sweepers, quality control lab, and skippers were computed in proportion to the exposures in the dry mill working area: a) $\text{Sweeper}_{<68} = \text{Mill}_{<68} * (\text{Sweeper}_{68-74} / \text{mill}_{68-74})$ b) $\text{Q.C.L.}_{<68} = \text{mill}_{<68} * (\text{QCL}_{68-70} / \text{mill}_{68-70})$ c) $\text{Skip}_{<68} = \text{Mill}_{<68} * (\text{Skip}_{68-71} / \text{mill}_{68-71})$
Service area	1) Exposures in 1964-1967 were 2 times higher than after 1967 due to contamination from the exhaust stack for the ventilation fan in the dry mill.** 2) Exposures were similar before 1964 and from 1967-1974.
Ore loading (OL)	1) A range of exposures was estimated before 1968: a) <u>High estimates</u> :** 1960-1968: 30% higher than after 1970. 1950-1959: 36% higher than in 1960-1969. <1950: Ore loader split his time 50% by the box car loading area and operator's room, and 50% in bagging. The exposure at the loading dock and in the operators room (150 f/cc) was slightly lower than in the dry mill (168 f/cc). b) <u>Low estimates</u> : company's estimates. ¹
River Dock and Car Cleaning (RD)	1) <u>High estimates</u> :** 1960-1969: 30% higher than in 1970-1974. 1950-1959: 40% higher than in 1960-1969. <1950: Exposure was computed as a proportion of exposure in ore loading: $\text{RD}_{<50} = \text{OL}_{<50} * (\text{RD}_{70-74} / \text{OL}_{70-74})$ 2) <u>Low estimates</u> : company's estimates ¹
Bagging	1) <u>High estimates</u> : Assumed a 3 fold drop in exposure in 1972 due to installation of automatic bagger.*** 2) <u>Low estimates</u> : Estimated from samples in 1968-1971; Assumed exposure is same before 1968 and in 1968-1971.

¹ The company estimated the lowest exposure.

** Based on the opinion of a former manager.

*** Based on NIOSH's experience as to the reduction in dust exposure due to this engineering change.

the range of 5 to 10% by weight, was anisotropic, and had an index of refraction parallel to the fiber length of approximately 1.63. Mineralogical analyses suggest the fibers to be of the tremolite series. Asbestos in the host rock was also found to be fibrous in habit.

Further examination of individual fibers by SEM/EDAX produced iron to magnesium peak intensity ratios in the range of 42 to 57% indicating, that despite the rather low refractive index, the fibers would be better described as actinolite (Deer et al., 1966).

Area samples of the airborne dust from the mill and screening plant were obtained from the company, and analyzed by phase contrast light microscopy per NIOSH Physical and Chemical Analytical Method No. 239. Additionally, 599 fibers (>5 um in length and > 0.45 um in width) from 8 of the airborne samples were sized according to length, width, and aspect ratio (table 2.7). Results indicate that 96% of the fibers had an aspect ratio greater than 10, 67% greater than 20, and 16% greater than 50.

Exposure estimates

Estimates of exposure were extremely high in the dry mill at the loading dock, and in the bagging area prior to 1971, and particularly prior to 1965 (table 2.8). Exposure estimates before 1964 for the drymill were 168 f/cc for working areas, 182 f/cc for sweepers, 88 f/cc for skipping, and 13 f/cc for the quality control laboratory; and during 1964-1971 estimates were 33, 36, 17, and 3 f/cc respectively. Exposure estimates prior to 1971 for mine jobs were 23 f/cc for drillers and were less than 2 f/cc for non-drilling jobs. Exposure estimates prior to 1971 for jobs at the river-loading station ranged from 3-82 f/cc for ore loading, 11 f/cc for the river office, 113 f/cc for the conveyor tunnel, 17-117 f/cc for the river dock and car cleaning, and 21 f/cc for the bin area. Exposures in all areas declined from 1972-1976, less than OSHA's temporary standard of 0.5 f/cc (OSHA, 1984), and 99.5% were and during 1977-1982 most exposure estimates were less than 1.0 f/cc.

Table 2.7

Number of fibers in 8 airborne filter samples by their
length, width and aspect ratios

Length (um)	Sample								Total	
	1	2	3	4	5	6	7	8	#	%
4.98-7.04	3	11	13	4	5	1	10	7	54	9
7.04-9.96	9	22	27	20	1	3	8	19	109	18
9.96-14.08	8	24	12	15	5	4	19	20	107	18
14.08-19.91	9	18	17	22	2	13	10	20	111	19
19.91-28.16	8	11	16	20	5	11	5	14	90	15
28.16-39.82	8	12	3	11	5	5	11	10	65	11
39.82-66.00	3	4	7	6	3	8	6	9	46	8
66.00-88.00	2	2	2	1	0	1	1	1	10	2
<88.00	0	2	3	1	0	0	0	1	7	1
Total	50	106	100	100	26	46	70	101	599	100
Width (um)										
0.44-0.62	34	84	63	59	14	23	52	77	406	68
0.62-0.88	12	17	29	31	9	19	14	70	151	25
0.88-1.24	2	3	5	8	0	2	3	4	27	5
1.24-1.76	2	2	3	1	3	2	1	0	14	2
1.76-2.49	0	0	0	0	0	0	0	0	0	0
<2.49	0	0	0	1	0	0	0	0	1	0
Total	50	106	100	100	26	46	70	101	599	100
Aspect Ratios										
< 5	0	0	0	0	0	0	0	0	0	0
5-10	0	4	3	2	7	1	4	3	24	4
10-20	16	35	41	29	7	6	15	27	176	29
20-50	23	51	46	58	11	28	36	52	305	51
50-100	10	13	8	10	1	10	15	17	84	14
<100	1	3	2	1	0	1	0	2	10	2
Total	50	106	100	100	26	46	70	101	599	100

The distribution of fiber/cc-years (f-y) is presented in table 2.9 for all workers included in the mortality study cohort. The average difference between the high and low estimates was 3.5 f-y, and was relatively small with respect to the high overall average. Thus, high estimates of exposure were used in the epidemiological analyses.

DISCUSSION

The questionable accuracy of the f-y index before 1968 is recognized for workers in drilling, bagging, and loading areas. The estimate of the cumulative exposure before 1968 in the mill is more reliable than in other areas, but even in the mill the estimates of the conversion ratio for mppcf to f/cc varied from 1.2 to 11.5. Moreover, a ratio of 4.0 may be more conservative in the mill than in the mine. Dement et al.(1983a) found the ratio to be 7.8 in preparation areas, and 3.0 in non-preparation areas of a chrysotile asbestos textile plant. McDonald et al.(1980) reported the ratio to be between 1 and 5 in Quebec chrysotile mines and mills.

Clearly, the effect of the assumptions, conversion factor, season, type and source of the sample, and the arithmetic procedure to estimate the average f/cc, need to be evaluated in more detail, and will be considered further in a future report. In any event, as we noted previously, the 'guesstimates' for some areas had only a slight effect as demonstrated by the small differences between high and low estimates of f-y (table 2.9).

The most recent filter samples collected in this study were in 1982. Results indicate that the 8-hour TWA fiber exposures in 1981-1982 were 0.6-1.0 f/cc for many mine and mill jobs. From 203 samples collected by the company in 1984, 92% of the 8-hour TWA exposures were less than 0.20 f/cc, 98% were less than 1.0 f/cc (Wolter, 1985). The average 8-hour TWA exposure from the 203 samples was reported by the company as 0.1 f/cc.

Table 2.8

Estimates of exposure (f/cc) by "Location-Operation" and year

"Location-Operation"	<50	50-59	60-63	64-67	68-70	71	72-74	75-76	77-79	80-82
<u>High estimates</u>										
Bus ride	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0.0	0.0	0.0
Mine office	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5	0.5
Mine miscellaneous	1.6	1.6	1.6	1.6	1.6	1.6	1.6	0.8	0.8	0.8
Drilling	23.0	23.0	23.0	23.0	23.0	9.2	9.2	0.6	0.6	0.6
Mine non-drilling	2.6	2.6	2.6	2.6	2.6	2.6	2.6	0.6	0.6	0.6
Transfer point	2.2	2.2	2.2	2.2	2.2	2.2	2.2	0.6	0.6	0.6
Dry mill sweeping	182.1	182.1	182.1	35.9	35.9	35.9	19.0			
Dry mill	168.4	168.4	168.4	33.2	33.2	33.2	16.6			
Old wet mill non-mwt		3.7	3.7	3.7	3.7	3.7	3.7			
Old & new wet mill mwt		7.0	7.0	7.0	7.0	7.0	7.0	0.6	0.6	0.6
New wet mill non-mwt							4.6	2.0	0.8	0.8
Quality control lab	13.1	13.1	13.1	2.6	2.6	2.6	2.6	0.6	0.6	0.6
Service area by mill	1.9	1.9	1.9	3.8	1.9	1.9	1.9	0.2	0.2	0.2
Skip area	88.3	88.3	88.3	17.4	17.4	17.4	4.8	0.6	0.6	0.6
Concentrate hauling	5.5	5.5	5.5	5.5	5.5	5.5	5.5	0.4	0.4	0.4
River station bin side	21.2	21.2	21.2	21.2	21.2	21.2	21.2	0.7	0.7	0.7
River conveyor tunnel	112.5	112.5	112.5	112.5	112.5	112.5	112.5	0.3	0.3	0.3
River office bin side	10.6	10.6	10.6	10.6	10.6	10.6	10.6	0.2	0.2	0.2
Ore loading	82.5	27.7	10.7	10.7	3.2	3.2	3.2	0.2	0.2	0.2
River dock	116.9	42.5	17.0	17.0	17.0	5.1	5.1	0.5	0.5	0.5
Verxite plant	22.6	22.6	2.8	2.8	2.8					
Bagging plant	12.9	12.9	12.9	12.9	12.9	12.9	6.0	1.2	1.2	1.2
Downtown office bldg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tails belt	7.3	7.3	7.3	7.3	7.3	7.3	7.3	0.7	0.7	0.7
Screen plant								0.5	0.5	0.5
<u>Low estimates+</u>										
Drilling	6.7	6.7	6.7	6.7	6.7	9.2	9.2	0.6	0.6	0.6
Ore loading	24.0	15.0	9.0	9.0	3.2	3.2	3.2	0.2	0.2	0.2
River dock	38.0	19.0	6.4	6.4	5.1	5.1	5.1	0.5	0.5	0.5
Bagging plant	4.6	4.6	4.6	4.6	4.6	4.6	4.3	1.2	1.2	1.2

+ Low estimates are the same as high estimates for all other areas

Table 2.9

The distribution, average, standard deviation,
and range of fiber/cc-years for the mortality study cohort

fiber- years	High estimate		Low estimate	
	#	%	#	%
<30	185	31.8	185	31.8
30-50	117	20.1	122	21.0
50-100	93	16.0	92	15.8
100-200	55	9.6	53	9.1
200-300	32	5.5	32	5.5
300-400	18	3.1	18	3.1
400-500	12	2.1	13	2.2
500-600	13	2.2	15	2.6
600-700	10	1.7	6	1.0
700-1000	15	2.6	14	2.4
1000-2000	25	4.3	25	4.3
>2000	6	1.0	6	1.0
Total	581	100.0	581	100.0
Average	196.3		192.8	
S.D.	376.8		374.6	
Minimum	0.0		0.0	
maximum	2615.8		2615.8	

III. MORTALITY STUDY

METHODS

Description of cohort and results of follow-up

The study cohort included 589 white male and female workers hired prior to 1970 and employed longer than 1 year with the company. Vital status of workers was determined as of Dec. 31, 1981. A person was considered as living on Dec. 31, 1981, if he or she (1) was actively employed at the Montana vermiculite facility, was contacted by telephone, (3) was said to be living in a personal interview with the person, a friend, or next-of-kin, (4) was receiving retirement benefits from the Social Security Administration (SSA), or (5) was paying into the SSA's retirement fund. A person was considered dead as of Dec. 31, 1981, if a death certificate was obtained, or a date of death was reported by the SSA.

Death certificates were obtained from the company and state vital statistics agencies. The underlying cause of death recorded the death certificates was coded for statistical analysis according to the Eighth Revision of the International Classification of Diseases, adapted (National Center for Health Statistics, 1968). Cause of death categories analyzed for this report are listed in table 3.1, and information on workers who died of a non-malignant respiratory disease or lung cancer is presented in Appendix IV.

Vital status was determined for 581 (98.6%) of the workers in the cohort, and 417 were alive and 164 were deceased. Death certificates were obtained for 162 of the deceased (98.8%), and the date of death was determined from the SSA for the 2 without certificates.

Of the 581 workers, 12 were females and 569 were males. Unless otherwise specified in this report, the females are included in the cohort. However, results are presented separately for the total cohort (males and females), and for males only.

Table 3.1

Causes of death selected for analysis

<u>Cause</u>	<u>8th Revision ICDA Codes</u>
All malignant neoplasms	140-209
Digestive cancer	150-159
Stomach cancer	151
Lung cancer	162-163
All diseases of circulatory system	390-458
Ischemic heart disease	410-413
All non-malignant respiratory disease	460-519
Pneumonia	480-486
Emphysema	492
Tuberculosis	10-19

At the same time that this study was conducted, a parallel but separate study of the mortality and morbidity of the vermiculite workers was being conducted by McGill University, Montreal, Canada (McDonald et al., 1985a,b). Results of a comparison of data collected by NIOSH and McGill are presented in Appendix V, and indicate that there were few discrepancies in the data for workers common to both studies.

Statistical methods

A man-years analysis was employed to evaluate the cohort's mortality experience as described by Monson(1974). Man-years at risk of dying were accumulated from date of hire to Dec. 31, 1981, or to date of death for those who died before 1982, by year of follow-up, age, latency, and f-y. The number of deaths expected to occur in the study cohort during the follow-up period was calculated based on U.S. white male death rates. The Standardized Mortality Ratio (SMR) was computed by dividing the number of observed by the number of expected deaths multiplied by 100%.

Two methods were used to estimate the exposure-response curve among workers with at least 20 years latency. With the first method, the cohort was stratified into groups based upon f-y. Then, threshold and non-threshold simple linear regression models were calculated from the SMR and the average f-y of the groups. When employing the non-threshold model, the regression coefficient for f-y was derived from the data while the intercept was set at 100. Thus, the non-threshold model predicted the SMR to be 100 at zero f-y. When employing the threshold model, the intercept and the regression coefficient for f-y were computed from the data.

With the second method, the conditional probability of dying by time from

hire was estimated using the model suggested by Cox(1972):

$$A(t, Z_1, Z_2) = A_0(t) \exp(B_1 Z_1 + B_2 Z_2)$$

where t = time from hire to death or last observation
 Z_1 = age at hire
 Z_2 = f-y

$A(t, Z_1, Z_2)$ = conditional probability of dying at t , age, and f-y

$A_0(t)$ = underlying probability of dying at t and zero f-y

B_1, B_2 = regression coefficients

The model provides an estimate of the instantaneous relative risk (RR) of dying at a time from hire and a value of f-y ($RR = \exp(B_2 Z_2)$). An assumption of the model is that the RR is constant over all values of age and time from hire. The maximum likelihood procedure was used to estimate the model's parameters (Cox, 1972).

RESULTS

Descriptive results

The average exposure was 196.3 f-y for the total cohort, 200.3 f-y for males, and 7.7 f-y for females (tables 2.9 and 3.2). The total cohort (males and females) contributed 13,880 man-years of follow-up, the average age at hire was 32.3 years, the average age at death was 62.0 years, and the average net tenure was 8.3 years (tables 3.2 and 3.3).

Man-years analysis by f-y and latency

Results of the man-years analysis are presented for the total cohort (males and females) in table 3.4. The SMR was significantly increased (p-value <5%) for lung cancer (215) and non-malignant respiratory disease

(246), but wasn't statistically increased for all causes (109), digestive cancer (72), diseases of the circulatory system (86), and ischemic heart disease (84).

Mortality from lung cancer was increased after 1950, and reached statistical significance after 1975 (table 3.5). Mortality from non-malignant respiratory disease (NMRD) was elevated after 1960, and also reached statistical significance after 1975. SMR's for digestive cancer were greater than 100 in 1950-54 and in 1970-74, but failed to reach statistical significance. The average latency (time from hire to death) was 21.8 years for lung cancer, and 23.6 years for non-malignant respiratory disease (NMRD).

Results of the man-years analysis are presented in table 3.6 by exposure group (<50, 50-99, 100-399, and >399 f-y). In the >399 f-y group, the SMR was significantly increased from all causes (157), all neoplasms (268), lung cancer (576), and NMRD (401).

Mortality wasn't significantly increased for any selected cause of death in the 50-99 and 100-399 f-y groups, but SMR's exceeded 100 for most causes of death. In the <50 f-y group, the SMR was significantly increased for NMRD (230), and was elevated for lung cancer (140) but failed to reach statistical significance. Below 50 f-y, the SMR was decreased for digestive cancer, ischemic heart disease (IHD), and diseases of the circulatory system (DCS).

Mortality from any cause, lung cancer, and NMRD was further evaluated by f-y with control for latency. The number of man-years of follow-up is presented in table 3.7. The group endpoints were selected so that the number of man-years of follow-up were similar in the higher exposure categories.

The SMR for death from any cause increased with latency (i.e. time since hire), and reached statistical significance after 20 years latency (table 3.8). The SMR was also significantly increased after 100 f-y among workers with greater than 20 years latency.

Table 3.2

Average fiber/cc-years and tenure by sex

	Fiber/cc years		Tenure	
	Males	Females	Males	Females
Average	200.3	7.7	8.3	7.6
Standard deviation	379.7	17.7	8.2	10.2
Number	569	12	569	12

Table 3.3

Distribution of males and total cohort* by age at hire,
age of deceased at death, and man-years

Age Interval	Age at hire		Age at death		Man-years	
	Males #	Total+ %	Males #	Total %	Males Man-Years	Total Man-Years
< 20	58	10.2	59	10.2	0	0
20-24	119	20.9	120	20.7	0	0
25-29	114	20.0	117	20.1	5	3.1
30-39	91	16.0	93	16.0	1	0.6
35-39	52	9.1	54	9.3	4	2.5
40-44	41	7.2	43	7.4	5	3.1
45-49	48	8.4	49	8.4	15	9.3
50-54	26	4.6	26	4.5	14	8.7
55-59	12	2.1	12	2.1	21	13.0
60-64	5	0.9	5	0.9	28	17.4
65-69	3	0.5	3	0.5	23	14.3
70-74	0	0	0	0	14	8.7
75-79	0	0	0	0	22	13.7
80-84	0	0	0	0	5	3.1
>85	0	0	0	0	4	2.5
Total	569	100.0	581	100.0	161	100.0
Average age	32.3		32.3		61.8	62.0

*Total cohort of males and females

Table 3.4

Observed (O) and expected (E) number of deaths
from selected causes, and SMR

Cause	O	E	SMR	95% lower	CI for SMR upper
Any cause	164	151.0	108.6	92.6	126.6
All malignant neoplasms	38	29.4	129.2	91.4	177.3
Digestive	6	8.4	71.8	26.4	156.3
Stomach	2	1.7	120.5	14.6	435.5
Lung	20	9.3	214.8**	131.2	331.7
DCS+	67	77.6	86.3	66.9	109.6
IHD+	46	54.6	84.3	61.9	112.4
NMRD+	21	8.5	246.3*	152.4	376.5
Pneumonia	1	3.1	31.9	0.8	177.8
T.B.	1	1.3	77.0	1.9	428.9
Emphysema	4	2.2	182.5	49.7	467.4

+ DCS: Diseases of the circulatory system; IHD: Ischemic heart disease;
NMRD: Non-malignant respiratory disease; .

