Respiratory Health in Workers Exposed to Man-made Vitreous Fibers[1-3]

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SUMMARY A study of the respiratory health of workers who produce man-made vitreous fibers (MMVF) included 1,028 men (median length of employment, 18 yr) in 7 fibrous glass and mineral wool plants. Health assessment was by respiratory questionnaire, ILO 1980 Classification chest radiograph readings, and pulmonary function testing. Results from an earlier environmental survey were combined with job histories to derive individual exposure estimates. The study population was found to be generally healthy, with respiratory symptoms not related to the fiber exposure and no detected adverse lung function consequences of that exposure. Radiograph readings revealed low category profusion of small opacities: of 941, 63 (7%) in category 0/1, 28 (3%) in 1/0, and 6 in 1/1, with none in higher categories. Prevalence of small opacities increased with age and cigarette smoking. A greater prevalence of small opacities was found among current smokers in the two plants producing both ordinary and fine fibers (for profusion > 1/0, 15% in these plants, 2% in all others). Among ex-smokers and never smokers, greater prevalence was observed in only one of these plants (14% versus 1%), the plant having the higher airborne concentrations of fibers less than 1 μm in diameter. Among current smokers, prevalence of small opacities of profusion > 0/1 increased with lengthening employment (beyond age and pack-years of smoking) in both plants producing ordinary and fine fibers and the five other plants combined. It is concluded that exposure to MMVF with small diameters may lead to low-level profusion of small opacities. However, without high-level profusion of these opacities in a population with a considerable range of exposure durations, a diffuse tissue reaction (e.g., fibrosis) seems unlikely but cannot be excluded.
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Introduction

Man-made vitreous fibers (MMVF), which include fibrous glass, mineral wool (rock and slag), and ceramic fibers, are manufactured from glass, from natural rocks and minerals, or from slags, the residues of smelting. They are used extensively in thermal, acoustical, and electrical insulation products as well as in reinforcing plastics and resins.

With many millions of tons of products with MMVF being manufactured annually in the United States and Europe, thousands of workers are exposed to these fibers in the workplace. The U.S. National Institute for Occupational Safety and Health (NIOSH) estimated that 200,000 U.S. workers experienced occupational exposure to fibrous glass in the early 1970s (1). Since that time the industry has had additional growth, some of it because of the substitution of these fibers for asbestos.

The most commonly recognized effects of contact with MMVF are acute irritation of the skin and, to a lesser extent, the eyes and upper respiratory tract, with symptoms abating after cessation of exposure. Although acute effects on the lungs have not been observed, the fibrous nature of these substances has resulted in concern about possible long-term respiratory effects. Moreover, at a time when there is an evolving consensus that biological effects of fiber exposure are related to dimension (with long, thin fibers apparently posing the greatest risk), environmental studies have shown that airborne dusts in all plants manufacturing MMVF contain fibers having a wide range of diameters and lengths, a high proportion being respirable. The relative frequency of fine fibers depends on the nominal diameter of the fiber being manufactured, with production of (nominally) small-diameter fibers resulting in the greatest airborne concentrations of long, thin fibers (2). Manufacture of fine MMVF accounts for less than 1% of production in the United States; total production, however, continues to increase in response to demand for special purpose insulation, primarily for aircraft and aerospace applications.

Although there are certain similarities between MMVF and asbestos fibers, there are important differences. Asbestos fibers split longitudinally, creating even thinner fibers, whereas MMVF break transversely, thus producing shorter and, therefore, possibly less hazardous fibers. Overall exposure levels also differ, with measured levels of airborne fiber concentrations in plants manufacturing MMVF being very low compared with those known to occur in occupational exposures to asbestos.

In order to assess the respiratory health of workers in this industry, a cross-sectional survey of current employees was begun in 1979. This study, in 7 plants manufacturing MMVF belonging to the sponsoring organization, the Thermal Insulation Manufacturers' Association (TIMA), was designed to include long-term employees exposed to various dimensions of fibrous glass and mineral wool. The study did not include workers manufacturing ceramic fibers or products containing those fibers.

Methods

Study Design and Plant Selection

In order to have the largest amount of exposure data available to investigate possible exposure-response relationships, only the 16 plants surveyed in an earlier environmental characterization study were consid-

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ered for inclusion in the present study (2); that study had included the 16 oldest U.S. plants engaged in MMVF production.

Eight plants were excluded for various reasons: textile production, unavailability because plant was sold, past asbestos use, and very large size with complex exposures requiring separate study. Seven of the remaining 8 were selected by the investigators for inclusion: two fibrous glass plants (Plants 1, 2) producing ordinary fibers (greater than 3 μm in diameter), 2 (Plants 3, 4) producing both ordinary and fine fibers (1 to 3 μm), 1 (Plant 5) producing only very fine fibers (less than 1 μm), and 2 mineral wool plants (fibers greater than 3 μm).

Products of these plants were primarily insulation materials but also included such items as roofing supplies, acoustical tiles and panels, automotive liners, and flexible and rigid fibrous glass ducts.

