FILE NAME: WR Grace (WRG)

DATE: March 7, 1986

DOC#: WRG341

DOCUMENT DESCRIPTION: 1986 Cohort study of mortality of vermiculite miners submitted to EPA

CODING FORM FOR SRC INDEXING REVISED 10/15/86

Microfiche No.	OTS0503695-1	
New Doc I.D.	89-8680167	Old Doc I.D. 8EHQ-0386-0473
Date Produced	Date Recieved 3/07/86	TSCA section 8E
Submitting Organization	WR GRACE & CO	
Contractor	MCGILL UNIV	
Document Title	COHORT STUDY OF MORTALITY OF VERMICULITE MINERS EXPOSED TO TREMOLITE WITH COVER LETTER DATED 030486	
Chemical Category	TREMOLITE	

Health, Safety and
Environmental Services
Industrial Chemicals Group

GRACE

W.R. Grace & Co.
62 Whittemore Avenue
Cambridge, MA 02140

(617) 876-1400

pg

~~2~~ 41 pp.

8EHQ-0386-0473
89-8680167
FLWP

EPA-OTS

000401449M

4 March 1986

Document Control Officer
Management Support Division
Office of Toxic Substances
U.S. Environmental Protection Agency
401 "M" Street, S.W.
Washington, D.C. 20460

Subject: Document Control Number 8EHQ-0383-0473

The McGill University study of the health effects of exposure to tremolite at the W. R. Grace & Co. (Grace) mine and mill in Libby, Montana, has been completed. Actually, independent but cooperative studies were done by the National Institute of Occupational Safety and Helath (NIOSH) and the McGill team which included Dr. J. C. McDonald, Dr. A. D. McDonald, and Dr. P. Sebastien. Combined results were presented verbally at a September 1985 conference on dust-related lung disease in Cambridge, England. The attached documents by the McGill team have recently been finalized and submitted to the British Journal of Occupational Medicine for publication. NIOSH has just completed their report and will be sending a copy directly to the EPA.

Somewhat different techniques were used by the two study groups but the results were similar. The relatively small differences are explained in the attached McGill reports. We believe that these reports contain all information requested in Frank B. Kover's letter of April 25, 1983. However, we can make members of the McGill team available for clarifications if necessary.

Please note that these are pre-publication documents and under normal circumstances are not distributed prior to publication.

Sincerely yours,

H. A. Eschenbach, Director
Health, Safety & Toxicology

HAE/cs

attachments

E227

00002

02/14/1996 EPA TSCA DOCKET

non-CBI per submitter 3-10-86 pg

~~CONFIDENTIAL~~
~~NOT TO BE QUOTED~~
~~BEFORE PUBLICATION~~

COHORT STUDY OF MORTALITY OF VERMICULITE MINERS EXPOSED TO TREMOLITE

J.C. McDONALD
A.D. McDONALD
B. ARMSTRONG
and
P. SEBASTIEN

SCHOOL OF OCCUPATIONAL HEALTH
McGILL UNIVERSITY, MONTREAL, CANADA

00003

02/14/1996 EPA TSCA DOCKET

1. Abstract

A cohort of 406 men employed before 1963 for at least one year in a vermiculite mine in Montana, was followed until July 1983. The vermiculite ore as fed to the mill contained 4 - 6% of amphibole fibre in the tremolite series. Vital status was established in all but one of the 406 and death certificates obtained and coded for 163 of the 165 men who had died. Compared with US white males, the cohort experienced excess mortality from all causes (SMR 1.17), respiratory cancer (SMR 2.45), non-malignant respiratory disease (SMR 2.55) and accidents (SMR 2.14). There were 4 deaths from malignant mesothelioma (proportional mortality 2.4%). Compared with Montana death rates, the SMR for respiratory cancer was somewhat higher (3.03). Man-year analyses of respiratory cancer and estimated cumulative exposure gave a relationship which did not depart significantly from linearity. The results of this and case-referent analyses indicate an increased risk of mortality from respiratory cancer in this cohort of about 1% for each fibre year of exposure. In relation to estimated exposure, the mortality experienced by the cohort from both lung cancer and mesothelial tumours was higher than in chrysotile mining.

02/14/1996 EPA TSCA DOCKET

2. Introduction

In April 1983, we were invited by W.R. Grace & Co, owners of a vermiculite mine in Libby, Montana, to investigate the health of their employees. Morbidity and mortality studies in the same population had been initiated by NIOSH in February 1982 but, because of the urgent decisions which faced them, the Company wished to have an independent inquiry as quickly as possible. Having assured ourselves that NIOSH and the employees' union had no objection to parallel and complementary studies, and indeed welcomed them, our research proposals were finalized and accepted in August 1983 and we began work in September. Our studies had four components: a cohort mortality study (described in this paper), a cross-sectional radiographic survey, an investigation of asbestos bodies in sputum, and an electron-microscopic analysis of lung tissue samples at autopsy from ex-employees. Findings from the last three studies will be reported separately (1, 2, 3), as will those of NIOSH. Although the NIOSH inquiries and our own were designed, conducted and analysed quite separately, we discussed and compared our data and methods at every stage. This was a valuable exercise; unnecessary differences and discrepancies were eliminated and the reliability of both sets of results increased.

Concern for the health of workers in this mine stemmed not from exposure to vermiculite, a micaceous mineral for which no adverse effect is suspected, but from the fact that the ore body is contaminated with fibrous amphibole deposits in the tremolite series. Fibrous tremolite and related minerals fall within the definition of asbestos (4) but have very limited value and are produced only in some very small mines in Northern Italy. On the other hand, they are common contaminants in various mining operations, notably the chrysotile mines of Quebec and certain talc mines in New York State. Other members of the amphibole family include crocidolite and amosite which are known to cause pulmonary fibrosis, lung cancer and malignant mesothelial tumors. Existing evidence

02/14/1996 EPA TSCA DOCKET

suggests indeed that most occupationally-related mesotheliomas are caused by amphibole fibres and few by chrysotile (5,6,7). The experience of men in the Libby mine exposed only to the tremolite group of fibres was therefore of practical concern and scientific significance.

Few observations on the health effects of tremolite have been made. Cohort studies of employees of talc mines in New York State, some of which may contain fibrous tremolite, showed an excess of pulmonary disease and lung cancer and one or two cases of malignant mesothelioma (8,9). In an autopsy study of 99 cases of malignant mesothelioma and matched controls, four cases with more than 10 million fibres of tremolite per g dried lung were observed compared with one control (10). The comparable figures, in cases and controls, for other asbestos fibres were:- chrysotile 39:33, amosite 12:1, crocidolite 9:0, anthophyllite 2:0. In lung tissue from chrysotile miners and millers, the quantity of tremolite appears similar to that of chrysotile, although only a minute fraction of the asbestos fibre mined (11,12). In a study of six mesothelioma cases from the Québec chrysotile mines, tremolite was the predominant fibre found in the lung tissue at autopsy (13). Experimental studies in animals have demonstrated that the carcinogenic potential of tremolite is similar to that of other fibrous amphiboles (14).

Evidence of pulmonary fibrosis was first noted in an X-ray survey of Libby employees in 1959 and, since Grace acquired the company in 1963, employees have been X-rayed annually. In the 1970's, pulmonary function tests were added and, later, a respiratory symptom questionnaire. Intensive efforts were made to minimize exposure and a vigorous anti-smoking campaign was instituted to further reduce the risk. Efforts made by the company to investigate pulmonary disease among workers included the search for death certificates for all known deceased employees. Individual exposures in terms of duration and dust concentration were also estimated. An analysis of these data revealed 16 lung cancers and 2 malignant mesotheliomas in a total of 109 deaths. This information was reported by the company to the US Environmental Protection Agency on March 24, 1983. A preliminary case-control analysis of these data by ourselves indicated that the lung cancer risk was probably related to cumulative exposure.

02/14/1996 EPA TSCA DOCKET

3.1 The production process - Vermiculite is a mineral derived from geological transformation of trioctahedral micas (15). On heating, the material expands approximately 15 times in volume and acquires useful properties. Expanded vermiculite is mainly used as an insulator against heat and noise in the construction industry and also as an absorbant low density filler and chemical carrier. Of the 325,000 tons of vermiculite concentrate (before expansion) used in the USA in 1984, 54% came from the Libby mine. According to legend, the vermiculite mountain in Libby was discovered in 1913 by Edward N. Alley: walking in a short tunnel in search of metal deposit, the flame of his mining candle came in contact with vermiculite and the immediate transformation by heat attracted his attention. Commercial exploitation started in 1923. Libby production, initially low, increased from 20,000 in 1940 to 150,000 tons in 1950 and 200,000 tons in 1970.