* p-value < 5%

** p-value < 1%

Table 3.5

Observed (O) and expected (E) number of deaths from
selected causes, and SMR, by year of follow-up

Cause of Death	Year of follow-up											
	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75+		
Any	0	0	0	2	8	12	18	26	41	57		
cause	E	0.1	0.8	5.3	9.7	13.5	18.2	25.8	30.5	47.2		
SMR	-	-	-	37.7	82.6	88.7	98.7	100.8	134.7	120.8		
All.	0	0	0	0	2	2	3	6	9	16		
malignant	E	0	0.1	0.7	1.5	2.3	3.3	4.7	6.2	10.6		
neoplasms	SMR	-	-	-	132.6	86.5	92.3	126.6	145.8	150.7		
Digestive	0	0	0	0	1	0	0	0	4	1		
cancer	E	0	0	0.3	0.6	0.8	1.0	1.36	1.61	2.71		
SMR	-	-	-	-	182.6	-	-	-	249.1	36.9		
Lung	0	0	0	0	1	1	3	4	2	9		
cancer	E	0	0	0.1	0.3	0.6	0.9	1.5	2.1	3.86		
SMR	-	-	-	-	343.1	181.3	333.9	272.2	94.7	233.1*		
DCS+	0	0	0	1	3	5	8	11	16	23		
E	0	0	0.2	2.1	4.7	7.0	9.6	13.6	15.8	24.5		
SMR	-	-	-	46.8	64.0	71.3	83.2	80.8	101.2	94.0		
IHD+	0	0	0	0	2	2	7	10	9	16		
E	0	0	0.1	0.9	2.9	4.7	6.7	9.6	11.7	18.1		
SMR	-	-	-	-	69.8	43.0	105.2	103.9	77.0	88.3		
NMRD+	0	0	0	0	0	0	3	3	5	10		
E	0	0	0	0.2	0.4	0.6	0.9	1.5	1.9	3.1		
SMR	-	-	-	-	-	-	322.4	205.3	270.5	325.3**		

+ DCS: Diseases of circulatory system

IHD: Ischemic heart disease

NMRD: Non-malignant respiratory disease

* p-value < 5%

**p-value < 1%

Table 3.6

Observed (O) and expected (E) number of deaths from selected causes, and SMR, by fiber/cc-years

Cause of Death		Fiber/cc-Year			
		< 50	50-99	100-399	>399
Any causes	O	60	75	34	45
	E	70.9	22.0	29.5	28.6
	SMR	84.6	113.8	115.2	157.1**
All neoplasms	O	13	4	6	15
	E	13.6	4.4	5.9	5.6
	SMR	95.6	91.6	102.4	268.1**
Digestive cancer	O	2	2	0	2
	E	3.8	1.2	1.7	1.6
	SMR	52.6	162.2	-	121.7
Lung cancer	O	6	2	2	10
	E	4.3	1.4	1.9	1.7
	SMR	139.9	142.6	106.2	575.5**
DCS+	O	23	12	16	16
	E	35.2	11.1	15.5	15.8
	SMR	65.3*	108.1	103.2	101.3
IHD+	O	15	9	10	12
	E	24.8	7.8	11.0	11.1
	SMR	60.6*	115.0	91.2	108.6
NMRD+	O	9	2	3	7
	E	3.9	1.2	1.7	1.8
	SMR	230.3*	166.5	179.5	400.7**

+ DCS: Diseases of circulatory system
 IHD: Ischemic heart disease
 NMRD: Non-malignant respiratory disease

* p-value < 5%

** p-value < 1%

Table 3.7

Man-years of follow-up
by latency and exposure

Latency+	Fiber/cc-years				Total
	< 50	50-99	100-399	>399	
< 10	3,684.0	765.3	851.5	411.4	5,712.2
10-19	2,320.7	730.0	922.3	679.5	4,652.5
>20	1,721.7	604.2	578.9	610.9	3,515.6
Total	7,726.4	2,099.5	2,352.7	1,701.8	13,880.4

+ Years since hire

Table 3.8

Observed (O) and expected (E) number of deaths from any cause, and SMR,
by latency and fiber/cc-years

		Fiber/cc-years				Total
Latency+		< 50	50-99	100-399	>399	
< 10	O	13	3	3	4	22
	E	16.5	4.5	5.6	3.6	30.2
	SMR	79.0	65.6	35.7	111.7	72.8
10-19	O	14	11	11	10	46
	E	19.2	6.2	11.2	9.5	46.2
	SMR	72.8	177.6	98.0	105.1	99.7
≥20	O	33	11	21	31	96
	E	35.2	11.2	12.7	15.5	74.6
	SMR	93.8	98.2	165.3*	199.5**	128.6*

* p-value < 5%

** p-value < 1%

+ Years since hire

Table 3.9

Observed and expected number of deaths from lung cancer, and SMR, by latency and fiber/cc-years

Latency+		Fiber/cc-years				Total
		< 50	50-99	100-399	>399	
< 10	O	2	0	0	2	4
	E	0.6	0.2	0.2	0.2	1.2
	SMR	331.1	-	-	1370.2*	347.3
10-19	O	2	0	1	1	4
	E	1.1	0.3	0.7	0.7	2.7
	SMR	185.2	-	139.2	182.2	148.8
> 20	O	2	2	1	7	12
	E	2.6	0.9	0.9	1.0	5.5
	SMR	76.7 ¹	219.8 ²	109.3 ³	671.4** ⁴	219.2* ⁵

+ Years since hire

1 95% confidence interval: 9.3, 277.2

2 95% confidence interval: 26.6, 794.0

3 95% confidence interval: 2.7, 609.1

4 95% confidence interval: 269.6, 1383.1

5 95% confidence interval: 113.3, 383.0

* p-value < 5%

** p-value < 1%

Table 3.10

Observed (O) and expected (E) number of deaths from
non-malignant respiratory disease, and SMR,
by latency and fiber/cc-years

		Fiber/cc-years				Total
Latency+		< 50	50-99	100-399	>399	
< 10	O	1	0	0	0	1
	E	0.6	0.2	0.2	0.2	1.2
	SMR	157.6	-	-	-	83.1
10-19	O	0	0	3	4	7
	E	0.9	0.3	0.6	0.5	2.4
	SMR	-	-	495.9*	774.5**	298.1*
≥20+	O	8	2	0	3	13
	E	2.3	0.7	0.8	1.1	5.0
	SMR	341.5**1	276.3 ²	-	278.4 ³	261.3**4

+ Years since hire

1 95% Confidence interval: 147.4, 672.9

2 95% Confidence interval: 33.4, 998.3

3 95% Confidence interval: 57.4, 813.4

4 95% Confidence interval: 139.1, 446.8

* p-value < 5%

** p-value < 1%

The lung cancer SMR for greater than 20 years latency was significantly increased in the >399 f-y group (SMR=671, p-value<1%), and was increased in the 50-99 f-y group (219), but failed to reach statistical significance (table 3.9). The SMR wasn't elevated in the 100-399 f-y group (SMR=109), and was decreased in the <50 f-y group (SMR=77).

Lung cancer among workers with less than 20 years latency was perhaps due to asbestos exposure, but the exposure-response association is unclear. The number of expected deaths was small in each f-y-latency subgroup, and the elevated lung cancer SMR in the 10-19 year latency group was not statistically significant, and did not increase with f-y.

The association between NMRD mortality and cumulative fiber exposure (table 3.10), under control for latency, is also unclear for several reasons. First, there was no consistent association between f-y and NMRD mortality in all latency groups. For greater than 20 years latency, an inverse relationship is suggested, and competing risks from lung cancer and accident mortality may be a partial explanation for this inverse trend. Accident mortality was significantly elevated for men with greater than 20 years latency (SMR=296), particularly among men in the 100-399 (SMR=635) and >399 f-y groups (SMR=567).

A second reason that makes the results for NMRD mortality difficult to interpret is that few deaths were certified due to asbestos related respiratory disease. Among all 21 NMRD deaths, only 5 deaths were due to pneumoconiosis, and in only 10 cases was fibrosis certified as an underlying or contributing cause of death. We cannot assume that the cause of death was, or was not, related to fiber exposure in the remaining cases.

Man-years analysis for males only

Clearly, results for lung cancer and NMRD for males were nearly identical to the results described above for the total cohort (table 3.11). For those

with greater than 20 years latency, the lung cancer SMR was 85 in the <50 f-y group, 225 in the 50-99 f-y group, 109 in the 100-399 f-y group, and 671 in the >400 f-y group. In addition, among those with greater than 20 years latency, the NMRD SMR was increased in most f-y groups, and was significantly increased in the <50 f-y group (328).

Man-years analysis by duration and intensity of exposure

In order to separately evaluate the contributions of duration and intensity of exposure, duration was defined as net tenure employed and intensity was defined as average exposure (f-y/duration). Workers with >20 years latency were selected for this analysis, and were stratified into 3 intensity groups (<5, 5-50, and >50 f/cc) and 4 tenure groups (<5, 5-10, 10-19, and >20 years).

Results of the man-years analysis are presented in table 3.12. The observed and expected number of lung cancer and NMRD deaths was small in the <5 f/cc intensity group, and prevented conclusions as to the mortality risk. As expected, the SMR for lung cancer and NMRD was increased among workers in the 5-50 and >50 f/cc intensity groups.

An important question is whether there is an increased lung cancer risk at an average exposure less than 2 f/cc, and particularly less than 0.1 f/cc (NIOSH(1980) recommended asbestos standard). Because the study data were not sufficient to estimate the SMR at average exposures less than 5 f/cc, conclusions must be based on estimates of the exposure-response association employing the f-y index.

Modeling the exposure-response association

Estimates of the regression coefficients for f-y in the lung cancer non-threshold model were 0.58-0.59 for males and the total cohort (table 3.13). Similarly, the regression coefficients for f-y in the lung cancer threshold model were 0.60-0.63 for males and 0.61-0.63 for the total group.

Statistical tests on the coefficients indicated that all coefficients for f-y were significantly different from zero.

Results for the survival model (table 3.14) with regard to lung cancer indicate that the regression coefficient for f-y was the same for males and the total cohort (0.0011). The contribution of age and f-y was statistically significant (p-value<5% from a likelihood ratio test). Regression coefficients in the survival model must be multiplied by 100 to be comparable to the coefficients in the linear models.

Estimated SMR's for lung cancer from the threshold and non-threshold models, and the predicted RR from the survival model, are presented in table 3.15 for males. The proportional increase in the RR at 50 f-y was 5.7% from the survival model, 29.6% from the non-threshold model, and 45.2% from the threshold model. Corresponding results at 5 f-y were 0.6%, 2.9%, and 4.5%.

DISCUSSION

An analysis of the association between asbestos exposure and lung cancer mortality is not complete without controlling for cigarette smoking. Smoking habit information was unavailable on the entire cohort and the number of lung cancer deaths was too small to provide sufficient statistical power to measure an odds ratio below 2.0 in a case-control study.

Because it was not possible to estimate the association between lung cancer mortality and cumulative fiber exposure with an internal control for smoking, an attempt was made to control for smoking effects using external comparison groups.

The distribution of workers by smoking habit is shown in table 3.16 for vermiculite workers and U.S. white males. The proportion of current and former smokers was at least 15.5% higher among 161 vermiculite workers employed from 1975-1982 with at least 5 years tenure, than among U.S. white

males in 1975. In addition, smoking and cumulative fiber exposure was correlated for workers employed in 1975-82 (table 4.9).

We attempted an external control for smoking, but results were inconclusive. The study cohort's lung cancer mortality experience was compared with that of coal and metal miners who had smoked. The mortality experience has been previously reported for 3,726 coal miners (Amandus et al., 1982; Costello, et al., 1974) and for 12,111 metal miners (Costello, 1983). SMR's were calculated for the coal and metal miners using U.S. white males as the standard population (table 3.17).

Because the average lung cancer latency was 21 years for the vermiculite cohort, and the average age at hire was 32 years, one would expect the greatest excess lung cancer attributable to fiber exposure to have occurred among those age 50-59. Indeed, in this age range (table 3.17) the lung cancer SMR was greater for workers in the study cohort with greater than 50 f-y than for coal and metal miners who had smoked. It would appear that fiber exposure above >50 f-y is perhaps associated with an excess lung cancer mortality over that due to smoking alone in coal and metal miners. However, smoking could not be controlled adequately. The vermiculite workers had a longer follow-up period than the coal and metal miners, and duration of smoking could still be a confounding factor.

Results from other studies in which individual exposures were calculated, are presented in tables 3.18 and 3.19. The slope of the exposure-response curve for lung cancer mortality was higher for the Libby workers than for workers exposed predominantly to chrysotile (Weill et al., 1979; McDonald et al. 1980; McDonald et al., 1984; Henderson et al., 1979), and for workers exposed to chrysotile, amosite, and crocidolite (Weill et al., 1979; and Henderson et al., 1979). However, the slope for the Libby workers wasn't as high as for workers exposed to chrysotile in asbestos textile plants (Dement et al., 1983a,b; McDonald et al., 1982, 1983).

Table 3.11

Observed (O) and expected (E) number of deaths from lung cancer and NMRD,
and SMR, for males by fiber/cc-years and latency

Latency+		Fiber/cc-years				Total
		< 50	50-99	100-399	>399	
<u>Lung Cancer</u>						
<10	O	2	0	0	2	4
	E	0.6	0.2	0.3	0.2	1.1
	SMR	338.7	0	0	1370.2*	351.8
10-19	O	2	0	1	1	4
	E	1.0	0.3	0.7	0.6	2.6
	SMR	196.5	0	139.2	182.2	152.8
≥20	O	2	2	1	7	12
	E	2.4	0.9	0.9	1.0	5.2
	SMR	84.7	225.1	109.3	671.3**	230.4*
Total	O	6	2	2	10	20
	E	4.0	1.4	1.9	1.7	9.0
	SMR	151.2	145.8	106.2	575.5**	223.2**
<u>NMRD</u>						
<10	O	1	0	0	0	1
	E	0.6	0.2	0.2	0.2	1.2
	SMR	162.1	0	0	0	84.5
10-19	O	0	0	3	4	7
	E	0.9	0.3	0.6	0.5	2.3
	SMR	0	0	459.9*	774.5**	304.9*
20+	O	7	2	0	3	12
	E	2.1	0.7	0.8	1.1	4.8
	SMR	327.8*	283.5	0	278.4	252.6**
Total	O	8	2	3	7	20
	E	3.6	1.2	1.7	1.8	8.2
	SMR	220.0	170.2	179.5	400.8**	243.0**

+ Years since hire

* p-value < 5%

** p-value < 1%

Table 3.12

Observed (O) and expected (E) number of deaths, from lung cancer
and NMRD, by average exposure and tenure
for workers with > 20 years latency

Average Exposure+		Tenure (years)				Total
		< 5	5-10	10-19	20+	
<u>Lung Cancer</u>						
< 5	O	0	0	0	1	1
	E	0.4	0.4	0.3	0.3	1.3
	SMR	-	-	-	365.3	76.4
5-50	O	3	1	0	1	5
	E	2.3	0.2	0.3	0.6	3.4
	SMR	129.5	482.0	-	161.5	146.8
> 50	O	0	3	0	3	6
	E	0.2	0.4	0.2	0.1	0.8
	SMR	-	867.5*	-	3444.4**	790.6**
<u>NMRD</u>						
< 5	O	0	1	0	0	1
	E	0.3	0.3	0.4	0.2	1.1
	SMR	-	328.8	-	-	89.1
5-50	O	9	0	0	0	9
	E	2.0	0.1	0.3	0.5	3.0
	SMR	443.3**	-	-	-	269.9**
> 50	O	0	2	1	0	6
	E	0.1	0.5	0.2	0.1	0.8
	SMR	-	406.0	590.4	-	365.1
<u>Man-Years</u>						
<5		239.8	192.3	186.7	209.5	828.3
5-50		1565.6	146.3	149.9	340.1	2201.9
>50		151.8	177.8	87.9	67.9	485.4

* p-value < 5%

** p-value < 1%

+ Average exposure = f-y/tenure

Table 3.13

Linear regression equations to predict the lung cancer SMR
from fiber/cc-years for workers with at least 20 years latency

Fiber/cc-years		Males		Total cohort	
Group	Average	SMR	SMR	SMR	SMR
<50	28.1	85	85	77	77
50-99	72.7	225		220	
50-399	151.1		167		164
100-399	209.6	109		109	
>399	957.1	671	671	671	671
Threshold model:					
	Intercept	82.53	69.53	77.30	64.77
	(SE)	(65.55)	(2.57)	(64.26)	(6.66)
	Coefficient	0.60*	0.63*	0.61*	0.63*
	(SE)	(0.13)	(0.005)	(0.13)	(0.01)
Non-threshold model:					
	Intercept	100.0	100.0	100.0	100.0
	Coefficient	0.58*	0.59*	0.58*	0.59*
	(SE)	(0.08)	(0.03)	(0.08)	(0.03)

* Coefficient is significantly different from zero, p-value < 5%

Table 3.14
Regression coefficients, and standard error, for
age and fiber/cc-years (f-y) in survival model for lung cancer
for workers with at least 20 years latency

		Males	Total Cohort
Age	Coefficient	-0.0212	-0.0222
	Standard Error	(0.0353)	(0.0353)
f-y	Coefficient	0.0011	0.0011
	Standard Error	(0.0004)	(0.0004)

Table 3.15

SMR and relative risk (RR) for lung cancer for males with greater than
20 years latency by fiber/cc-years

fiber/cc years	Threshold Linear Model SMR	Non-threshold Linear Model SMR	Survival Model RR
0	69.5	100.0	1.000
5	72.6	102.9	1.006
25	85.2	114.8	1.028
50	100.9	129.6	1.057
100	132.4	159.2	1.116
% increase for 5 f-y*	4.5	2.9	0.6
% increase for 50 f-y*	45.2	29.6	5.7

* Relative to zero f-y.

Table 3.16

The proportion of current and former smokers among U.S.
white males and vermiculite workers

Year	current %	former %	total %
<u>U.S. white males*</u>			
1955	52.6	10.9	63.5
1957	52.0		
1964	52.9	22.2	75.1
1965	51.1		
1966	51.9	23.6	75.1
1967	49.1		
1968	47.0		
1969	44.0		
1970	42.3	32.6	74.9
1971	47.0		
1972	48.0		
1974	42.7		
1975	39.3	29.2	68.5
1976	41.9		
1977	41.0		
1978	37.5		

Vermiculite workers

<u>1975-1982</u>	<u>35.0</u>	<u>49.0</u>	<u>84.0</u>
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*Information from U.S. Public Health Service (1979)

Table 3.17
Observed number of lung cancer deaths (O), death rate per
100,000 man-years (O/MY), and SMR, by age

Age at follow-up									
Study Group	40-49			50-59			60-69		
	O	$\frac{O}{MY}$	SMR	O	$\frac{O}{MY}$	SMR	O	$\frac{O}{MY}$	SMR
Active coal miners+	1	20	61	4	69	62	8	362	144
Ex-coal miners+	0	0	0	1	99	87	3	150	59
Metal miners+	51	**	157	52	**	162	16	**	296
Vermiculite workers									
>1									
year									
tenure++									
<50 f-y	1	197	546	1	156	135	0	0	0
50-100 f-y	0	0	0	1	442	385	1	641	234
100-399 f-y	0	0	0	1	373	318	0	0	0
>399 f-y	1	862	2412	9	1574	1333	4	1428	538
Total group	2	56	202	12	407	392	5	346	145

+ Current smokers at beginning of the mortality follow-up

** Estimates of man-years were unavailable.

++ Workers with 20 or more years latency.

Table 3.18

Results of the exposure-response association for
lung cancer mortality from asbestos studies++

Chry. only		Weill		Total Group		Dement		McDonald		This study		Henderson		McDonald et al.	
Chry.	only	Chry & Croc		mppcf-		mppcf-		mppcf-		mppcf-		mppcf-		(1982)(1983)(1984)	
yrs	SMR	yrs	SMR	yrs	SMR	yrs	SMR	yrs	SMR	yrs	SMR	yrs	SMR	Pa. S.C. Conn.	
6	56	11	100	5	77	0.5	140			7	77	62	198	mppcf- yrs	SMR
						5	279					182	180	<10	67 143 167
						23	352	30	104	38	164	352	328	10-20	84 183 102
64	77	77	53	30	70	64	1099	100	140			606	450	20-40	156 304 105
				125	144	137	1818	300	142	239	671	976	778	40-80	160 420 163
654	182	698	241	400*	226			500	170					>80	416 1032 55
								1200	268						

* Weill et al. (1979) used 400 to represent this group with >200 mppcf-years.

+ Exposure is calculated as the midpoint of exposure groups reported by Dement et al. (1979).

** Fiber-years was converted to mppcf-years using a conversion factor of 4.0 f/cc:mppcf.

++ Weill et al. (1979); Dement et al. (1983b); McDonald et al. (1980), Hendersen et al. (1979); McDonald et al. (1982, 1983, 1984).