Exposure Estimation

The glass commonly used for the manufacture of fibrous glass is a borosilicate type; the batch usually contains silica, soda ash, boric oxide, fluorspar, rutile, and clay. The materials are conveyed pneumatically from storage silos to a mixer, and then are fed into a furnace. Insulation wool is produced by feeding the molten glass through a forehearth to centrifugal spinners where the fiber is forced out of small orifices in the spinner head. The fibers are attenuated by compressed air or steam, and the binder is sprayed on the fibers. The fine and very fine fibers are produced by passing the molten glass through a bushing plate located at the bottom of a forehearth where large diameter fibers are formed. The fine fibers are produced from the primary fibers by flame attenuation.

In slag wool manufacturing, slag and coke are melted and allowed to flow in open channels to rotary spinners. Fiber attenuation is achieved by blowing air under high pressure around the spinners.

Because of free crystalline silica in the batch mixing areas and phenol-formaldehyde in the binder mixing areas, workers in those areas were excluded from the study.

Estimation of workers' exposure to airborne fibers was based on a survey conducted by the University of Pittsburgh during 1974 and 1975, in which approximately 600 samples were collected in the 7 plants included in the present study (2). A similar survey, using the same sampling methods and sample analyses, collected 201 samples in 1980 as part of the present investigation; results showed that exposures had not changed significantly since the earlier study. The Pittsburgh survey provided estimates of fiber concentration levels in all areas of each plant for all time periods since opening of the plants; these were the same as those used by Enterline and Henderson (3) and Enterline and Marsh (4, 5). These estimates were obtained by considering 4 categories for the concentration of airborne fibers, as determined by both optical microscopy (OM) and electron microscopy (EM): 0.001 to 0.01, 0.01 to 0.1, 0.1 to 1.0, and greater than 1.0 fibers/ml. Areas were classified into these categories based on the median measurement for that area; the level assigned to an area was the geometric mean of that category: 0.0032, 0.032, 0.32, or 1.5 fibers/ml, respectively (6). For several production lines, median concentration levels differed from the beginning of the line to the end, but all jobs on the lines were labeled identically in the work histories; in such cases, the median concentration for the entire line was used.

These exposure estimates were used in conjunction with individual job histories to calculate total accumulated exposure and average concentration of exposure for each eligible employee. Calculations were performed separately for fibers identified by OM (1 to 3 μm in diameter) and by EM (less than 1 μm), as well as their sums (≤ 3 μm). Total length of plant employment and time spent in jobs at or above several fiber concentration levels were also calculated for both the OM-sized and EM-sized fibers.

Employee Eligibility

In order to maximize the likelihood of detecting adverse health effects resulting from fiber exposure, a minimum of 10 years of employment was required for participants from Plants 1 to 4. Because Plants 5 to 7 were small, a minimum of only 5 yr was required in these plants. Male employees with 1 month or more in the batch or binder areas, as well as female employees (less than 5% of the work force), were excluded. Because the study was designed to include approximately 200 workers from each plant, additional inclusion restrictions were imposed at the larger plants; these excluded employees with lengthy work in clerical positions. In 6 plants, recruitment efforts were directed at all employees meeting the inclusion criteria; in the largest plant (Plant 1), a random sample from the eligible employees was selected for recruitment.

Using official employee rosters from each plant (e.g., state tax and social security reporting forms), job histories were obtained for 375 randomly selected employees not originally identified by plant personnel as eligible. Of these, only 4 (1%) qualified for inclusion in the study. Thus, identification of the target population was excellent, with few eligible employees having been omitted from recruitment efforts.

Respiratory Health Assessment

A modified version of the American Thoracic Society-Division of Lung Diseases (ATS-DLD) questionnaire (7) was administered in all 7 plants by the same trained interviewer.

Participants were judged to have lower respiratory symptoms if they reported having usual cough, phlegm, or wheezing, current attacks of shortness of breath with wheezing, or breathlessness when walking with others; upper respiratory symptoms if current sinus trouble or postnasal drip; chronic bronchitis if usual cough and phlegm for more than 3 months in each of the last 2 yr. Dyspnea levels were defined as: Grade 1, shortness of breath when hurrying on level ground or walking up a slight hill; Grade 2, when walking with others one's own age; Grade 3, when walking at own pace on level ground; Grade 4, when washing or dressing.

Chest roentgenograms were taken at local facilities and sent to our unit. After all films were received they were placed into random order and read independently by 3 outside readers experienced in the use of the ILO 1980 Classification of Radiographs (8). Films judged unreadable by 2 of the 3 readers were excluded from analysis.

The median of the 3 readings was used as the summary reading. For shape of small opacity (rounded or irregular), at least 2 readers had to agree on presence and shape in order for a summary reading to be determined.