At the present time, mining is conducted on benches or levels that extend laterally from the surface to more than 300 vertical feet below the original surface of the mountain. Although equipment has changed over the years, ore has always been extracted by the classical technique of drilling, blasting, loading (with shovels or front-end loaders) and hauling to the mill or transfer point. Drilling was considered the most dusty operation and, in 1970, new drills with baghouses were introduced.

After removal of coarse rock, the ore is blended and fed at controlled rates to the top of the mill. At this point the granules are about 1 cm in diameter and contain approximately 20% vermiculite. Accompanying minerals are augite, biotite, calcite, diopside, hornblende, magnetite, quartz, sphene and tremolite-actinolite (16). Milling takes advantage of differences in particle shape to separate the thin flakes of vermiculite from the blocky waste particles. The finished concentrate in 1984 contained 80-95% vermiculite. Before 1954, the milling was basically a dry screen process. A second mill, operating a wet process, was added in 1955 to

02/14/1996 EPA TSCA DOCKET

accomplish the first stages of separation. Work in the dry mill was very dusty but became much cleaner after 1965 when ventilation equipment was installed. In 1974, for hygienic and technical reasons, both dry and wet mills were shut down and ore was processed in a new mill built nearby which operated on an entirely wet process in which separation was made by vibrating screens, roll screens, Humphrey separators and flotation. The new wet mill operates continuously, producing 1,100 tons of concentrate each day in 1984; this is then dewatered, dried and hauled to the screening plant. All the mill water is reclaimed after clarification in a tailings pond.

The screening operation separates grades of vermiculite concentrate, differing in particle size and industrial application. The techniques for handling and shipping concentrate at Libby have been changed several times with the object of controlling dust exposure. At present most of the concentrate is shipped by rail, the loading station being equipped to reduce dust exposure; bagging is still used to a small extent.

3.2 Study group - Our cohort comprised all male employees with a company record of employment starting before 1 January 1963 and a net period of at least one year. These criteria were met by 406 men. Twelve were first employed before 1940, and the remainder thereafter. The vital status of each man on 1 July 1983 was sought. Inquiries were first made of relatives and friends by a recently retired long-term company employee. For all those reported dead, the date and place of death were investigated; for those reported alive, the address and telephone number were requested. In cases in which these inquiries failed to produce a satisfactory result, information was submitted to drivers' licence bureaus. Finally, the results of searches of social security files for NIOSH were consulted for those men who could not otherwise be traced.

The number found to be living on 1 July 1983 was 226 and 165 were reported dead. A further fourteen men could only be traced through social security files; these men were known to be living on 31 December

02/14/1996 EPA TSCA DOCKET

1981, but their subsequent status was not established. They were included in the man-years analysis until the date at which they were lost to view. Death certificates were sought in the state in which each of the 165 deaths was thought to have occurred. Copies of death certificates were obtained for 163 men. The registered cause of death was coded by a single qualified nosologist according to the eighth revision of the International Classification of Diseases. The causes of death are shown in Table 1.

3.3 Mineralogy - It is well established that the vermiculite deposit in Libby is contaminated by asbestiform fibres (17). Their presence in airborne dust was first mentioned in 1956 in the report of an industrial hygiene survey by the Montana State Board of Health but only very recently has further information become available on the nature of Libby fibres (16).

A systematic study by analytical transmission electron microscopy of airborne fibres collected on membrane filters in various locations of the mine and mill is now in progress. Preliminary findings on samples from the wet mill indicate that fibres exhibit several morphologies. They may be straight with uniform diameter, have a lath or needle shape or be curved; they may be found intermingled with other platy particles (see Figure 1). So far, the ranges for diameter, length and aspect ratio are 0.1 - 2 μm, 1 - 70 μm and 3 - 100 respectively. A fairly high proportion (62%) of fibres have been found longer than 5 μm. Comparison of electron and optical microscope counts shows that about a third of the total airborne fibres are detected by the optical technique used for measuring exposure to asbestos at the work place (18).

Elemental chemical analysis of individual fibres by energy dispersive spectrometry (19) yielded unsuspected and complicated results. Although the chemistry of many fibres was compatible with minerals of the tremolite-actinolite series, the sodium content of some was too high to meet the

02/14/1996 EPA TSCA DOCKET

criteria for tremolite according to the classification of the International Mineralogical Association (20). Some sodium-rich fibres either displayed no calcium reponse (with both B sites in the theorectical formula of amphiboles occupied by sodium), and so could be called magnesio-riebeckite, or displayed an intermediate calcium response (sodium distributed between A site and B site) and could be called richterite. X-ray diffraction analysis of Libby samples by Atkinson et al (16) detected what they called "sodium tremolite" but it was not stated whether it was in fibrous form. They also observed by optical microscopy that comminution of massive amphibole crystals produced cleavage fragments resembling fibres. These observations indicate the complexity of the Libby situation; the airborne fibres are probably a mixture of different types of asbestiform and massive amphiboles. In addition, there may also be some exposure to quartz since this mineral was identified in some ore samples (16) although not reported in air samples taken in government or company surveys.

3.4 Exposure estimates - Regardless of their nature, we had to estimate for each member of the cohort the cumulative fibre exposure as measured by standard optical microscope technique (18) (the so-called 'regulatory fibres'). Work histories based upon 42 defined job categories were obtained from the company together with detailed information on the process, its changes with time and the introduction of control measures. Analysis of the process and observations made during two field visits (by P.S.) showed that the 42 job categories described the working operations with good specificity. Our general strategy for estimating cumulative exposures was a) to take maximum advantage of existing air measurements and b) to concentrate efforts on the past dry mill period (before 1975) when substantial exposures occurred. Altogether, results of 1363 air measurements were available for the period before 1975. They were extracted from reports of surveys carried out by the company, the Montana State Board of Health, the National Center for Urban and Industrial Health and the Bureau of Mines. Efforts to monitor the work environment which prior to 1967, were virtually restricted to measurements of dust concentration in the dry mill using the midget impinger method, increased substantially

02/14/1996 EPA TSCA DOCKET

in the 1970's with the introduction of the membrane filter method (21). In the entire period before 1965 only 48 environmental measurements were made; this increased to 385 for the period, 1965-69, and to 930 for the period 1970-74. Both static and personal sampling had been used. As most of the personal samples were short-term, they probably reflected ambient concentrations rather than time-weighted average exposures.

A modified version of the exposure-zone concept (22) was applied in using air measurement data to estimate exposure. Bearing in mind that at any time, a worker is somewhere, doing something, we defined 28 operation-locations (Table 2). These were defined to ensure that every available air measurement could be unequivocally allocated. Information on location was used to classify static samples and that on operation to classify short-term personal samples. Operation-locations were further divided in time periods bounded by dates of significant change in process or in control procedures. In the calculation of cumulative exposure, grouped air measurement data were averaged using the technique of Oldham (23), which provides "a minimum variance unbiased estimate" of the arithmetic mean in skewed log normal distributions.

In the dry mill, midget impinger measurements were made in 1944,1956 and 1958 and much more regularly in the period 1962-69. High dust concentrations (38.9 mpcf geometric mean) significantly dropped by a factor of about 4.6 in 1965 after the installation of a major piece of ventilation equipment, known as the scirocco fan. There was no clear indication of further consistent decrease in concentrations in the dry mill after 1965 and concentrations were taken as constant. Measurements by the membrane filter method in the period, 1970-74, revealed a mean concentration of 22.1 f/cc. It was therefore assumed that the concentration in f/cc for the period before 1965 was 4.6 times higher, i.e. 101.5 f/cc. Only two operation-locations were considered in the dry mill: dry mill working (except sweeping) and dry mill sweeping. Personal samples indicate that sweepers in the dry mill were exposed to concentrations about 20% higher.

02/14/1996 EPA TSCA DOCKET

For the other operation-locations fibre measurements were available only for the recent periods. When the data were considered inadequate to describe past conditions, because of changes in process or control practice, arbitrary correction factors were applied. This was done after discussion in depth with company's representatives and especially with a previous manager who spent almost all his career in Libby and who had extensive knowledge of the operations.