Table 3.19

Regression equations to estimate the SMR and RR
for lung cancer from mppcf-years

Asbestos Study	Regression Coefficients			
	Threshold model		Non-threshold model	
	Intercept	mppcf-yr	Intercept	mppcf-yr
Weill et al.(1979) ⁺¹				
Total Group	74.3	0.39	100	0.31
Chry. Only	59.7	0.19	100	0.12
Chry. & Croc.	67.4	0.24	100	0.19
Dement et al.(1983b) ⁺¹	172.0	12.37	100.0	13.08
McDonald et al.(1982) ^{*2}			100.0	5.1
McDonald et al.(1983) ^{*2}			100.0	5.9
Henderson et al.(1979) ^{*1}			100.0	0.66
McDonald et al.(1980) ^{*2}			100.0	0.14
This study ¹	62.7	2.55	100.0	2.37

+ Equations computed from authors' published data which are presented in table 3.18

* Equations published by authors

1 Equations predict SMR

2 Equations predict RR

Table 3.20

Distribution of airborne fibers (length > 5 um and width > .45 um) by length and aspect ratio

	length				Aspect Ratio				Total #			
	5-10		≥10		<10		10-15			≥15		
	#	%	#	%	#	%	#	%		#	%	
<u>Dement and Harris*</u>												
Textile	(Prep.) C-1	333	44	427	56	448	59	45	6	267	35	760
	(Twist.) C-2	135	34	260	66	204	52	21	5	170	43	395
	(Weave.) C-3	133	31	293	69	218	51	15	4	193	45	426
Friction	(Mix.) C-4	48	32	100	68	62	42	9	6	77	52	148
	(Form.) C-5	42	42	59	58	50	50	4	4	47	47	101
	(Fin.) C-6	74	30	169	70	151	62	12	5	80	33	243
Cement Pipe	(mix.) C-7	52	45	63	55	57	50	7	6	51	44	115
	(form.) C-8	20	36	36	64	20	36	4	7	32	57	56
	(fin.) C-9	19	26	55	74	21	28	2	3	51	69	74
Amo.Pipe Ins.	(mix.) C-10	41	41	59	59	33	33	16	16	51	51	100
	(form.) C-11	27	44	34	56	28	46	10	16	23	38	61
	(fin.) C-12	7	48	29	52	27	48	9	16	20	36	56
This study		163	27	436	73	24	4	88	15	487	81	599

* Data abstracted from Harris and Dement (1979);

prep. = preparation, twist. = twisting, weave. = weaving, mix. = mixing

form. = forming, fin. = finishing

There are various explanations for the differences in slope among studies including (1) physical characteristics of fibers, (2) cohort effect, (3) competing risks, (4) exposure to different fiber types, (5) misclassification of exposure, (6) misclassification of disease, and (7) imprecision of the estimate of the SMR at low f-y.

In order to determine whether differences in fiber dimensions could explain the difference between slopes in this and other studies, results of fiber dimensions were compared between samples collected in this study, and samples reported on by Dement and Harris (1979) collected in plants that manufactured textiles, friction products, asbestos cement, and amosite insulation.

Because Dement and Harris, employed electron microscopy and we used optical microscopy to measure fiber dimensions, only fibers longer than 5 μ m and wider than 0.45 μ m were considered. (Although thinner fibers could have been detected optically, we arbitrarily chose 0.45 as a cut-off in our fiber counting).

Results of this comparison (table 3.20) indicate that the proportion of fibers (longer than 5 μ m and wider than 0.45 μ m) with aspect ratio >15 was 81% in our vermiculite samples, and was 35-45%, 33-52%, 44-69%, and 36-51% respectively in samples from textile, friction product, asbestos cement pipe, and amosite insulation plants.

These results would suggest that the tremolite-actinolite fibers contaminating the Montana vermiculite ore have a higher aspect ratio than amphibole and chrysotile fibers in other industries. However, Dement and Harris showed that for all fibers counted using the EM, the textile fibers tended to be longer and thinner than in the other applications. Thus, the aspect ratio of textile fibers may be higher for the shorter than the longer textile fibers. In any event, these and other results reported by Langer et

Table 3.21

Lung Cancer SMR by tenure (years) for workers with >20 years latency+

This study		Dement et al.		McDonald et al.		Hughes et al.		McDonald et al.			
Tenure	SMR	Tenure	SMR	Tenure	SMR	Tenure	SMR	Tenure	SMR	PA	SC
1mth-1	97	1mth-5	207	1mth-5	91	1mth-2	74	<1	70		78
1-5	106	5-20	246	5-20	137	2-10	80	1-5	32		164
5-20	240	>20	728	>20	161	>10	215	5-20	129		304
>20	510							>20	160		317

+ Dement et al.(1983b), McDonald et al.(1980), Hughes et al.(1980),
McDonald et al.(1982, 1983)

al.(1974) offer a possible explanation for the higher slope for lung cancer in this study than in the studies of Henderson et al.(1979), Weill et al.(1979), McDonald et al.(1984), and McDonald et al.(1980).

Another possible explanation for the difference in slopes between this and other studies is due to a cohort effect. As noted by Dement et al.(1983b), Henderson et al.'s cohort may have had a lower force of mortality since they were a survivor group of retirees.

Differences in the arithmetic method for computing the 8-hour TWA exposure may also explain differences in the exposure estimates among studies. Dement et al.(1983b) used a log-linear model to estimate the geometric mean f/cc. For our data we found that the geometric mean was 2-4 times lower than the arithmetic mean in some areas where the distribution of exposures was skewed. However, even a factor of 4 cannot entirely explain the 6-fold difference in slopes between our and Dement et al.'s study.

Lung cancer mortality results are presented by tenure in table 3.21 for studies in which individual cumulative fiber exposures have been estimated. The similarity of the excess lung cancer risk among studies with respect to tenure may suggest that missclassification of exposure is perhaps a partial explanation of the differences in slope.

An objective of this study was to estimate the exposure-response curves in order to identify a level of fiber exposure which does not result in excess mortality from lung cancer, non-malignant respiratory disease, or other causes of death. The current OSHA standard for amphiboles is 2.0 f/cc, but OSHA has considered a temporary standard of 0.5 f/cc, and is considering levels of 0.1, 0.2, or 0.5 f/cc (OSHA, 1983, 1984). The current MSHA (1983) standard is 2 f/cc, and NIOSH (1980) presently recommends a standard of 0.1 f/cc. Thus, 5 f-y (0.1 f/cc over a working life-time of 50 years), 25 f-y (0.5 f/cc over 50 years), and 100 f-y (2 f/cc over 50 years) are important cumulative exposures to consider.

Results from this study are unclear as to the increase in the relative risk of lung cancer at exposures less than 50 f-y. Results for workers with at least 20 years latency indicate that 5 f-y is associated with a 2.9% increase in the SMR based on the non-threshold linear model, and a 0.6% increase in the relative risk based on the survival model. In contrast, the results of the man-years analysis suggest a decreased lung cancer mortality below 50 f-y. Clearly, the small number of data points used to derive the linear models, and the large confidence interval for the SMR for lung cancer below 50 f-y, add to the uncertainty of the estimated increases in lung cancer risk below 50 f-y.

Results of studies of the lung cancer mortality risk due to chrysotile exposure are also conflicting below 50 f-y. Dement et al.(1983b) reported a significant lung cancer mortality excess below 27 f-y in textile workers, which was confirmed in this and another plant by McDonald et al.(1982, 1983). In contrast, McDonald et al.(1980) and Hughes et al. (1979) didn't find an excess mortality below 30 mppcf-y among workers predominantly exposed to chrysotile. McDonald et al.(1980) reported that the conversion factor was likely 1 to 5 mppcf:f/cc in Quebec chrysotile mines and mills, and thus, 30 mppcf-years in Quebec mines could perhaps be equivalent to 30-150 f-y.

Another source of bias among studies is the choice of the standard population, and this must be considered when interpreting the man-years results. Because conclusions as to the intercept of the exposure-response curve may vary with the standard population, the slope rather than the intercept of the exposure-response curve becomes a reasonable parameter upon which to base recommendations for health standards.

With regard to mesothelioma, 2 cases were observed by Dec. 31, 1981. The two cases were hired in 1946, died between 1979-1980, had a latency of 33 years, had a tenure less than 20 years, had an exposure greater than 300 f-y,

and worked more than 70% of their tenure in the dry mill. The proportional mortality rate for mesothelioma was 3.6% (2/56) for dry mill workers, 7.1% (2/28) for dry mill workers with greater than 20 years latency, 2.1% (2/96) for the total cohort with greater than 20 years latency, and 1.2% (2/164) for the total cohort. The proportional mortality rate for mesothelioma among workers with at least 20 years latency was similar to results of studies of other amphibole exposed workers (McDonald et al., 1977)

CONCLUSIONS

Conclusions from the mortality study are as follows:

1. A cumulative fiber exposure above 400 f-y is associated with an increased risk of lung cancer mortality.
2. Cumulative fiber exposures of 50 to 399 f-y are also associated with increased risks of lung cancer mortality. Based on the survival model, 50 f-y is associated with a 5.7% increase in the lung cancer RR over that due to zero f-y. Based on the non-threshold model, 50 f-y is associated with a 29.6% increase in the SMR for lung cancer mortality over that due to zero f-y.
3. Cumulative fiber exposures less than 50 f-y are associated with increased risks of lung cancer mortality. At 5 f-y, the relative risk for lung cancer is increased 0.6% from the survival model, and 2.9% from the non-threshold model.
4. Estimates of the increase in lung cancer risks were not controlled for the effect of smoking, and smoking must be considered as a possible confounder.
5. The proportional mortality for mesothelioma is similar to that reported in other populations exposed to amphiboles.

IV. MORBIDITY STUDY

METHODS

Radiographic examinations were administered to active workers in 1959, and annually from 1964-1982. A questionnaire on the occupational and smoking history and respiratory symptoms was administered after 1975. Radiographs were unavailable for more than 50% of the workers who were employed less than 5 years, or who terminated prior to 1975 (table 4.1). Therefore, the study sample was restricted to 191 men employed during 1975-1982 with at least 5 years tenure. Chest radiographs were available for 184 men and questionnaires for 121.

All available radiographs of workers were interpreted independently by 3 'B' readers using the ILO classification (ILO, 1980). The most recent radiographic results were evaluated in this study from films taken in 1981-1982 for 134 workers, in 1976-1980 for 49 workers, and prior to 1975 for only 1 worker (table 4.2).

Radiographic findings evaluated were (1) small opacities with a profusion greater than or equal to ILO category 1/0, (2) unilateral or bilateral pleural change, which includes pleural plaque or diffuse thickening on the wall, diaphragm, or other site, but excludes costophrenic angle obliteration, (3) unilateral or bilateral pleural calcification on the wall, diaphragm, or other site, and (4) unilateral or bilateral pleural plaque or diffuse pleural thickening on the lung wall. A final determination for the profusion of small opacities was derived from a median of the 3 readers, and for each pleural finding from a consensus of the readers.

Respiratory symptoms considered included cough, phlegm, dyspnea, and wheezing. An affirmative answer to the following questions were considered evidence of the symptom:

Cough:	Do you usually cough for more than 3 months in a year?
--------	--

Table 4.1

Number of workers with and without radiographs available,
by last date employed and tenure*

Year last worked	Tenure (years)									
	0		<1		1-4		5-10		>10	
	film	NO film	film	NO film	film	NO film	film	NO film	film	NO film
<70	0	86	6	704	17	267	9	59	10	47
71-74	0	1	1	13	9	34	3	7	12	7
75-82	0	0	7	143	68	55	85	4	121	6

* Includes male and female employees

Table 4.2

Number of male workers by year of most recent radiographic exam

<u>Year of last radiograph</u>	<u>#</u>	<u>%</u>
1982	14	7.6
1981	120	65.2
1978-1980	33	17.9
1975-1977	16	8.7
<1975	1	0.5
Total	184	100.0

Phlegm: Do you usually raise mucous, sputum, or phlegm for 3 or more months in a year?

Dyspnea: (1) Do you usually notice shortness of breath after quickly walking up one flight of stairs?

(2) Do you usually have to walk slower on level ground than other people your own age because you get short of breath?

(3) Do you usually notice shortness of breath after walking at your own pace on level ground?

(Answers to questions (1), (2) and (3) were considered as mild, moderate and severe dyspnea respectively. There were no mild cases, and dyspnea is defined as an affirmative response to question (2) or (3)).

Wheezing: Does your chest sound whistly or wheezy?

Individual cumulative fiber exposure estimates (f-y), tenure, and age were calculated as of the date of the most recent radiographic examination.

RESULTS

DESCRIPTIVE RESULTS

The average age, tenure, and f-y was similar among the 191 men who met the sample inclusion criteria, and the 184 men who had radiographs available (tables 4.3-4.4). For men with radiographs available, the average age, tenure, and cumulative fiber exposure was 44 years, 14 years, and 119 f-y respectively.

RADIOGRAPHIC FINDINGS

The prevalence of small opacities (profusion greater than 1/0) was 10%, any

Table 4.3

The average and standard deviation (S.D.) of age, tenure, and fiber-years exposure for all men in the study sample*

		Age at exam+	Age in 1982	Tenure	Fiber-years
All workers*	Average		46	14	123
	S.D.		12	8	281
	Number		190	191	191
Workers with radiographs+	Average	44	46	14	119
	S.D.	12	12	8	277
	Number	183	183	184	184

* All male workers employed from 1975-1982 with at least 5 years tenure

+ Most recent radiographic examination

Table 4.4

Distribution of age, tenure, and fiber-years

	All workers in study sample*		Workers with an X-ray+	
	#	%	#	%
<u>Age</u>				
20-29	15	7.9	20	10.7
30-39	52	27.4	55	30.0
40-49	49	25.8	46	25.7
50-59	33	17.4	30	16.6
>60	41	21.6	32	17.1
Total	190	100.0	183	100.0
<u>Tenure (years)</u>				
6-10	77	40.3	76	41.3
11-15	52	27.2	49	26.6
16-20	23	12.0	23	12.5
21-25	18	9.4	17	9.2
26-30	10	5.2	10	5.4
>31	11	5.8	9	4.9
Total	191	100.0	184	100.0
<u>Fiber-years</u>				
0-15	64	33.5	63	34.2
16-30	30	15.7	29	15.8
31-86	47	24.6	44	23.9
>86	50	26.1	48	26.1
Total	191	100.0	184	100.0

- * All male workers employed from 1975-1982 with greater than 5 years tenure
 + All workers in the study sample with an available radiograph. Age, tenure, and f-y are computed as of the date of the most recent radiograph.

Table 4.5

Radiographic findings by fiber-years

Radiographic finding		Fiber-years				Total
		0-15	16-30	31-85	>86	
Small Opacities+	Yes	0	1	3	14	18
	No	63	28	41	34	166
	Total	63	29	44	48	184
	% Yes	0	4	7	29	10
Any pleural change+	Yes	4	1	8	15	28
	No	59	28	36	33	156
	Total	63	29	44	48	184
	% Yes	6	3	18	31	15
Pleural calcification*	Yes	1	0	3	3	7
	No	62	29	41	45	177
	Total	63	29	44	48	184
	% Yes	2	0	7	6	4
Pleural thickening on the wall+	Yes	4	1	6	13	24
	No	59	28	38	35	160
	Total	63	29	44	48	184
	% Yes	6	3	14	27	13

+ Association with fiber-years is significant (p-value < 5%)

* Association with fiber-years is not significant (p-value > 5%)

Table 4.6

Cases of small opacities

Case	Age at time of Radiograph	Median Profusion Category	type opacity+ Reader			f-y	Total tenure (years)	Date of hire
			A	B	C			
1	61	1/2	ST	TS	ST	1013	30	52
2	64	1/1	ST	TS	SS	407	15	62
3	44	1/0	ST	SS	SS	1231	30	50
4	60	1/2	ST	QT	TS	114	30	50
5	48	2/2	SS	SP	SS	27	15	67
6	69	1/0	TS	TQ	TT	63	29	47
7	67	1/1	ST	TT	ST	352	18	58
8	67	1/0	TS	QT	QT	310	43	37
9*	63	2/1	TU	TQ	PS	124	11	65
10	61	2/2	TT	TT	TU	660	23	53
11*	58	2/2	ST	TT	SS	1796	28	48
12	59	1/2	SS	QT	SS	77	36	46
13	53	2/1	SP	QS	SS	2327	32	45
14	43	1/0	ST	TQ	ST	33	14	66
15	63	3/3	ST	TT	SS	133	16	61
16	66	1/1	SS	TS	SP	130	13	65
17	66	1/0	ST	QT	TT	150	16	60
18	47	1/0	TS	TQ	ST	116	19	63

* Large opacity present

+ According to the ILO classification scheme, the type of opacity recorded first is that primarily present, and that recorded second is that of secondary predominance.

Table 4.7

Number of workers by radiographic category of
profusion of small opacities and reader

Profusion Category	Reader			Median*
	A	B	C	
0/0 0/0-0/1	166	151	166	166
1/0	3	14	7	6
1/1	5	9	5	4
1/2	3	3	3	2
2/1	1	4	0	2
2/2	4	1	1	3
2/3	1	0	0	0
3/2	0	1	1	0
3/3	1	1	1	1
3/+	0	0	0	0
Total	184	184	184	184

* The median of the profusion categories from readers A, B, and C

pleural change was 15%, pleural calcification was 4%, and pleural change on the wall was 13% (table 4.5). The association between each radiographic finding and f-y was significant (p-value <5%), except for pleural calcification.

Information on the 18 cases of small opacities is presented in table 4.6. All readers reported only irregular opacities (no rounded) in 9 cases, and 2 readers reported only irregular opacities in 15 cases. All readers agreed that irregular opacities were primarily present in 12 cases, and 2 readers agreed in 17 cases. Finally, at least 2 readers reported large opacities in 2 cases on a background of irregular opacities.

Comparison of readers

The distribution of films by reader and radiographic category of small opacities is presented in table 4.7. Results indicated that readers A and C reported a similar prevalence of small opacities (10%), while reader B reported the highest prevalence (16%). In any event, a 6% difference in prevalence is well within limits of inter-reader variability for films predominantly classified into ILO category 1 (Reger et al., 1973; Amandus et al., 1974).

The exposure-response association with control for age and cigarette smoking

Because age and cigarette smoking could confound the exposure-response relationship, the associations between radiographic finding, age, smoking, and f-y were evaluated (table 4.8). The prevalence of small opacities significantly increased with age (p-value<5%), and although markedly higher among current smokers (12%) than ex and non-smokers (4-6), the association with smoking failed to reach statistical significance. The prevalence of any pleural change was similarly related to age, but was not associated with cigarette smoking habit. Similar results were found for the correlation between smoking, age, and f-y (table 4.9).

Table 4.8

Radiographic findings by age and cigarette smoking habit

Radiographic finding		Cigarette smoking habit+			Age*	
		Current smoker	Ex-smoker	Never smoker	24-44	>45
Small Opacities	Yes	7	5	1	2	16
	No	49	75	24	109	57
	Total	56	80	25	111	73
	% Yes	12	6	4	2	22
Any pleural change	Yes	14	3	10	18	
	No	49	66	22	101	55
	Total	56	80	25	111	73
	% Yes	13	18	12	9	25

+ Smoking habit is not significantly associated with small opacities or any pleural change (p-value > 5%).

* Age is significantly associated with small opacities and pleural change (p-value < 5%).

Table 4.9

Fiber-years by smoking habit and age

Fiber-years					
	<86		≥ 86		Total Number
	Number	%	Number	%	
<u>Smoking Habit*</u>					
Current	42	75	14	25	56
Ex	60	75	20	25	80
Never	22	88	3	12	25
<u>Age+</u>					
< 45	96	86	15	14	111
≥ 45	40	55	33	45	73

* Association with f-y is not significant (p-value > 5%)

+ Association with f-y is significant (p-value < 5%)

Table 4.10

Radiographic finding by fiber-years (f-y) under control for age and smoking habit*

Age	Smoking habit	f-y	Small Opacities				Any pleural change			
			Yes	No	Total	% Yes	Yes	No	Total	% Yes
<45	Current smoker	<86	1	33	34	3	1	33	34	3
		≥86	0	5	5	0	1	4	5	20
	Ex-smoker	<86	0	41	41	0	5	36	41	12
		≥86	0	8	8	0	2	6	8	25
	Never smoker	<86	0	16	16	0	1	15	16	6
		≥86	1	0	1	100	0	1	1	0
≥ 45	Current smoker	<86	1	7	8	13	1	7	8	13
		≥86	5	4	9	56	4	5	9	44
	Ex-smoker	<86	1	18	19	5	4	15	19	21
		≥86	4	8	12	33	3	9	12	25
	Never smoker	<86	0	6	6	0	1	5	6	17
		≥86	0	2	2	0	1	1	2	50

+ The association between f-y and radiographic finding within each age-smoking habit group was not significant (p-value > 5%).

