Radiographic Abnormalities in Vermont Granite Workers Exposed to Low Levels of Granite Dust*

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The issue of whether low levels of granite dust exposure lead to radiographic abnormalities after a lifetime of exposure has not been settled. In 1983, we carried out a radiographic survey of the Vermont granite industry, consisting of quarry and stone shed workers who had been exposed to the low dust levels prevailing in the industry since 1938 to 1940. Films were read by three "B" readers, using the ILO classification system, which requires the identification of both rounded and irregular opacities, as well as combinations of both. X-ray films were taken of 972 workers, out of a total work force of approximately 1,400. Of these films, 28 (3 percent) were interpreted by either two or three of the three readers as showing abnormalities consistent with pneumoconiosis. Only seven films (or 0.7 percent of the entire cohort) showed nodular or rounded opacities of the type typically seen in uncomplicated silicosis. The remainder of the abnormal x-ray films showed irregular opacities, largely in the lower lung zones, which are of uncertain significance, but may be related to heavy cigarette smoking and aging, and possibly dust inhalation. In addition, total gravimetric dust concentrations in the workplace were measured; 417 respirable-size mass samples showed concentrations of 601 μg/cu m ± 368 μg/cu m. Using previously published estimates of 10 percent quartz in granite dust, the average quartz concentration was 60 μg/cu m. Twelve percent of the samples exceeded 100 μg/cu m, the current OSHA standard for quartz. We conclude that control of quartz exposure in the Vermont granite industry to levels which are on average less than the current OSHA standard has essentially eliminated definite radiographic changes of silicosis. The significance of the irregular opacities in the lower lung zones seen on a majority of the 28 x-ray films judged to be abnormal is not clear. *(Chest 1991; 100:1507-14)*

DIH = Division of Industrial Hygiene; ILO = International Labour Office; mppcf = million parts per cubic foot; OSHA = Occupational Safety and Health Administration; pqr = rounded abnormality; stu = irregular or reticular abnormality

Studies of the health of workers in the Vermont granite industry have provided a great deal of information on the health effects of quartz dust inhalation since 1929, when the first comprehensive study of the industry was published.[1] This study detailed an excessive morbidity and mortality from silicotuberculosis and led to regulations which reduced granite dust levels below 10 million parts per cubic foot (mppcf), which was accomplished in 1938 to 1940.

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At the same time the Division of Industrial Hygiene (DIH) of the Vermont State Health Department began annual radiographic surveys to assess the effect of dust regulation on the prevalence of silicosis. These studies[2-4] showed that as workers with silicosis retired or left the industry because of illness and as new workers were hired, the percentage of those with radiographic abnormalities declined. In 1964, it was stated that no new cases of silicosis had been detected in workers exposed only to the dust levels prevailing since 1938 to 1940.[4]

Nevertheless, in 1974, a study analyzing the results of the radiographic survey of 1970 to 1971 suggested that abnormalities were present in approximately 30 percent of the work force.[5] Although most of these were of low grades of profusion (*ie*, severity) and comprised both irregular (stu) and rounded (pqr) shadows, 67 x-ray films (or 8.5 percent of the total) were assigned profusion scores of 2 or 3, which was believed to be consistent with definite pneumoconiosis; however, the x-ray films in this survey were interpreted by only a single noncertified reader, and workers who were exposed only to the low dust levels after 1938 were not analyzed as a separate group. The important question of whether quartz levels below 10 mppcf, which is the basis for the current OSHA standard of 100 μg/cu m, were adequate to prevent radiographic silicosis was not answered.

