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Respiratory health of brickworkers in Cape Town, South Africa

Background, aims and dust exposure determinations

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MYERS JE, LEWIS P, HOFMEYR W. Respiratory health of brickworkers in Cape Town, South Africa: background, aims and dust exposure determinations. *Scand J Work Environ Health* 1989;15:180-187. The respiratory health and work environment of 575 brickworkers in five brickworks in Cape Town, South Africa, were investigated by means of a questionnaire, a physical examination, pulmonary function testing, chest radiography, and dust measurements. This study presents the background, aims, and methods of the determining dust exposure assignments. The mean concentrations of respirable dust and total dust were 2.22 and 15.16 mg/m³, respectively, with a mean free-silica percentage of 2.1 %. Subjective and objective, as well as categorical and continuous, dust indicators were constructed for subsequent analyses, together with findings from the health survey, which are reported elsewhere.

Key terms: brickmaking, exposure index, respirable dust, respirable free silica, total dust.

There are few published studies on the dust exposure of brickworkers and even fewer on the respiratory health of these workers (1, 2). The available results have generally not been published in the scientific literature (3-5). The studies span the period from 1936 to 1975 and have generated disparate data of different degrees of precision, derived from different definitions of outcome and methods of measurement, which frustrate attempts at comparison.

Documented dust levels (1-11) have frequently exceeded legally enforceable or recommended levels for total dust (4-250 mg/m³), respirable dust (0.3-23 mg/m³), and respirable free silica (usually less than 10 %). Most studies show respirable free silica percentages to be lower in brickworks dust than in other siliceous dusts (up to 40 %).

There is pathological evidence for mild fibrogenicity of brick and clay dust under experimental laboratory conditions (12-14). Clinical information and data from compensation authorities in several countries (15, 16) show the undoubted existence of silicosis cases among workers with many years of service in brickworks and no other history of dust exposure. Epidemiologic findings are contradictory, some studies reporting pneumoconiosis associated with exposure to brick dust (5, 9, 17) and others either reporting no radiographic changes (3, 4, 18) or poorly defined radiographic changes (1, 2).

There is a noticeable absence in the literature of investigations into the prevalence of respiratory abnormalities other than pneumoconiosis among brickworkers; this lack is surprising given the high levels of dust exposure recorded. Two studies have attempted to investigate symptoms (3, 9), while four have included lung function parameters (3, 17, 19) for brickworkers. None have investigated the interrelationships between radiographic abnormality, lung functions, symptoms, and dust exposure. The purpose of this study was to apply standardized techniques for determining dust levels and respiratory abnormality prevalences.

This study of five brickworks in the Cape Province of South Africa was accordingly designed to (i) ascertain the levels and types of dust exposures in different workplaces, (ii) determine the prevalence of respiratory abnormalities among brickworkers (abnormalities of interest comprised symptoms, signs, reductions in lung function values, pneumoconiosis, and other radiographic changes), (iii) ascertain the interrelationships between the various respiratory abnormalities detected in the survey, (iv) investigate the relationships between respiratory abnormalities, dust exposure, smoking history, occupational history, and past medical history with a view to establishing their relative contributions to the prevalence of respiratory abnormalities, and (v) investigate the adequacy of the American Conference of Governmental Industrial Hygienists' threshold limit values (20) for different components of brickworks dust for the prevention of respiratory ill effects. Workers and trade union and management personnel participated in the study.

This paper presents results from an industrial hygiene survey in which the dust levels to which workers were exposed in different parts of the brickworks were measured, including total dust (all airborne particles

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irrespective of size), respirable dust (particle diameter less than 5 to 7 μm), and the free-silica percentage composition of the respirable fraction. The measurements were then used to construct objective dust indicators which could be used to divide the study population into different exposure groups and assign exposures to individuals within the groups. The relationships between the subjective and objective indicators of dustiness, and the interrelationships between the different objective measures of dustiness, were examined with a view to assessing the validity of possible screening measures for detecting a silica exposure hazard in this industry.