Table 4.11

Logistic Model

	Regression Coefficients			SE of Coefficients		
	Intercept	f-y	Age	Intercept	f-y	Age
<u>Total Group</u>						
Small Opacities	-9.6*	.0026*	.131*	2.11	.001	.036
Any Pl. Change	-4.3*	.0008	.051*	0.94	.001	.019
Pl. Calc.	-8.0*	-.0010	.097*	2.17	.002	.039
Pl. Th. Wall	-4.3	.0008	.046*	.99	.001	.020
<u>Current and former Smokers Only</u>						
Small Opacities	-9.39*	.0021	.131*	2.29	.001	.040
Any Pl. Change	-4.14*	.0005	.052*	1.05	.001	.022
Pl. Calc.	-7.25*	-.0021	.087*	2.27	.003	.044
Pl. Th. Wall	-4.31*	.0005	.052*	1.12	.001	.023

*p-value < 5%

Under joint control for smoking habit and age, results of the association between radiographic findings and f-y are presented in table 4.10. Of the 13 cases of small opacities with data available on their smoking habit, 9 were older than age 45, had smoked cigarettes, and had accumulated greater than 86 f-y. Of the 24 cases with any pleural change, 14 were older than age 45 and 21 had smoked cigarettes.

It was difficult to measure the association between f-y and radiographic finding under joint control for smoking and age because of the small number of cases among non-smokers and the tendency for most cases to be older, to have smoked, and to have a high f-y. Therefore, in the remainder of the analyses, the exposure-response association was controlled only for age.

Modeling the exposure-response association

Separate logistic models were estimated for the entire sample and for workers who had smoked. The models predict the prevalence of each radiographic finding based on age and f-y (table 4.11). Results indicated that small opacities, any pleural change, pleural calcification, and pleural change on the wall were significantly related to age. However, with age in the model only small opacities was significantly related to f-y (p-value<5%).

An external control for smoking and age

In order to further evaluate the prevalence of small opacities with an external control for smoking, results were compared between the vermiculite workers and workers in 3 comparison groups employed in industries without an asbestos exposure. These groups include (1) 'blue-collar' workers in industries where there is no known risk of pneumoconiosis (Petersen et al., 1984; Castellan et al., 1985, Abrons et al., 1985), (2) workers employed in non-asbestos cement plants (Abrons et al., 1985), and (3) coal miners with less than 5 years employment in mining (Althouse, 1981).

Data for these comparison groups were re-analyzed, and workers were

excluded from analysis if (1) they had worked in another dusty trade, (2) their radiograph showed a profusion of only rounded opacities greater than category 0/1, or (3) they had never smoked cigarettes regularly.

Results for current and former smokers older than age 45 are presented below:

Current and former smokers age 45-60

	<u>Small Irregular Opacities</u>	<u>No Small Irregular Opacities</u>	<u>total</u>	<u>%</u>
Blue collar workers	1	108	91	1.1
Cement workers	12	326	338	3.6
Coal miners	1	318	319	0.3
Vermiculite				
<50 f-y	1	17	18	5.5
50-100 f-y	1	8	9	11.1
>100 f-y	4	9	13	30.8

Results of this comparison indicate that the prevalence of irregular opacities (profusion greater than category 1/0) is greater in each vermiculite exposure group than in the comparison groups. However, this difference is statistically significant only for the >100 f-y group.

These results should be interpreted cautiously because the number of vermiculite workers was small, radiographs for workers in the comparison groups were generally better quality, and different sets of readers classified the films in the comparison and study groups. Additionally, small opacities were not found in vermiculite workers with less than 30 f-y.

RESPIRATORY SYMPTOMS

The prevalence of respiratory symptoms for 121 workers with questionnaires available was 9.9% for phlegm, 6.6% for cough, 22.3% for wheezing, and 19.8% for moderate and severe dyspnea (table 4.12). Results also indicate that the prevalence of each respiratory symptom increased with f-y, particularly after 30 f-y. The association with f-y was significant only for dyspnea (p-value <5%).

Results for the association between symptoms and f-y under control for age and smoking habit are presented in tables 4.13-4.16. Although the prevalence of each symptom increased with age and smoking, the association with age was significant only for cough, phlegm, and dyspnea (p-value <5%). In addition, smoking was only significantly related to wheezing.

The prevalence of each symptom increased with f-y among current and ex-smokers, but under joint control for smoking and age a statistical association between symptoms and f-y was not found. However, the number of cases were small and statistical power was low.

Modeling the exposure-response association

A logistic model was estimated to predict the prevalence of dyspnea from f-y and age. Results of the logistic analysis are presented separately in tables 4.17-4.18 for the total group and for smokers only. Results indicate that at age 44 (the mean age of the sample) the estimated prevalence of dyspnea is 17.5% at 5 f-y and 19.1% at 50 f-y. The odds ratio is 1.012 at 5 f-y and 1.130 at 50 f-y.

An external control for smoking and age

Similar to the analysis of the radiographic findings, the association between dyspnea and asbestos exposure was evaluated with an external control for smoking and age. Results were compared between the study sample and comparison groups. (Coal miners were excluded because low tenure in a coal mine has been found to be associated with an increased prevalence of

Table 4.12

Respiratory symptoms by fiber-years

Symptom		<u>Fiber-years</u>			
		0-15	15-30	31-86	> 86
Cough*	Yes	0	0	4	4
	No	49	20	24	20
	Total	49	20	28	24
	%	0	0	14	17
Phlegm*	Yes	3	0	6	3
	No	46	20	22	21
	Total	49	20	28	24
	%	6	0	21	13
Wheeze*	Yes	7	2	10	8
	No	42	18	18	16
	Total	49	20	28	24
	%	14	10	36	33
Dyspnea+	Yes	3	2	8	11
	No	46	18	20	13
	Total	49	20	28	24
	%	6	10	29	46

* Association with fiber-years not significant (p-value > 5%)

+ Association with fiber-years significant (p-value < 5%)

Reporting phlegm number and percentage of workers fiber-years controlling for age and smoking habit

* Association between age and phlegm is significant (p-value < 5%)
+ Association between smoking and phlegm is not significant
** Association between f-y and phlegm is not significant in any age smoking group.

Table 4.14

The number and percentage of workers reporting
Cough by fiber-years controlling for age and smoking habit

	Fiber/cc-years										Total	
	<86					>86						
	Cough		Cough		Total	Cough		Cough		Total		
Yes	No	Yes	No	Yes		No	Yes	No				
Age*												
<45	2	68	2.9	70	0	10	10	0	2	78	80	2.5
>45	2	25	7.4	27	4	10	14	28.6	6	35	41	14.6
Smoking Habit+												
Current Smoker	2	28	6.7	30	2	5	7	28.6	4	33	37	10.8+
Ex-Smoker	1	49	2.0	50	2	14	16	12.5	3	63	66	4.5+
Non-Smoker	1	16	5.9	17	0	1	1	0	1	17	18	5.6+
Age Smoking habit*+												
<45 Current Smoker	1	22	4.3	23	0	3	3	0	1	25	26	3.8
Ex-Smoker	1	33	2.9	34	0	7	7	0	1	40	41	2.4
Non-Smoker	0	13	0	13	0	0	0	0	0	13	13	0
> 45 Current Smoker	1	6	14.3	7	2	2	4	50.0	3	8	11	27.3
Ex-Smoker	0	16	0	16	2	7	9	22.2	2	23	25	8.0
Non-Smoker	1	3	25.0	4	0	1	1	0	1	4	5	20.0
Total	4	93	4.1	97	4	20	24	16.7	8	113	121	6.6

* Association between age and cough is significant (p-value < 5%)

+ Association between smoking and cough is not significant

** Association between f-y and cough is not significant in any age-smoking group.

Table 4.15

Reporting wheezing number and percentage of workers
fiber years controlling for age and smoking habit

Age*	Fiber/cc-years										Total	
	<86					≥86						
	Wheezing		Wheezing		Wheezing		Wheezing		Wheezing		Total	
	Yes	No	Total	%	Yes	No	Total	%	Yes	No	Total	%
<u>Age*</u>												
<45	13	57	70	18.6	2	8	10	20.0	15	65	80	18.8
≥45	6	21	27	22.2	6	8	14	42.9	12	29	41	29.3
<u>Smoking Habit*</u>												
Current Smoker	9	21	30	30.0	5	2	7	7.1	14	23	37	37.8
Ex-Smoker	7	43	50	14.0	3	13	16	18.8	10	56	66	15.2
Non-Smoker	3	14	17	17.6	0	1	1	0	3	15	18	16.7
<u>Age-Smoking habit**</u>												
<45 Current Smoker	7	16	23	30.4	2	1	3	66.7	9	17	26	34.6
Ex-Smoker	4	30	34	11.8	0	7	7	0	4	37	41	9.8
Non-Smoker	2	11	13	15.4	0	0	0	0	2	11	13	15.4
≥45 Current Smoker	2	5	7	28.6	3	1	4	75.0	5	6	11	45.5
Ex-Smoker	3	13	16	18.8	3	6	9	33.0	6	19	25	24.0
Non-Smoker	1	3	4	25.0	0	1	1	0	1	4	5	20.0
Total	19	78	97	19.6	8	16	24	33.3	27	94	121	22.3

* Association between age and wheezing is not significant

+ Association between smoking and wheezing is not significant.

** Association between f-y and wheezing is not significant in any age-smoking group.

Table 4.16

Reporting dyspnea number and percentage of workers
fiber years controlling for age and smoking habit

Fiber/cc-years												Total	
<86												>86	
	Dyspnea			Dyspnea			Dyspnea			Dyspnea			Total
	Yes	No	Total	%	Yes	No	Total	%	Yes	No	Total		
Age*													
<45	8	62	70	11.4	3	7	10	30.0	11	69	80	13.8*	
>45	5	22	27	18.5	8	6	14	57.1	13	28	41	31.7*	
Smoking Habit*													
Current smoker	5	25	30	16.7	2	5	7	28.6	7	30	37	18.9	
Ex-smoker	7	43	50	14.0	9	7	16	56.3	16	50	66	24.2	
Non-smoker	1	16	17	5.9	0	1	1	0	1	17	18	5.6	
Age Smoking Habit*													
<45 Current smoker	4	19	23	17.4	0	3	3	0	4	22	26	15.4	
Ex-smoker	4	30	34	11.8	3	4	7	42.8	7	34	41	17.1	
Non-smoker	0	13	13	0	0	0	0		0	13	13	0	
>45 Current smoker	1	6	7	14.3	2	2	4	50.0	3	8	11	27.3	
Ex-smoker	3	13	16	18.8	6	3	9	66.7	9	16	25	36.0	
Non-smoker	1	3	4	25.0	0	1	1	0	1	4	5	20.0	
Total	13	84	97	13.4	11	13	24	45.8	24	97	121	19.8	

* Association between age and dyspnea is significant, (p-value < 5%), and the association between dyspnea and f-y, controlling for age is significant (p-value < 5%).

+ Association between smoking and dyspnea is not significant.

*+ Association between f-y and dyspnea, controlling for smoking and age, not significant.

Table 4.17

Logistic models for dyspnea

<u>Group</u>	<u>Intercept</u>	<u>Age</u>	<u>f-y</u>
Smokers Only	-3.3799	0.04128	0.00245
Total Group	-3.7260	0.04668	0.00236

Table 4.18

Estimated prevalence (%) and odds ratio (OR) for
dyspnea from the logistic model*

fiber-years	%	OR
0	17.3	1.000
5	17.5	1.012
25	18.2	1.063
50	19.1	1.130
100	21.1	1.278
200	25.5	1.632
500	41.6	3.404
1000	70.8	11.588

*Based on the total group model computed for age 44

Table 4.19

Prevalence (%) of small irregular opacities by cumulative exposure from this and other studies⁵

Jones		Rossiter		This Study		Berry		Finkelstein		
mppcf- years	% IR*	mppcf- years	% IR ³	mppcf- years++	fiber/cc years	% IR	fiber/cc years	% OP ¹	fiber/cc years	%**
0	1.8	<10	1.8	0-3.75	0-15	0	<25	0	<50	0.5
5.4	3.1			3.75-7.5	15-30	4	25-50	0	50-100	3.4
12.1	6.0			7.5-21.5	30-86	7	50-100	37.5	100-150	6.5
17.2	9.6			>21.5	>86	29	100-150	27.0	150-199	7.9
30.3	28.6	10-100	3.3				150+	34.1		
		100-200	6.3							
		200-400	8.7							
		400-800	12.0							
		>800	17.2							

* IR = irregular opacities

** Asbestosis defined from radiographic findings and other medical data

++ Applied conversion factor of 4.0 f/cc per mppcf

1 Workers employed before 1951, OP: small irregular or rounded opacities

2 Workers employed after 1950, OP: small irregular or rounded opacities

3 Thetford mines in Quebec

4 Asbestos mines in Quebec

5 Jones et al.(1980), Rossiter et al.(1972), Berry et al.(1979), Finkelstein et al.(1982).

respiratory symptoms). Results of this comparison are presented below:

Current and former smokers age 45-60

<u>Age</u>	<u>Study Group</u>	<u>dyspnea</u>	<u>no dyspnea</u>	<u>total</u>	<u>% dyspnea</u>
<45	Blue collar	23	385	408	5.6
	Cement	29	593	622	4.7
	Vermiculite				
	<50 f-y	5	44	49	10.2
	50-100 f-y	4	8	12	33.0
	>100 f-y	2	4	6	33.0
>45	Blue collar	8	83	91	8.8
	Cement	26	315	341	7.6
	Vermiculite				
	<50 f-y	2	13	15	13.3
	50-100 f-y	1	6	7	15.0
	>100 f-y	<u>5</u>	<u>5</u>	<u>10</u>	<u>50.0</u>

Similar to the results for small opacities, the prevalence of dyspnea was greater for the vermiculite-exposure groups than for the comparison groups. However, the difference in prevalence of dyspnea between the control and study groups was only statistically significant at exposures above 50 f-y for ages <45, and at exposures above 100 f-y for age 45-60.

DISCUSSION

Radiographic findings were consistent with an asbestos etiology. Irregular shaped opacities were found predominantly in 17 of the 18 cases of small opacities, and category 1 profusion of small opacities was found in 12 of the 18 cases.

In a parallel but separate radiographic study, McDonald et al found a higher prevalence of small opacities (18%) than we found in our study (10%). A comparison of the radiographic findings of the two studies showed that differences in film quality likely explain the difference in prevalence (Appendix V). In any event, the odds ratio at the average age of the NIOSH

study sample (44 years) was estimated to be 1.014, 1.139, 1.297, and 3.769 at 5, 50, 100, and 500 f-y respectively. Corresponding figures for the McGill study are 1.018, 1.191, 1.419, and 5.755. Although predicted prevalences differed, the estimates of the relative risk were similar at low exposures.

We previously described the results of Lockey et al.'s study of 512 workers at an Ohio fertilizer company which processed vermiculite concentrate from the Libby site. Lockey et al. (1984) found 1 case of irregular opacities (0.2%), 11 cases of pleural change (2.2%), and 11 cases of costophrenic angle blunting (2.2%). Corresponding results from our study are 18 cases (10%), 28 cases (15%), and 16 cases (8.7%) respectively. Additionally, Lockey et al. found 7 cases ($7/512=1.4\%$) with a history of pleural effusion, and we found 1 case ($1/184=0.5\%$) with a history of radiographic evidence of pleural effusion.

The difference between studies in radiographic findings may be explained by differences in cumulative fiber exposure. To check this we compared results among fertilizer plant workers and vermiculite miners with similar f-y. In the Ohio fertilizer plant, the maximum individual cumulative exposure was reported to be 39 f-y and the average exposure was 3 f-y (calculated from Lockey et al.'s published results). For comparison, we considered 91 vermiculite workers with less than 30 f-y and an average exposure of 13 f-y.

The prevalence of small opacities, pleural findings, and pleural effusions for our 91 workers (Lockey et al.'s sample) was 1.1% (0.2%), 8.0% (2.0%), and 0.0% (1.4%) respectively. Additionally, our logistic models, based on the average age and f-y in the Lockey et al. study, predicted the prevalence of small opacities and pleural change to be 0.9% and 8.0%. Although the prevalence of small opacities and pleural findings was at least 4 times greater for the vermiculite miners than the fertilizer plant workers, the difference in prevalence was marked only for pleural change. The reason for proportionately more cases of pleural change, and fewer cases of pleural

effusion, at the Libby mine and mill than at the fertilizer plant is unclear.

Results on the exposure-response relationship from this and other studies are presented in table 4.19. For this comparison, our exposure measurements were converted to mppcf using the conversion factor of 4.0 f/cc:mppcf. The slope for our exposure-response curve for the prevalence of small opacities was similar to the slope in the study by Jones et al. (1980) for asbestos cement workers exposed to chrysotile and crocidolite, by Berry et al. (1979) for asbestos textile workers exposed to chrysotile and crocidolite, and by Finkelstein et al. (1982) for asbestos pipe and insulation workers (Finkelstein reported the prevalence of certified asbestosis which includes radiographic, pulmonary function, and clinical findings). However, our slope was higher than the slope in the study by Rossiter et al. (1972) for Quebec chrysotile miners and millers.

Results from different studies are also presented by years tenure and time from hire in table 4.20. Our results were consistent with other studies, and indicated that the prevalence of small opacities increased markedly after 15-20 years tenure or after 15 years from time of hire.

Although the prevalence of small opacities and dyspnea in this study was different, the slope for f-y was similar in the respective logistic models. This is perhaps due to the correlation between small opacities and dyspnea. Results indicated (table 4.21) that 5 (83%) of 6 cases of small opacities reported dyspnea, and 19 (17%) of 96 non-cases reported dyspnea. (Only 6 of the 18 cases in the study had a respiratory system questionnaire available).