The present study details the results of an industry-wide radiographic survey done in 1983, which includes, with few exceptions, only those workers ex-

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Table 1—*Characteristics of Workers Interpreted as Showing Parenchymal Opacities Consistent with Pneumoconiosis*

Patient	Age, yr	Years Worked	Occupation	Smoking Status/yr*	Profusion† A	Profusion† B	Profusion† C	Type of Opacity, Primary/Secondary‡
1	59	37	Draftsman	CS/39	2/3	2/3	1/1	s/p
2	53	13	Sandblaster	CS/40	2/2	2/2	0/0	s/s
3	52	34	Cutter	CS/35	2/3	3/2	1/1	s/s
4	59	22	Lumper	CS/43	0/1	2/1	2/2	s/s
5	58	43	Foreman	CS/8	1/2	2/2	1/1	p/p
6	52	30	Lumper	ES/37	2/1	1/2	1/1	p/s
7	58	36	Draftsman	NS	1/1	2/1	1/1	p/p
8	42	9	Maintenance	ES/20	1/2	1/0	1/0	s/s
9	58	37	Cutter	ES/10	1/1	1/1	1/0	p/p
10	57	33	Sawyer	ES/24	1/1	1/0	1/0	s/s
11	64	38	Boxer	CS/40	0/0	1/0	1/0	s/s
12	59	38	Cutter	ES/20	1/1	1/1	0/0	s/s
13	76	60	Manager	NS	1/0	1/0	0/0	s/s
14	51	23	Polisher	ES/28	1/0	1/0	0/0	s/s
15	63	35	Cutter	ES/30	1/0	1/1	0/0	s/s
16	40	15	Lumper	ES/28	1/0	0/1	1/0	s/s
17	48	30	Washstand	CS/34	1/0	0/0	1/0	s/s
18	62	43	Maintenance	ES/35	1/0	0/0	1/0	s/s
19	60	37	Polisher	CS/47	1/1	0/1	1/0	s/s
20	48	32	Cutter	ES/15	1/1	1/1	0/1	p/p
21	57	34	Diamond saw	CS/39	1/0	0/0	1/0	s/s
22	43	27	Polisher	CS/30	1/1	1/1	0/1	s/s
23	58	27	Sandblast	ES/30	1/1	1/0	0/0	s/s
24	59	36	Polisher	CS/32	1/1	0/0	1/0	s/s
25	42	18	Maintenance	CS/15	1/0	0/0	1/0	s/s
26	43	16	Derrickman	CS/28	1/1	U§	1/1	p/p
27	55	33	Polisher	CS/41	1/0	0/1	1/1	s/s
28	67	43	Quarry	ES/30	1/1	2/1	0/1	p/p

*CS, current smoker; ES, ex-smoker; and NS, nonsmoker.
†A, B, and C represent readers of roentgenograms.
‡s, Irregular; and p, rounded.
§Unreadable.

posed to granite dust after the reduction of dust exposure levels in 1938. The duration of observation encompasses up to 60 years of exposure (see Table 1; case 13), or an average working lifetime, to dust levels which on average have been in compliance with the current OSHA standard for quartz exposure. Results of concurrent dust sampling for total respirable dust and estimations of quartz exposures will also be presented.

Materials and Methods

All workers employed in 1983, including quarry, stone shed, and office workers, were offered 14 × 17-in chest roentgenograms, which were taken in a mobile van provided by the Appalachian Laboratory of Occupational Safety and Health. Work histories which had been recorded in previous surveys were updated. Workers not previously logged into the files had complete occupational histories taken, including the type of job (such as cutter, polisher, sawyer, etc), the name of the shed where employed, and the duration of employment. Histories of work in jobs other than the granite industry were included. Smoking history, using NHLBI/ATS procedures, was also recorded, including years smoked, how much, when quit, and type of smoking (cigarettes, pipe, etc).

Three certified "B" readers independently interpreted the x-ray films, without knowledge of the work history, according to the UICC/ILO format (1980). Our definition of an abnormal x-ray film was that either two or three of the three readers assigned a profusion score of 1/0 or greater to the film, identifying abnormalities consistent with pneumoconiosis, either of the rounded (pqr) or irregular (stu) type. The final reading of a film was the average of the abnormal profusion scores. One worker with definite silicosis was excluded because his major work experience (15 years) occurred in Canada.