The estimated average levels of exposure at the 28 operation-locations, 1945-82, are shown in Table 2. Recent values (1975-1982) were calculated in the same manner from data provided by NIOSH, where all available air measurements had been collected. As the company had introduced a systematic air sampling program in 1975, the number of measurements for this period was much higher than in the past. As these recent measurements had been made by long-term personal sampling, the operation-location model may be less appropriate since the same sample may cover more than one operation-location. However, recent fibre counts were low so it is unlikely that this materially affected the accuracy of our cumulative exposure estimates.

The work histories were available in terms of job category, not operation-location. We therefore used job descriptions to estimate for each job the period of time and the number of hours spent by workers in different operation-locations; the cumulative exposure was then calculated. Again, the help of company representatives made this possible.

3.5 Statistical analysis - The mortality of the total cohort was compared to that of US white males using the person-years at risk method to compute expected numbers of deaths and hence standardised mortality ratios (SMR's). These computations were made using Monson's computer program (24), from which US national age-specific death rates, available to 1975, were also taken. Additional analyses of mortality from respiratory cancer were made using Montana death rates from published figures for numbers of deaths, together with appropriately interpolated estimates of population

02/14/1996 EPA TSCA DOCKET

from censuses. Respiratory cancer death rates for Montana were computed for the period up to 1978, and the US National rates for this cause updated to this year for comparability.

Analysis of the relationship between mortality and exposure to fibrous dust was performed in two ways. Firstly, the exposure cumulated to the end of each month of each man's life, or until the end of 1982 for those who survived until then, was calculated. Person-years at risk were then divided into four groups according to cumulative exposure to fibres, and expected deaths and SMR's computed for each group. A linear relationship between SMR and cumulative exposure was then fitted using the GLIM program in the manner described by Hanley and Liddell (25). Secondly, relative risks were estimated from case-control sets chosen from within the cohort. Controls for each case were chosen as men surviving beyond the age of death of the case, who had been born and had started work at Libby mine within three years of the case. For each control,exposure was cumulated to the age of death of the matching case. Estimates of linear increase in relative risk (odds ratio) per unit exposure were made using the method of conditional likelihood. (26)

4. Results

The mortality experience of the cohort as a whole is summarized in Table 3. Mortality for all causes was in excess of that expected for US white males by 24 deaths (SMR 1.17). The SMR for all causes rose from 0.79 for the first 9 years from first exposure, when 'healthy worker' selection effects would be expected to be strongest, to 1.31 after 20 years from first exposure. There was a substantial excess of deaths from respiratory cancer (SMR 2.45), from non-malignant respiratory disease (SMR 2.55), and from accidental causes (SMR 2.14). There was no evidence of excess deaths from cancers of non-respiratory sites. Eight of the non-malignant respiratory disease deaths were certified as due to pneumoconiosis (ICD 514 or 515). Of the 18 deaths due to accidental causes, five occurred while the men were employed at the mine and the other thirteen after they had left. There were four deaths from

02/14/1996 EPA TSCA DOCKET

mesothelioma; one was coded by the nosologist to respiratory cancer (ICD 165), one to pneumoconiosis (ICD 515), and two to neoplasm without specification of site (ICD 199). Three of the cases were pleural and one peritoneal. In addition, there was one death certified as due to mediastinal cancer (ICD 163) in a man 9 years after first employment. At autopsy the pathologist did not consider this a mesothelioma.

Using Montana death rates instead of US national rates reduced the number of respiratory cancer deaths expected from 9.41 to 7.60, increasing the SMR from 2.45 to 3.03. SMR's for respiratory cancer (using Montana death rates) by cumulative exposure are given in Table 4. It is reasonable to focus attention on the SMR's 20 or more years from first employment, when risk due to fibre exposure would be expected to be most evident.

A linear relationship between these SMR's and cumulative exposure (see Figure 2) is given by the equation SMR = 1.52 + 0.011 f.y. or, expressed as a relative risk, RR = 1 + 0.007 f.y. Alternatively by forcing the line through SMR = 1 at zero exposure, the equation SMR = 1.00 + 0.013 f.y. was obtained. The observed deviation from linearity could be explained by chance (X^2(3df) = 3.47) and the trend has high statistical significance (X^2(1df) = 18.9, p <0.001). The constrained line may be interpreted to imply an increase in SMR for respiratory cancer of about 1.3% for each fibre-year of cumulative exposure.

There is also evidence in Table 4 of excess mortality from lung cancer less than 10 years from first employment. The two cases in the lowest exposure category could not have been due to work at Libby. One was a man who was first employed at age 66 and died aged 69; the other joined at age 25 and died aged 28. The two other deaths in the short latency category were 8.9 and 9.1 years from first employment. They had both substantial levels of cumulative exposure (470 and 522 f.y.) so a causal hypothesis is less easily dismissed.

Case-control analyses of exposure-response were carried out for the 23 deaths coded to respiratory cancer (ICD 160-163), the 8 coded to pneumoconiosis (ICD 514-515) and (with some overlap) the 4 mesotheliomas. Results are presented in Table 5. A statistically significant linear relationship was found between relative risk for respiratory cancer and cumulative exposure which is clearest in cases occurring 20 or more years from first employment (X^2(1df) = 7.04, p <0.01). In this group the linear increase in relative risk is estimated at 1.0% per fibre-year (95% confidence interval 0.3 - 9.7). This relationship is described by the equation RR = 1.00 + 0.010 f.y. Although

02/14/1996 EPA TSCA DOCKET

positive relationships with cumulative exposure were also observed with pneumoconiosis and with mesothelioma, numbers were small, confidence intervals wide, and conventional levels of statistical significance were not reached.

5. Discussion

The cohort studied was not a large one but quite sufficient to demonstrate that the workers in this mine experienced a serious hazard from lung cancer, pneumoconiosis and mesothelioma. This was presumably attributable to the fibrous amphibole contaminant of the vermiculite ore and mainly to dust conditions prior to 1974, particularly in the dry mill. No precise comparison with the New York State studies can be made but the crude SMR's for lung cancer were similar, 2.4 in this study, 2.8 in the study by Kleinfeld et al (8) and 3.2 in that by Brown et al (9). Not suprisingly, the SMR obtained in the parallel study by NIOSH (10), 2.2, was very close to our own. In all these studies, cases of mesothelioma were reported.

The findings in the NIOSH study, although close to our own, were not identical for four main reasons: 1) Their cohort was larger and included men first employed before 1969, but observation terminated 18 months earlier. 2) Their cohort was based on work history records, ours on computerized company work history files. Sixteen men (alive in 1981) who had started before 1963 according to the former probably more correct records had not done so according to the latter, and were thus not included in our cohort. Conversely, two men were included in the McGill cohort although their work history records indicated that they had started in 1963. 3) Athough we used the same basic exposure data, we did not treat it or interpret it in exactly the same way 4) The same death certificates were coded by the same nosologist but with some differences. As a result of these various minor differences our risk estimates were higher than those of NIOSH.

02/14/1996 EPA TSCA DOCKET

Our analyses of respiratory cancer mortality in relation to accumulated expsoure do not in themselves establish a linear relationship. But, given the findings from other asbestos-exposed cohorts (5), it seems reasonable to expect a similar exposure-response pattern in this group also. On that assumption, our findings suggest that the observed slope (about 1% increase in lung cancer per fibre year of exposure) is the same as that calculated by Doll & Peto (27) for chrysotile textile workers.
This slope was substantially steeper than that estimated for Québec chrysotile miners and millers (28) in whom the proportional mortality from mesothelioma was also much lower. Having regard for the fact that a) the Canadian miners were also exposed to tremolite fibres, albeit in very low concentrations, and b) tremolite is present at autopsy in lung tissue of these miners in similar amounts to chrysotile (12) and in higher amounts in cases of mesothelioma (13), one is forced to question the relative carcinogenic potency of chrysotile even in the mines and mills where it is produced. The rarity of mesothelioma (1 case) in the South Carolina chrysotile textile plant where lung cancer was in great excess appears to exclude any simple explanation based solely on fibre type per se. However, whereas the textile process - carding in particular - may well separate the chrysotile bundles into finer more carcinogenic fibrils, few of which reach the pleura, amphibole fibres (including tremolite) are much less susceptible to longitudinal division but remain able to penetrate more deeply than chrysotile. For mesothelioma, penetration is the prerequisite. For lung cancer, which is initiated in the airways, as indeed is asbestosis, length, thinness and durability of the fibrils together with tobacco smoke and perhaps other carcinogens are more important parameters than ability to penetrate.