Pulmonary function testing was conducted at each plant site in a mobile laboratory using a Pulmolab (Model 5000; Cardio-Pulmonary Instruments, Houston, TX). This unit measures forced expiratory flows and volumes, lung volumes, and single breath carbon monoxide diffusing capacity (D_{LCO}). Calibration for all measured parameters was performed at the beginning and middle of each testing day.

Spirometry was conducted standing; noseclips were used. At least 3 satisfactory forced expiratory maneuvers were recorded. A forced expiratory maneuver was considered satisfactory if its curve had a sharp initial flow and showed smooth continuous effort extending until flow ceased or 7 s elapsed. At least 2 curves of satisfactory shape with forced vital capacity (FVC) within 5% of the largest were required. The values of FVC, forced expiratory flow between 25 and 75% of FVC (FEF_{25-75}), and forced expiratory volume in one second (FEV_1) used in statistical analyses were averages from the 2 satisfactory maneuvers with the greatest total of percent of predicted for $FEV_{0.5}$ and FEF_{25-75}. Both $FEV_{0.5}$ and FEV_1 were computed using backward extrapolation from the steepest part of the curve.

Residual volume (RV), measured by the nitrogen washout technique, was considered satisfactory when 2 tests were within 10% or 200 ml, whichever was larger. The smaller RV was used in analysis. Total lung capacity (TLC) was calculated as the sum of RV and the larger of FVC or a slow vital capacity. The D_{LCO} was taken as the average of 2 measurements within 10% of each other in which the alveolar volume (inspired volume plus multibreath residual

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TABLE 1

STUDY PARTICIPANTS BY PLANT

Plant* (Fiber Type)	Number	Median Age	Median Years Employed in Plant	Black (%)	Current Cigarette Smokers (%)	Never Cigarette Smokers (%)
1 (Ordinary)	260	48 (29 – 66)†	20 (10 – 34)†	14	47	22
2 (Ordinary)	244	44 (28 – 66)	17 (10 – 34)	25	52	20
3 (Ordinary/Fine)	110	52 (32 – 64)	28 (9 – 38)	1	37	25
4 (Ordinary/Fine)	217	48 (30 – 66)	18 (11 – 31)	6	38	28
5 (Very Fine)	107	34 (24 – 65)	9 (4 – 30)	3	50	23
6 (Mineral Wool)	34	38 (27 – 60)	16 (8 – 29)	31	56	38
7 (Mineral Wool)	56	43 (24 – 63)	14 (5 – 42)	0	50	20
Total	1,028	46 (24 – 66)	18 (4 – 42)	12	47	24

* These plants were numbered, respectively, 6, 18, 4, 1, 15, 11, 5, in the environmental study (3).
† Range.

volume) (ALVOL) was at least 85% of TLC and the breath-holding time was 10 to 14 s.

Statistical Analysis

Multiple logistic regressions were used to test for a relationship between possible explanatory variables and dichotomous response variables (e.g., presence of small opacities of a specified profusion level, presence of symptoms); multiple linear regressions were used in the case of continuous response variables such as the pulmonary function measurements. These regressions were run on the smoking groups separately as well as on these groups combined, allowing for smoking main effects and interaction terms. Tests for the significance of the exposure variables were performed after allowing for other factors such as age, height, race, and smoking.

Response variables were examined for influence of all exposure variables: fiber type, plant, average and cumulative dust levels (by both optical and electron microscopy counts, as well as their sum), length of exposure, and time spent at or above specific fiber concentration levels. Logarithms of the exposure measurements were also used to allow for a possible exponential relationship.

Results

Participation

Of the 1,148 employees asked, 1,028 (90%) participated in some phase of the study; participation rates were similar in all 7 plants. Health response data were, for various reasons, not complete for all participants: of those eligible, interviews were obtained for 79%, function testing was done in 78%, and radiography was done in 83%. Of those who did not participate on-site, most (67%) were unavailable at the time of testing (e.g., vacation, sick leave).

Of the 1,028 participants, 35 had been employed in a plant job with silica exposure, and an additional 36 may have had silica exposure in maintenance jobs. Analyses comparing these 2 groups of workers with those with no silica exposure found no differences in any respiratory health measures and these workers were retained in the study.

Population Description

Median age of the 1,028 participants was 46.3 yr; 12% were black and 88% were white. Median length of employment in the plants was 18.0 yr; 21 participants were found not to have the minimal required length of employment because of leaves of absence but were retained in the study.

Among the eligible employees, those who participated in various study phases and those who did not had comparable ages and employment durations. For example, the radiography participants had mean age of 45.9 yr and mean employment of 19.0 yr, whereas these parameters for nonparticipants were 46.6 yr and 18.9 yr, respectively.

Interviews with 912 employees found 48% cigarette smokers (currently smoking or stopped within the past year), 29% ex-smokers (stopped more than 1 yr before), and 24% never cigarette smokers. Of these 912 employees, 187 (21%) had been employed previously in jobs potentially harmful to respiratory health (27 of these 187 had multiple previous exposures); 38 had worked for more than 1 yr in a foundry, 29 for more than 1 yr in mining or quarrying, 120 had sandblasted, 12 had worked with asbestos, and 15 had worked in a cotton mill.