To assess the reliability of the readers, a stratified random sample of 98 x-ray films was reread using the following strata definitions and sampling fractions: (1) all 28 films which had been classified as abnormal (*ie*, two or three readers assigning scores of 1/0 or greater); (2) a random sample of 20 of the 62 films which were assigned a score of 1/0 or greater by a single reader; and (3) a random sample of 50 of the 882 films considered normal (profusion less than 1/0 by all readers).

Dust measurement used a stratified statistical sampling plan which provided a representative distribution of samples from small, medium, and large sheds and in different occupational groups over a full calendar year. Personal breathing-zone samplers, which deposited on polyvinyl chloride filters only respirable-size particles, were used. Samples were collected during an entire shift, with the pumps shut down during lunch break. Pumps were run at 2 L/min, and flow rates were calibrated before and after sampling. Filters were weighed before and after the collection period for total gravimetric dust. Our effort to analyze quartz using x-ray diffraction techniques was unsuccessful. The major problem was the use of different-sized filter holders, which led, we believe, to divergent results. Previous workers had used infrared spectroscopic analytic techniques.[6]

Data analysis and processing used the SPSS, SAS, and BMDP statistical software packages as implemented on a computer (VAX 8600). Comparison between subgroups of subjects were made using analysis of variance, two-sample t-test statistics, χ^2 statistics, and logistic regression methods. Quantification of reader repeatability used McNemar and kappa statistics.[7]

RESULTS

Out of a total of approximately 1,400 granite workers in the work force, 972 had x-ray films taken; 31 of those were women, all but one of whom was an office worker. Of the workers who did not have x-ray films taken, 102 were absent on the day of the survey, and the remainder refused.

Of the x-ray films, 28 (3 percent) were interpreted by either two or three of the three readers as showing abnormalities (either rounded or irregular) consistent with pneumoconiosis, in a profusion score of 1/0 or greater. Table 1 lists these 28 workers, with relevant work and smoking histories, the type of abnormality (stu being irregular or reticular, and pqr being rounded) assigned by each reader, and the profusion score. In only seven x-ray films did all three readers agree that an abnormality was present. Of the 28 films, 21 showed as the primary abnormality an stu type of opacity, a definition decided by averaging the readers' designation; this was generally true of the secondary readings as well. Seven of the 28 abnormal x-ray films (or 0.7 percent of total cohort) showed rounded opacities (pqr) of the type typically seen in early silicosis.

The grades of profusion were extremely low. Only four x-ray films were judged by two or more readers to have profusion scores of 2/1 or higher; all of these films showed irregular shadows of the stu type. The location of the stu changes, even at low grades of profusion, tended to be in the lower lung zones. One of the abnormal films was that of a worker employed prior to 1938; he had had proven pulmonary tuberculosis and had been exposed to high dust levels before 1938. No case showed suspected active tuberculosis, but several showed calcifications consistent with healed granulomatous disease. No large opacities were observed nor were eggshell calcifications.

Several men with the stu type of abnormality had notably low exposures to granite dust. One had worked as a lumper (a worker who moves the stone around the sheds to different processes, and who is exposed to general shed air) for six years and for the remainder of his 37 years had been a draftsman, with no exposure to dust. One worker has been employed as a maintenance man for only nine years, and another worked exclusively in an office as a draftsman. The occupations of men showing radiographic abnormalities included the spectrum of job categories, although six of the abnormal roentgenograms occurred in polishers.

The characteristics of the workers with radiographic abnormalities in comparison with the other workers having chest roentgenograms is shown in Table 2. Compared with the remainder of the work force, those with abnormalities were older and had worked longer and smoked longer and more heavily. All of these differences were significant, except for smoking status, which approached significance ($p=0.063$).

