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Cohort study of mortality of vermiculite miners exposed to tremolite

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ABSTRACT A cohort of 406 men employed before 1963 for at least one year in a vermiculite mine in Montana was followed up 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 were obtained and coded for 163 of the 165 men who died. Compared with white men in the United States, 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). Four deaths were 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 relation that 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.

In April 1983 we were invited by WR 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 facing 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 finalised 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 necropsy from ex-employees. Findings from the last three studies are reported separately,[1-3] as are 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.

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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 because 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 limited value and are produced only in some 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 cause pulmonary fibrosis, lung cancer, and malignant mesothelial tumors. Existing evidence suggests indeed that most occupationally related mesotheliomas are caused by amphibole fibres and few by chrysotile.[5-7] The experience of men in the Libby mine exposed only to the tremolite group of fibres was therefore of practical concern and scientific importance.

Few observations on the effects on health 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 a postmortem study

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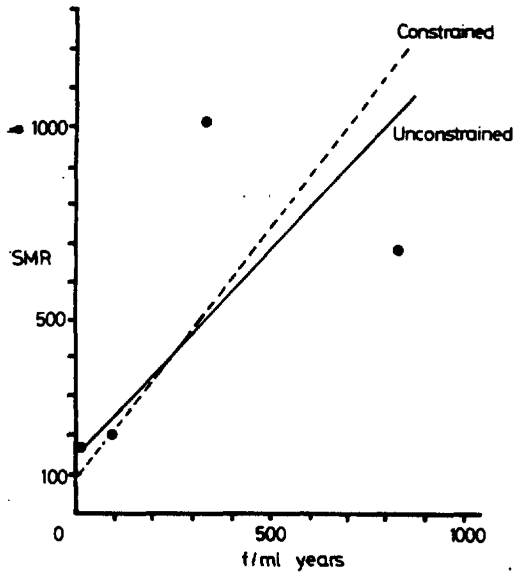

Fig 2 *Respiratory cancer SMRs 20 or more years from first employment exposure (f/ml years).*

ogist did not consider this a mesothelioma.

Using Montana death rates instead of United States national rates reduced the number of expected deaths from respiratory cancer from 9·41 to 7·60, increasing the SMR from 2·45 to 3·03. Table 4 gives the SMRs for respiratory cancer (using Montana death rates) by cumulative exposure. It is reasonable to focus attention on the SMRs 20 or more years from first employment, when risk due to exposure to fibres would be expected to be most evident.

A linear relation between these SMRs and cumulative exposure (see fig 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 (χ^2 (3df) = 3·47) and the trend has high statistical significance (χ^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 from the data in table 4 of an 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 at 69; the other joined at 25 and died at 28. The two other deaths in the short latency category were 8·9 and 9·1 years from first employment. Both had 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 eight coded to pneumoconiosis (ICD 514–515), and (with some overlap) the four mesotheliomas. Results are presented in table 5. A statistically significant linear relation was found between relative risk for respiratory cancer and cumulative exposure which is clearest in cases occurring 20 or more years from first employment (χ^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 0·1–9·7). This relation is described by the equation RR = 1·00 + 0·010 f/y. Although positive relations 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.

Discussion

The cohort studied was not large but sufficient to show 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 before 1974, particularly in the dry mill. No precise comparison with the New York State studies can be made but the crude SMRs 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

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

Cause of death	*No of cases*	*Time from first employment (years)*	*β = % increase in relative risk (OR) per f/ml year (95% CI)*	*χ^2 (1df) for $H_0:\beta = 0$*
Respiratory cancer	4	0–9	2·1 (0·0, 66)	3·08
(ICD 160–163)	4	10–19	0·4 (−0·1, 8·5)	1·23
	15	≥20	1·0 (0·1, 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

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brane filter method between 1970 and 1974 showed a mean concentration of 22·1 f/cc. It was therefore assumed that the concentration in f/cc before 1965 was 4·6 times higher—that is, 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.

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 with the company's representatives and especially with a previous manager who had spent almost all his career with Libby and who had extensive knowledge of the operations.

Table 2 shows the estimated average levels of exposure at the 28 operation locations from 1945 to 1982. Recent values (1957–82) 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 programme 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. Recent fibre counts, however, 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 duration 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.

STATISTICAL ANALYSIS

The mortality of the total cohort was compared with that of white men in the United States using the person-years at risk method to compute expected numbers of deaths and hence standardised mortality ratios (SMRs). These computations were made using Monson's computer program,[24] from which United States 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 from censuses. Death rates for respiratory cancer for Montana were computed for the period up to 1978, and the United States national rates for this cause updated to this year for comparability.

Analysis of the relation between mortality and exposure to fibrous dust was performed in two ways. Firstly, the exposure cumulated to the end of each

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), hygiene laboratory (0·2), old wet mill (5·1), river station conveyor tunnel (118·5).
No measurements available for figures in italics.
*Time periods over which the estimates apply.

the material expands about 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 absorbent low density filler and chemical carrier. Of the 325 000 tons of vermiculite concentrate (before expansion) used in the United States 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 tons in 1940 to 150 000 in 1950 and 200 000 in 1970.

At present 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 classic 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 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 1100 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 exposure to dust. 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.

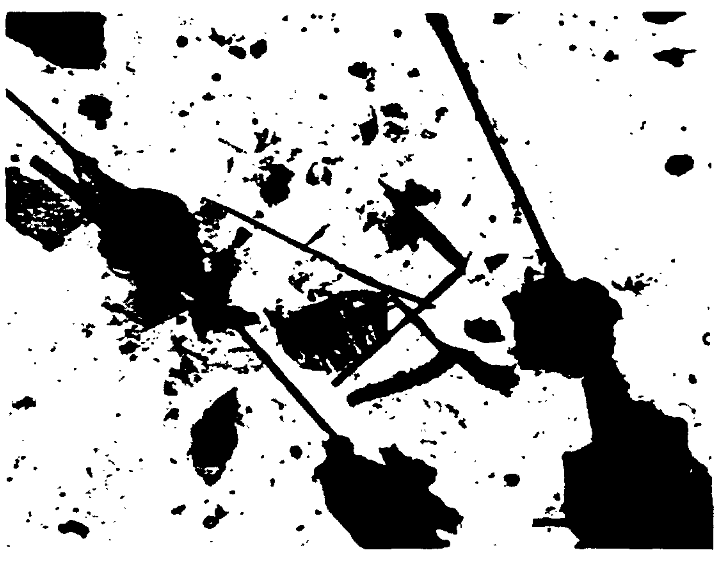

Fig 1 *Dust particles and fibres collected on membrane filter in new wet mill. Transmission electron microscope view (1 mm = 0·24 μm).*

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