There were considerable differences among the plants in age of workers and length of employment (table 1). There was also a wide range in the percentages reporting previous employment in

TABLE 2

PREVALENCE (%) OF SELECTED SYMPTOMS BY SMOKING CATEGORY

Cigarette Smoking Category	Symptom							
	Lower Respiratory	Upper Respiratory	Chronic Bronchitis	Dyspnea (Grade ≥ 1)	Dyspnea (Grade ≥ 2)	Shortness of Breath with Wheezing	Wheezing	Asthma After Being Hired
Never smoker, n = 215	22	37	5	24	1	5	8	2
Ex-smoker, n = 261	22	38	2	35	6	8	13	4
Current smoker, n = 436	56	42	16	42	6	7	30	3
Total, n = 912	38*	40	9*	36*	5*	7	20*	3

* Significant differences among smoking categories, $p < 0.05$ (χ^2 test with 2 df).

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an industry with potential respiratory risk: 11% in Plant 3, 51% in Plant 7. Most of those in Plant 7 indicated previous sandblasting exposure, although plant management reported no known abrasive blasting with sand in this rural area. Many workers reporting sandblasting possibly referred to plant clean-up jobs, which included blasting with ferrous shot or water (referred to as sandblasting although sand was never used). If sandblasting experience is ignored, the overall percentage reporting such employment is 10%, ranging from 8% (Plant 5) to 16% (Plant 6).

Estimation of Worker Exposure

The plant manufacturing very fine fibers (Plant 5) exhibited the highest concentrations of airborne fibers for both OM-sized and EM-sized fibers. For fibers 1 to 3 μm in diameter, the median concentration was 0.210 fibers/ml in Plant 5; all other medians were less than 0.032 fibers/ml. For fibers less than 1 μm in diameter, the median concentrations were 0.928 fibers/ml for Plant 5, 0.203 fibers/ml for Plant 3, and less than 0.040 fibers/ml for all other plants.

Total accumulated dust exposures exhibited similar trends: median cumulative EM-sized fiber exposures were 7.4 fibers/ml/yr for Plant 5, 4.3 fibers/ml/yr for Plant 3, and 0.8 fibers/ml/yr for all other plants.

Symptoms

Most respiratory symptoms were significantly related to cigarette smoking (table 2), and among current smokers were significantly related to either years or pack-years of smoking.

A high prevalence (36%) of Grade 1 + dyspnea was unexpected in this actively employed population. Pulmonary function results showed that those without dyspnea had higher values for spirometry and lung volume measurements than those with Grade 1 dyspnea only, thus validating the responses to this question. Overall, 4 persons reported Grade 3 dyspnea; none reported Grade 4.

Among current smokers, those with previous hazardous employment had greater prevalences of lower respiratory symptoms (65 versus 54%) and wheezing (40 versus 27%), but this increase was not observed among ex-smokers and never smokers.

For current smokers, there were differences across the plants for several symptom prevalences (table 3), which were significant after adjusting for pack-years and previous employment. For 3 symptoms (lower respiratory, wheezing, shortness of breath with wheezing), the elevated prevalences occurred in the mineral wool plants, primarily in Plant 7. By contrast, Plant 7 exhibited very low rates for upper respiratory symptoms.

There were no dose-response relationships for any symptoms with any of the quantitative measures of exposure, either within the mineral wool plants or within the entire population. Moreover, symptom prevalences among ex-smokers and never smokers demonstrated no differences between the plants, nor any relationship with exposure dose.

TABLE 3

PREVALENCE (%) OF SELECTED SYMPTOMS AMONG CURRENT SMOKERS BY PLANT

Plant (Fiber Type)	Symptom: Lower Respiratory	Upper Respiratory	Chronic Bronchitis	Dyspnea (Grade ≥ 2)	Shortness of Breath with Wheezing	Wheezing	Number of Persons
1 (Ordinary)	61	48	17	7	4	34	108
2 (Ordinary)	43	37	17	7	7	22	121
3 (Ordinary/fine)	63	69	25	13	9	39	32
4 (Ordinary/fine)	53	32	8	3	4	28	74
5 (Very fine)	58	46	10	2	4	25	57
6 (Mineral wool)	63	53	26	16	16	42	19
7 (Mineral wool)	84	16	16	4	24	52	25
Total	56*	42*	16	6	7*	30*	436

* Significant difference among plants at $p < 0.05$ (χ^2 test with 6 df using logistic regression, after adjusting for pack-years).

Radiography

Overall film quality was excellent, with only 7 of the 948 chest radiographs judged unreadable by 2 of the 3 readers; these were excluded from all analyses. Nine films were judged unreadable by 1 of the 3 readers; a total of 64 were classified by median judgment as poor quality but nevertheless readable.