A comparison of those workers who did and did not participate in roentgenographic screening was made based on available work histories and smoking questionnaire data. Of the approximately 400 workers who did not participate, 239 had participated at other times in either the DIH surveys or in our research project in some aspect, such as having pulmonary function tests or routine x-ray films at the Barre Chest Clinic.

Table 2—*Comparison between Workers with and without Abnormal Chest Roentgenograms**

Data	Abnormal (n=28)	Normal (n=922)	Comparison; p Value
Age, yr	54±9	42±13 (missing=1)	t (df=947)=5.07; p<0.001
Years in granite industry	31±11	18±12 (missing=4)	t (df=944)=5.78; p<0.001
Smoking history†			
Current smokers	12 (43)	422 (46)	
Ex-smokers	14 (50)	295 (32)	χ^2 (df=2)=5.53;
Nonsmokers	2 (7)	203 (22) (missing=2)	p=0.063
Years smoked	25±13	14±13 (missing=3)	t (df=945)=4.28; p<0.001
No. of cigarettes per day	28±18	20±17 (missing=5)	t (df=943)=2.44; p=0.015
Pack-years	39±28	20±22 (missing=6)	t (df=942)=4.65; p<0.001

*Table data are means ± SD (unless otherwise noted).
†Data are number of subjects; numbers within parentheses are percents of abnormal or normal group.

Table 3—*Comparison of Participants with Nonparticipants*

Data	X-ray Film	No X-ray Film	Comparison; p Value
Job			
Shed	706 (86)	117 (14)	
Quarry	121 (63)	70 (37)	χ^2 (2)=61.9;
Office	112 (69)	50 (31)	p<0.001
Age, yr	42±13	46±13	t (1,185)=−4.09; p<0.001
Years in granite	18±12	20±13	t (1,180)=−2.44; p=0.015
Smoking status*			
Current smokers	434 (80)	108 (20)	
Nonsmokers	205 (79)	56 (21)	χ^2 (2)=0.75;
Ex-smokers	309 (81)	71 (19)	p=0.688
Years smoked	15±13	17±15	t (1,177)=−2.19; p=0.029
No. of cigarettes per day	20±17	19±15	t (1,172)=0.87; p=0.385
Pack-years	20±22	23±25	t (1,171)=−1.48; p=0.139

*Data are numbers of subjects; numbers within parentheses are percents.

Table 3 compares workers who participated in the 1983 chest roentgenographic survey with workers who did not but who had, on other occasions, participated in some fashion in health evaluation and had adequate work histories and smoking histories. The data indicate that a proportionately higher number of shed workers (86 percent) participated, compared to quarry (63 percent) and office (69 percent) workers. In addition, those who participated appear to be younger and to have worked for fewer years in the granite industry. They also appear to have smoked for fewer years compared to nonparticipants, although their overall pack-year burden appears similar, and their smoking status does not appear to differ. Among shed workers, participants were younger and did not differ in other respects. Similarly, participants among quarry workers tended to be younger, to have worked in the industry for a shorter period of time, and to have smoked for fewer years. Participants who were office workers had smoked fewer years and also had lower pack-year burdens compared to nonparticipants.

Regarding the reliability of the readers in classifying the 98 x-ray films which were read a second time, 23 films were judged abnormal (as opposed to 28 on the first reading), and 75 were normal. Twenty of the films were read as abnormal in both readings. Three films were judged abnormal on the second reading which had been normal on the first reading. Eighty-seven x-ray films were assigned the same classification on both readings; 11 were classified differently. Therefore, 87 (or about 89 percent) of the 98 x-ray films were reread with the same result. The McNemar test was performed to see if successive readings tended to lead to more instances of an "abnormal" first reading and "normal" second reading (eight cases) compared to the reverse situation; however, no such asymmetry was detected ($p=0.132$). To quantify reliability, a kappa statistic, which is a measurement of the percentage of agreement in the first and second readings over and above chance agreement, was computed. An acceptable kappa value of 0.71 ($p<0.05$) was obtained.