If a linear relationship between lung cancer risk and accumulated exposure be accepted, a 1% increase in mortality per fibre year has practical implications for control in this industry. At present airborne fibre concentrations, reported by the Company to average about 0.1 f/ml , the estimated risk of lung cancer over a working lifetime, might be increased by about 5%. However, this estimate is associated with considerable statistical uncertainty and could vary in either direction by a factor of perhaps two or three.

02/14/1996 EPA TSCA DOCKET

From the viewpoint of epidemiological methodology, it may be worth noting that the exposure-response conclusions from this study confirmed the preliminary case-control analysis of incomplete data made in 1983 mentioned in the Introduction. However, as exposure levels had been underestimated, the slope of the line proved less steep than it had then appeared. Rapid analyses of this kind (29) deserve to be used more often for immediate assessment of occupational hazards.

6. Acknowledgements

This research was supported by a grant to McGill University by W.R. Grace & Co., with whose help the cohort was identified and past exposures estimated. We received assistance from several agencies in the follow-up and in particular we acknowledge the invaluable contribution of Mr. Earl Lovick in all aspects of the study.

02/14/1996 EPA TSCA DOCKET

Table 1 Male deaths by age and certified cause

Cause of death (ICD code)	Age at death (years)			Total
	<45	45-64	≥65	
All causes	11	79	75	165*
Malignant neoplasms:				
Larynx (161)	0	0	0	0
Trachea bronchus & lung (162)	1	16	4	21
Pleura & mediastinum (163)	0	2	0	2
Oesophagus & stomach (150-1)	0	1	1	2
Colon & rectum (152-3)	0	2	0	2
Other abdominal (154-9)	0	2	1	3
Other (140-149, 160, 164-208)	0	8	5	13
Heart disease (390-429)	1	21	32	54
Respiratory tuberculosis (010-018)	0	1	0	1
Other respiratory (480-519)	0	9	12	21
Cerebro-vascular (430-458)	0	4	7	11
External causes:				
Accidents (E 800-949)	4	8	6	18
Other E(950-998)	2	2	1	5
Other causes	2	3	5	10
Causes not known	1	0	1	2

* including 4 deaths from malignant mesothelioma coded ICD 163(1), 199(2) and 515(1)

02/14/1996 EPA TSCA DOCKET

Table 2 Estimated average prevailing fibre concentrations (f/ml) at main work location-operations; 1945-82

	1950		1960		1970		1980
Mine pit-working			2.3			*	0.6
-drilling		*12.5*			* 5.2	*	0.8
Tails belt operation			7.9			*	0.7
Transfer point			2.8			*	0.6
Dry mill -working		101.5	*		22.1	*	
-sweeping		*124.9*	*		27.2	*	
New wet mill					* 3.9	* 1.5 *	0.8
Mill lunch room		*7.0*	*		2.4	*	0.5
Service area		*1.0*	*	*2.0* *	0.9	*	0.2
Skip boot		*68.8*	*		15.0 * 2.0	*	0.6
River station-dock			12.0			*	0.7
-office			4.7			*	0.2
Railroad by-standing	*36.0* *	*18.0*	*	*6.0*	* 1.2	*	0.5
Concentrate-loading	*24.0* *	*15.0*	*	*9.0*	* 4.8	*	0.2
-bagging			24.0		* 5.5	*	1.2
-hauling			5.4			*	0.4
Testing-laboratory			2.9			*	0.6
-van			1.0			*	0.5

Fibre concentrations were taken as constant for the relevant periods at the following locations: bus transfer (1.2), mine lunch room (0.9), mine office (0.5), screen plant (0.5), verxite plant (6.0), office building (<0.04), laboratory (0.2), old wet mill (5.1).

No measurements available for figures in italics. Asterisks delineate the time periods over which the estimates apply.

02/14/1996 EPA TSCA DOCKET

00019

Table 3 Deaths and SMRs by cause and time since first employment (*Reference : US white males)*

Cause of death	ICD (8th rev)	Time since first employment (y)							
		<10		10-19		≥20		Complete cohort	
		0	SMR	0	SMR	0	SMR	0	SMR
All Causes		17	0.79	45	1.11	103	1.31	165	1.17
Malignant neoplasms									
Respiratory	160-163	4	5.02 *(1.35-12.85)*	4	1.66 *(0.45-4.24)*	15	2.42 *(1.35-3.99)*	23	2.45
Abdominal	150-159	1	0.86	1	0.44	5	1.11	7	0.88
Other		0	-	2	0.69	11	1.83	13	1.26
Circulatory disease	390-458	3	0.31	20	0.93	42	0.97	65	0.87
Non malignant									
Respiratory disease	460-519	0	-	7	3.36	14	5.30	21	2.55
External causes									
Accidents	800-949	5	1.80	4	1.46	9	3.11	18	2.14
Other	950-998	1	1.02	3	2.22	1	0.72	5	1.28

95% confidence intervals in parenthesis

02/14/1996 EPA TSCA DOCKET

02020

Table 4 Deaths from respiratory cancer (ICD 160-163), SMRs and cumulative exposure *(Reference : Montana males)*

		Cumulative Exposure (fib $ml^{-1} \cdot y$)				
		0, <25	25,< 200	200,<500	≥ 500	All
Mean net length of service (y)		3.0	13.8	11.0	16.0	8.7
Mean concentration (fib ml^{-1})		5.8	10.0	49.7	64.2	17.6
Mean cumulative exposure* (fib ml^{-1})		12.5	77.3	332.4	836.1	144.6
Time from first employment (y)						
< 10	0	2	0	1	1	4
	SMR	6.67	0.00	9.09	20.00	5.80
10 - 19	0	1	2	1	0	4
	SMR	1.35	2.94	3.27	0.00	2.06
≥ 20	0	4	3	5	3	15
	SMR	1.68	1.85	9.80	6.77	2.85
All	0	7	5	7	4	23
	SMR	2.04	1.97	7.53	5.58	3.03

* cumulated to end of service

02/14/1996 EPA TSCA DOCKET

Table 5 Estimates of exposure - response from case - referent analysis

Cause of death	No. of cases	Time from first employment (y).	β = % Increase in relative risk (O.R.) per fib ml^{-1} year (95% CI)	X^2(1 df) for H_o:β=0
Respiratory cancer (ICD 160-163)	4	0 - 9	2.1 (0.0, 63)	3.08
	4	10-19	0.4 (-0.1, 8.5)	1.23
	15	≥ 20	1.0 (0.3, 9.7)	7.04
	23	all	0.7 (0.1, 3.0)	7.49
Pneumoconiosis (ICD 515)	8	all	0.3 (0.0, 4.1)	2.42
Mesothelioma (ICD various)	4	all (≥ 20)	0.2 (-0.2, 100+)	0.10