The estimated increase in the predicted prevalence of small opacities at exposures less than 100 f-y attributable to fiber exposure over that due to smoking is unclear. Results from the model for small opacities suggest that the estimated prevalence at 5 f-y and at age 53 (midpoint of age group 45-60) is 6.6%, and this is markedly higher than the prevalence in the comparison groups of smokers (0.3% to 3.6% for coal miners, cement workers, and blue collar

Figure 4.1

Prevalence of radiographic opacities by cumulative exposure
from asbestos studies

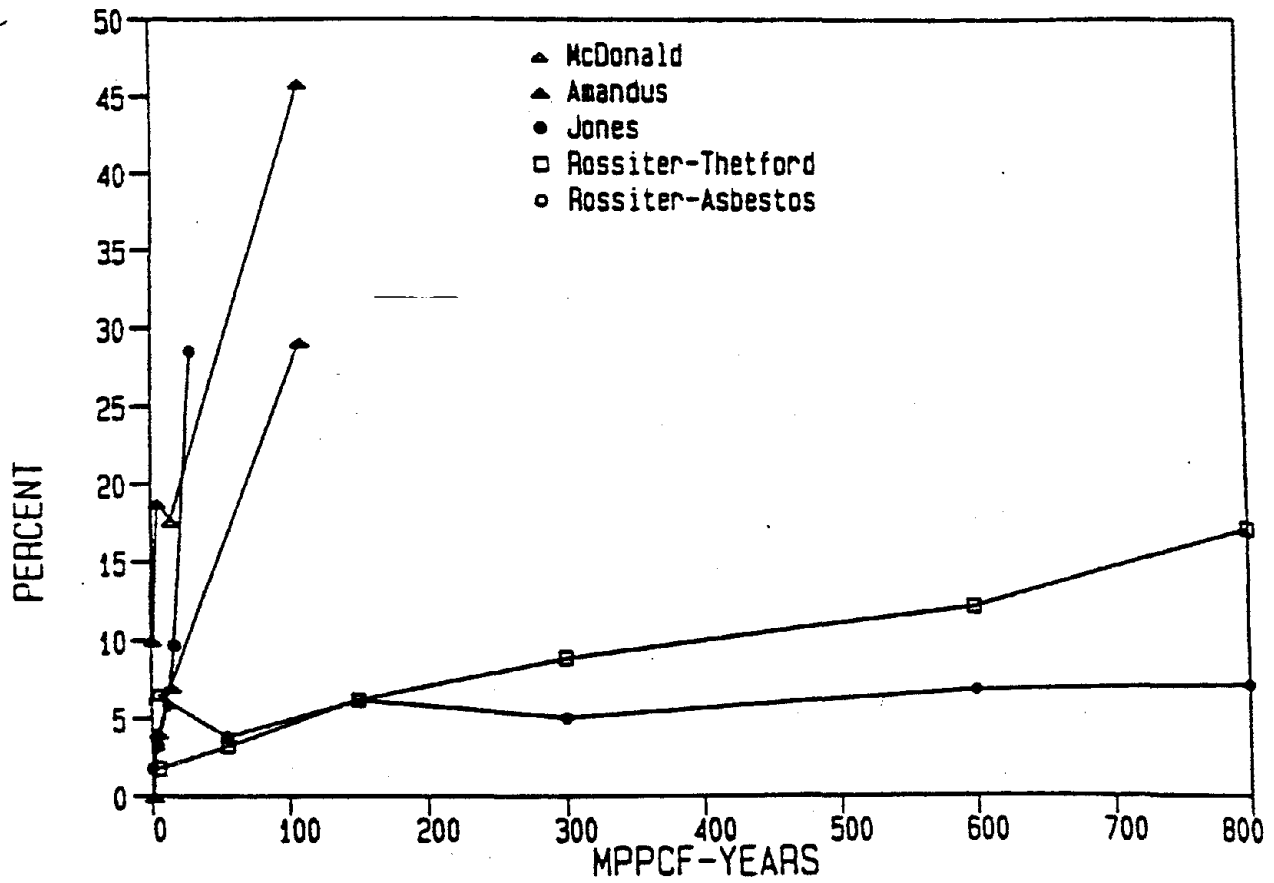


Figure 4.2

Prevalence of radiographic opacities by exposure
(fiber-years) and asbestos study

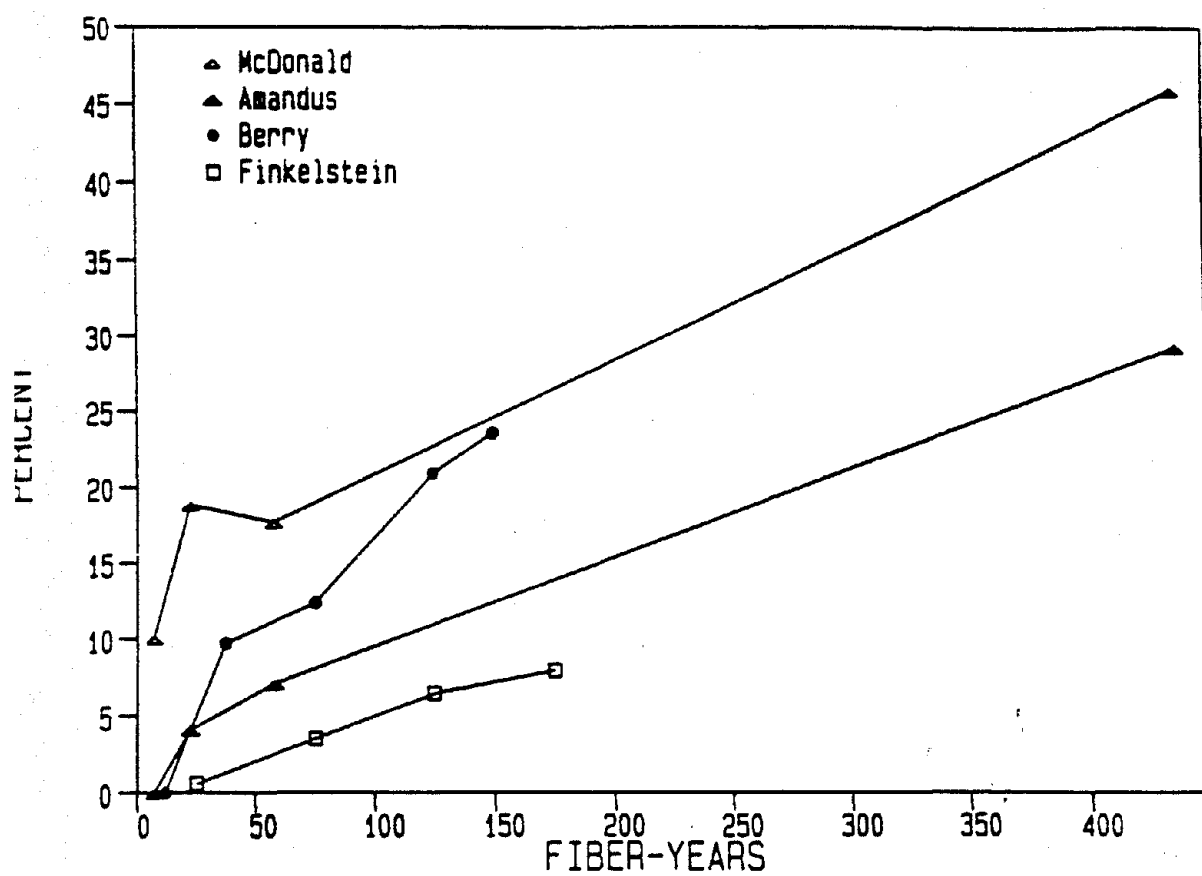


Table 4.20

Prevalence of irregular opacities, with profusion greater
than 1/0, category by tenure (years) time since hire (years)

from this and other studies

Author						
Rossiter et al. (1972)						
	Tenure:	10-30	>30			
	%:	5	18			
Weiss et al. (1971)						
	Tenure:	<20	>20			
	%:	23.2	68.8			
Hobbs et al. (1980)						
	Tenure:	<1	1-2	2-3	3-4	4-5
	%:	0.6-1.4	4.2	4.6	7.8	26.8
						52.1
This study						
	Tenure:	<15	≥ 15			
	%:	3	41			
	Time from hire:	0-10	11-20	≥21		
	%:	0	10	28		
Irwig et al. (1979)						
	Time from hire:	>1	1-3	3-7	7-15	>15
	%:	2.3	4.6	4.6	13.9	26.7
Selikoff et al., (1980)						
	Time from hire:	20-29	30-39	≥40		
	%:	59	80	87		
Finkelstein et al. (1982)						
	Time since hire:	<5	6-10	11-14	>15	
	% asbestosis:	28	13	37	68	

Table 4.21

Number of workers with small opacities by dyspnea, age, and smoking habit

Age	Smoking Habit	Small Opacities							
		Yes				No			
		Dyspnea		Total	%	Dyspnea		Total	%
		Yes	No			Yes	No		
<45	Current	0	0	0	0	4	22	26	15
	Ex-	0	0	0	0	7	34	41	17
	Non-	0	0	0	0	0	13	13	0
Sub-total		0	0	0	0	11	69	80	14
≥45	Current	1	1	2	50	2	7	9	22
	Ex-	4	0	4	100	5	16	21	24
	Non-	0	0	0	0	1	4	5	20
Sub-total		5	1	6	83	8	27	35	23
Total		5	1	6	83	19	96	115	17

workers). Thus, the combined effect of smoking and fiber exposure, under control for age, would seem to be greater than that from smoking alone. However, the model was based on cases of small opacities for workers with high exposure, and the prevalence at low exposure must be estimated by extrapolation. In contrast to the results from the model, only 1 case of small opacities was found among workers with 16-30 f-y, and no cases were found below 30 f-y. Thus, the small number of cases and sample size prevented a strict control for cigarette smoking and assessment of confounding.

CONCLUSIONS

Conclusions with respect to radiographic findings and respiratory symptoms are as follows:

1. The estimated prevalence of small opacities based on the logistic model at age 44 was 2.14% at 5 f-y and 2.40% at 50 f-y. The odds ratio computed from the model was 1.013 at 5 f-y and 1.139 at 50 f-y.
2. The radiographic findings generally occurred among older workers who have smoked cigarettes.
3. The estimated prevalence of small opacities and dyspnea at exposures above 100 f-y is likely greater than that due to smoking and age in NIOSH samples of coal miners, cement workers, and blue collar workers.

V. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Results from this study suggest that job exposure estimates prior to 1974 were extremely high, while the average job exposure estimates from 1974 to 1982 were less than 1 f/cc. Based on the company's report of an evaluation of 203 samples in 1984 (Wolter, 1985), the average exposure (f/cc) was less than 0.1 f/cc.

The results strongly impact on dust control and surveillance activities. Indeed, if one assumes that (1) smoking is not a confounder, (2) the models

employed in this study are appropriate, and (3) the health risk associated with a certain level of f-y is similar whether accumulated in a 'high' or 'low' average exposure environment, then we conclude that any level of exposure is associated with some risk. Additionally, 5 f-y is likely associated with at least a 1% increased risk of lung cancer, radiographic small opacities, and dyspnea. If 5 f-y is considered as an average exposure to 0.1 f/cc over a 50 year working lifetime, NIOSH's recommended standard of a TWA of 0.1 f/cc (NIOSH, 1980) is not a conservative standard for amphibole fibers.

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Appendix I

History of Plant Changes

1. Loading dock

< 1950	Loaded concentrate into boxcars at a downtown loading site.
50-59	Loaded at the river loading dock into railroad hopper cars.
1960's	Installed ventilation and covered hopper cars. (Phased out boxcars in early 60's.)
1970	Built bag house; air conditioned operator's office in early 70's; more ventilation of cars.
1979	Moved operator's room uphill from dock.

Mr. Earl Lovick, retired plant manager, speculated that exposures before 1950 at the loading dock were slightly less than in dry mill. Exposures in the 60's were 1/2 - 1/3 lower than in 50's. One worker was employed at the dock before 1950 and spent most of his time in a 'control' room near the loading dock, where his exposure was very high. One worker was a dock hand and was not near the loading area. Both workers were employed as export operators (baggers).

2. Service area

1964:	Exhaust fan installed, and exhaust was found to contaminate the service area.
1968:	Re-routed exhaust stack.

Earl Lovick believed exposures were similar before 1964 and after 1968 in service area; but higher in 1964-1968 period.

3. Mine testers and mill testers

Frequently the same people do both jobs.

4. Skipper

The control room was air conditioned and pressurized in 1972. Exposures were higher after 1972 than before 1972.

5. Export operator

Valve pack-bagging machine installed in 1972.
Hand filled and sewed before 1972.

6. Loading dock foreman

A hood was installed on the front end loader about 1970, and later the cab was pressurized.

7. Drilling

In 1970 a new drill was purchased which had a dust control bagging system.

8. Mill

1935-1954 - Only the dry mill operated.

1954-1964 - The dry and wet mills operated.

1960 - Flotation plant installed.

1965-1973 - Fan in mill installed.

1973 - New wet mill started in April, 1973.

1974 - Old wet and dry mill closed in September, 1974.

1973-1974 - Old and new mills were operated by the same work force. The company estimated that workers split their time 50:50 between new and old mill in 1973, and 75:25 in 1974.

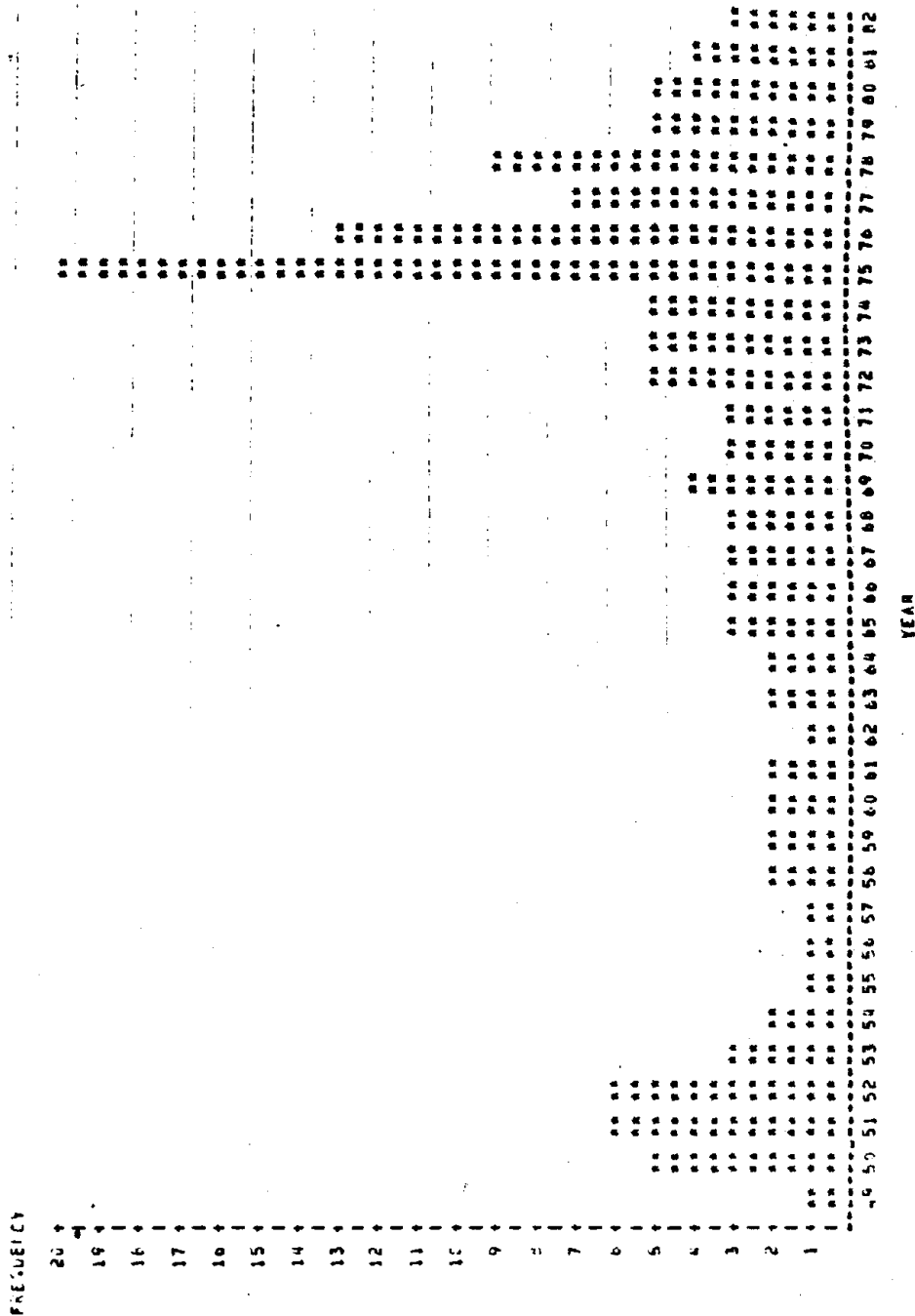
9. Transfer point

1974 - The operator's booth was pressurized.

1960's - A new transfer point station was constructed.

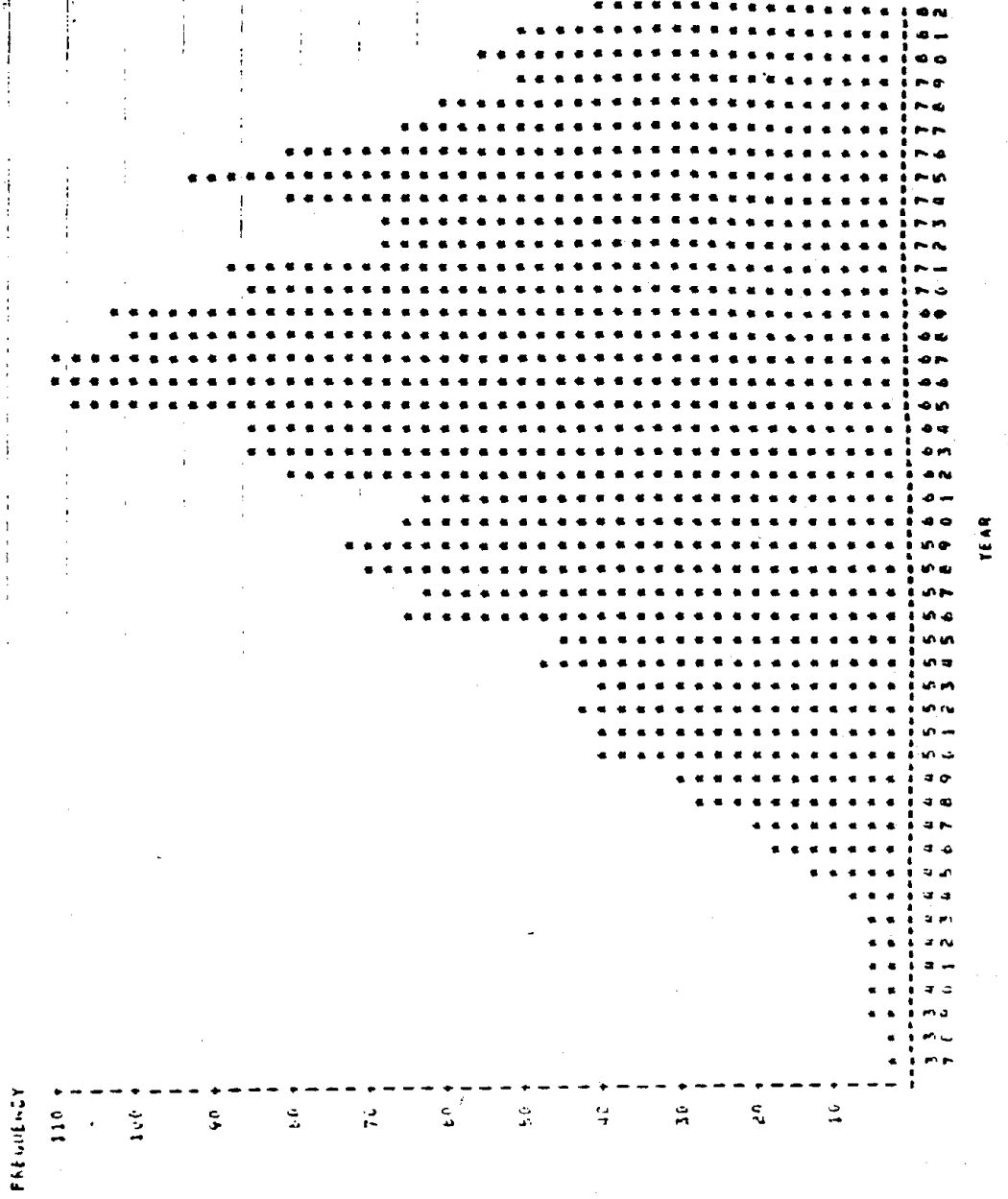
Number of workers employed by
area and year

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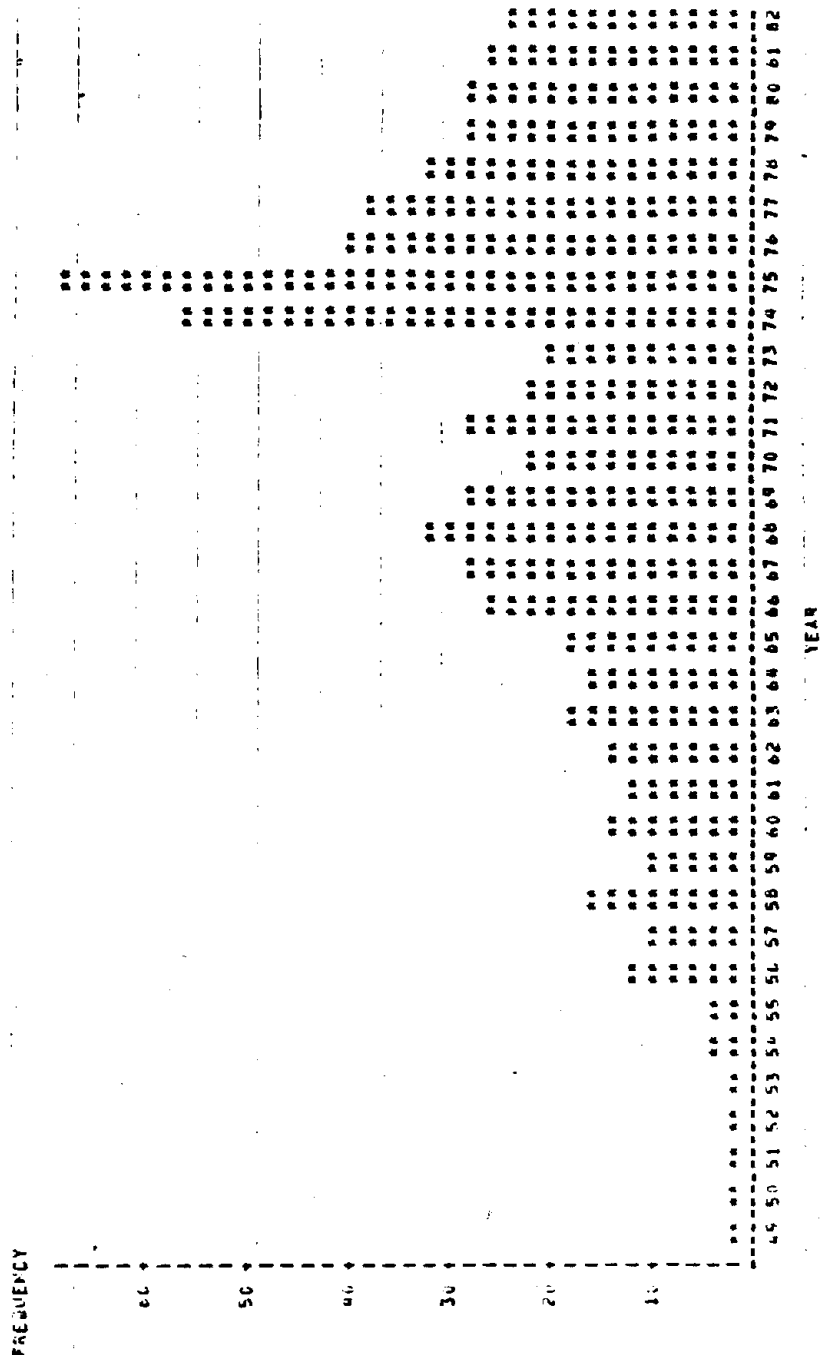