Using the majority opinion, few films exhibited pleural abnormalities: 15 had pleural thickening, 16 had obliteration of the costophrenic angle, 1 had pleural calcification, and 1 had pleural plaques. These were not associated with previous asbestos exposure, and the low prevalences of pleural changes tends to confirm that no significant asbestos was used in these plants.

None of the 941 readable films was judged to show large opacities. For profusion of small opacities, 847 (90%) were classified as category 0/0. Of the 94 films (10%) judged to show small opacities, 63 were categorized as 0/1, 25 as 1/0, and 6 as 1/1. None was higher than 1/1. Of the 94 films with profusion ≥ 0/1, 55 were categorized by at least 2 readers as having irregular opacities as the primary shape and 15 as having rounded. For the remaining 24, the 2 readers indicating presence of small opacities disagreed on shape.

The probability of having small opacities was significantly related to age and cigarette smoking category both for profusion of categories ≥ 0/1 and ≥ 1/0 (figure 1).

There was a significant relationship between presence of small opacities and fiber type category: 8% (22 of 292)

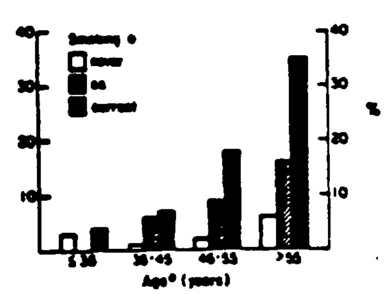

Fig. 1. Percentage with profusion of small opacities ≥ 0/1, by age and cigarette smoking categories.

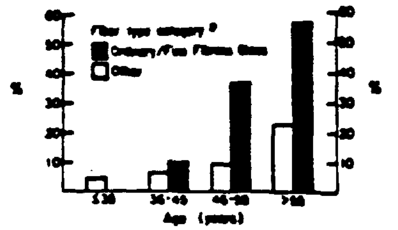

Fig. 2. Percentage with profusion of small opacities ≥ 0/1 among current smokers, by age and fiber type category.

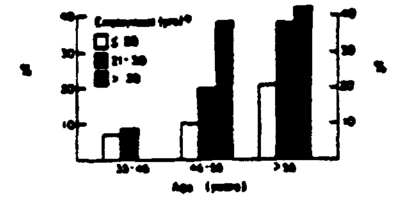

Fig. 3. Percentage with profusion of small opacities ≥ 0/1 among current smokers, by age and length of employment.

of the radiographs from the ordinary/fine fiber category were read as profusion ≥ 1/0, with only 2% (8 of 478), 0% (0 of 86), and 1% (1 of 85) from the ordinary, very fine, and mineral wool categories, respectively, showing this profusion level. All 6 of the 1/1 films were from the ordinary/fine fiber category. These differences were not explained by gross defects in film quality because exclusion of the 64 films of poor quality left the prevalences essentially unchanged.

For both profusion levels (≥ 0/1, ≥ 1/0) these increased rates in the ordinary/fine fiber category were observed in both plants in this category for current smokers (for profusion ≥ 1/0, 12% in Plant 3, 15% in Plant 4, 2% in other plants combined) but only in Plant 3 for ex-smokers and never smokers (12% in Plant 3, 1% in Plant 4, 1% in the others). These differences were significant ($p < 0.01$) after adjusting for age, and among smokers, pack-years. See figure 2 for the effect among smokers within various age categories.

The preceding analyses were also performed for prevalences of small irregular opacities. Although prevalences were lower than when shape was ignored, exactly the same patterns across plants were observed.

For current smokers, presence of small opacities, profusion ≥ 0/1, was also related to several quantitative exposure variables; these were, in decreasing order of significance: time above the second OM-sized fiber level, duration of employment, cumulative EM-sized fiber exposure, and time above the lowest fiber level (all p values < 0.025). The results for length of employment are illustrated in figure 3. The relationships with these exposure variables were significant after adjustment for age, pack-years, and ordinary/fine fiber type. Moreover, after adjusting for one or more of these exposure variables, the ordinary/fine fiber type continued to be significant ($p < 0.01$).

Although there was an indication of a possible relationship between profusion ≥ 1/0 and employment duration among current smokers, this was not significant, possibly because of the small number ($n = 21$) of cases.

Among ex-smokers and never smokers, after age and Plant 3 had been accounted for, no other variables were found to be significantly related to presence of small opacities (only 33 cases ≥ 0/1).

Because of the observed relationship between small opacities (≥ 0/1) and length of employment among smokers, the 163 smokers with over 20 yr employment were analyzed separately. Several measures of exposure were significantly related to presence of small opacities (≥ 0/1): cumulative EM-sized fiber exposure, average EM-sized fiber concentration, average total fiber concentration, and time above the second OM-sized fiber level (table 4).

Although all regressions allowed for a possible effect of previous hazardous employment (never close to statistical significance), all analyses were repeated excluding persons with such employment; no changes in the overall results were observed.