Because the workers' characteristics in Table 2 are related to each other, their association with radiographic abnormality may overlap. To examine the effects of these different variables, we used logistic regression modeling techniques which incorporated smoking status (S), age (A), years in granite (G), and pack-years smoked (P). For this analysis, 941 workers on whom complete historic data were available were used.

The relationships among these four variables are summarized in Table 4, which shows correlation coefficients for relationships among age, years in granite, and pack-years smoked, and comparisons of the mean values of these variables among smoking categories. As might be expected, age, years in granite, and pack-years are all positively correlated. Ex-smokers are the oldest and have worked longest in granite; nonsmokers are the youngest and have worked the shortest time; current smokers are in the middle.

Table 4—*Means and Standard Errors by Smoking Status**

Data	Smokers (n=433)	Ex-smokers (n=306)	Nonsmokers (n=202)	Total (n=941)
Age, yr	41±1	45±1	38±1	42±0.4
Years in granite industry	18±1	21±1	15±1	18±0.4
Pack-years	26±1	25±1	0	20±1

*Relationships among predictor variables were as follows: for age vs years in granite, $r=0.846$ ($p<0.001$); for age vs pack-years, $r=0.381$ ($p<0.001$); and for years in granite vs pack-years, $r=0.333$ ($p<0.001$).

Logistic regression modeling allowed us to examine the effects of various combinations of variables. The six possible models containing two variables and their interactions were obtained, and the statistical significance of each variable in all models is indicated in the following tabulation, where asterisks indicate that coefficient is significant at $p<0.05$:

Model 1: A*	S	A×S
Model 2: A*	P*	A×P
Model 3: G*	P*	G×P*
Model 4: G*	S	G×S
Model 5: P*	S	P×S
Model 6: A	G	A×G

All models fit the data reasonably well using the Hosmer-Lemeshow goodness-of-fit criteria. In addition, plots of the empirical logits vs each of the explanatory variables appeared linear.

A review of these six models revealed that the number of pack-years (P) was always significantly associated with radiographic abnormality, while smoking status (S) never achieved significance. Years in granite (G) and age (A) were individually of significance, except when included together, as in model 6; however, if the nonsignificant age-by-granite-years interaction term (A × G) was removed from this model, years in granite (G) became significant ($p=0.022$), while age did not ($p=0.191$). This suggested that the observed statistical significance of age (A) in models 1 and 2 was primarily due to its high correlation with years in granite.

Model 3 therefore appeared to be the most promising, since all model variables achieved significance. In order to verify this choice, age was used in conjunction with the other model 3 variables to determine if knowledge of age would improve the model; however, age did not achieve significance ($p=0.477$) in this context. We therefore concluded that the prediction of abnormal radiographic results was most effectively accomplished by model 3, which

Table 5—*Coefficients of Logistic Regression Model 3*

Predictor	Parameter Estimate	SE	p Value	Odds Ratio
Pack-years (P)	0.0686	0.0222	0.001	1.071
Years in granite (G)	0.1384	0.0311	<0.001	1.148
Interaction (G × P)	−0.0016	0.0007	0.013	0.998
Constant	−7.7542	1.0310	<0.001	. . .

used years in granite, pack-years, and their interaction. Formal stepwise logistic regression procedures also yielded the same results for the best model.

Parameter estimates for the final model are presented in Table 5. They indicate the following: (1) the more years worked in granite, the higher the odds of an abnormal x-ray film; (2) similarly, the more pack-years smoked, the higher the odds of an abnormal x-ray film; and (3) the negative interaction suggests that the effect of the two variables on the log odds is not simply additive; for example, the effect of years in granite is stronger for a light smoker than for a heavy smoker. Conversely, the effect of smoking is stronger for an individual who has not worked long in granite than for one who has.

