Lung Function Consequences of Dust Exposure in Asbestos Cement Manufacturing Plants

File: Asbestos

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A comprehensive study of health effects associated with the mixed dust exposure in this industry has included the collection of clinical, radiographic, lung function, and dust exposure data on 859 workers in two plants. Evidence is presented supporting a dose-response relationship between indexes of dust exposure and lung function, similar to the previously reported relationship with extent of x-ray film changes using the ILO U/C classification.

Lung volumes and maximum expiratory flow rates decrease in relation to increasing cumulative dust exposure while pulmonary diffusing capacity (D_L) is not dust-dose related. Workers who had crocidolite exposure had smaller lung volumes, lower expiratory flow rates, and reduced D_L when compared with those having only chrysotile exposure.

When the study population is divided into exposure groups, data thus far analyzed suggest that the chest x-ray film will reveal small opacities as early as significant functional changes can be detected, but individuals may have functional reduction prior to the appearance of x-ray film changes.

It has been the aim of investigators studying the inorganic dust diseases to establish which methods of biologic monitoring are most sensitive in detecting the earliest changes of diffuse pulmonary involvement and measuring the progression of the disease over time. This objective can be realized through data collected from a carefully designed epidemiologic study of workers exposed to a well-characterized environment, which usually requires analysis of past and present dust levels. The resulting dust dose-biologic response relationship will provide the basis for establishment of safe dust levels in industry and make it possible for those responsible for maintenance of the workers' health to use the most sensitive methods of monitoring that will provide the earliest indicators of an adverse effect on the lungs.

In a study of workers engaged in the manufacturing of asbestos cement building products, we have shown previously a clear relationship between cumulative total dust exposure and prevalence and profusion of radiographic opacities in the lung fields.[1] Since these workers are exposed to both asbestos fiber and free silica dust, attention was directed to the separation of small rounded from small irregular opacities. Pulmonary physiologic patterns emerged that were consistent with the hypothesis

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that the rounded opacities were primarily associated with a silica effect and that irregular opacities indicated the effect of inhaled asbestos. The generally narrow range of asbestos-silica distribution of total dust exposure is perhaps the primary reason that analysis of constituent dust exposures could not confirm the suggestion that small irregular opacities indicated asbestosis, while the rounded shadows resulted from silicosis.

It is the purpose of this report to examine the various indexes of pulmonary function and relate reduction in mean values, as compared with a standard group, to dust exposure. In order to do this, the effects of age, race, smoking, and presence of radiographic changes have been accounted for, and the influence of fiber type has been examined. Finally, a threshold dust level has been established for this industry, below which significant reduction in mean values cannot be demonstrated. The relative value of simple and more complex pulmonary function tests in detecting a dust effect is evaluated.

METHODS AND MATERIALS

Subjects for Study

All workers who were employed in two asbestos cement manufacturing plants in the New Orleans area on Nov 3, 1969, were recruited for this study. A major reduction in work force in one of the plants shortly after initiation of this investigation necessitated special effort in recruiting into the study the 184 individuals laid off, with the result that 70% of them participated. The total study population, in whom complete studies of pulmonary function are available, numbers 859, or 91% of those who would have been available on the day the study began, before the reduction in number of workers employed. Pulmonary function data collection were completed in November 1971. Because of the small number of female employees in these plants (37), the study group consists only of men.

The average age of the participants in the study was 45 years, ranging from 21 to 79 years. They had an average of 17 years of dust exposure, with a range of one month to 45 years. Analysis of ethnic distribution revealed that 396 (46%) were white and 463 (54%) were black. Fifty-one percent of the entire group were current smokers, 26% were exsmokers, and 23% had never smoked. The proportion of smokers decreased from 61% in the lowest dust exposure group to 41% in the highest dust level group.

Pulmonary Function

Expiratory flows and volumes were determined with a 13.5 liter water-sealed spirometer, with calculations of vital capacity (VC), forced vital capacity (FVC), forced expiratory volume, one second (FEV_1), FEV_1/VC, and forced expiratory flow, 25% to 75% ($FEF_{25\%-75\%}$). Functional residual capacity (FRC) was determined by the closed-circuit helium dilution method and led to calculation of residual volume (RV) by subtraction of the expiratory reserve volume obtained during the equilibration procedure and of total lung capacity (TLC) by addition of VC to RV. We determined pulmonary diffusing capacity (transfer factor) ($D_{L_{CO}}$) by the breath-holding carbon monoxide technique, using an automated apparatus for timing of events and valve sequencing, by which inspired, alveolar, and washout volumes as well as breath-holding time are preset.[2] Diffusion constant (K_{CO}) was calculated as a ratio of $D_{L_{CO}}$ to alveolar volume (V_A), obtained by addition of inspired volume to the separately determined residual volume, ie, D_L/V_A. For purposes of comparison V_A was also determined by dilution of helium during the single breath. Two levels of exercise on a chair ergometer were chosen to approximate 1 and 1.5 liters of oxygen uptake ($\dot{V}_{O_2}$) while measurements of total ventilation and oxygen and carbon dioxide concentrations of the expired air allowed calculation of actual $\dot{V}_{O_2}$. Ventilation was then corrected to the two standardized levels of $\dot{V}_{O_2}$.

Radiographic

An EPA and two oblique chest x-ray films were obtained on each study participant. Only the posteroanterior films were read using the ILO U/C International Classification for the Pneumoconioses by two members of the committee that devised the classification. Analysis of the oblique projections will form the basis of a future report. Films of 69 unexposed controls who had never worked in this industry were randomly interspersed among the films of the workers and were all read as 0/0 (66) or 0/1 (3), for small opacities. The heading "any x-ray change" in this report is defined as category 1 or more for small opacities or grade 1 or more for pleural thickening. "No x-ray change" refers to those subjects who did not exhibit these changes on the x-ray film. A radiographic classification was assigned to an x-ray film if that classification was read by either of the expert readers. Agreement on the readings between the two readers has been analyzed and is considered very good. Using the stated definitions, 584 (68%) of the 859 total population had no x-ray change while 275 (32%) had any x-ray change; 130 (15%) had showed pleural changes only, 71 (8%) had small opacities only, and 74 (9%) had opacities and pleural changes.