02/14/1996 EPA TSCA DOCKET

220000022

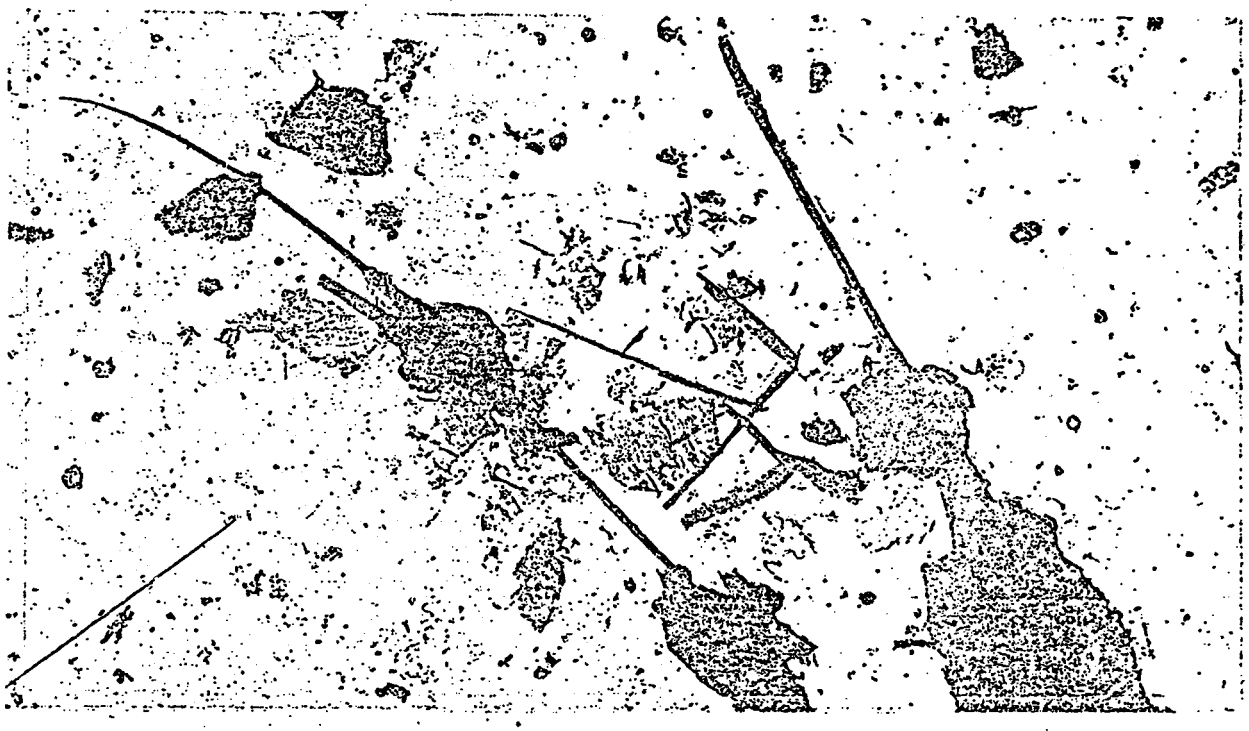
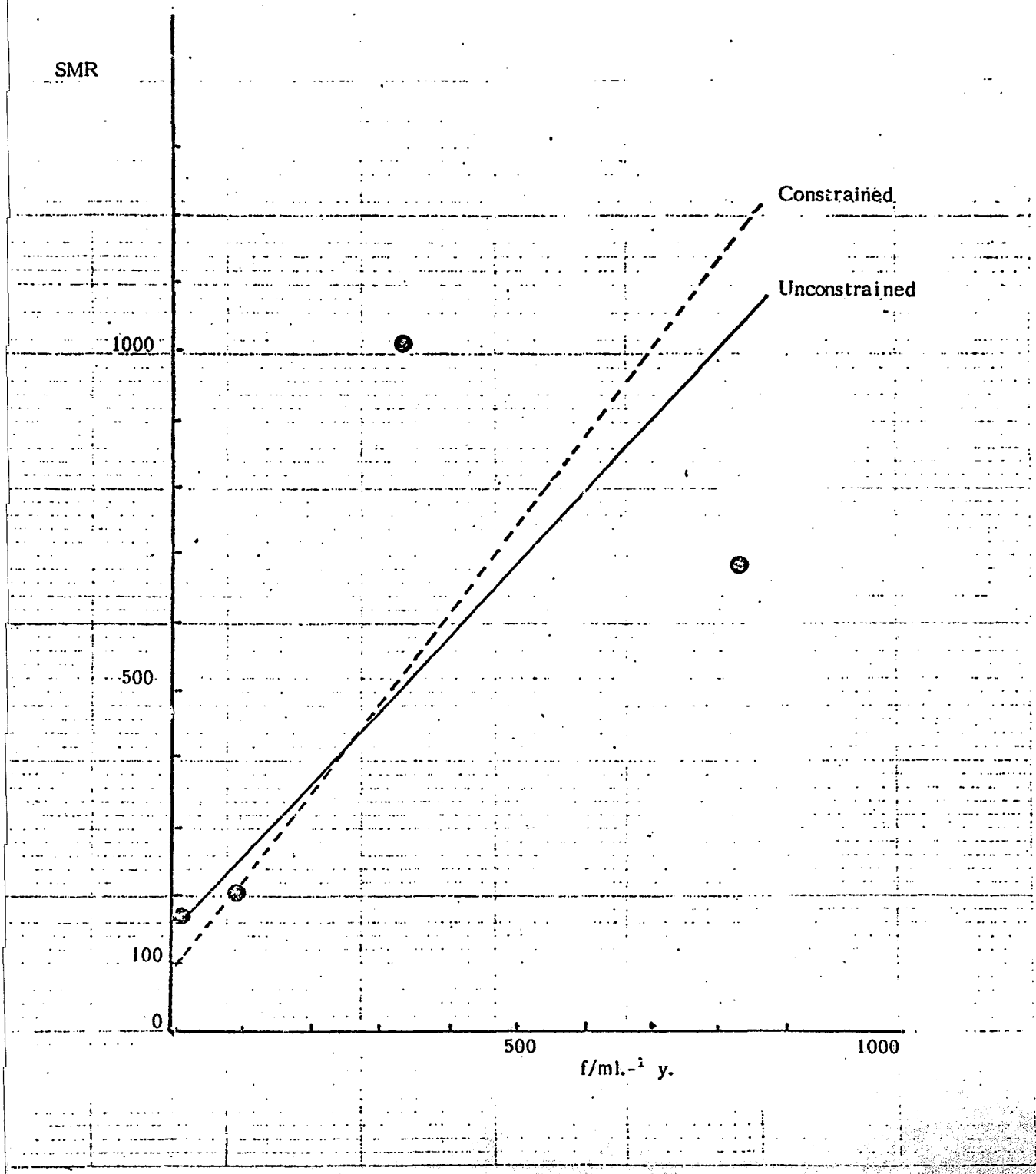


Figure I - Dust particles and fibres collected on membrane filter in the new wet mill. Transmission electron microscope view. (1 mm = 0.24 µm)

00023

02/14/1996 EPA TSCA DOCKET

Figure 2 - Respiratory cancer SMRs 20 or more years from first employment and cumulative exposure (f/ml.$^{-1}$ y.)



00024

02/14/1996 EPA TSCA DOCKET

REFERENCES

1. McDonald JC, Sébastien P, Armstrong B (1985)
   Radiological survey of past and present vermiculite miners exposed to amphibole fibres in the tremolite series
   Brit J Indust Med(in press)

2. Sébastien P, Armstrong B, Case B, McDonald JC (1985)
   Estimation of amphibole exposure from asbestos body and macrophage counts in sputum: a survey in vermiculite mines
   Presented at VI International Symposium on Inhaled Particles, Cambridge, Sept. 2-6, 1985

3. Sébastien P, Green F, Case B, Harley R, McDonald AD, McDonald JC (1985)
   Tremolite and chrysotile fibres in human lung. Presented at VI International Symposium on Inhaled Particles, Cambridge, Sept. 2-6, 1985

4. Ross M, Kuntze RA, Clifton RA (1984)
   A definition for asbestos
   In: Levadie, B. ed: Definitions for asbestos and other health-related silicates. ASTM, Philadelphia: 139-147

5. McDonald JC (1984)
   Mineral fibres and cancer
   Ann Acad Med Singapore 13(S): 345-352

6. Report of the Royal Commission on matters of health and safety arising from the use of asbestos in Ontario (1984)
   Queen's Printer for Ontario, Toronto

7. Acheson ED, Gardner MJ (1983)
   Asbestos: the control limit for asbestos
   Health and Safety Commission, HMSO, London

8. Kleinfeld M, Messite J, Kooyama D (1967)
   Mortality experience in a group of asbestos workers
   Arch Environ Hlth 15: 177-180

9. Brown DP, Dement JM, Wagoner JK (1979)
   Mortality patterns among miners and millers occupationally exposed to asbestiform talc
   In: Lemen R, Dement JM, eds, Dust and disease, Pathotox, Park Forest South, 111: 317-324

10. McDonald AD, McDonald JC, Pooley FD (1986)
    Mineral content of lung in mesothelial tumours in North America
    Ann Occup Hyg 26: 417-422

11. Pooley FD (1976)
    An examination of the fibrous mineral content of asbestos in lung tissue from the Canadian chrysotile mining industry
    Environ Research 12: 281-298

02/14/1996 EPA TSCA DOCKET

12. Rowlands N, Gibbs GW, McDonald AD (1982)
Asbestos fibres in the lungs of chrysotile miners and millers. A preliminary report
Ann Occup Hyg 26: 411-415

13. Churg A, Wiggs B, Depaoli L, Kampe B, Stevens B (1984)
Lung asbestos content in chrysotile workers with mesothelioma
Amer Rev Respir Dis 130: 1042-1045

14. Wagner JC, Chamberlain M, Brown.RC, Berry G, Pooley FD, Davies R, Griffiths DM (1982)
Biological effects of tremolite
Brit J Cancer 45: 352-360