In order to summarize the relationship of abnormalities, pack-years, and years in granite, Table 6 shows predicted percentages of radiographic abnormality levels for selected values of years in granite and pack-years. For comparison, Table 7 contains actual observed percentages for ranges of pack-years and years in granite. The selected values were chosen to correspond approximately with the values for pack-years and years in granite in Table 7. Predicted percentages should be similar to observed percentages but do not match identically for several reasons: (1) the "observed" table (Table 7) groups data into ranges of pack-years and years in granite, while the "predicted" table (Table 6) involves specific values of pack-years and years in granite for a hypothetic individual and their predicted probability of having an abnormal x-ray film; (2) some cells of the "observed" table (Table 7) include a small number of individuals, making these percentages less precise; and (3) the logistic regression model presents a "smoothed" interpretation of trends

Table 6—*Predicted Percentages of Abnormal Radiographic Findings*

Years in Granite Industry	Pack-years				
	0	5	20	40	60
7.5	0.1	0.2	0.4	1.1	3.4
10	0.2	0.2	0.5	1.4	3.8
20	0.7	0.8	1.4	2.8	5.5
30	2.7	2.9	3.9	5.6	8.1
40	9.8	10.0	10.4	11.0	11.6

Table 7—*Observed Percentages of Abnormal Radiographic Findings with Sample Sizes**
(number abnormal in parentheses)

Years in Granite Industry	Pack-years				
	0-9	10-29	30-49	50+	Total
0-15	0.0	0.8 (1)	0.0	15.4 (2)	0.7 (3)
n	237	129	58	13	437
16-25	0.0	4.3 (3)	2.0 (1)	2.6 (1)	2.3 (5)
n	58	70	49	38	215
26-35	1.5 (1)	0	8.0 (4)	12.1 (4)	4.7 (9)
n	67	43	50	33	193
36-45	8.7 (2)	10.5 (2)	14.3 (4)	10.0 (2)	11.5 (10)
n	23	19	28	20	90
45-60	25.0 (1)	. . .	0.0	. . .	16.7 (1)
n	4		2		6
Total	1.0 (4)	2.3 (6)	4.8 (9)	8.7 (9)	3.0 (28)
n	389	261	187	104	941

*Numbers within parentheses are actual numbers abnormal.

in the data, developed using all of the data, rather than simply summarizing a few subsets of workers.

In summary, workers who have spent more years in the granite industry have a greater chance of radiographic abnormality; workers who smoke more also have a greater chance; however, the effect of smoking and years in granite is not simply additive. In addition, the influence of the number of years worked in granite and pack-years tended to minimize the association of age and smoking status with radiographic abnormalities.

Nevertheless, a few important caveats should be noted. Among these are that the analysis is based on a low prevalence of abnormal roentgenograms, with low degrees of profusion. This is illustrated by the fact that in only seven x-ray films did all three readers agree that an abnormality was present. In Table 7, the number of abnormal films is indicated in parentheses, illustrating the small numbers in each cell. Slight variations in radiographic interpretations, as may happen when profusion scores are low, could change both the observed and predicted percentages dramatically. Secondly, using years in granite as an index of exposure may not be an accurate measure of the burden of granite dust in individual cases. This is particularly true, since our estimates of dust exposure suggest that a portion of the work force has been exposed to excessive dust levels. Finally, and perhaps most important, we have included both pqr and stu types of abnormalities as being consistent with pneumoconiosis, as required by the ILO format, without proof that reticular shadows in fact represent early silicosis. Had we used only the x-ray films showing nodular densities, the observed and predicted percentages would be far lower.