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FREQUENCY BAR CHART



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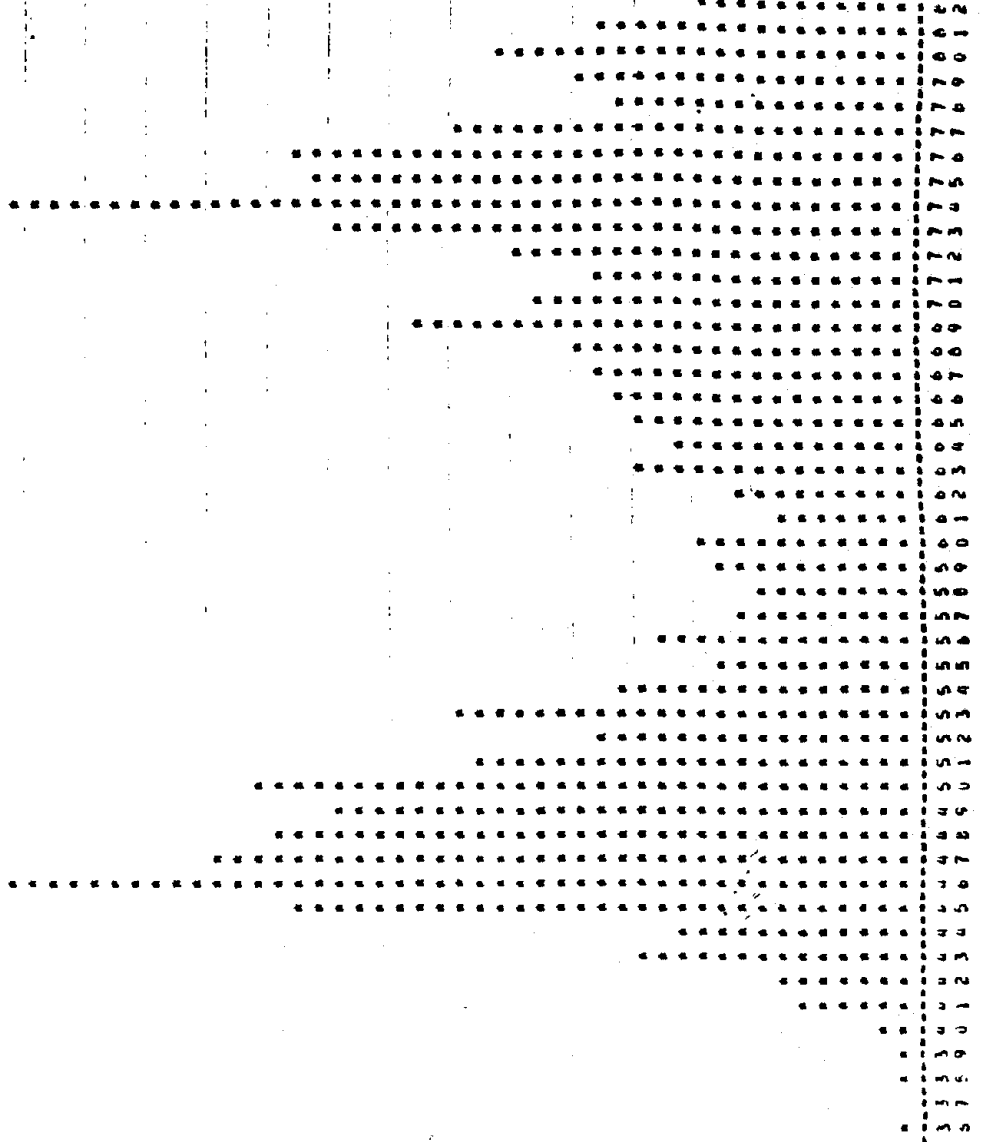


AREA CONSTRUCTION

FREQUENCY FOR CHART

FREQUENCY

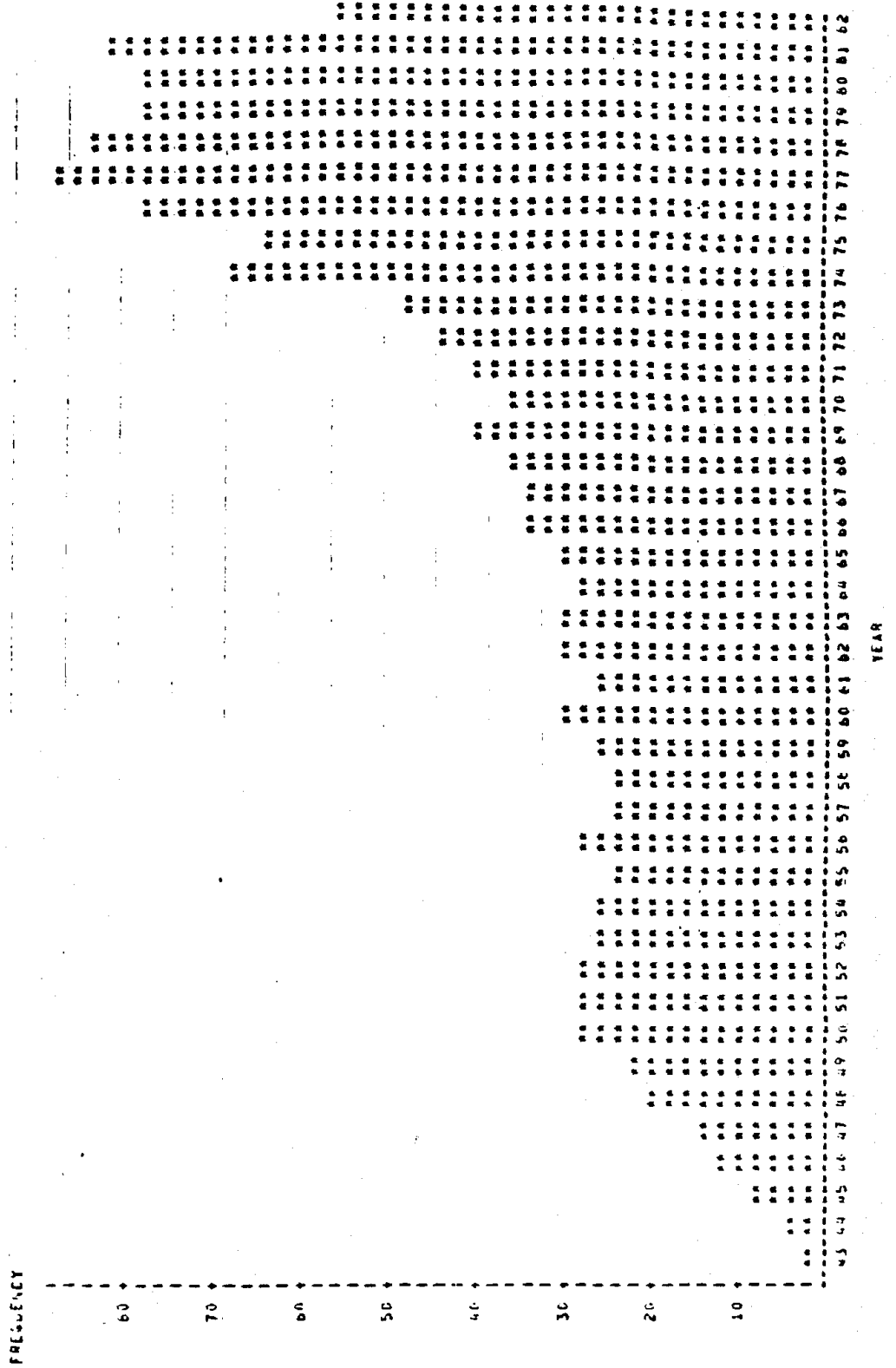
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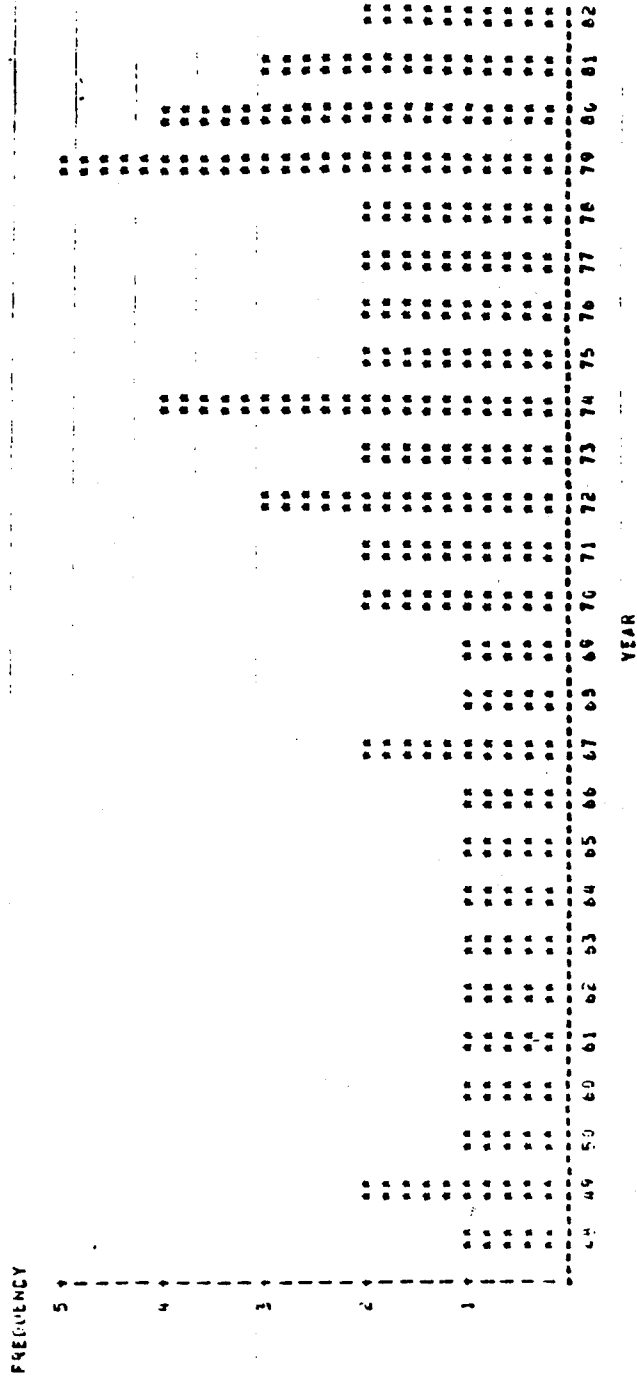
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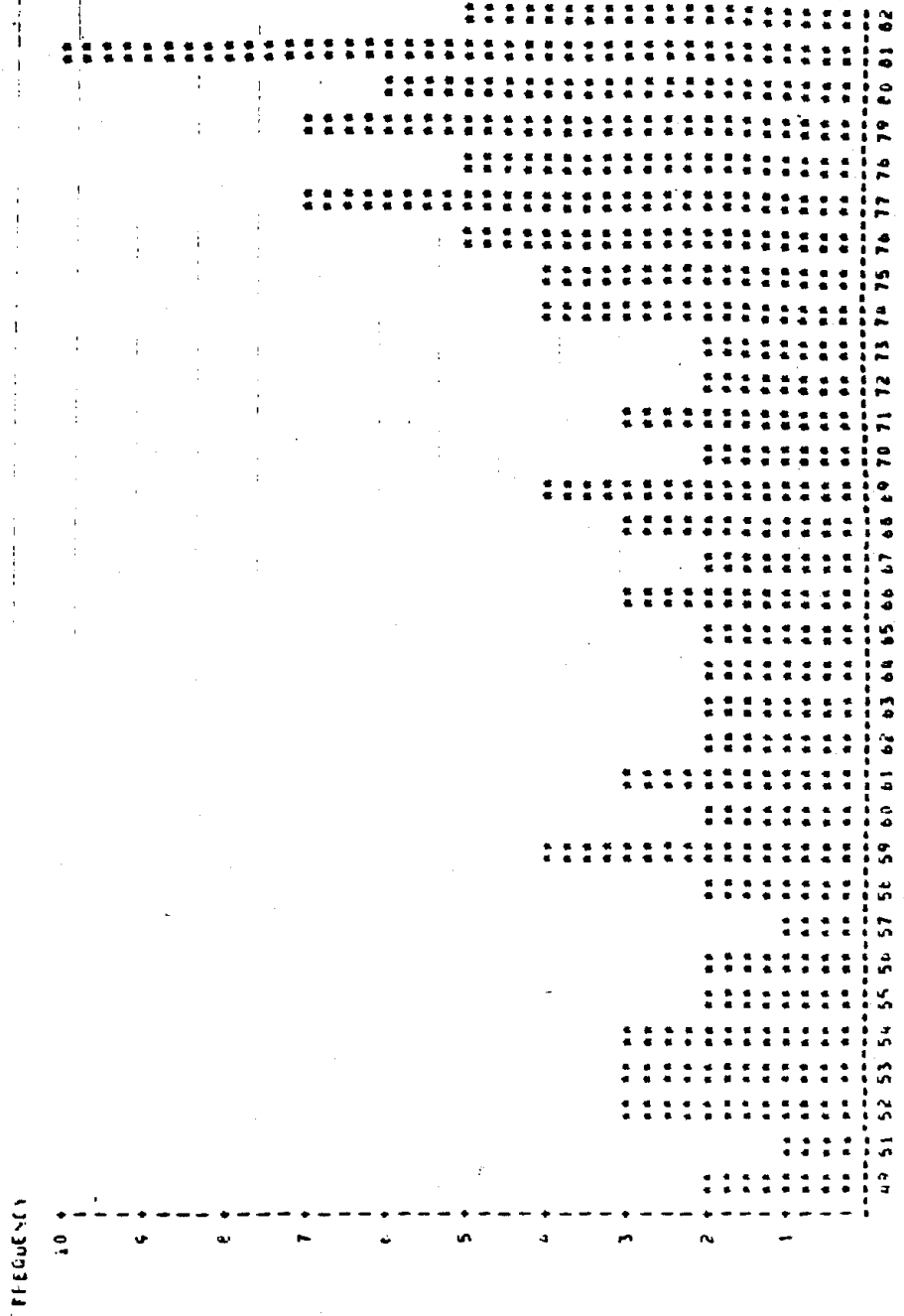
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FREQUENCY BAR CHART



FREQUENCY BAR CHART



RAS

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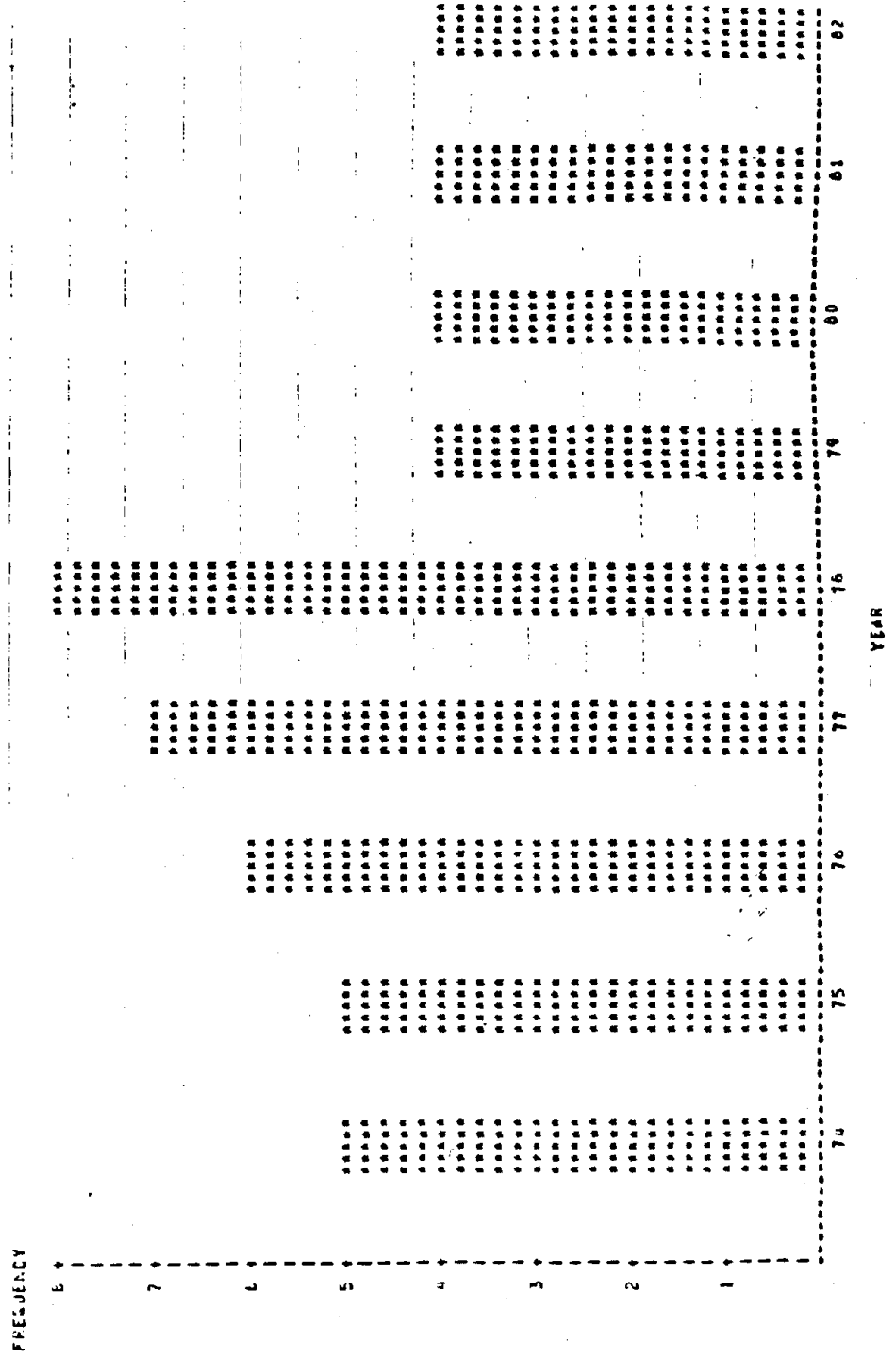
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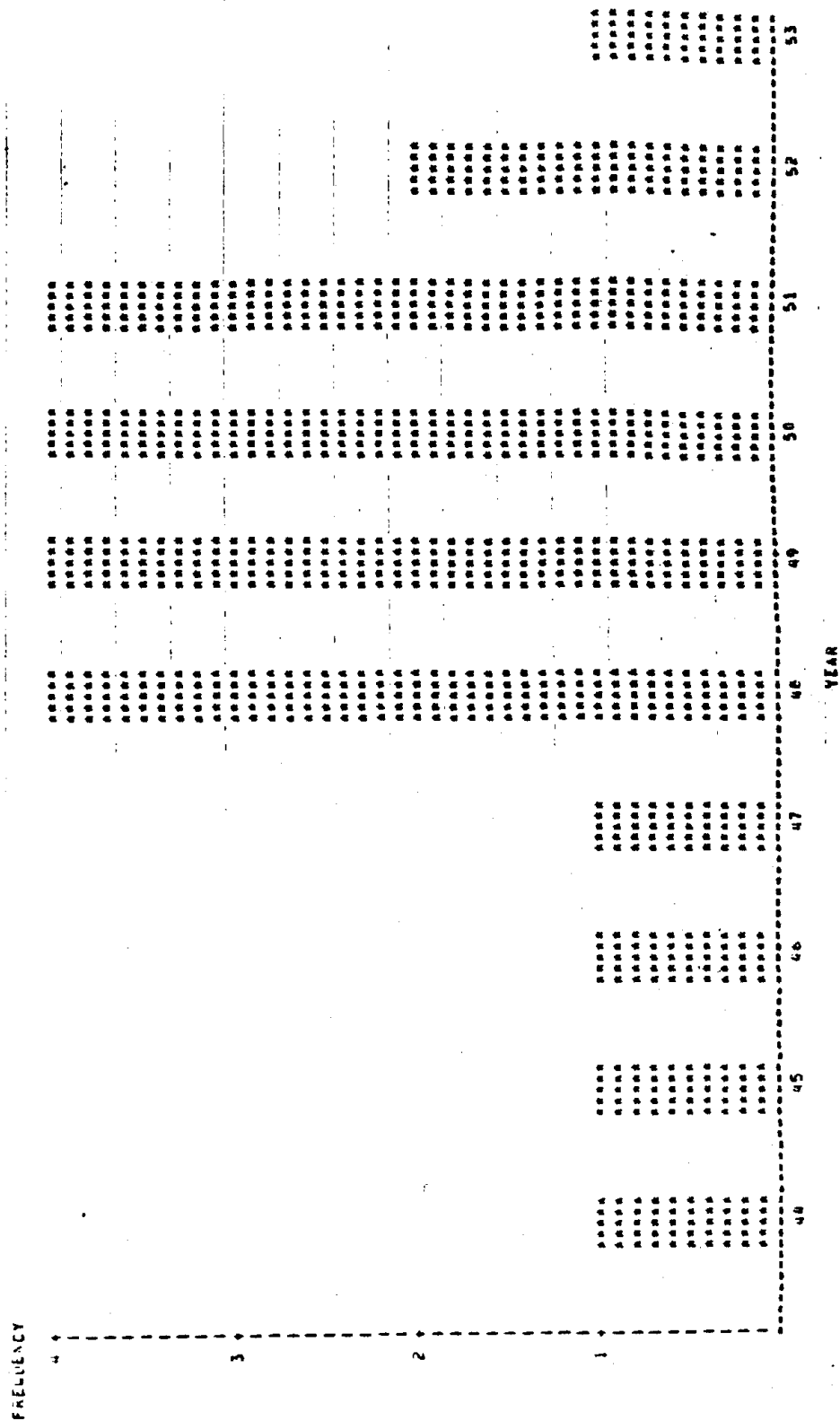
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YEAR