Dust Exposure Assessments

Plant A produced only shingles, while plant B initially produced shingles and roofing, later adding pipe and, ultimately, flooring was added to the operations. In both plants, each work area was assigned a code number. In many instances several code numbers had several identical job titles. Detailed job histories that contained the work area code number, job title, and dates of starting and finishing each job were transcribed from personnel records. Because code numbers and job titles had changed frequently over the years, repeated consultation with personnel officers and older employees was required to describe jobs properly.

For plant A, dust exposure assessments were based on dust samples collected at various dates between 1952 and 1969. The primary instrument used was the midget impinger. These dust samples were collected by federal and state agencies and industry, and the results were provided to us by the companies. For periods prior to 1952, estimates of exposure were made by interviewing employees of long service in an effort to compare recent dust levels with conditions of earlier dust exposure. Results and presampling estimates were recorded in million particles per cubic feet of air (mppcf). Plant B provided an exposure coding for each job identified, ranging from 5 mppcf to over 50 mppcf, also based on midget impinger sampling data.

The primary type of asbestos used in plant A was chrysotile. A small amount of amosite was added to all corrugated products in 1957 and minimal amounts of crocidolite to corrugated bulkhead alone in 1962. Before 1957 no silica was added, but the cement at that time contained a high concentration of silica. Analyses of the dust samples suggested that the proportion of silica in the airborne dust was only slightly less than that in the product.

Plant B had a wider range of jobs and exposure than plant A. Chrysotile was the primary type of fiber used; a small amount of crocidolite was added to one product; no amosite was used. Silica was added to three of the four products, and mica and talc were used in two of the four. Both

plants provided information regarding the percent of each type of fiber and of silica used in the products manufactured.

Comparison of Dust Exposure Measures in the Two Plants

The aim was to grade equal dust exposures in the two plants equally. However, because dust sampling was carried out by various industrial hygienists, agencies, and apparatus, comparability is not precise. These considerations also imply that the dust levels in this study cannot necessarily be taken to be the same as in any other study. An exception to this is in a mortality study of retired asbestos workers where the same industrial hygiene team and methods were used as in plant B.[3]

Calculation of Dust Exposure for Each Person

There were 146 and 241 different job titles identified at plants A and B, respectively. There were ten mutually exclusive dust exposure categories at plant A and 57 such categories at plant B. Using the detailed occupational history that had been abstracted for each person, total dust exposure for an individual was calculated by multiplying the dust exposure level of each job by the time spent in the job. The results were totaled for all jobs and expressed in mppcf-yr.

Ethnic Differences and Standardization of Lung Function

Preliminary analyses showed that there were considerable differences in pulmonary function between the black and white subjects included in this study. A detailed analysis of these differences suggested that they were related to size differences in chest volume for given height in blacks and whites.[4] Calculations based on anthropometric data on African and Europeans from Rhodesia[5] gave a 13.2% difference in chest volume, which agrees almost completely with differences in the major lung volume indexes between blacks and whites in a subgroup (244) of this population who had had little exposure to asbestos dust and who had no major respiratory symptoms or radiographic changes. This subgroup will be termed the standard group in this report. As an example, in this standard group after increasing the total lung capacity of the blacks by 13.2% there was no difference in the relations to age and height in the two races. Standardizing to age 40 years and height 175 cm (5 feet 9 inches) the whites and blacks had average total lung capacities of 6.32 and 6.31 liters, respectively. Remarkable agreement with these ethnic differences in lung function has also been reported recently.[6]

The factor, 13.2% has been used to scale total lung capacity, VC, FVC, FEV, FEF, and the alveolar volumes. A smaller increase of 8% was proposed for functional residual capacity and residual volume, again based on anthropometric data. For diffusing capacity a factor of 8% was also proposed, with a corresponding factor for the diffusion constant of −4.6%.

Application of these scaling factors to the lung function indexes for the blacks eliminated any racial difference. A common regression equation proved to be applicable for each index, and details of these common regression equations calculated from the standard low-exposure group are given in Table 5 of a previous publication.[4] Whenever standardized values are presented in this report, they are based on these regression relations after scaling the indexes for the blacks by the factors given above. For example, a man aged 40 years with a height of 175 cm (5 feet 9 inches) would have a standard total lung capacity of 6.31 liters. If his actual total lung capacity were 6.0 liters, then his standardized value would be 95.1%.

This standard group will always have average standardized values of 100%, and the expected value for any other group will also be 100%. For tests of significance, the observed standardized value has always been compared to the expected value of 100%.

Effect of Smoking

In order to determine whether smoking affected the relationship of pulmonary function and dust exposure, this relationship has been separately analyzed for smokers, exsmokers, and nonsmokers in the total study population. When indexes of pulmonary function in each of the smoking groups were compared with those in the standard group, in which smoking habits were mixed, it initially appeared that synergism between smoking and exposure existed, since function in relation to the standard group was lower in each exposure category in the smokers than in the nonsmokers; the difference between the two groups generally increased with exposure and age. As described in the previous section, the standardization or prediction equations used in this study were based on a standard population, consisting of 142 current smokers, 45 exsmokers, and 57 nonsmokers of cigarettes. A detailed analysis of $FEF_{25\%-75\%}$, in the standard group, now also divided into subgroups according to smoking habits, showed that not only did the smokers have reduced function, but also that the $FEF_{25\%-75\%}$, declined with age much faster in the smokers than in nonsmokers, with exsmokers intermediate (Fig 1). A similar pattern was found for other indexes of ventilatory function. When these differing regressions for each smoking group are used to "predict" or "standardize" lung function (ie, correcting for smoking habits), the exposure-function relations do not differ significantly between smoking groups. It was also found that the proportion of nonsmokers is almost constant in the five exposure groups (23%), while the proportion of current smokers actually declines from 60% to 40% as exposure increases. For these reasons it was concluded that the effect of exposure to asbestos is not influenced appreciably by smoking habits and that there is no synergism between smoking and asbestos dust as regards an effect on pulmonary function in this population. It was, therefore, thought reasonable that in the following analyses, smoking need not be considered and the overall regression relations published previously[4] are used to provide the standardized values of pulmonary function against which the effects of exposure are assessed. This matter is discussed further in a separate publication.[7]

RESULTS

Characteristics of Subjects in Regard to Dust Exposure

The study population of 859 men is classified by dust exposure group, race, smoking history, and x-ray results changes in Table 1, and by total dust exposure group, age, and constituent exposure pattern in Table 2. The whites tended to have had a higher total of exposures than the blacks, 51% of the former and 43% of the latter being in the two highest exposure groups. There were also a higher proportion of smokers in the lowest exposure group, and an increase from 18% to 36% in the proportion of exsmokers, as exposure increased. The proportion with small opacities of category 1 or more as recorded by either of two readers rose markedly with exposure from 4% in the lowest group to 30% in the highest. There was also a rise in the proportion with pleural changes from 11% to 30% with increasing exposure.