The average total dust concentration of 417 samples was 601 μg/cu m ± 368 μg/cu m, with a range of 153 μg/cu m to 2,320 μg/cu m. Using the quartz estimates of 10 percent in granite shed dust published by previous workers,[6,8] the average quartz exposure was 60 μg/cu m. Of the total respirable dust samples, 11.5 percent (48 samples) exceeded 1,000 μg/cu m, the median value of which was 1,209 μg/cu m. This same percentage therefore exceeded the current OSHA standard of 100 μg/cu m for crystalline silica. The values for total dust concentration are similar to the values reported by previous workers.[6,8]

Discussion

These results indicate that radiographic abnormalities in the Vermont granite work force are occurring at a low level, that the changes observed are of low grades of profusion, and that the predominant change is of the irregular or reticular type (stu), which is not thought to be typical of early silicosis. This occupational disease is generally manifested by small nodulations or rounded densities which tend to be located in the upper lobes.[9] Standard texts on occupational lung disease and on chest diseases[10-13] almost uniformly describe typical silicosis as showing upper lobe nodulations or mottling (*eg*, rounded densities), conforming to the pathologic appearance of whorled collections of avascular collagen.[14] Irregular shadows may be seen in mixed dust exposures in acute silicosis,[9,11] in which nodularities are poorly defined. Irregular shadows have also been described as an early manifestation of simple silicosis, usually associated with hilar enlargement.[13]

The significance of the stu changes seen in 21 of the 28 workers is uncertain. In comparison with the entire work force, the 28 men were older, had smoked more, and had longer occupational exposure to granite dust. It has been stated that older, heavily smoking men may develop an increase in irregular shadows as an indication of peribronchial fibrosis associated with pathologic changes of chronic bronchitis.[15] In addition, the study published in 1974[5] of this same population suggested that a relationship existed between irregular shadows and smoking, rather than with granite dust exposure. When workers with predominant stu changes are looked at individually, specific workers would seem not to have had sufficient exposure to result in silicosis. Thus, one of those with profusion of 2/2 irregular densities had worked for only six years as a lumper (a man who is exposed to general shed air) and for the remainder of his 37 years in the industry had been a draftsman with insignificant exposure to the shed's general air. He smoked three packs of cigarettes per day and within a year of his x-ray film developed inoperable bronchogenic carcinoma. Another worker had only nine years of employment in a job category which involved low levels of granite dust, an exposure which appears to be too short to lead to silicosis. A third with stu densities had worked only as a draftsman, work which is not done where the granite is processed. These examples serve to show that irregular shadows consistent with pneumoconiosis may occur in workers with low or negligible exposures to granite dust.

Although the accepted radiographic appearance of silicosis is nodulations or rounded opacities, some early studies suggest that linear shadows may be the first indication of silicosis. Pancoast and Pendergrass[16] suggested that an invasion of perivascular-peribronchial-lymphatic structures and the hilus by dust-laden phagocytes could lead to accentuated hilar and linear markings. This theory apparently lost favor but was revived by Cole and Cole.[17] Of considerable interest is the description of radiographic changes by Russell et al,[1] in their classic study of Vermont granite workers. These investigators[1] state that the earliest radiographic change is fullness of the hilar shadows incident to lymphatic blockage and deposition of dust in the glands. The second change is development of linear markings, or "trunk shadows," which become diffused throughout the lung as silicosis advances. Russell et al[1] specifically state that "definite mottling and nodular formations at the junction of linear shadows were not in evidence."

Nevertheless, to state that the irregular shadows seen in the present studies are similar to those described by Russell et al[1] is probably not justified, particularly because the dust exposures at that time were far greater than the exposures occurring in the Vermont granite workers since 1938. The most important objection is that no radiographic-pathologic correlation exists of contemporary workers exposed both to dust at low levels and to cigarettes. Craighead and Vallyathan[18] demonstrated fibrosis in the lungs of Vermont granite workers with normal x-ray films; quartz was not evident by ordinary light microscopy but only with scanning electron microscopy in conjunction with backscatter imaging and x-ray spectrometry. Only 1 of the 15 workers showed a silicotic nodule, and no smoking histories were available. Quartz is certainly present in the lungs of current granite workers.[11] Whether the fibrosis seen in these cases is related to quartz or to other factors such as smoking is uncertain.