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FREQUENCY BAR CHART

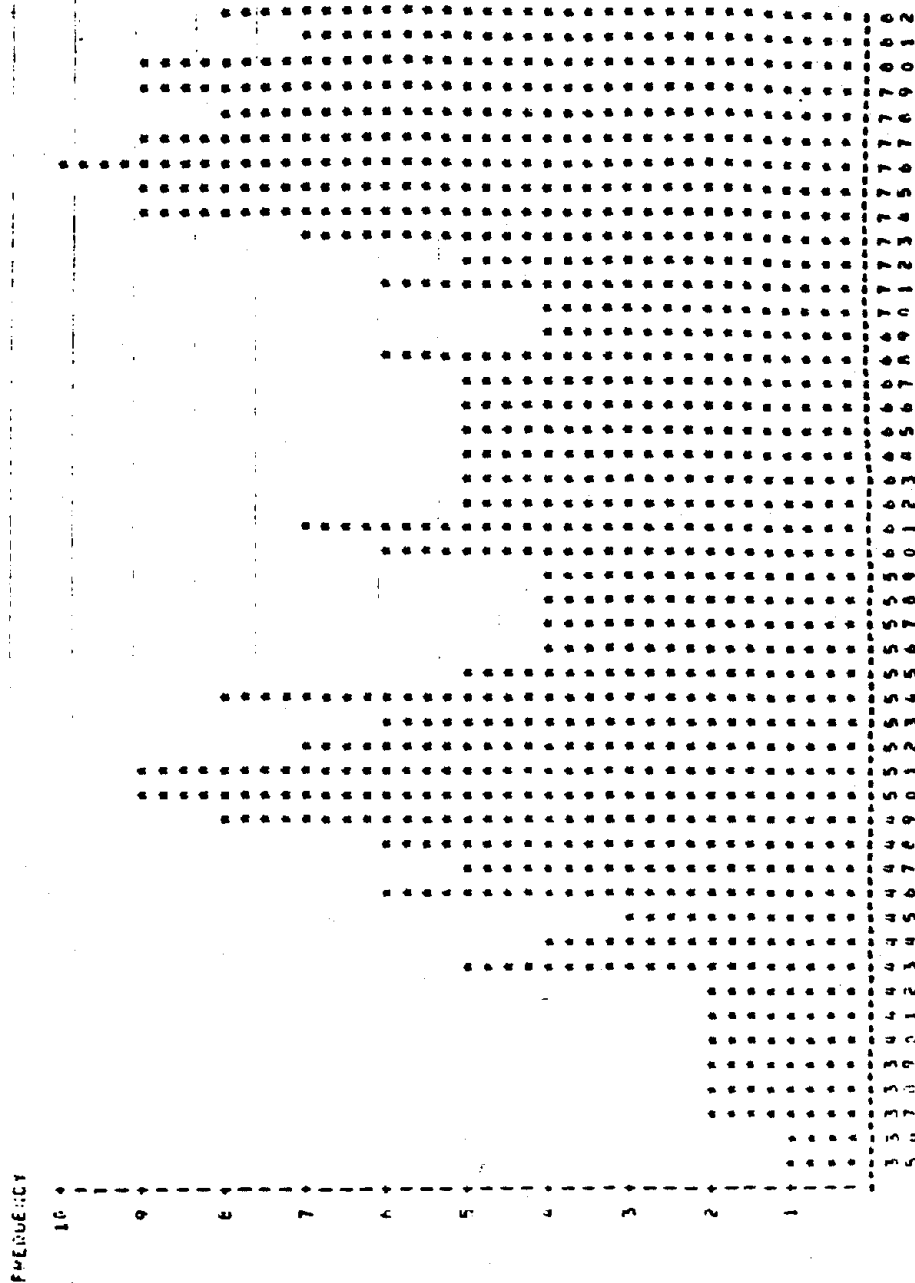


AREAS/EXPANDER PLANT
FREQUENCY BAR CHART

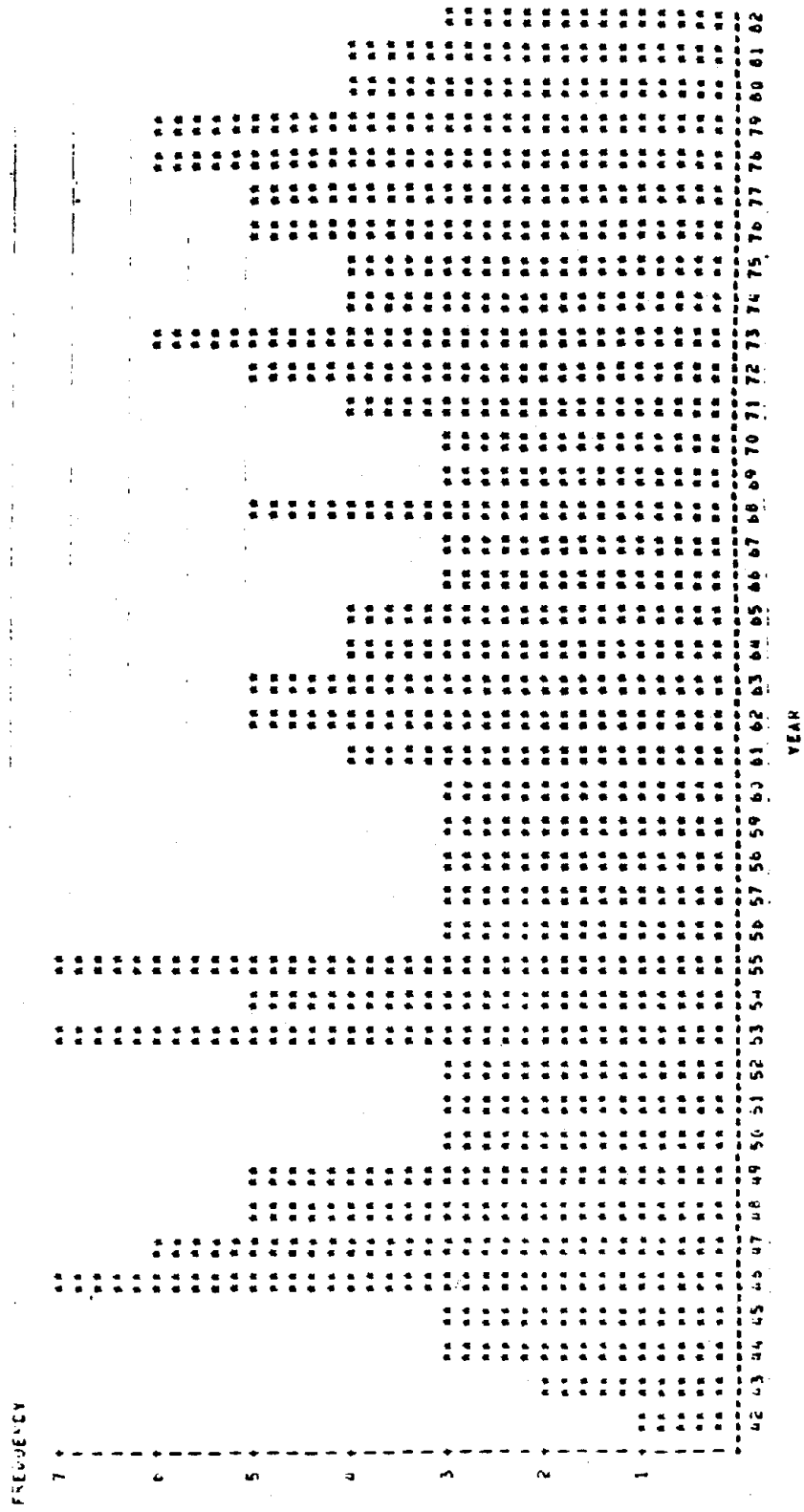


AREA MANAGERS

FREQUENCY BAR CHART



FREQUENCY RAP CHART



Appendix II

Calculation of exposure estimates prior to 1968 for Location-Operations in which assumptions were made

Samples were unavailable in most LO except the dry mill prior to 1968. Exposure estimates for the LO were calculated based on the midjet impinger results, the conversion ratio, and assumptions concerning past exposures. The calculation of exposure estimates (table 2.8) are presented in detail in this appendix for these LO.

<u>Area description</u>	<u>Method of calculation</u>
-------------------------	------------------------------

Drilling

High Estimate < 1970:

Assume that the average f/cc was 2 1/2 times greater in 1968-70 than in 1971-74, due to employing the new drill. The average exposure from samples in 1971-74 was 9.2 f/cc. Exposures prior to 1971 were estimated to be $9.2 \times 2 \frac{1}{2} = 23.0$.

Low Estimate < 1970:

The estimate was derived from 7 samples in 1967-70. Exposures ranged from 0.7-12.4 f/cc, and the average was 6.7.

Dry Mill Sweeping < 1964

The average f/cc was assumed to be the same in 1964-1967 and 1968-1971. In 1967-74, the sweeper's average exposure was 35.9 and the dry mill exposure was 33.2 f/cc; the ratio was 1.081 (35.9/33.2). Thus, the exposure prior to 1964 was estimated to be $1.081 \times$ (drymill exposure before 1964) = $1.081 \times 168.4 = 182.1$

Drymill - non-millwright < 1964+

Assumed that the exposures were the same in 1964-67 and 1968-71. Exposure before 1964 was calculated as the average mppcf * conversion factor (f/cc:mppcf) = $42.1 \text{ mppcf} \times 4.0$
f/cc:mppcf = 168.4 f/cc

Drymill-millwright

Used estimates from the dry mill working area.

Quality control lab < 1964

The ratio of exposure in the quality control lab and dry mill in 1968-1970 was 2.6/33.2(.078.)
Exposure in the quality control lab before 1964 was estimated as the dry mill exposure before 1964 * 0.078 = $168.4 \times 0.078 = 13.1$ f/cc.

Service Area

An exhaust fan was installed in 1964 in mill, and the exhaust contaminated the service area. The stack was re-routed in 1968. Assumed that exposures in 1964-67 were 2 times higher than after 1967. Also assumed that the exposure before 1964 were equal to exposures from 1968-74. From sample information the exposure in 1968-74 was estimated to be 1.9. Exposures in 1964-67 = $1.9 \times 2 = 3.8$ f/cc.

Skip area < 1964

The average exposure in the skipping area from 1967-71 was divided by the average exposure in the dry mill from 1967-71 ($17.4/33.2=0.524$ f/cc.) Exposures before 1964 were estimated as $168.4 * 0.524 = 88.3$ f/cc.

Ore-loading < 1969

High estimate:

< 1950: Assumed that an ore loader split his time 50% by the box car and operator's room, and 50% in bagging. Assumed that the exposure at the box car loading site and in the operator's room was 150.0 f/cc. Assume exposure in bagging was 15.0 as suggested by the company. The ore loading exposure = $(50\% (150.0) + (15.0))/2 = 82.5$ f/cc.

1950-59 Assumed that exposures were 38.6% higher in 1950-59 at the river loading dock, than in 1960-69. Estimated exposure as $10.7/.386 = 27.7$

1960-67 Assumed exposures were 30% higher at the river loading dock from 1960-69, than after 1970. Exposure after 1968 estimated as 3.2 f/cc from 1968-1974 samples. Exposures from 1960-69 estimated as $3.2/0.30=10.7$ f/cc.

Low estimate

Company estimates for 1950-69:

< 1950	-	24
1950-59	-	15
1960-69	-	9

River dock and car cleaning

High Estimate:

<1950 The ratio of exposures from 1970-1974 at the river dock and ore loading is 1.417 ($5.1/3.6$). Before 1950, the exposure is derived as $1.417 * \text{exposure at the ore loading prior to 1950} (1.417 * 82.5 = 116.9 \text{ f/cc})$.

1950-1959 Assume a 40% increase in the exposure in 1960 ($17/0.4 = 42.5$ f/cc).

1960-1969 Assume a 30% increase in 1970 ($5.1/.3 = 17.0$ f/cc).

1970-1974 Based on samples collected in 1970-1974, the average exposure = 5.1 f/cc.

Low Estimate:

Company's

estimates	< 1950 = 38
	1950-1959 = 19
	1960-1969 = 6.4
	1970-1974 = 2.0

Verxite Plant

In 1942, State of Montana reported one sample (5.65 mppcf). Using the conversion factor, exposure is $5.65 \times 4.0 = 22.6$ f/cc. This is an estimate for exposure before 1960. After 1960, NIOSH data is used to estimate exposure from 1960-1970.

Bagging Plant

High estimate:

Automatic bagger installed in 1972. Assume a 3 fold drop in exposure. Exposure in 1970-1974 is estimated from sample data as 4.3 f/cc. Exposure before 1970 is 12.9 f/cc (3×4.3).

Low Estimate:

Exposure estimated from samples taken in 1968-1971 = 4.6

Appendix III

Algorithms for the computation of Job exposure estimates

The 8-hour time weighted average exposure for a job was computed by multiplying the number of hours worked in a LO by the average LO exposure estimate, summing the products over all LO, and dividing by 8 hours. For example, a transfer point operator (job code 1.8) worked 8.5 hours over his shift; 2 hours (area 230), 6.5 hours (area 60), and 1 hour traveling by bus to and from the mine and town (area 10). The 8 hour TWA exposure estimate for a transfer point operator was calculated as follows in each year:

- (1) 1 hour exposure in area 10 + 2 hours x exposure in area 230
+ 6.5 hours x exposure in area 60 / 8.0 hours
- (2) On the list of algorithms this will be represented as:
(1A10 + 2.0A230 + 6.5A60)/8.0
- (3) The exposure estimate prior to 1974 is:
(1*1.2 + 2*7.3 + 6.5*2.2)=3.8 f/cc.

The algorithms employ job and LO codes. Refer to the coding schemes presented in this appendix for a description of the codes. Results of LO exposure estimates by year are presented in in Table III-1.

<u>Job Code</u>	<u>Years</u>	<u>Algorithm*</u>
1.1	all	1A10 + 8.5A52
1.2-1.7,1.9	all	1A10 + 8.5A58
1.8	all	1A10 + 2A230 + 6.5A60
2.0	all	1A10 + 3A52 + 5.5A58
2.1	all	1A10 + 4.5A30 + 4A40
4.1	all	1A10 + 8A79
4.2-4.3	< 73	1A10 + 8A85
	73	1A10 + 4A85 + 4A87
	74	1A10 + 2A85 + 6A87
	75+	1A10 + 8A87
4.4	all	1A10 + 5A76 + 3A79
4.5	< 54	1A10 + 2.5A128 + 6A79
	54-72	1A10 + 2.5A128 + 3A79 + 3A86
	73	1A10 + 2.5A128 + 1.5A79 + 1.5A86 + 3A87
	74	1A10 + 2.5A128 + 0.75A79 + .75A86 + 4.5A87
	75+	1A10 + 2.5A128 + 6A87
4.6		<u>Minetester:</u>
	< 73	1A10 + 4.5A40 + 3A58 + 0.5A79
	73	1A10 + 4.5A40 + 3A58 + 0.25A79 + 0.25A87
	74	1A10 + 4.5A40 + 3A58 + 0.0625 + .1875A87
	75+	1A10 + 4.5A40 + 3A58 + 0.5A87
		<u>Milltester:</u>
	< 73	1A10 + 3.5A79 + 4.5A100
	73	1A10 + 1.75A87 + 4.5A100 + 1.75A79
	74	1A10 + 0.87A79 + 2.63A87 + 4.5A100
	75+	1A10 + 3.5A87 + 4.5A100
		Estimates for job code 4.6 = (minetester + milltester)/2
4.7	< 54	1A10 + 4.5A79 + 4 A128
	54-72	1A10 + 2.5A79 + 2A85 + 4A128
	73	1A10 + 2A87 + 1.25A79 + 1.25A85 + 4A128
	74	1A10 + 3.5A87 + 0.5A79 + 0.5A85 + 4A128
	75+	1A10 + 4.5A87 + 4A128
4.8	all	1A10 + 8A130
4.9	< 54	1A10 + 6A79 + 2A128
	54-72	1A10 + 3A79 + 3A85 + 2A128
	73	1A10 + 1.5A79 + 1.5A85 + 3A87 + 2A128
	74	1A10 + 0.75A79 + 0.75A85 + 4.5A87 + 2A128
	75+	1A10 + 6A87 + 2A128

5.1	< 73	$1A10 + 4.5A79 + 3.5 A128$
	73	$1A10 + 2.25A79 + 2.25A87 + 3.5A128$
	74	$1A10 + 1.5A79 + 3.5A87 + 3.5A128$
	75+	$1A10 + 4.5A87 + 3.5A128$
5.2	< 73	$1A10 + 8A8.5$
	73	$1A10 + 4A85 + 4A87$
	74	$1A10 + 2A85 + 6A87$
	75+	$1A10 + 8A87$
5.3	>73	$1A10 + 8A301$
5.4	< 73	$1A10 + 5.5A80 + 3A128$
	73	$1A10 + 2.75A80 + 2.75A87 + 3A128$
	74	$1A10 + 1.3A80 + 4.2A87 + 3A128$
	75+	$1A10 + 5.5A87 + 3A128$
5.5	< 73	$1A10 + 5.5A86 + 3A128$
	73	$1A10 + 2.75A86 + 2.75A87 + 3A128$
	74	$1A10 + 1.3A86 + 4.2A87 + 3A128$
	75+	$1A10 + 5.5A87 + 3A128$
7.1-7.3	all	$1A10 + 8.5A128$
7.5-7.6		
7.9		
7.4	< 73	$1A10 + 4.5A79 + 4A128$
	73	$1A10 + 2.25A79 + 2.25A87 + 4A128$
	74	$1A10 + 1.5A79 + 3.5A87 + 4A128$
	75+	$1A10 + 4.5A87 + 4A128$
7.7	< 73	$1A10 + 1A79 + 7 A128$
	73-74	$1A10 + 0.25A79 + 0.75A87 + 7A128$
	75+	$1A10 + 1A87 + 7 A128$
7.8	all	$6A210 + 2.5A128$
9.0	< 73	$0.5A79 + 1.5A128 + 6 A220$
	73-74	$0.25 A79 + 0.25 A87 + 1.5 A128 + 6 A220$
	75+	$0.5 A87 + 1.5 A128 + 6 A220$
9.1	all	$8 A140 + 0.5A170$
9.2	all	$A200$
9.3	all	$A180$
9.4	all	$A190$
9.5	all	$5.5A170 + 2.5A150 + 0.5A160$