Subjects and methods

Production process

General production characteristics for bricks and tiles are provided in the encyclopedia of the International Labour Office (9). Briefly described, the raw materials comprise different sorts of clay, shale, fly ash, and ground coal, and they are transported by a loader from the quarry or raw materials storage to the preparation department. They travel by conveyer belt via a box feeder, where checks are conducted for large metallic or other foreign bodies that might damage machinery in the preparation plant. Several rolling and grinding machines reduce the size of the material, and some water is added to dampen the mix, which passes in plastic form to extruding machines from which it emerges as a continuous brick shape and is cut by wire into individual bricks. Offsetters then sort the "green" bricks and place them onto trolleys, which are wheeled into drying tunnels and exposed to air heated by coal fires. Dryer operators load the wet bricks into the dryers, remove them when dry, and are responsible for cleaning the tunnels of dust and soot. In summer, bricks may be stacked outside by packers, where they are dried by wind and sun. Trammers transport the bricks in trolleys or barrows from the making section to the dryers and from the dryers to one of three types of kilns for firing. The old-fashioned Hoffmann kilns and the Downdraught kilns use finely ground coal for fuel. Bricks may be loaded either manually or by a hystel into these kilns. Setters stack the kilns manually with "green" bricks, while drawers manually unpack the baked bricks. The automatic oil-fired kiln constitutes a continuous process system with all the bricks packed on moving trolleys which proceed at a predetermined rate through a kiln tunnel in which they are first dried and then baked. No workers are involved in this process. Bricks are also layered with sand and coal into pyramids called clamps by clamp packers in the yards, where they burn for several weeks. Some baked and "green" bricks travel by conveyer to the rockface department, where machines render their surfaces uneven or remove their corners. Finished bricks are sorted and packed in the yard. There are various types of cleaning work done around the factory. The work process is mainly labor-intensive and has not changed

over the years in the various plants. Even the most modern plant with the automatic kiln has been in operation for 35 years.

Job ranking for dustiness

The survey team performed detailed inspections of all the workplaces in the five factories. Before the industrial hygiene survey, questionnaires had been administered to the workers to obtain their subjective estimates of dustiness for different workstations and information relating to their current and previous employment histories. On the basis of this information jobs were ranked by dustiness into three groups. As the factories differed slightly in the combination of tasks undertaken to produce bricks, but the jobs themselves were generally similar, it was decided to adopt a job-based approach in characterizing dust exposure rather than a factory-based approach. For instance, a worker in a preparation plant in one factory works under conditions similar to those of someone in a similar department in another factory. The same applies to most jobs except those for which the production technology is unique, as with the automatic kiln in one of the factories.

Sampling

The team planned the sampling strategy, and the job categories that were by consensus subjectively characterized as involving high, medium, and low dust exposure were selected for monitoring. The numbers of people in these job categories in each factory were supplied by the management. The selection of the sample subjects was made according to procedures described by the National Institute for Occupational Safety and Health (NIOSH) (21) and resulted in a sample size large enough to be able to detect with a confidence level of 95 % at least one worker from the highest exposure subgroup (the top 20 % of the range) for the job category concerned. The numbers of measurements are presented in table 1.

For all the factories the numbers of workers to be monitored were chosen to cover all workers in a typical day shift. The differences in the sample proportions across factories relate to differing shift-work schedules. The resulting total for the respirable dust samples was 135. In addition, it was decided to determine simultaneously the free-silica content of at least two of the aforementioned samples from each worker category in table 1, a total of 35 samples being obtained for free-silica content.

Measurements

The measurement procedures were based on methods published by NIOSH (21). The monitoring was jointly supervised by the team throughout the survey. Worker participation in the team meant that the likelihood was reduced that the conditions monitored would deviate too greatly from usual standards of dustiness,

Table 1. Workers selected for monitoring by job category.^a

Job category	Factory 1		Factory 3		Factory 4	
	Selected	Total	Selected	Total	Selected	Total
Preparation operator	7	11	7	11	7	11
Offsetter	11	43	8	14	8	14
Clamp packer	9	18	—	—	—	—
Cleaner	4	4	1	1	4	4
Drier	7	11	8	14	—	—
Drawer	9	18	6	14	—	—
Fireman	9	18	8	14	—	—
Downdraught kiln worker	8	14	—	—	—	—
Green rockface operator	7	11	—	—	—	—
Burnt rockface operator	7	11	—	—	—	—
Total	78	242	38	68	19	29

^a Factories 2 and 5 had closed down by the time of the dust survey, but were similar enough in all respects to the other plants to have workers included in the health survey.

housekeeping, shift lengths, and job content. Measurements were felt to be maximally representative of the average work conditions. At each factory preliminary meetings of the survey team were held to select randomly the requisite number of workers for personal monitoring, to determine how long each measurement should take (up to 8 h), and whether repeat samples were required in the case of noncontinuous, irregular, batch, or task work in order to obtain average exposures for discontinuous work. Every effort was made to obtain full-shift samples for as close to 8-h periods as possible. The overwhelming majority of the measurements are representative of an 8-h workshift. In some cases work stopped early for the day, and the sampling time was less. In cases in which, after consultation with the worker monitored, we were unsatisfied that the period of measurement was in every way typical and representative of the work, the sample was discarded. As such, these shorter measurements were felt to be reasonably accurate time-weighted averages.