In Table 2, where average age is given for each dust exposure group, it is apparent that while the lowest ex-

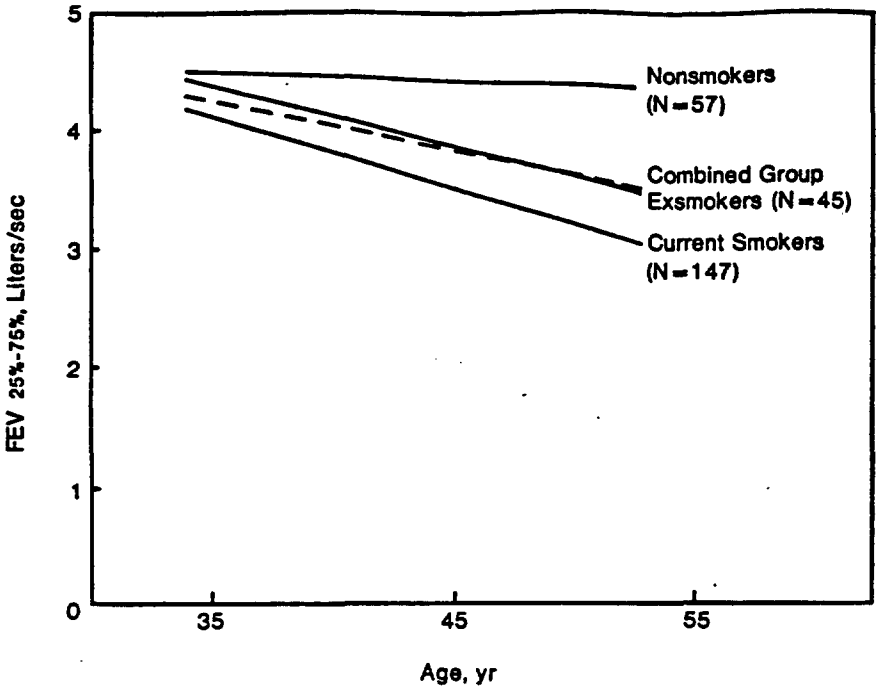

Fig 1.—Relation between $FEV_{25\%-75\%}$ and age for the smokers, exsmokers, and nonsmokers in the standard group (height taken as 175 cm [5 feet 9 inches]).

Table 1.—No. of Subjects by Exposure Group, Race, Current Cigarette Smoking Habits, and Radiographic Change

Category	Total Dust Exposure, mppcf-yr* <50	50-100	100-200	200-400	400+	Totals
All men	233	92	130	245	159	859
Whites	98	43	52	126	77	396
Blacks	135	49	78	119	82	463
Smokers	139	45	68	119	65	436
Exsmokers	43	28	30	67	57	225
Nonsmokers	51	19	32	59	37	198
No x-ray changes	202	73	85	138	86	584
Small opacities only	6	3	8	29	25	71
Pleural changes only	22	14	28	40	26	130
Both small opacities and pleural change	3	2	9	38	22	74

* Million particles per cubic feet-years.

Table 2.—Exposure Characteristics of Subjects in Each Total Dust Exposure Group

Index	Total Dust Exposure, mppcf-yr* <50	50-100	100-200	200-400	400+	Totals
Number	238	89	129	244	159	859
Average age	35.3	46.4	48.2	48.8	52.2	45.3
Years in industry	5.9	17.8	20.7	21.9	24.9	17.4
Total dust, mppcf-yr	19.2	71.4	146.0	303.0	565.4	225.3
Chrysotile index	3.1	11.2	22.4	51.3	104.4	39.3
Crocidolite index	0.1	0.3	0.8	4.2	2.8	1.9
Amosite index	0.1	0.3	0.3	0.3	0.8	0.3
Silica index	3.8	13.6	32.2	88.0	139.7	58.2

* Million particles per cubic feet-years.

posure group is much younger, average age does not differ much in the remaining four groups. The average exposure indexes, including simply years in the industry, rise steadily. The exception is the crocidolite index that is very low in the first three exposure groups, rises strikingly in the fourth and drops slightly in the fifth group. This pattern may be explained by the date of opening of the pipe manufacturing section in plant B.

Lung Function Changes With Exposure

In a previous section, the need to scale the values for the pulmonary function indexes for the blacks to account for ethnic differences was discussed. The effect of this scaling is to eliminate the problem that would otherwise be caused by the differing proportions of white and black subjects in the five exposure groups. Also, smoking habits have been discussed but for the reasons indicated previously, no correction for smoking has been made in the following analyses.

Table 3 shows how each pulmonary function index varied with exposure. For example, total lung capacity declined from 6.25 liters on average in the lowest exposure group to 5.85 liters in the highest. The changes in average values in some of the other indexes are more marked, for example, for the indexes of flow. Also shown, in parentheses for each index, is the average standardized value, taking into account age and height. As the standardizing relations were determined from people within this study population, the expected value for each group is 100% and so each standardized value has been compared with 100%.