Analyses of the smoking groups combined found that the interaction between current smoking and these several exposure variables was significant but that the main effects of the exposure variables were not. Thus, the dose-response relationship among current smokers was significantly different from the lack of a relationship found among ex-smokers and never smokers.

Pulmonary Function

Of the 897 employees who participated in lung function testing, 836 had satisfactory spirometry, 824 repeatable lung volume measurements, and 796 repeatable pulmonary diffusing capacity results.

Percentages of predicted (based on nonsmoker values) were calculated for each person using published equations (9-12) that take into account age, height, and race. Mean percentages of predicted (table 5) were generally high, with significant differences between the cigarette smoking groups. Among current smokers, there was a significant correlation with pack-years of cigarette smoking.

For all symptoms, those with the symptom had significantly ($p < 0.001$) lower spirometric measurements and higher lung volumes than those without the symptom, after adjusting for age, height, race, and smoking.

To assess the relationship between lung function and profusion of small opacities, residuals were obtained from internal regression equations (using age, height, race, and 2 smoking category-by-age interaction terms); FEV_1, FEF_{25-75}, $FEV_1/FVC\%$, and D_{LCO} exhibited a significant trend in mean residuals by profusion of small opacities (table 6). After adjusting for profusion, there were no significant differences in pulmonary function by pri-

TABLE 4

PERCENTAGE WITH SMALL OPACITIES ≥ 0/1 BY AGE, FIBER TYPE CATEGORY, AND CUMULATIVE ELECTRON MICROSCOPY (EM) EXPOSURE; CURRENT SMOKERS WITH ≥ 20 YEARS EXPOSURE

	Ordinary/Fine Plants Exposure Level*			Other Plants Exposure Level*		
Age (yr)	< 0.1	0.1 – 0.8	> 0.8	< 0.1	0.1 - 0.8	> 0.8
36 – 45	–	13 (1/8)	0 (0/1)	9 (1/11)	0 (0/3)	0 (0/4)
46 – 55	–	25 (2/8)	48 (10/21)	8 (2/24)	15 (3/20)	18 (2/11)
> 56	–	29 (2/7)	75 (9/12)	14 (1/7)	18 (2/11)	40 (6/15)
All ages (> 36)	(n = 0)	22 (5/23)	56 (19/34)	10 (4/42)	15 (5/34)	27 (8/30)

* Cumulative EM fiber exposure (fibers/ml/yr).

TABLE 5

PULMONARY FUNCTION (MEAN PERCENT OF PREDICTED) BY CIGARETTE SMOKING CATEGORY

		Cigarette Smoking Category		
Function	n	Never	Ex	Current
FVC	836	110*	110	108
FEV_1	836	109*	106	98
FEV_1/FVC, %†	836	80*	77	78
FEF_{25-75}	836	94*	83	75
RV	824	114*	130	137
VC	824	112*	111	107
TLC	824	108‡	111	111
DL	798	121*	118	104
DL/ALVOL	798	117*	111	98

Definition of abbreviations: FVC = forced vital capacity; FEV_1 = forced expiratory volume in one second; FEF_{25-75} = forced expiratory flow during the middle half of the FVC; RV = residual volume; VC = vital capacity; TLC = total lung capacity; DL = diffusing capacity; DL/ALVOL = ratio of diffusing capacity to alveolar volume.

* Significant difference among smoking categories by analysis of variance, $p < 0.001$.

† Mean value in each smoking category.

‡ Significant difference among smoking categories by analysis of variance, $p < 0.02$.

mary type of small opacities (rounded versus irregular).

For current smokers, comparisons across plants revealed that after adjusting for known factors (age, height, race, pack-years), there were significant differences for some of the lung volumes (RV, TLC) and for diffusing capacity (DL, DL/ALVOL), but that these differences showed no consistent or meaningful pattern. For example, DL and DL/ALVOL were lower in Plant 3 than in the other plants, but none of the other functions were, whereas RV was high in Plants 5 and 7, but all other functions were comparable. There were no differences for the spirometric measurements, and similar analyses of ex-smokers and never smokers found no differences for any functions. These results do not support the hypothesis that fiber type or plant variables are having important effects on pulmonary function among current smokers.

Combining the smoking groups, FEV_1, FEF_{25-75}, and $FEV_1/FVC\%$ were found to be significantly related to length of employment and time above the lowest fiber concentration level, after adjusting for known factors, including smoking effects. The coefficients of these variables, however, were positive, indicating increasing function with increasing exposure time (employment time coefficients: 0.009 L/yr for FEV_1, 0.019 L/s/yr for FEF_{25-75}, 0.140%/yr for $FEV_1/FVC\%$). Detailed analyses of residuals and weighted regressions failed to account for these findings. When these regressions were performed on the smoking categories separately, no significant relationships (p values > 0.10) were found.

Analyses for RV, RV/TLC, and TLC showed similar results: coefficients were negative, indicating a decrease in these functions with increasing exposure time; these results were generally consistent for the smoking groups.

No exposure relationships were found for the measures of diffusing capacity.