Twenty-three constant flow Casella and du Pont (P 2000 and P 4000) pumps were used for the measurements, all of which were personal samples. The pumps were calibrated before and after the measurements, and periodic checks were made to see that they were working efficiently. Where technical difficulties (eg, substantially decreased flow rate) were encountered, measurements were discontinued. Abnormal work routines by workers or absences from production were also noted, and all these readings were discarded. Pumps were connected to SKC dust cyclones which deliver dust particles in the respirable range (less than 5 to 7 μm in diameter) to the filter. Glass fiber filters were used for gravimetric measurements unless free-silica determinations were also made, in which case cellulose nitrate filters were used. The latter were desiccated under standard conditions before and after the dust measurement. Filter weights were in milligrams and accurate to four decimal places. The scale was calibrated before each daily weighing session and then zeroed after every three readings. A mean value of five determinations was recorded as the weight of respirable dust.

Nonrespirable dust in the collecting chamber of the cyclone holders was removed and weighed. This weight was added to the weight of respirable dust trapped on the filter, and the sum was recorded as the value for total dust in milligrams. Free silica was determined as alpha-quartz by means of X-ray diffraction (8). Five replicate counts were done on each of the 35 samples, and the mean value was taken as the weight of free silica. Two samples were excluded from the analysis because of indeterminate job category, and four for unavailability of a respirable dust measurement for that sample.

Derivation of the exposure indicators

On the basis of the percentage concentration of free silica in the different workstations, the respirable dust threshold limit value-time-weighted average (TLV-TWA) (20) was calculated. The means and standard deviations for the total and respirable dust measurements in different job categories were then calculated, and the overall weighted means for the three levels of dustiness obtained. Jobs that were not measured were allocated on the basis of work process observations to one of the three dustiness groups. Job categories inserted in this way into the low-exposure group would be expected to be exposed to even lower levels of dust than those monitored. As far as the high-exposure group is concerned, maintenance workers are exposed to high levels of dust as they frequently but intermittently spend time mending machinery in the dusty sections, while cleaners are generally exposed to high dust levels partly generated by themselves when sweeping. The categories inserted into the medium-exposure group would be typically exposed at this level.

Where the average group means of the respirable dust levels exceeded the free-silica TLV, a silica hazard was presumed to exist, while dust levels of 5 mg/m^3 for respirable (22) and 10 mg/m^3 for total (23) dust were taken to constitute general dust hazards. The whole number nearest the weighted group mean was used as the dust score for the subjects in this group.

These scores were then used to generate objective measures of individual dust exposure.

Results

Prior dustiness assessment

Generally speaking, the conditions were rather dusty with much pollution from coal fires in the kilns and from burning clamps. Housekeeping was poor with dust accumulations on most surfaces. There was no evidence of any dust extraction mechanism or exhaust ventilation of either a local or general nature in any of the factories, and the use of personal protective equipment was not evident. There appear to be seasonal fluctuations in general dustiness. In the dry season the workers were generally exposed to a continuous cloud of dust generated by continuous truck and trolley movement along roadways that are poorly maintained and not kept damp. Such exposure particularly affects outside workers at the clamps and workers in the preparation department, where front-end loaders generate much dust by their movements. Inside the factory poor housekeeping led to the generation of dust even in the cleaner departments when settled dust was disturbed or swept. During the survey, which took place in the dry season, housekeeping, especially in the making section, was reportedly better than average, while outside roadways were kept damper than usual.

Table 2 shows the grouping system derived by the team for job categories in the low, medium, and high dust exposure groups.

Raw materials

The raw material consisted of 59 to 79 % free or bound silica and of 12 to 25 % aluminum trioxide. Talc was only present in trace quantities.

Mean values and threshold limit values by job category

The results of the free-silica determinations and respirable dust levels for 29 samples are presented in table 3. The TLV-TWA values for respirable dust containing free silica are shown. Table 4 shows the mean dust values and the presence or absence of dust and silica hazards for different factories and workstations. Where the mean respirable dust level exceeded the TLV-TWA in table 3, a silica hazard (20) was deemed to exist. A general dust hazard was considered to exist in areas where the total dust concentration exceeded 10 mg/m³ (23).

Mean dust exposure and hazard type by dustiness group

Table 2 shows the mean dust values for the job categories ranked by levels of dust exposure. Table 5 shows the results of rounding off the three group

Table 2. Mean dust values by dustiness group.