For total lung capacity, the standardized value drops from 98.2% to 94.0% with increasing exposure. While it is reduced significantly in the lowest exposure group, the largest and most significant changes occur in the two highest exposure groups. Figure 2 shows that the reduction in the lowest exposure group occurs entirely in those with x-ray changes. Those with x-ray changes have much lower total lung capacity, but even in those with no x-ray

Table 3.—Pulmonary Function Indexes *

Index	Dust Exposure, mppcf-yr† <50	50-100	100-200	200-400	400+	Totals
Number	233	92	130	245	159	859
Total lung capacity, liters	6.39	6.39	6.18	5.99	5.83	6.14
	(98.2)‡§	(99.8)	(98.0)	(95.2)‖	(94.0)‖	(96.7)‖
Vital capacity, liters	4.72	4.41	4.42	4.04	3.84	4.26
	(98.4)§	(98.1)	(97.4)§	(93.1)‖	(91.8)‖	(95.5)‖
FVC, liters	4.63	4.32	4.16	3.94	3.73	4.16
	(98.2)§	(98.3)	(97.8)	(93.1)‖	(91.6)‖	(95.5)‖
FEV_1, liters	3.80	3.48	3.28	3.11	2.94	3.33
	(98.0)§	(99.1)	(97.4)§	(93.0)‖	(92.1)‖	(95.5)‖
FEV_1/VC(%)	80.4	78.8	77.4	77.0	76.2	78.0
	(99.5)	(101.3)	(100.2)	(99.9)	(100.1)	(100.0)
$FEF_{25\%-75\%}$, liters/sec	4.21	3.81	3.50	3.32	3.02	3.59
	(97.7)	(98.2)	(94.5)	(89.9)‖	(85.6)‖	(92.8)‖
Functional residual capacity, liters	2.96	3.13	3.04	2.99	2.89	2.99
	(98.6)	(98.6)	(96.4)	(94.5)‖	(91.4)	(95.8)‖
Residual volume, liters	1.62	1.93	1.88	1.89	1.93	1.83
	(98.5)	(101.2)	(96.8)	(96.6)	(95.7)	(97.5)§
RV/TLC(%)	25.3	30.0	30.0	31.5	32.8	29.7
	(100.0)	(100.9)	(99.0)	(102.3)	(102.5)	(101.0)
Diffusing capacity, ml/min/mm Hg	34.1	32.9	31.1	29.9	30.0	31.6
	(97.5)	(103.6)	(100.8)	(97.7)	(101.8)	(99.5)
Diffusion constant, D_L/V_A	6.04	5.78	5.68	5.66	5.79	5.80
	(99.1)	(193.9)	(103.4)	(103.5)¶	(108.8)‖	(103.3)‖
Alveolar volume (multibreath), liters	5.66	5.77	5.52	5.30	5.23	5.47
	(98.0)§	(101.5)	(98.5)	(94.9)‖	(94.9)‖	(97.0)‖
Alveolar volume (single-breath), liters	5.22	5.07	4.94	4.66	4.61	4.89
	(99.3)	(98.2)	(97.8)	(92.7)‖	(93.3)‖	(96.0)‖
Number	216	70	97	170	103	656
Ventilation at oxygen uptake of 1.0 liters/min	25.1	25.7	25.6	26.0	26.5	25.7
	(100.2)	(102.3)	(102.6)	(103.6)¶	(105.6)‖	(102.4)‖
Ventilation at oxygen uptake of 1.5 liters/min	37.8	39.2	37.8	39.2	39.4	38.6
	(100.4)	(104.2)	(100.6)	(104.3)‖	(104.6)¶	(102.5)‖

* Average values and values standardized for age, height, and race for the five total dust-exposure groups.
† Million particles per cubic feet-years.
‡ Number in parentheses below average value refers to average % standardized.
Significance of difference between standardized value and 100%: § $P < .05$; ‖ $P < .001$; ¶ $P < .01$.

changes there are significant reductions in the two highest exposure groups.

Vital capacity (Fig 2) and FEV_1 (Fig 3) show the same pattern of marked reductions in function in those with x-ray changes, but also significant changes in the highest exposure groups for the total group and in those with x-ray changes. Forced vital capacity is not shown in the Figures because it is almost indistinguishable from VC. The FEV_1/VC ratio shows no effect of exposure confirming that FEV_1 and VC show the same relation to exposure.

The changes in the $FEF_{25\%-75\%}$ (Fig 3) are larger than for any of the other indexes, but it is also the most variable being about 2.4 times as variable as the FEV_1.

Functional residual capacity (Fig 2) is also a highly variable index. The pattern of change is similar to that for FVC and VC, showing reduced values with increased exposure, but in the no x-ray change group it is only in the highest exposure group that the average standardized value differs significantly from 100%. Residual volume shows a tendency to fall with increasing exposure, but not significantly so. However, its ratio to total lung capacity shows very little evidence of an exposure effect, indicating that the two indexes move in the same direction.

Pulmonary diffusing capacity (Fig 4) shows only an irregular pattern with exposure, although it does show a paradoxical tendency to rise with increasing exposure in those without roentgenographic changes and to fall in those with roentgenographic changes. Since alveolar volume decreases with increasing exposure, there must be compensatory changes in the diffusion constant. Figure 5 shows that the diffusion constant rises with increasing exposure and that it is apparently unaffected by the disorder that causes the roentgenographic changes.

The two standard indexes of ventilation during exercise show similar results. The ventilation rate at an oxygen uptake of 1 liter/min (Fig 4) rises with exposure in the total group and in those with x-ray changes. The pattern in those with no roentgenographic change is less regular, so that virtually all the rise with exposure may be attributed to the increas-