Discussion

Assessment of the respiratory health of 1,028 workers engaged in the production of MMVF gave the impression of a generally healthy population experiencing no substantial lung disease.

In all studies, large unexplained variability in symptom prevalences, as determined by standardized questionnaire, occurred both within and between surveyed populations. For this reason it is impossible to firmly establish the "background" prevalences that can be expected in a working population not occupationally exposed to any respiratory risk. Despite this difficulty, it is unlikely that any of the observed symptom prevalences were significantly elevated in this population. Indeed, the prevalence of bronchitis seemed low, particularly among never smokers and ex-smokers. The relationship of symptom prevalences with pulmonary function measurements and cigarette smoking, as well as with the level of smoking among current smokers, supports the validity of the questionnaire responses.

Although an increased prevalence of certain symptoms was detected among current smokers in the 2 mineral wool plants, statistical significance was attained in only 1 of these plants, and no dose-response relationships were found. Bronchitis rates were not elevated in these plants and the nonsmokers exhibited no increased symptoms.

It is concluded that prevalences of respiratory symptoms are not increased in this population and no coherent pattern of symptoms in relation to exposure to MMVF emerges.

Lung function testing also failed to detect any adverse effect of exposure, although measurements were related to age, height, race, cigarette smoking status, and level of smoking. Using published equations to provide external comparisons, mean values for all smoking groups were near or above 100% of predicted.

After taking into account other influencing factors, there was no adverse association between functional measurements and any of the indexes of exposure to MMVF. In fact, after age and smoking were taken into account, the associations of RV and expiratory flow rates with length of exposure suggested a possible "healthy worker" effect.

The negative findings concerning symptoms and pulmonary function testing in this study are consistent with the generally reassuring results of all reports published to date. Several surveys of working populations failed to detect any chronic respiratory effects of exposure to MMVF (13–16). The single histologic study also reported negative results, with lungs of exposed workers exhibiting no differences from those of matched control subjects (17). Although some mortality studies showed

TABLE 6

MEAN RESIDUALS* FOR SELECTED FUNCTIONS BY PROFUSION OF SMALL OPACITIES

Profusion of Small Opacities	FVC (L)	FEV_1 (L)	FEF_{25-75} (L/s)	FEV_1/FVC (%)	RV (L)	TLC (L)	DL_{CO} (ml/min/mmHg)
0/0	0.003	0.010	0.026	0.117	0.004	0.014	0.083
([illegible])†	(0.566)‡	(0.561)	(1.081)	(7.203)	(0.807)	(0.782)	(4.866)
0/1	−0.056	−0.082	−0.153	−0.494	−0.046	−0.080	−0.806
(51)	(0.661)	(0.573)	(0.787)	(7.308)	(0.828)	(0.988)	(4.828)
1/0	0.014	−0.116	−0.274	−2.737	0.091	0.117	−1.881
(20)	(0.596)	(0.534)	(0.863)	(10.672)	(0.787)	(1.088)	(6.517)
1/1	−0.676	−0.663	−0.783	−3.940	0.079	−0.625	−1.435
(8)	(0.843)	(0.554)§	(1.002)§	(6.187)§	(0.460)	(1.091)	(6.405)§

* Observed-predicted (using age, height, race, and 2 smoking-by-age interaction variables).

† Number in category with good spirometry.

‡ Standard deviation.

§ Significant gradient in mean residuals across profusion categories by simple linear regression on categories coded 1,2,3,4; $p < 0.025$.

an increased risk of nonmalignant respiratory disease, there was no indication of increased lung cancer risk (3, 4, 18-20), and animal inhalation studies produced adverse respiratory effects only after either intratracheal injection or direct installation of fibers into the pleural space (21-25).

However, reported findings of new and updated studies presented at the WHO International Occupational Health Conference on the Biological Effects of Man-Made Mineral Fibres (Copenhagen, 1982), while providing no cause for alarm concerning health risks from MMVF, were not entirely negative.

In a U.S. mortality study, there was no overall excess of lung cancer among 14,884 fibrous glass workers, but an increase was observed (47 observed, 36.0 expected) among those with over 30 yr of follow-up from initial exposure (5). The 1,846 mineral wool workers in this study exhibited an overall excess of lung cancer mortality (45 versus 28 expected). Both groups of workers were found to have an increased risk of death caused by nonmalignant respiratory disease. A European study of 17,083 employees, although not completed, reported a significant excess of lung cancer deaths (12 versus 5.6) among those followed over 30 yr (26). Similar results were reported from another U.S. study (4,394 workers), which found an excess of lung cancer deaths (11 versus 6.2 expected) among workers with over 20 yr of employment and 30 yr of follow-up (27). No mesotheliomas were found in the U.S. studies, but one was found in the European studies.

It is difficult to interpret the results of these mortality studies with regard to exposure to MMVF because none found a dose-response relationship and none had smoking information available. The past use of asbestos in some of the U.S. mineral wool plants introduces further uncertainty regarding these results.