15. Rousseaux JM, Rouxhet PG, Vielvoye LA, Herbillon AJ (1973)
The vermiculization of trioctahedral micas. The K Level and its correlation with chemical composition
Clay Min 10: 1-16

16. Atkinson GR, Rose D, Thomas K, Jones D, Chatfield EJ, Going JE (1981)
Collection, analysis and characterization of vermiculite samples for fibre content and asbestos contamination.
US Environmental Protection Agency, Contract No.68-01-5915

17. US Department of Labor (1980)
Asbestiform and/or fibrous minerals in mines, mills and quarries
Mine Safety and Health Administration,

18. Walton WH (1982)
The nature, hazards and assessment of occupational exposure to airborne asbestos dust: a review
Ann Occup Hyg 25: 117-247

19. Sébastien P, Gaudichet A, Billon-Galland MA, Janson X (1980)
Spectrométrie X par dispersion d'énergie en microscopie électronique à transmission: application à la caractérisation des fibres minérales
J Microsc Spectrosc Electron 5: 83-97

20. International Mineralogical Association (1978)
Nomenclature of amphiboles
Can Mineral 16: 501-520

21. Edwards GH, Lynch JR (1968)
The method used by the US Public Health Service for enumeration of asbestos dust on membrane filters
Ann Occup Hyg 11: 1-6

22. Corn M, Esmen NA (1979)
Work place exposure zones for classification of employee exposures to physical and chemical agents
Ann Ind Hyg Assoc J 40: 47-57

02/14/1996 EPA TSCA DOCKET

23. Oldham PD (1965)
On estimating the arithmetic means of lognormally-distributed populations
Biometrics 213: 235-239

24. Monson R (1974)
Analysis of relative survival and proportional mortality
Computers and Biomedical Research 7: 325-332

25. Hanley J and Liddell FDK (1985)
Fitting a relationship between exposure and SMRs
J Occup Med (in press)

26. Thomas DC (1981)
General relative risk models for survival time and matched case-control analysis
Biometrics 37: 673-686

27. Doll R, Peto J (1985)
Effects on health of exposure to asbestos
Health and Safety Commission, HMSO, London

28. Liddell FDK, Thomas D, Gibbs GW, McDonald JC (1984)
Fibre exposure and mortality from pneumoconiosis, respiratory and abdominal malignancies in chrysotile production in Quebec, 1926-75
Ann Acad Med Singapore, 13 S: 340-344

29. Oakes D, McDonald JC (1982)
Restricted cohort study designs
Scand J Work Environ Hlth 8 S: 30-33

02/14/1996 EPA TSCA DOCKET

non-CBI per submitter 3-10-86 pg

CONFIDENTIAL NOT TO BE QUOTED BEFORE PUBLICATION

RADIOLOGICAL SURVEY OF PAST AND PRESENT VERMICULITE MINERS EXPOSED TO TREMOLITE

J.C. McDONALD

P. SEBASTIEN

and

B. ARMSTRONG

SCHOOL OF OCCUPATIONAL HEALTH

McGILL UNIVERSITY, MONTREAL, CANADA

00028

02/14/1996 EPA TSCA DOCKET

1. Abstract

Chest radiographs taken by a standard technique were obtained from 173 current employees (164 males and 9 females) of a vermiculite mine in Montana, from 80 of 110 past employees resident within 200 miles and from 47 men from the same area without known dust exposure. In 43 of the 80 and 24 of the 47, an earlier chest X-ray was retrieved from the hospital archives. All 367 films were assessed blind and independently by three experienced readers using the ILO 1980 classification. Median radiographic assessment scores were analysed in relation to estimated cumulative exposure to the amphibole fibres which contaminate the vermiculite. Logistic regression analyses showed independent effects of age, smoking and exposure on the prevalence of small opacities and of age and probably of exposure on pleural thickening. Overall, the data suggest that by retirement age, the increase in prevalence of small opacities ($\geq$ 1/0) lies between 5% and 10% per 100 f/ml years. This gradient may be somewhat steeper than for chrysotile miners and millers, but not much so.

00029

02/14/1996 EPA TSCA DOCKET

2. Introduction

The survey described in this paper is one of a series of studies undertaken to assess the health effects of work in a vermiculite mine in Libby, Montana. Two complementary programs of research were initiated by NIOSH and ourselves, primarily because of contamination of the ore body with fibrous amphibole deposits in the tremolite series. A history and description of the mining and milling processes were given in our report on a cohort mortality study in this group of workers (1). These data showed substantial excess mortality compared to US white males from respiratory cancers (SMR = 2.45), non-malignant respiratory disease (SMR = 2.55) and malignant mesothelioma (Proportional mortality = 2.4%). The NIOSH mortality study of a more broadly defined cohort obtained similar results from independantly assembled data (2).

Vermiculite, a micaceous mineral which expands on heat treatment has many uses in construction industries, agriculture and packaging. The largest known vermiculite deposit, at Libby, Montana, has been commercially mined since 1923. At first it was on a very small scale but, after 1939, when two companies merged, production increased: 20,000 tons were shipped in 1940, 150,000 tons in 1950 and about 200,000 tons annually, since 1972.

The Libby deposit is mined using the open pit mining technique incorporating rubber-tire loaders and trucks for both ore and waste removal. Waste is discharged at the perimeter of the mined area while the ore is hauled to a transfer point for blending and wet beneficiation. During early years of the operation, all functions of mining and milling were performed in a dry state, resulting in very dusty conditions. A series of process improvements resulted in present mine personnel operating from within enclosed air-controlled cabs and a totally wet beneficiation process. Vermiculite concentrate is graded into five size fractions before shipment to expansion plants in various parts of the United States.

02/14/1996 EPA TSCA DOCKET

Fibrous tremolite has little commercial value and only one or two very small mines in Northern Italy produce it. On the other hand it is a fairly common contaminant in various exploited minerals, notably some talc deposits of New York State, and in the Québec chrysotile mines where it is present in trace amounts. There has been no previously published radiological survey of tremolite miners as such, but several studies of talc miners and millers exposed to varying levels of mineral fibre and silica (3). Pleural thickening was frequently found in these workers but parenchymal opacities much less so. These observations are not easily interpreted in terms of tremolite fibre, because of the other components in the airborne dust.

3. Material and methods

3.1 Study groups - Chest radiographs were obtained from persons in three groups. The first comprised all 164 men and 9 women employed by the company on July 1, 1983. The second was selected from 110 past male employees, resident within 200 miles of the mine. This information was known as all had been traced as surviving members in the mortality cohort, the criteria for inclusion of which were employment of at least one year and date of hire before 1 January 1963. Eighty of the 110 thus identified accepted the company's invitation to come to the hospital in Libby for a chest X-ray. The third group comprised 47 men without known dust exposure who attended the hospital during the same period for a 'routine' chest X-ray, mostly in connection with other local employment. The latter group was not selected or matched in any way with the mine workers and was intended only to control the reading process. All 291 men (and 9 women) in the three groups were X-rayed by a standard technique, based on that outlined in Appendix A of the 1980 ILO Guidelines (4). In 43 of the 80 ex-employees and in 24 of the 47 unexposed subjects, an earlier chest X-ray was located in the hospital film archives. The earlier films for the ex-employees had usually been taken shortly before leaving the company and by a generally less satisfactory radiological technique. In total, 367 films were thus ...led for classification.

02/14/1996 EPA TSCA DOCKET

3.2 Reading procedures - The films, with identity obliterated, were renumbered in random order and classified independently by three experienced readers. The ILO 1980 International Classification and standard sets of films were used. The readers were told only that the films were mainly from mineworkers with varying exposure to mixed dusts and that about 20% of the series were unexposed subjects. Preliminary tabulations after the readings were completed showed that, overall, 56% of the recent films were considered of good quality, 36% fair, 7% poor and 0.4% unreadable. The corresponding ratings for the older films were 22%, 53%, 23% and 2%. Although the readers were very experienced and had worked together often, inter-observer variation remained. Agreement between all three readers on the presence or absence of changes was acheived in about 90% of readings for pleural calcification, costo-phrenic angle obliteration and pleural thickening on the diaphragm. The rate fell to about 80% for small parenchymal opacities and for pleural plaques or diffuse thickening.