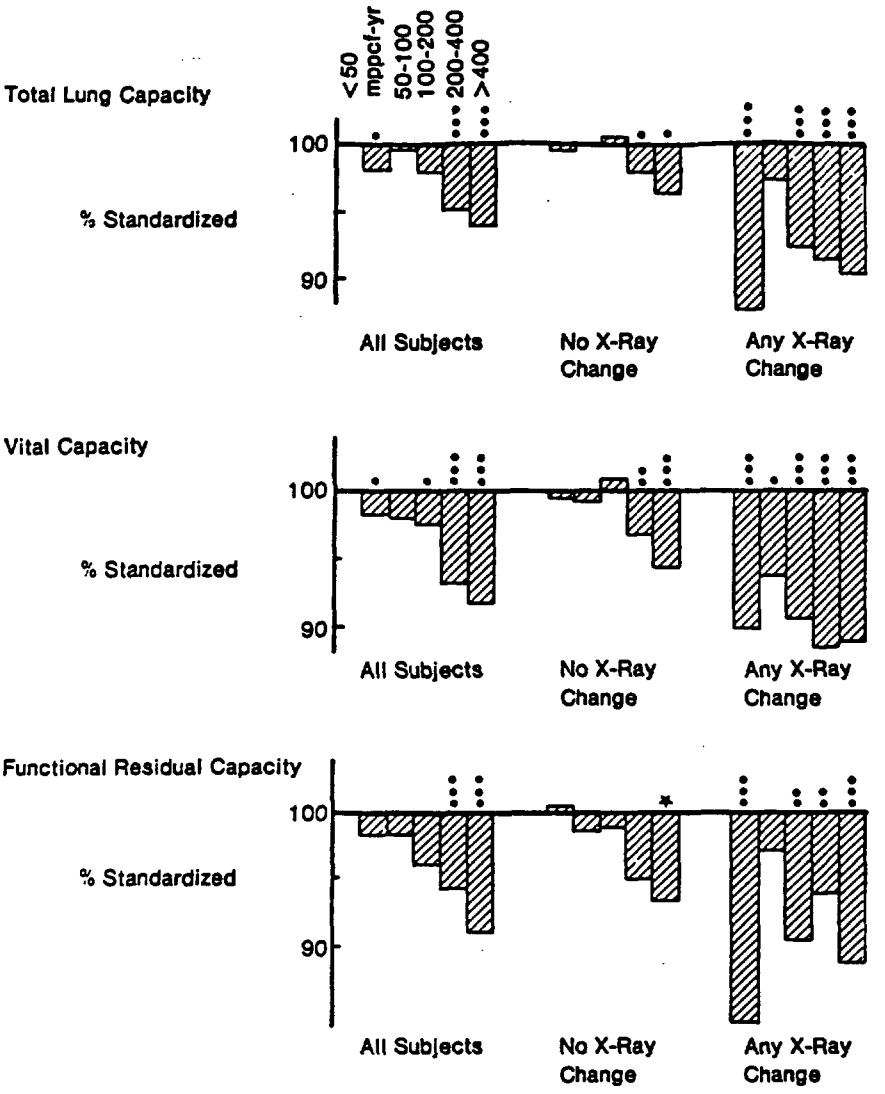

Fig 2.—Relation between lung volumes and dust exposure.

Table 4.—Characteristics of Workers Who Had More Than 75% of Their Employment or Had Never Been in the Pipe Area

	75% or More In Pipe Area	Never Worked In Pipe Area
Number	108	100
Total years of exposure	22.8	23.0
Total exposure, mppcf-yr*	324	290
Crocidolite exposure	8	0.6
Chrysotile exposure	48	52
Silica exposure	120	78
Age	49	52
Proportion of smokers, %	51	51

* Million particles per cubic feet-years.

ing proportion of people with roentgenographic changes.

Other Analyses

As well as the averages for each exposure group, the proportions in the tails of the distributions of standardized values were considered. These proportions followed the patterns expected from the pattern of the averages, and suggest that the effect of exposure was to reduce function overall rather than in a few susceptible individuals. Figure 5 shows that for FEV_1 the distribution of standardized values in the highest exposure group is a little skewed compared to that for the lowest exposure group, but that the major difference between the distributions is one of position. This confirms for this index the general impression of a general reduction in function as the main response to dust exposure.

The comparison of average standardized values in the five exposure groups makes no assumptions about the linearity of the changes in function with respect to dust exposure. Linear regression of the standardized values of lung function on total exposure confirms the findings based on the main analysis. All regression coefficients of function on exposure are highly significant ($P < .001$) except those for residual volume ($P < .01$) and for diffusing capacity, FEV_1/VC ratio and RV/TLC ratio that are not significant.

Effect of Crocidolite

In one of the two plants studied, crocidolite has been used regularly in the pipe making area only, although a few other people have been slightly exposed in maintenance work. In an attempt to separate the effects of crocidolite from those of chrysotile, two groups of workers were defined who had worked for between 20 and 30 years in the industry. One group had worked for at least 75% of their time in the pipe area and the other group had never worked in that area.

Table 4 lists some of the characteristics of these groups. The crocidolite group had exposure to considerably more crocidolite, slightly more silica, and somewhat less chrysotile. Mean age was slightly younger and there was an identical proportion of smokers.

Table 5 shows the average pulmonary function values, expressed as the proportion of the standardized values. The crocidolite group had smaller major lung volumes, lower FEV, and reduced diffusing capacity. On additional analysis, it was found that in this group of workers these differences in lung function were not

accounted for by the differing mean values for silica exposure, and, in fact, when the study population was divided into high and low silica exposure groups, average lung function values were higher in those with high silica exposure.

COMMENT

The role of pulmonary function in the detection and quantitation of adverse effects related to asbestos dust exposure has received considerable attention during the last 15 years. While initial reports were concerned primarily with the characterization of the physiologic pattern in well advanced asbestosis associated with radiographic abnormalities, more recent investigation has been directed toward the use of pulmonary function to detect the earliest adverse biologic response before the appearance of radiographic changes. Attempts have also been made to resolve the unsettled question of the relative sensitivity of differing measurements of pulmonary function in detecting this early dust effect. The task has been complicated by recent evidence indicating that the biologic effects associated with asbestos fiber inhalation probably depends, to considerable extent, on the type of occupational exposure, eg, mining and milling, manufacturing, and application, as well as fiber type. Nonfibrous dust exposures in asbestos-exposed workers, particularly dust of the fibrogenic variety, provide further complicating features that require analysis. While the ultimate objective to use lung function as an indicator of a departure from respiratory health is to develop dose-response relationships and threshold limits of exposure below which the production of disease is prevented, the difficult task of reconstructing past dust exposures has limited markedly the available information pertaining to this important objective.

Most studies of pulmonary function in asbestosis directed attention to the well-established disease, in which predictably the major abnormalities included reduced pulmonary volumes with "stiff" lungs and disturbance of alveolar gas transfer.[1-13] In general, it