Radiographic evidence of silicosis in a cohort of workers cannot be meaningfully discussed without a consideration of dust exposure. When dust controls were introduced into the industry in 1938 (especially the stone sheds—the quarries did not have strict dust control until 1950, when all drilling became wet), average dust counts, estimated from samples collected in impingers, were on average less than 10 mppcf. In 1957, Hosey et al[3] suggested that dust levels had decreased in the period after 1940, averaging 5 mppcf, although they stated that approximately 10 percent of the samples were over that limit. In a further follow-up in 1964, dust levels were all less than 10 mppcf.[4] Subsequent studies measured mass respirable samples using personal breathing-zone samplers; in 1970 to 1971, an average daily dust exposure was stated to be 529 μg/cu m, with an average quartz concentration of 9 percent as measured by infrared spectroscopy.[6] It was not stated what percentage of samples exceeded the threshold limit value of 100 μg/cu m. In that publication, it was stated that 10 mppcf was equivalent to 1,000 μg/cu m of respirable dust; at 10 percent quartz, this would be equal to 100 μg/cu m, the current OSHA standard. A subsequent article regarding total dust and percentage of quartz in the Vermont industry, which included new data collected in 1976 to 1977, concluded that quartz percentages varied between 9 and 11 percent.[8] The arithmetic mean values for total respirable dust in 1970 to 1971 were 560 μg/cu m ± 490 μg/cu m and in 1977 were 563 μg/cu m ± 380 μg/cu m. These large standard deviations suggest that a certain percentage of workers were exposed to excessive quartz levels at the time when these measurements were made. In the absence of current quartz determinations, we have assumed that previous estimates of 10 percent quartz obtain. The ratio of locally quarried granite vs imported granite is 60/40, whereas in the 1970s, it was estimated to be 70/30 (Norman James, Barre Granite Association, personal communication, March, 1991).

We should comment on the relatively low turnout of the current workers for the radiographic survey; 23 percent of those working declined to participate. During the period when the DIH was conducting annual radiographic surveys, the participation rate was tending to go down: in the late 1960s and early 1970s, the percentage of workers having x-ray films taken was over 90 percent; however, on the last survey (which was carried out in 1975), 18 percent of the workers declined to participate.

The important question is whether those participating in the survey were in some way different from those who did, specifically, that they might have a higher prevalence of radiographic abnormality, and because of fear of having disease discovered decided not to participate. We attempted to compare those who did and did not have roentgenograms in 1983 (on whom we had adequate historic information) and did find certain differences, as outlined in Table 3. We found that stone shed workers participated to a greater extent than the quarry or office workers. The latter group could reasonably suspect they had no occupational disease. Quarry workers, who have traditionally had low participation rates, once down in the "hole," do not like the inconvenience of having to make a trip to the surface and then descend. We also speculate that public media statements that routine x-ray films should be avoided may have played some part in the decisions not to participate.

We have, of course, used the prevalence of radiographic abnormalities as the end point for a discernible effect of harmful levels of dust and smoking. Other health-related aspects of granite dust exposure are the relationship between low levels of dust and the decrement of pulmonary function change. Several previous publications have addressed this issue,[19-22] which is still under debate and investigation. Another issue is whether low levels of granite dust, which do not produce radiologic evidence of silicosis, lead to symptoms of bronchitis independent of smoking habits.

We conclude that maintaining average crystalline silica exposures below the current OSHA standard of 100 μg/cu m has been effective in reducing radiographic evidence of silicosis to a very low prevalence. The radiographic abnormalities which were present were of mild degrees of profusion and were in some complex way probably related to smoking as well as dust exposure. The predominant radiographic abnormality was of the irregular or reticular type, rather than the upper lobe nodulations classically described in silicosis, but it is not possible to say what these changes represent.

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