Recent animal experiments with MMVF confirmed the results of earlier studies: MMVF injected intrapleurally or intraperitoneally produced mesotheliomas, but none was produced by inhalation. Inhalation studies with glass fibers produced no or mild fibrosis; fewer lung tumors occurred in exposed rats than in unexposed control animals (28-31). Inhalation of very high concentrations of ceramic fibers produced interstitial fibrosis and neoplasms in the lung tissue of animals (29). Several studies showed that pitting, corrosion, progressive shell formation, decreasing fiber diameter, fracturing, and dissolution of MMVF occur *in vivo* and *in vitro* (28, 30, 32-34). These findings concerning the durability of MMVF in lung tissue may help to explain the discrepancies reported in the literature between intrapleural injection and inhalation studies.

A recent cross-sectional survey of 340 employees of a U.K. fibrous glass plant reported that 13% of the chest radiographs of men exhibited small opacities of category 1/0 or higher (35). Although this study had considerable technical limitations, the presence of small opacities was related to previous employment in dusty trades and general environmental exposures, but there was no relationship with exposure to MMVF as measured either by length or intensity of exposure. Although FEV_1 and VC were low, neither functional measurements nor symptoms were related to exposure to MMVF. Two smaller studies of mineral wool workers found no evidence of adverse functional effects (36, 37).

The present study, also presented at the Copenhagen Conference, while finding no adverse exposure effects as measured by symptom prevalence and function testing, found that the presence of small opacities was related to some measures of exposure.

Classification of chest radiographs demonstrated a low prevalence of small opacities, with no large opacities. Films considered to show small opacities were almost exclusively in the lowest profusion categories (0/1 or 1/0) on median reading. On individual readings, a choice of these ILO categories indicates that the reader favored (0/1) or seriously considered (1/0) a negative judgment.

Prevalence of small opacities rose as both age and smoking increased, findings that have been reported elsewhere (38-40). Among current smokers, probability of small opacities was positively associated with exposure duration; however, among ex-smokers and never smokers, there was no association with exposure measures.

With respect to fiber type, exposure to a mixture of ordinary and fine fibers significantly increased the probability of low-level small opacities among current smokers, an effect observed in both plants. They have produced fine fibers for a sufficiently long period to make the detection of an effect possible. Among ex-smokers and never smokers, this effect was observed only in the dustier plant. Thus, in the generally less dusty plant, an increased prevalence occurred only among smokers, whereas in the dustier plant, an increased prevalence was observed in all smoking categories. If the higher dust levels contributed to the increased prevalence of small opacities, then a fiber dose-response relationship should be demonstrable in this fiber type category after smoking has been taken into account. In fact, such a relationship was found only among current smokers. This could be a result of the smaller number of ex-smokers and never smokers with small opacities, but it may also reflect the recognized difficulties of individual exposure reconstruction.

If the increased probability of small opacities is attributable to exposure to fibers with the smallest diameter, then the plant manufacturing very fine fibers, whose average fiber concentration levels were considerably higher than all other plants, would be expected to exhibit increased prevalence of small opacities. In fact, they were very low in this plant. Because these workers were the youngest (median age, 34 yr) and overall had the shortest employment duration (a median of 5 yr; only 14 employed for more than 10 yr), longer follow-up is required to fully assess radiographic outcome in this exposure category.

The focus of environmental characterization, and therefore exposure reconstruction, has been on qualitative and quantitative aspects of airborne fibers in this study. Although this approach seems well based in prioritizing concern about potential respiratory health effects, we recognize that further exploration of nonfibrous particulates and gaseous inhalants in this industry is a logical next step.

Inevitably, attention will be directed to the potential biologic significance of the correlations found in this study between low profusion of small opacities and some indexes of exposures. Possibly there is minimal dust accumulation, retention, and persistence of MMVF with fine diameters in lung tissue. If so, these effects, in general, are attaining the radiographic detection limit only in current smokers, perhaps

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because of less effective clearance of particulates. The absence of intermediate or higher profusion of small opacities, in a population with a considerable range of exposure durations, suggests that a progressive, diffuse tissue reaction (e.g., fibrosis) is unlikely, yet it cannot be excluded.

Because interobserver variability is greatest at these lowest profusion levels (0/1, 1/0) and because of the important influences of age and smoking on the probability of detecting these opacities, the presence of small opacities at these levels has a low order of specificity for an occupational exposure effect. Clearly, the findings reported here should be considered preliminary, requiring replication and confirmation before firm conclusions can be drawn. The suggestion that fibers with fine diameters may be having an effect on lung parenchyma makes it prudent to continue biologic surveillance of workers exposed to MMVF with small and very small diameters. This approach is particularly indicated when a working population may have had relatively short-term exposure on average and the potential anticipated biologic response is suspected of having a long latency period. In general, however, the minimal evidence of respiratory effects detected in this investigation, which cannot, at present, be considered clinically significant, is encouraging concerning the question of potential health effects of exposure to MMVF.

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