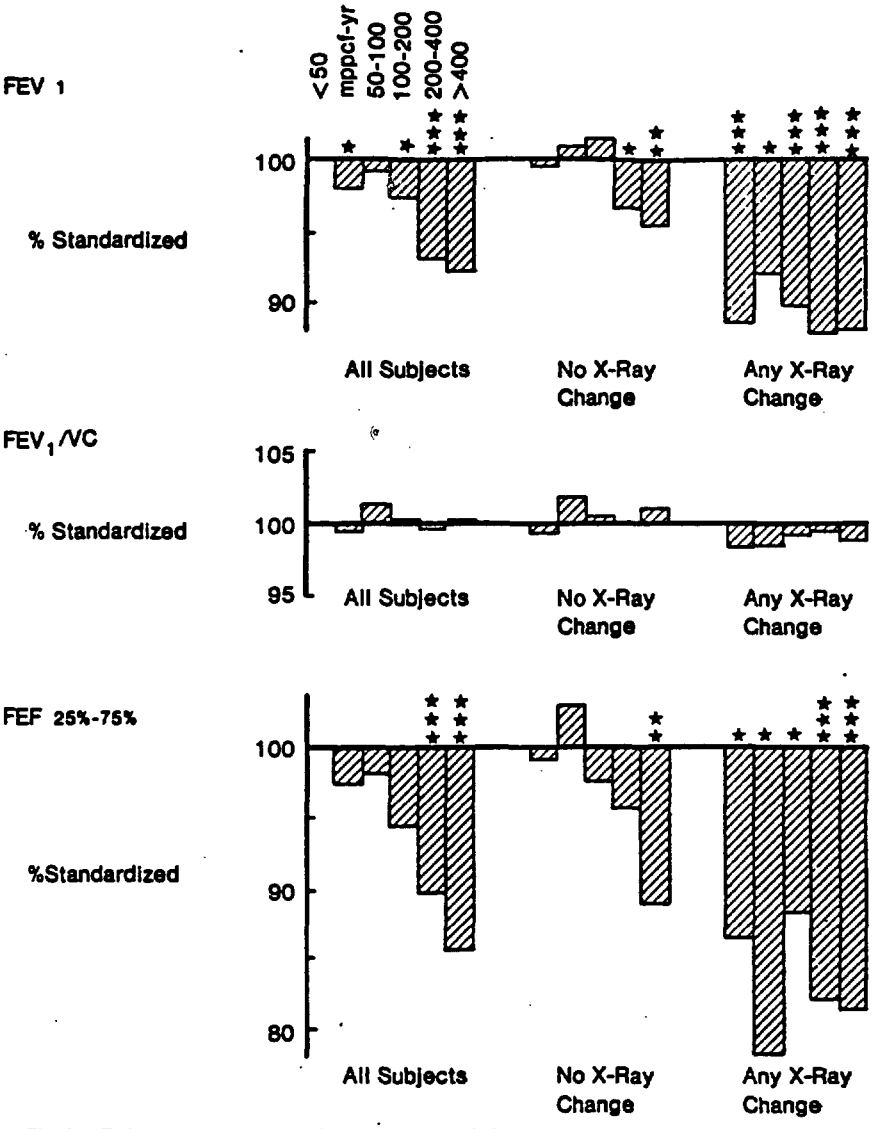

Fig 3.—Relation between expiratory flow and dust exposure.

Table 5.—Lung Function (Standardized Values)*

	75% or More in Pipe Area	Never Worked in Pipe Area	P
Vital capacity	92.7	97.9	<.01
Functional residual capacity	95.2	95.1	...
Residual volume	97.2	94.5	...
Total lung capacity	94.6	97.6	<.1
RV/TLC ratio	103.1	98.4	...
Forced vital capacity	92.1	98.5	<.01
FEV_1	91.2	98.2	<.01
$FEF_{25\%-75\%}$	84.5	88.0	...
FEV/VC ratio	98.4	100.2	...
Diffusing capacity	95.5	103.2	<.02
Diffusion constant	102.7	105.5	...
Alveolar volume (single breath)	91.1	98.4	<.01
Alveolar volume (multibreath)	93.7	97.8	<.1
Ventilation at oxygen uptake of 1.5 liters/min	105.2	106.0	...

* Values in workers who had spent more than 75% of their employment or had never been in the pipe area. Men, 20 to 30 years in the plant.

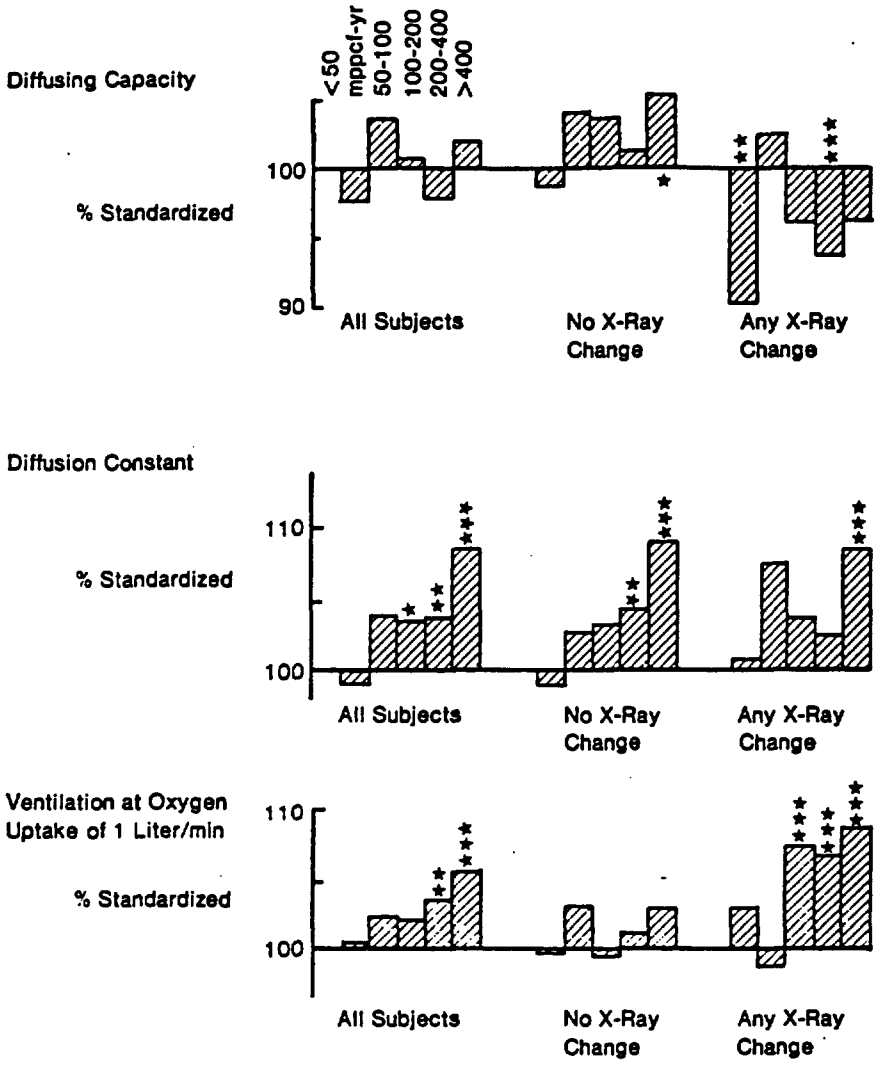

Fig 4.—Relation between indexes of gas exchange and dust exposure.