9.7	73+	A990
9.8	all	A220

* All totals are divided by 8 hours. For example for job 1.1: Exposure over an 8 hours shift = $[1A10+8.5A52]/8$

Codes for Location-Operations*

Code	Description
10	Bus ride
30	Mine office
40	Mine miscellaneous (guard shack, lunch room, service area)
52	Drilling
58	Mine-non drilling equipment operators (patrol, truck driver, shovel operator and oiler, loader operator).
230	Tails belt
60	Transfer point
76	Dry mill sweeping
79	Dry mill - non-millwright
85	Old wet mill - non-millwright
86	Old and new wet mill - millwright
87	New wet mill
128	Service area around mill
100	Quality control lab
130	Skipping
210	Bagging Plant
220	Downtown office
140	Concentrate hauling
200	Verxite plant
170	River office (Bin side)
180	Ore loading
190	River dock and car cleaning
150	River station (Bin side area samples, samples on the front end loader operator at bins)
160	River conveyor tunnel
301	Screen plant

* Codes were assigned by P. Sebastien in the McGill study McDonald et al (1985 a,b) , and adopted as a matter of convenience. However, several ACAE were not distinguished by McGill (codes 80, 86, 87, 301, and 502)

Job Codes for Work Histories*

Mine Classifications

<u>Classification No.</u>		<u>Job Description</u>
	<u>Drillers:</u>	
1.1		Wagon Drill Operator
1.1		Wagon Drill Helper
1.1		Rotary Driller
1.1		Secondary Driller
	<u>Operators:</u>	
1.2		Shovel
1.2		Shovel Oiler
1.3		Patrol
1.2		Bulldozer
1.4		Dozer
1.5		Dump Dozer
1.2		Halt Track
1.6		Euclid
1.7		Wheel End Loader
	<u>Transfer Point Operator:</u>	
1.8		C-9 Operator
1.8		C-9 Beltman
1.9	<u>Dumpman</u>	
2.0	<u>Powderman</u>	
2.1	<u>Foreman</u>	

Mill Classifications

	<u>Dry Mill Operators:</u>	
4.1		Assistant Mill Operator
4.1		Head Mill Operator
	<u>Wet Mill Operator</u>	
4.3		Jig Operator
4.2		Flotation Operator
4.4	<u>Sweeper</u>	
4.5	<u>Millwrights</u>	
4.6	<u>Testers</u>	

Classification No.Job Description

4.7

Research Workers

4.8

Skip Operator

4.9

Shifters

5.1

Dry Mill Supervisor

5.2

Wet Mill Supervisor

Screen Plant

5.3

Operator

5.4

Dry Mill Millwright

5.5

Wet Mill Millwright

Service ClassificationsMechanics

7.1

Garage Cleanup

7.1

Truck Greaser

7.1

Mechanic-all

Machinists

7.2

Machinists

7.2

Lathe Operator

Sheet Metal Workers

7.3

Welders-all

7.3

Welder & Layout Man

Electricians

7.4

7.5

Instrument Man

7.6

Warehouse ManConstruction Workers

7.7

Construction Worker

7.7

Carpenters 105.7

Construction Truck Driver

7.7

Common Laborer

Export Operators

7.8

Sacker and Loader

7.9

Steam Engineer

Miscellaneous classifications

<u>Classification No.</u>	<u>Job Description</u>
9.1	<u>Concentrate Haulers</u>
9.1	Ore Hauler, dust truck Kenworth Driver
9.2	<u>Expanding Plant Operator</u>
9.2	<u>Expanding Plant Loader</u>
9.3	<u>Ore Loader</u>
9.4	<u>Dock Hand</u>
9.5	<u>Loading Dock Foreman</u>
9.7	Downtown Lab.
9.8	Clerical and Other Personnel Downtown (Don't travel to "hill")
9.0	Managers who work downtown and travel to hill

* This classification scheme was developed by the company and made available to NIOSH

Table III-1

Job exposure estimates by year

<u>Area</u>	<u>Year</u>								
	<u><50</u>	<u>50-59</u>	<u>60-63</u>	<u>64-67</u>	<u>68-70</u>	<u>71</u>	<u>72-74</u>	<u>75-76</u>	<u>77-82</u>
<u>High estimates</u>									
<u>Mine</u>									
Drillers	24.6	24.6	24.6	24.6	24.6	9.9	9.9	0.6	0.6

Table III-1

Job exposure estimates by year

Area	Year								
	<50	50-59	60-63	64-67	68-70	71	72-74	75-76	77-82
<u>High estimates</u>									
<u>Mine</u>									
Drillers	24.6	24.6	24.6	24.6	24.6	9.9	9.9	0.6	0.6
Shovel opr.	2.9	2.9	2.9	2.9	2.9	2.9	2.9	0.6	0.6
Patrol opr.	2.9	2.9	2.9	2.9	2.9	2.9	2.9	0.6	0.6
Dozer opr.	2.9	2.9	2.9	2.9	2.9	2.9	2.9	0.6	0.6
Dump dozer opr.	2.9	2.9	2.9	2.9	2.9	2.9	2.9	0.6	0.6
Euclid opr.	2.9	2.9	2.9	2.9	2.9	2.9	2.9	0.6	0.6
Loader opr.	2.9	2.9	2.9	2.9	2.9	2.9	2.9	0.6	0.6
Transfer pt.	3.8	3.8	3.8	3.8	3.8	3.8	3.8	0.7	0.7
Dumpman	2.9	2.9	2.9	2.9	2.9	2.9	2.9	0.6	0.6
Powderman	10.6	10.6	10.6	10.6	10.6	5.4	5.4	0.6	0.6
Foreman	1.5	1.5	1.5	1.5	1.5	1.5	1.5	0.7	0.7
<u>Mill</u>									
Operator	168.6	168.6	168.6	33.4	33.4	33.4	16.8		
Flotation opr.		3.9	3.9	3.9	3.9	3.9	4.2	2.0	0.8
Jig op.	3.9	3.9	3.9	3.9	3.9	3.9	4.2	2.0	0.8
Sweeper	177.1	177.1	177.1	35.0	35.0	35.0	18.3		
Millwright	127.0	96.7	66.5	16.4	15.8	15.8	7.3	1.6	0.7
Tester	47.2	47.2	47.2	10.1	10.0	10.1	4.6	1.3	0.7
Research	95.8	75.3	54.7	13.4	12.4	12.4	5.6	1.2	0.6
Skip opr.	88.5	88.5	88.5	17.6	17.6	17.6	5.0	0.6	0.6
Shifter	126.9	96.1	65.2	14.9	14.5	14.5	6.1	1.6	0.7
Dry mill sup.	95.7	95.7	95.7	20.6	19.7	19.7	7.8	1.2	0.5
Wet mill sup.		3.9	3.9	3.9	3.9	3.9	4.2	2.0	0.8
Screen plt opr							0.7	0.5	0.5
Dry mill mwrt	116.6	116.6	116.6	24.4	23.7	23.7	8.8	1.5	0.6
Wet mill mwrt	5.7	5.7	5.7	6.4	5.7	5.7	5.0	1.5	0.6
<u>Service</u>									
Mechanic	2.2	2.2	2.2	4.2	2.2	2.2	2.2	0.2	0.2
Machinist	2.2	2.2	2.2	4.2	2.2	2.2	2.2	0.2	0.2
Welder	2.2	2.2	2.2	4.2	2.2	2.2	2.2	0.2	0.2
Electrician	95.8	95.8	95.8	20.7	19.8	19.8	7.0	1.2	0.6
Instrumentman	2.2	2.2	2.2	4.2	2.2	2.2	2.2	0.2	0.2
Warehouseman	2.2	2.2	2.2	4.2	2.2	2.2	2.2	0.2	0.2
Construction	22.9	22.9	22.9	7.6	6.0	6.0	3.9	0.4	0.3
Bagging opr	10.2	10.2	10.2	10.9	10.2	10.2	5.1	1.0	1.0
Steam engineer	2.2	2.2	2.2	4.2	2.2	2.2	2.2	0.2	0.2

Miscellaneous									
Manager-dntn	10.9	10.9	10.9	2.8	2.4	2.4	1.2	0.2	0.1
Conc. hauling	6.2	6.2	6.2	6.2	6.2	6.2	6.2	0.4	0.4
Expanding Plt	22.6	22.6	2.8	2.8	2.8				
Ore loader	82.5	27.7	10.7	10.7	3.2	3.2	3.2	0.2	0.2
Dock hand	116.9	42.5	17.0	17.0	17.0	5.1	5.1	0.5	0.5
loading dk for	20.9	20.9	20.9	20.9	20.9	20.9	20.9	0.4	0.4
Dntn lab							0.5	0.5	0.5
Dntn clerical	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Low estimates*

drillers	7.3	7.3	7.3	7.3	7.3	9.9	9.9	0.6	0.6
powderman	4.5	4.5	4.5	4.5	4.5	5.4	5.4	0.6	0.6
bagging opr	4.0	4.0	4.0	4.6	4.0	4.0	3.8	1.0	1.0
ore loader	24.0	15.0	9.0	9.0	3.2	3.2	3.2	0.2	0.2
dock hand	38.0	19.0	6.4	6.4	6.0	5.1	5.1	0.5	0.5

* Low estimates are the same as high estimates for all other areas.

APPENDIX IV

List of workers who died of lung cancer
and non-malignant respiratory disease

Table IV-1

Workers who died of a non-malignant
respiratory disease (ICDA 460-519)

Case	ICDA Code	Cause of death Description	Sex	Latency years	Fiber- years	Year of hire	Year of birth	Age at death	Tenure
1	470	Flu	M	12.4	124.4	1965	1914	63.4	11.0
2	485	Bronchopneumonia	M	22.6	30.2	1946	1889	79.9	1.3
3	491	Chronic Bronchitis	M	31.8	48.5	1941	1906	67.6	2.1
4	492	Emphysema	M	30.7	35.8	1944	1892	82.7	1.6
5	492	"	M	6.6	14.7	1966	1908	64.6	4.1
6	492	"	M	15.4	252.7	1946	1908	53.0	11.0
7	492	"	M	32.5	1657.5	1946	1891	87.2	9.4
8	514	Pul. Congestion and Hypostasis	M	31.8	40.7	1947	1897	81.9	1.8
9	515.0	Silicosis	M	23.2	33.2	1947	1915	55.4	3.0
10	515.2	Asbestosis	M	41.2	1405.2	1937	1904	73.9	8.3
11	515.2	"	M	21.9	2026.3	1944	1899	67.3	17.1
12	515.2	"	M	16.8	2393.2	1944	1899	54.1	14.2
13	515.2	"	M	19.9	137.8	1954	1912	62.2	19.3
14	517	Other chronic inters. Pneum.	M	11.3	578.3	1957	1904	63.6	11.3
15	517	"	M	22.1	76.9	1949	1926	44.7	3.4
16	517	"	M	28.4	49.3	1946	1909	66.3	2.2
17	518	Bronchiectasis	M	14.2	1963.3	1949	1913	50.9	14.2
18	519.2	Other lung disease	M	18.6	895.1	1959	1921	56.6	18.6
19	519.3	COPD	M	32.9	93.0	1946	1911	67.7	4.1
20	519.3	"	F	32.1	20.1	1949	1909	72.3	1.8
21	519.3	"	M	28.3	14.5	1951	1919	60.4	5.0

Table IV-2

Workers who died of Lung Cancer (ICDA 162-163)

Case	ICDA code	Sex	Latency	Fiber- years	Age at death	Year of Hire	Year of Birth	Tenure (years)
1	162.1	M	15.5	407.0	63.8	1962	1978	15.3
2	162.1	M	32.6	320.4	55.4	1935	1968	32.6
3	162.1	M	21.4	40.3	58.1	1948	1970	1.8
4	162.1	M	9.1	852.8	57.7	1957	1966	9.1
5	162.1	M	24.0	715.9	53.9	1957	1981	9.6
6	162.1	M	22.4	24.6	48.6	1947	1969	1.1
7	162.1	M	14.1	323.0	53.0	1946	1960	14.1
8	162.1	M	19.0	42.6	52.1	1944	1963	9.8
9	162.1	M	3.0	8.5	28.0	1952	1955	2.9
10	162.1	M	34.1	1723.8	67.1	1946	1980	29.0
11	162.1	M	26.8	81.8	56.8	1946	1973	23.4
12	162.1	M	29.9	1797.7	57.6	1948	1978	28.2
13	162.1	M	2.6	0.0	62.2	1947	1950	1.0
14	162.1	M	26.5	489.3	49.8	1951	1978	5.1
15	162.1	M	38.5	864.2	66.0	1938	1976	5.1
16	162.1	M	15.0	45.2	59.4	1948	1963	2.0
17	162.1	M	34.0	72.4	63.9	1947	1981	3.2
18	162.1	M	28.5	1239.1	50.1	1948	1977	24.3
19	163.1	M	9.0	783.9	53.5	1958	1967	9.0
20	162.1	M	30.8	464.5	58.9	1945	1976	9.8

Appendix V

**A Comparison of Data Collected by
NIOSH and McGill University**

Separate studies of the mortality and morbidity of the Libby, Montana vermiculite workers were conducted by NIOSH and McGill University. This is a report on the comparison of data collected by the two groups.

Mortality Cohorts

With regard to the studies of mortality, NIOSH included all workers hired before 1970 with at least 1 year tenure. McGill defined its cohort as all workers employed before Jan 1, 1963 with at least 1 year tenure. The McGill cohort consisted of 406 males, and the NIOSH cohort consisted of 589 males and females. By definition, all workers in the McGill cohort should have been in the NIOSH cohort.

The data collected by the two groups has been compared. Results of this comparison are as follows:

1. 2 workers in McGill's cohort were hired in 1963; (one on 4-1-63, and the other on 6-13-63.
2. 178 workers in the NIOSH cohort were excluded from the McGill cohort. Of the 178, 162 didn't meet McGill's cohort definition, while the remaining 16 males excluded by McGill did meet their definition (table V-1). Of these 16 males, 2 have >20 years tenure, and 14 have <20 years tenure, 9 have <50 f-y, 5 have 50-399 f-y, 2 have >400 f-y, 10 were hired before 1960, 6 were hired from 1960-1963, and none were deceased on December 31, 1981.

3. Discrepancies in the data collected are presented in tables V-2 to V-6. With regard to nosology (table V-2), ICDA codes obtained by NIOSH and McGill matched in 149 of the 164 deaths. There were no discrepancies in lung cancer, 3 discrepancies in silicosis or asbestosis (ICDA code 515), and 2 in ischemic heart disease (ICDA codes 410-413). The misclassification of causes of death was slight, as expected, because the same nosologist coded the certificates independently for NIOSH and McGill.

Mesothelioma was listed as an underlying or contributing cause of death in 4 cases (table V-3). Only 2 died by December 31, 1981, and the same ICDA code (199) was assigned by NIOSH and McGill for these 2 cases.

A substantial discrepancy between the data from the two groups in date of birth (table V-4), employment dates (table VII-5), and tenure (table V-6) was found in only a few workers.

Results of the comparison indicate that NIOSH and McGill's data was similar. Discrepancies were minimal, and should not have caused a substantial difference in the mortality findings between the two studies. The 16 workers excluded by McGill were all living on December 31, 1981, and most had low tenure and low f-y.

Morbidity Studies

NIOSH and McGill also conducted cross-sectional studies to estimate the exposure-response relationship for radiographic findings. Although the two

study designs differed markedly, 135 workers were common to both studies. In each study, the worker's most recent radiograph was collected and interpreted by 3 physicians, and only 1 physician participated in both studies (Reader B).

Reader B interpreted NIOSH and McGill films for 135 workers common to both studies. A comparison of the reader B's findings for those NIOSH and McGill films showed that the major radiographic category of profusion of small opacities differed in 17.8% (24/135) of the films (table V-7). The radiographic category was higher on the McGill than the NIOSH film in 12.6% (17/135) of the cases, and lower for the McGill than NIOSH film in 5.2% (7/135) of the cases. The results suggest that the difference in prevalence between studies may be due to differences in film quality.

Table V-1

Men in the NIOSH cohort, but not in the McGill cohort*

Case	Year of		Fiber-
	Hire	Tenure	years
1	49	20.3	546.0
2	59	5.7	17.5
3	59	4.2	12.1
4	62	12.0	126.4
5	61	1.1	76.6
6	45	1.1	25.1
7	46	3.8	18.8
8	45	1.4	31.2
9	53	23.9	1029.4
10	60	4.1	39.1
11	58	4.1	15.9
12	61	2.4	150.4
13	56	4.2	46.2
14	61	1.7	5.7
15	56	4.5	13.0
16	61	4.8	202.5

* All workers were living on December 31, 1981.

Table V-2

Discrepancies in cause of death
in NIOSH and McGill data

Case	McGill Code	NIOSH Code	Reported on the Death Certificate	NIOSH Cause of Death	McGill Cause of Death
*1	517.0	515.2	Asbestosis, lung cancer	Asbestosis	Other chronic Int. Pneum.
2	413.0	431.0	Cerebral hem. hypertension	Cer. Hem hyper.	Angina pectoris
3	431.9	430.9	Cerebral hem. w/o hyper.	Cer. Hem w/o hyper	Subarachnoid hem. w/o hyp.
4	579.1	571.9	Cirrhosis of liver	cirrhosis of liver	error in code
5	412.3	410.9	Acute MI, Emphysema, asbes.	Acute MI	Chronic. Ischemic. Ht. Dis.
*6	515.0	412.4	CVD + hyper, silicosis	CVD	Silicosis
*7	819.9	823.9	Truck accident	Traffic Accident	Non-traffic accident
8	515.2	517.X	Tracheo bronchitis, Pul. cor pulmonale	Other chronic int. pneumonia	Asbestosis
9	430.9	442.X	Cerebral vascular accident	Ruptured	Subarachnoid hem.w/o hyper
10	342.0	340.0	None		
11	930.0	593.2	Cardio-renal failure, post surgical shock		
12	412.3	440.9	Art. Ht. Dis	Aneurysm kidney die.	Surgical complications
13	985.0	955X	Suicide	Arteriosclerosis	IHD & AHD
14	922.9	965X	Homicide, gunshot	Suicide	Unk. injury
15	429.9	410.9	None	Assault	Gunshot wound
				M.I.	Ill defined heart disease

* Discrepancy in codes for asbestosis or silicosis

+ Discrepancy in codes for ischemic heart disease

Table V-3

Cases for whom mesothelioma is listed on the death certificates as
an underlying or a contributing cause of death

Case	Year of Death	NIOSH	ICDA Code	McGill
1	82	199.1		163.0
2	83	515.2		515.2
3	79	199.0		199.0
4	80	199.0		199.0

Table V-4

Discordant dates of birth in NIOSH and McGill data

Case	Date of Birth		Vital Status
	NIOSH	McGill	
1	9/20/20*	11/22/06	Died, 1982
2	9/20/11+	9/20/00	living
3	3/30/20	3/30/22	living
4	4/13/88*	4/13/81	Died, 1950
5	5/12/19	5/12/13	Died, 1982
6	12/25/41*	12/25/14	living

* Keypunch error - McGill data are correct

+ Confirmed by company personnel records collected by NIOSH.

Table V-5
Discordant Date of Hire in NIOSH and McGill Data on 1 Worker

Date of Hire		Date of Separation	
NIOSH	McGill	NIOSH	McGill
5/4/48	5/43	5/7/52	3/21/56

Table V-6
Workers for whom the difference between the
NIOSH and McGill tenure is greater than 2 years

Case	NIOSH Tenure	McGill Tenure
1	28.5	30.5
2	26.2	20.4
3	3.9	8.9

Table V-7

The major radiographic category reported by Reader B on
a NIOSH and McGill film for 135 workers common to both studies

ILO Radiographic Category		McGill Study ILO Radiographic Category				Total
		0	1	2	3	
NIOSH Study	0	98	13	1	0	112
	1	7	13	2	0	22
	2	0	0	0	1	1
	3	0	0	0	0	0
Total		105	26	3	1	135