3.2 Exposure estimates - Work histories were used to obtain the dates and duration of work in various locations. The mean airborne fibre concentrations for each location-operation, year by year, were estimated from all available midget impinger and membrane filter measurements after a detailed site visit and review by one of us (PS). The methods of estimation and results are described fully in the mortality paper (1).

3.4 Statistical analysis - Radiographic readings from the three readers were combined as a median score. Two methods were used to investigate relationships between X-ray changes and exposure to fibrous dust. Firstly, the prevalence of abnormalities was tabulated in five cumulative exposure groups, after stratification in three age groups (20-39, 40-59, 60 +) to reduce confounding. Age-standardised prevalence rates were then computed for each exposure group, the combined population being taken as standard. Secondly, logistic regression analyses for selected abnormalities were carried out in which age, smoking and cumulative exposure were entered into the regression equation. Age was considered as a continuous variable, and

02/14/1996 EPA TSCA DOCKET

smoking in three groups:- never smoked, ex-smoker and current smokers. The logistic regression analysis and the fitting of linear exposure-response lines to the grouped prevalences were carried out using the GLIM computer package(5).

4. Results

The prevalence of the main radiographic changes in the current male employees and the sample of past employees, based on their most recent films, is presented in Table 1. The overlap between the two groups is confined to men aged 40 and over. Even in these older men, the rates for both parenchymal and pleural changes differ considerably but, perhaps not more than might be explained by differences in mean levels of cumulative exposure. A steep age gradient in both groups is also evident, probably attributable in part to exposure. Of the 47 unexposed subjects, 32 were aged 40 or more; small opacities were read in 1, pleural thickening on the chest wall in 4 (8.5%) and pleural calcification in 2 (2.7%).

Age standardised prevalences of small opacities and pleural thickening by cumulative exposure are given in Table 2. Because of small numbers and, in particular, since very few young men had achieved high cumulative exposures, these standardised rates are subject to rather large standard errors in the higher exposure groups. Notwithstanding these problems, the trend of increasing prevalence of small opacities with increasing exposure is unlikely to be due to chance, (X^2(1df) = 5.4, p ≈ 0.02). The corresponding trend for prevalence of pleural thickening of the chest wall is less strong (X^2 (1df) = 2.6, p ≈ 0.10).

Prevalence of abnormalities by cumulative exposure for men aged 60 and over is given in Table 3. Here too there is an association of small opacities with exposure (X^2(1df) = 6.4, p ≈0.01) and a weaker one for pleural change (X^2(1df) = 0.9, p >0.20).

Results of the logistic regression analyses of abnormalities are given in Table 4. These show the independent effects of each of the three factors examined (cumulative exposure, age, and smoking), after allowing for the other two. Clear effects of cumulative exposure and age on the prevalence of small opacities are apparent and there is also some indication of a smoking

02/14/1996 EPA TSCA DOCKET

effect ($p \simeq 0.02$). The prevalence of pleural thickening on the chest wall is affected by age and more weakly by cumulative exposure ($p \simeq 0.02$). There is no consistent evidence of a smoking effect. The data are insufficient to determine whether there are interactions between the factors.

The estimated exposure-response relationships for small opacities are graphed in Figure 1, together with prevalences by cumulative exposure. The graph shows the linear relationships computed from Table 2 and 3, and that predicted from the logistic regression equation for age 65. The latter includes two curves, one for current smokers and one for non-smokers. The curve for ex-smokers would be intermediate. For all these relationships, standard errors of slopes and intercepts are large.

Among the 43 ex-employees for whom an earlier X-ray had been obtained, small opacities ($\geq 1/0$) were read in 18 (42%) of the 1983 films and 9 (21%) of the films taken on average 8.9 years earlier. This difference derived from 10 men whose readings had deteriorated and 2 whose readings had improved. In the 24 pairs from unexposed men, on average 7-8 years apart, no abnormality was read in the earlier film and one only in the later film. Since there was virtually no change in the cumulative exposure of the 43 ex-employees between their two X-rays, the substantial increase in prevalence was presumably due in part to aging and in part to differences in radiographic technique.

5. Discussion

The usual criticism leveled at cross-sectional morbidity studies in working groups is that selection may have removed a disproportionate number of employees who had suffered the ill-effects of occupational exposure. It would of course be equally wrong to study only ex-employees. We tried in this survey to acheive a balance by including both present and past employees and analysing their joint experience. In addition to the logistic regression analysis presented in Table 4, another

02/14/1996 EPA TSCA DOCKET

analysis was made in which a fourth variable for ex or current employment was included. This showed that, having allowed for the other three factors, rates of change were higher in past than present employees but, statistically, not significantly so. The coefficient for the relationship to exposure was, in fact, the same whether or not the fourth variable was included. We believe, therefore, that it is reasonable to base our estimate of exposure-response on the experience of the combined sample. Even so, the relationships illustrated in Figure 1 entail very great uncertainty, for which there are several reasons. Firstly, the exposure estimates, especially for the important period before about 1972, were approximate. Secondly, radiographic techniques and X-ray readings are major sources of variation. Thirdly, age, smoking and probably other environmental factors all contribute to radiographic change. Finally, the study sample was quite small. In the absence of other information, our data provide the only indication of risk in relation to exposure. Of the four lines shown in Figure 1, the two based on logistic regression and the one for men aged 60 or more are roughly parallel, and probably more valid than that based on age-standardization. These three lines suggest that by retirement age the increase in prevalence of small parenchymal opacities ($\geq 1/10$) lies between 5% and 10% per 100 f/ml years. At present exposure levels in the Libby operation, reported by the company to average 0.1 f/ml, no excess of radiological change should be detectable after a working life of 40 years. The imprecision associated with radiological technique and reading error would be far greater than the expected level of risk.

There are few other data sets against which these findings can be compared. Our original studies of Québec chrysotile miners (6) gave a slope of about 0.6% per 100 fibre years and a later analysis (7), confined to men aged 60-69 with an average gross service of 42.3 years, gave a lower estimate (0.2%). Both these estimates were based on men still at work and it was concluded that the true gradients were probably steeper. A more recent study of the Québec workers (8) was based on current and past employees, used X-rays taken with a similar technique to that at Libby and one of the three readers took part in both studies. That study gave a slope of 4% per 100 fibre years, about half that in the present survey.

02/14/1996 EPA TSCA DOCKET

The radiographic study by NIOSH (2) was based on the most recent chest X-rays (188 in all) available in the local hospital for men employed 5 or more years and at some time since 1974. These men were all current employees at the time of the X-ray, were somewhat younger than those in our sample but had been employed nearly 4 years longer and at a slightly higher average level of exposure. Despite this, and the fact that one of the readers was common to both studies, the prevalence rates of both parenchymal and pleural changes were substantially higher in our study than theirs. The slope of the logistic regression line for small opacities ($\geq$ 1/0) and cumulative exposure was also somewhat steeper in our data. We believe that these differences were due to better film quality and perhaps to the inclusion of ex-employees in our survey. This underlines the problems and imprecision of radiographic estimates of exposure-response in dust-exposed workers.

Acknowledgement

This research was supported by a grant to McGill University from W.R. Grace and Co. The chest X-rays were taken at St. John's Lutheran Hospital, Libby, Montana under the supervision of Dr Tyler Gill and read by Dr John Gilson, Dr Robert Jones and Dr Geoffrey Sheers. The active participation of past and present employees and the Company is gratefully acknowledged.

00036

02/14/1996 EPA TSCA DOCKET

References

1. McDonald JC, McDonald AD, Armstrong B, Sébastien P. (1985). Cohort study of mortality of vermiculite miners exposed to tremolite. Brit J Industr Med (in press).

2. Amandus HE, Wheeler R (1985). Mortality of vermiculite miners exposed to tremolite asbestos (to be published).

3. Dement JM, Zumwalde RD, Gamble JF, Felluer W, DeMeo MJ, Brouwn DP, Wagoner JK (1980). Occupational exposure to talc containing asbestos. NIOSH Technical Report, US Government Printing Office, Washington DC.

4. International Labour Office (1980). Guidelines for the use of the ILO international classification of radiographs of pneumoconioses. Occupational Safety and Health Series 22(Rev 80). ILO, Geneva.