was thought that a significant effect on the airways does not result from asbestos dust exposure. In several recent studies, however, data have been presented that imply that the early adverse effect of asbestos dust exposure may indeed be on airways function with particular reference being made to the "small airways." This latter effect can be expected to precede radiographic evidence of parenchymal disease.[14-15]

All of the studies reviewed above are importantly limited by inadequate data in regard to individual asbestos exposure of the workers under investigation. In most cases, when the degree of exposure was estimated, it could be expressed only in terms of total years on the job. It has, therefore, not been possible to establish dose-response relationships in any meaningful way. Results from a study of over 1,000 Quebec chrysotile mining workers who had dust exposure estimated from their work history and periodic dust levels determined by sampling, indicated that simple spirometric measurements including inspiratory capacity, FEV, and FVC are most sensitive for the detection of early dust effects, while the diffusing capacity at rest is a poor indicator of level of exposure.[16] The dose-response relationship was better in nonsmokers than in smokers, and the effect of dust exposure and smoking on lung function did not appear to be additive.

We have reported previously the radiographic patterns associated with the mixed fibrogenic dust exposure in the same workers as in this investigation who have been exposed to both asbestos and silica.[1] The prevalence of both small rounded and small irregular lung opacities has been correlated with increasing levels of total dust exposure, findings similar to those reported by the Quebec group. These relationships have been established in spite of the inherent limitations and uncertainties of grading past dust exposures. Confidence in these dust assessments has been strengthened by the results of this investigation of the effect of exposure on pulmonary function. Progressive reduction in a number of lung function measurements is clearly associated with increasing level of total dust exposure in this population. Of particular interest is the demonstration of the dose-response relationship in those workers without radiographic evidence of a dust disease, an indication that individuals may have reduction in pulmonary function prior to the time when radiographic abnormalities appear. The relationship between dust exposure and pulmonary function is maintained after the effect of age, height, ethnic group, smoking history, and presence of radiographic changes have been considered. Previous investigators have not taken these important variables fully into account.

In this study, simple spirometric measurements of pulmonary volumes and maximum expiratory flow rates have provided the benefit of full biologic monitoring in assessment of an adverse functional effect on respiratory health. Vital capacity, FEV_1, and $FEF_{25-75\%}$, are indicators of an early detrimental effect as sensitive as or more sensitive than measurements such as total lung capacity, pulmonary diffusing capacity, and exercise tests. They suggest that an early effect on the airways may, indeed, develop as a consequence of asbestos exposure. These conclusions are based on cross-sectional and prevalence data that have been analyzed up to this point and future examination of longitudinal data now being generated could result in modifications of the conclusions concerning the relative usefulness of the various lung function tests.

Biologic monitoring of workers exposed to a hazardous dust must be directed to the detection of early unfavorable changes in the hope that removal from exposure will prevent the progression of disease. Since chest radiography and pulmonary function are most widely used to monitor the respiratory health of asbestos-exposed workers, it is appropriate to review the relative sensitivity of these two methods in detecting an adverse biologic response to dust exposure in this industry. At the top of Fig 6, selected simple spirometric measurements in average percent of the standardized value are plotted by exposure group. It can be seen that after a cumulative exposure of 100 mppcf-yr there is a gradual reduction in the mean values as dust exposure increases. At the lower half of the figure, the proportion of workers with irregular or rounded small opacities at the one or two category levels, is plotted for each exposure group. It is apparent that the major increase in workers at each level of radiographic change also begins to appear after a cumulative exposure of 100 mppcf-yr, which again reveals a dose-response relationship. One must conclude from these data that in considering groups of workers with varying levels of dust exposure, radiographic evidence of small opacities within the lung fields and pulmonary functional change are equally sensitive in detecting diffuse parenchymal abnormalities associated with exposure to these fibrogenic dusts. However, it must be remembered that even in the absence of x-ray film changes, individuals may show decline in pulmonary function unexplained by other factors and presumably related to dust exposure. The reverse is also true, ie, radiographic abnormalities may appear before changes in pulmonary function. It is suggested that both methods of biologic monitoring be used in order to detect the earliest abnormalities in the largest number of exposed workers.

In contrast to studies of mortality from malignant diseases in asbestos-exposed workers, there seems to be little interaction between cigarette smoking and the diffuse fibrogenic effect of dust exposure in this industry. As indicated previously, this is demonstrated by the equally good exposure-pulmonary function relationship in nonsmokers after allowance for personal smoking habits. This is not to say that cigarette smoking has not reduced pulmonary function in workers who smoke; that it has is shown by a lower position of pulmonary function measurements, while the additional rate of decline resulting from dust exposure is similar for the smoking groups.

The diffuse parenchymal and possible airways damage associated with asbestos dust exposure seem to be relatively unaffected by host factors, as evidenced by the distribution of pulmonary function in the lowest and highest exposure groups. In the FEV_1, for example, we demonstrated primarily a shift in the group mean observed values (downward in the high-exposure group), rather than a significant "skewing" or "tailing" effect.

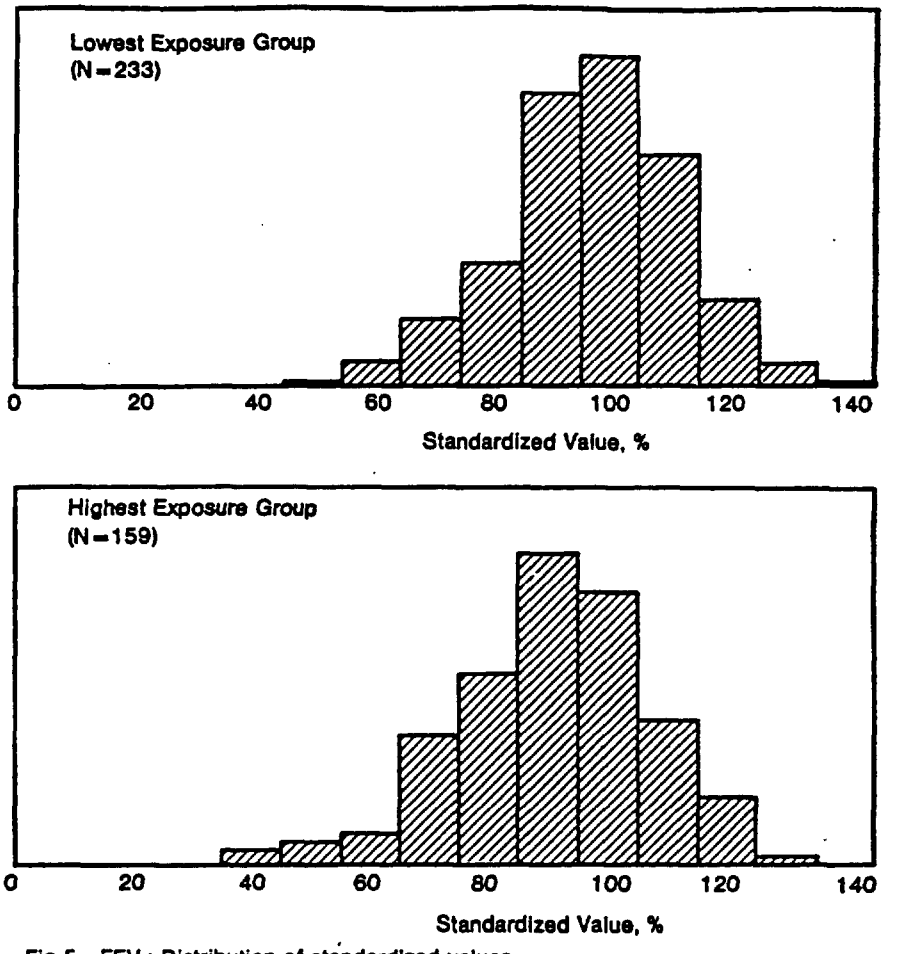

Fig 5.—FEV_1: Distribution of standardized values.

Available evidence suggests that crocidolite asbestos has a greater carcinogenic effect than chrysotile.[3] This suspicion has led previously to a different standard for these two fiber types in the United Kingdom. It has not been demonstrated previously that crocidolite has a more marked effect on the diffuse pulmonary parenchymal process. Although crocidolite exposures in the pipe-making area of one of the two plants studied were considered reasonably low, there appears to have been a significantly greater adverse effect on pulmonary function in workers exposed to crocidolite than on a matched group in

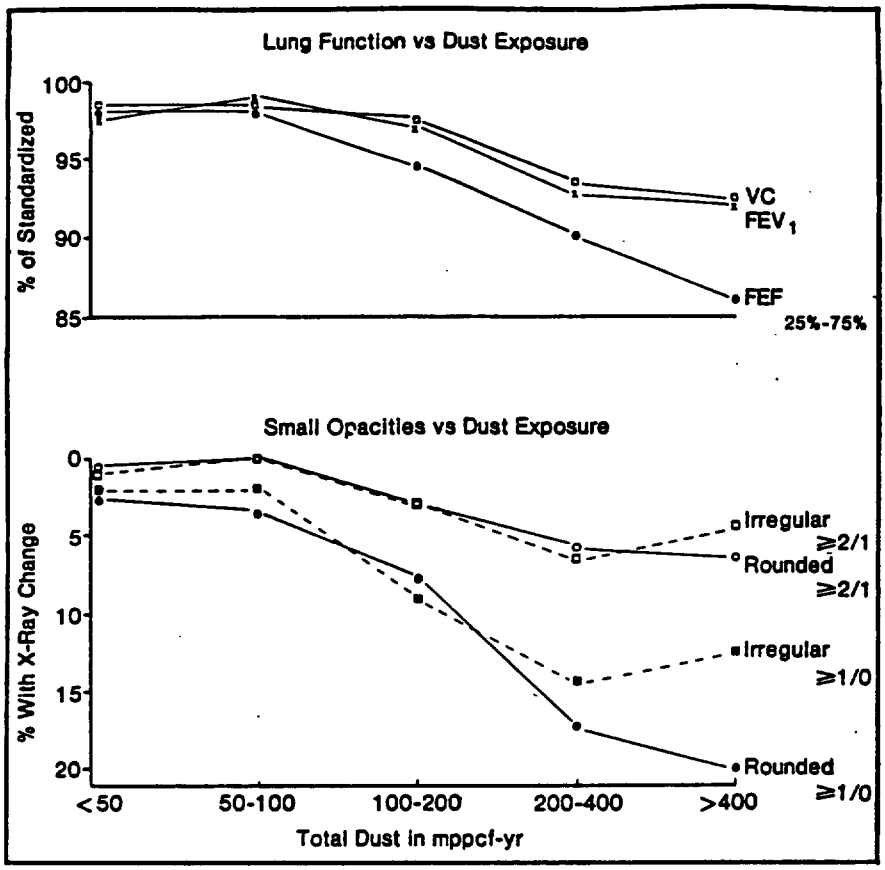

Fig 6.—Selected spirometric indexes of lung function and prevalence of small opacities on the chest x-ray films in relation to dust exposure.

the same plant for whom no crocidolite exposure was documented. The crocidolite group has smaller lung volumes, lower FEV_1, and reduced D_L. This subject will be separately considered in the future report.

Finally, threshold limit values must obviously take into consideration all demonstrated adverse health effects. This report considers only the diffuse fibrogenic effect of asbestos exposure in the asbestos cement products manufacturing industry. However, the data from this study demonstrate not only a dose-response relationship but suggest that a threshold dust level exists in this industry below which diffuse pulmonary fibrosis does not occur. While past dust levels were expressed in total particulate units, conversion to fiber levels is desirable for evaluation of asbestos exposure. A conservative calculation using data obtained previously from simultaneous sampling with the impinger and fiber counting method, leads to a conversion ratio of 2 fibers/ml for 1 mppcf.[17] The cumulative total dust exposure level of 100 mppcf-yr would therefore be equivalent to 200 fiber/yr or an exposure to 5 fibers/ml for a working lifetime of 40 years. While it is hoped that this level of exposure is "safe" in regard to the development of diffuse lung changes, any such analysis must be cautiously interpreted, since follow-up of exposed workers continuing well beyond the time of their active employment may increase the incidence of radiographic and functional abnormalities. These important additional data should result from the longitudinal investigation that involves a cohort of this population. A mortality study of all workers who have ever been employed in these two plants will determine if there is an excess risk of the development of neoplasms in workers employed in this industry.

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