5. Baker RJ, Nelder JA (1978). The GLIM System; Release 3, Numerical Algorithme Group, Oxford.

6. Rossiter CE, Bristol LJ, Cartier PH, Gilson JC, Grainger TR, Sluis-Cremer GK, McDonald JC (1972). Radiographic changes in chrysotile mine and mill workers of Quebec. Arch. Environ Health 24: 388-400

7. Liddell FDK, Gibbs GW, McDonald JC (1982). Radiological changes and fibre exposure in chrysotile workers aged 60-69 years at Thetford Mines. Ann Occup Hyg 26: 889-898

8. McDonald JC, Gibbs GW, Oakes D (1984). Radiographic response to cumulative chrysotile fibre exposure in production workers 8-29 years after first employment. Presented at XXI International Congress on Occupational Health, Dublin.

02/14/1996 EPA TSCA DOCKET

Table 1 Percentage of radiographic changes by age

Age	Current employees. n	Mean cumulative exposure (f ml^{-1} y)	Small opacities ≥ 1/0	Pleural thickening (chest wall)	Pleural calcification	Past employees n	f ml^{-1} y*	Small opacities ≥ 1/0	Pleural thickening (chest wall)	Pleural calcific
20-39 y	80	13.4	2.5	7.5	1.3	1	6.0	-	-	-
40-59 y	69	57.3	13.0	20.3	5.8	30	160.2	33.3	40.0	16.
≥60 y	15	103.5	26.7	40.0	6.7	49	96.1	40.8	61.2	36.
All	164	40.1	9.1	15.9	3.7	80	118.9	37.5	52.5	28.

02/14/1996 EPA TSCA DOCKET

00038

Table 2 Age standardised prevalence of abnormalities by cumulative exposure

Cumulative exposure (fib ml^{-1} y)		Number in group	Small opacities ≥ 1/0		Pleural thickening of chest wall	
Group	Mean		Number	Prevalence%*	Number	Prevalence%*
<10	4.1	92	7	*10.6*	15	*23.3*
10, < 20	17.5	64	12	*18.4*	14	*21.7*
20, < 100	53.9	53	10	*15.4*	22	*38.7*
100, < 200	144.4	16	8	*31.3*	6	*22.2*
≥ 200	495.8	19	8	*27.9*	11	*38.5*
Total	65.9	244	45	*18.4*	68	*27.9*

* Directly age standardised, total study group taken as standard

02/14/1996 EPA TSCA DOCKET

63000 00039

Table 3 Prevalence of abnormalities in men aged 60 or more by cumulative exposure

Cumulative exposure (fib ml^{-1} y)		Number in group	Small opacities ≥1/0		Pleural thickening of chest wall	
Group	Mean		Number	Prevalence%	Number	Prevalence%
< 10	6.5	15	2	13.3	7	46.7
10,<20	19.0	17	6	35.3	9	52.9
20,<100	56.7	16	6	37.5	10	62.5
100,<200	153.4	8	6	75.0	5	62.5
≥200	463.4	8	4	50.0	5	62.5
Total	97.9	64	24	37.5	36	56.3

02/14/1996 EPA TSCA DOCKET

000040

Table 4 Logistic regression analysis of exposure-response relationships

Test for:	In the presence of:	Small opacities 1/0 X^2 (df)	P	Pleural thickening of chest X^2 (df)	P
Cumulative exposure	Age, smoking	10.9(1)	p<0.001	5.9(1)	p<0.025
Smoking	Age, cumulative exposure	8.2(2)	p<0.025	4.6(2)	p=0.10
Age	Cumulative exposure, smoking	27.2(1)	p<0.001	28.1(1)	p<0.001

Estimated coefficients

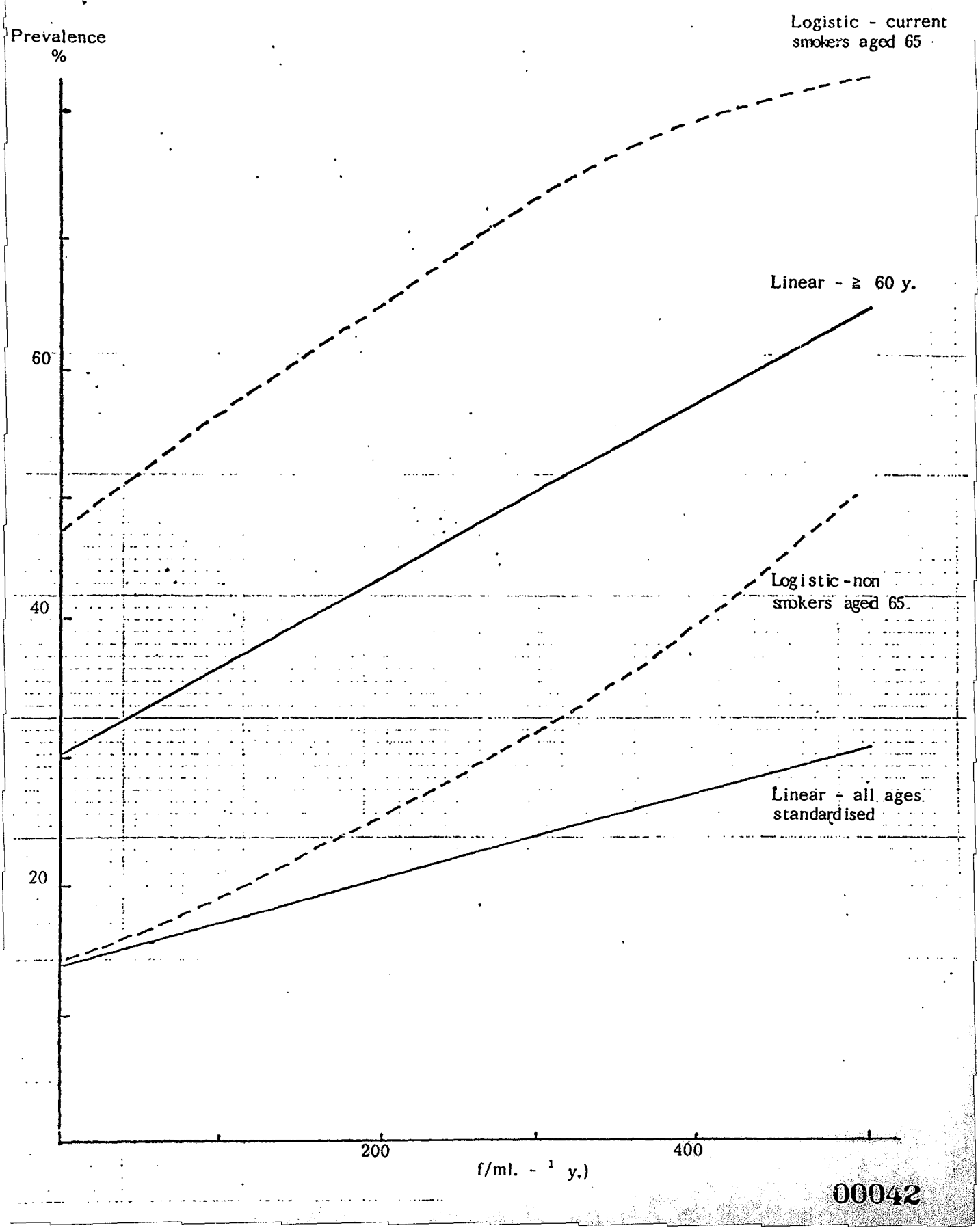
Small opacities: $\text{Log}\left(\frac{P}{1-P}\right) = -7.27 + 0.0035\,(\text{cum. exp.}) + 0.084\,(\text{age}) + \begin{cases} 0.82 & \text{if ex-smoker} \\ 1.72 & \text{if current smoker} \end{cases}$

Pleural thickening: $\text{Log}\left(\frac{P}{1-P}\right) = -5.62 + 0.0024\,(\text{cum. exp.}) + 0.088\,(\text{age}) + \begin{cases} -0.41 & \text{if ex-smoker} \\ 0.42 & \text{if current smoker} \end{cases}$

02/14/1996 EPA TSCA DOCKET

00041

Figure 1 - Prevalence of small opacities (≥ #/0) and cumulative exposure (f/ml.-^{1} y)



02/14/1996 EPA TSCA DOCKET

CERTIFICATE OF AUTHENTICITY

THIS IS TO CERTIFY that the microimages appearing on this microfiche are accurate and complete reproductions of the records of U.S. Environmental Protection Agency documents as delivered in the regular course of business for microfilming.

Data produced 1 (Month) 19 (Day) 87 (Year) Barbara Smith Camera Operator

Place Syracuse (City) New York (State)

AMTEK corp

02/14/1996 EPA TSCA DOCKET