Job category	Respirable dust			Total dust			Silica	
	Number of samples	Mean (mg/m ³)	SD (mg/m ³)	Number of samples	Mean (mg/m ³)	SD (mg/m ³)	Number of samples	%
<i>Group 1: low dust exposure</i>								
Offsetter	16	0.96	0.41	6	4.69	2.90	2	0
Fireman	8	1.10	0.50	8	4.63	2.20	1	0
Drier operator	11	1.04	0.67	11	6.86	4.60	4	1.3
Trammer	—	.	.	—	.	.	—	.
Quality controller	—	.	.	—	.	.	—	.
Charge hand	—	.	.	—	.	.	—	.
Security guard	—	.	.	—	.	.	—	.
Clerk	—	.	.	—	.	.	—	.
Group mean	35	1.02	0.51	25	5.63	3.42	7	0.7
<i>Group 2: medium dust exposure</i>								
Setter	—	.	.	—	.	.	—	.
Clamp packer	2	0.40	0.01	2	15.20	17.04	—	.
Packer	—	.	.	—	.	.	—	.
Preparation plant	16	2.44	1.40	12	16.89	13.17	4	2.8
Hyster operator	—	.	.	—	.	.	—	.
Rockface machine	11	2.13	1.44	11	15.18	10.70	6	4.6
Group mean	29	2.18	1.42	25	16.04	12.39	10	3.9
<i>Group 3: high dust exposure</i>								
Drawer	19	8.33	6.23	16	51.01	27.30	7	2.5
Kiln cleaner	4	9.09	2.52	4	40.27	36.07	2	1.9
Cleaner	—	.	.	—	.	.	—	.
Maintenance worker	—	.	.	—	.	.	—	.
Downdraught kilns	9	2.67	3.00	8	24.43	15.87	3	5.7
Group mean	33	6.71	4.80	28	41.88	25.29	12	3.2
Total	97			78			29	

Table 3. Free-silica determinations: dust levels and threshold limit status by job and factory. (ACGIH = American Conference of Governmental Industrial Hygienists, TLV = threshold limit value)

Workplace	Respirable dust (mg/m ³)	Silica (mg/m ³)	Silica (%)	ACGIH TLV respirable dust (mg/m ³)	Respirable dust/TLV
<i>Factory 1</i>					
Drawer downdraught	0.300	0.028	9.3	0.882	0.340
Drawer downdraught	3.222	0.132	4.1	1.640	1.964
Drawer downdraught	3.941	0.146	3.7	1.753	2.248
Drawer hoffmann	14.306	0.099	0.7	3.715	3.851
Drawer hoffmann	10.640	0.116	1.1	3.236	3.288
Drawer hoffmann	11.363	0.128	1.1	3.199	3.553
Drawer hoffmann	3.546	0.016	0.5	4.080	0.869
Drawer hoffmann	15.056	0.188	1.3	3.078	4.891
Drier operator	0.929	0.000	0.0	5.000	0.186
Drier operator	2.452	0.011	0.5	4.084	0.600
Fireman	0.320	0.000	0.0	5.000	0.064
Flu cleaner	6.256	0.075	1.2	3.126	2.001
Flu cleaner	8.770	0.230	2.6	2.163	4.054
Rockface burnt	1.006	0.000	0.0	5.000	0.201
Rockface burnt	2.945	0.070	2.4	2.285	1.289
Rockface burnt	3.204	0.062	1.9	2.541	1.261
Rockface burnt	1.824	0.046	2.5	2.211	0.825
Rockface green	2.299	0.208	9.0	0.905	2.540
Rockface green	0.510	0.059	11.6	0.737	0.692
<i>Factory 3</i>					
Drawer	0.189	0.016	8.5	0.956	0.198
Drawer	1.123	0.049	4.4	1.572	0.715
Drier operator	0.835	0.000	0.0	5.000	0.167
Drier operator	0.350	0.016	4.5	1.522	0.230
Offsetter	2.078	0.000	0.0	5.000	0.416
Offsetter	0.823	0.000	0.0	5.000	0.165
Prep box feeder	3.886	0.119	3.1	1.975	1.967
Prep wet pan	1.368	0.048	3.5	1.815	0.754
<i>Factory 4</i>					
Prep cleaner	2.167	0.100	4.6	1.512	1.433
Prep driver	1.508	0.000	0.0	5.000	0.302

means to the nearest whole number. The weighted mean percentage of free silica for the medium (3.9 %) and high (3.2 %) exposure groups together (where a silica hazard existed) was 3.6 %. In these two categories the average brickworker was exposed to a weighted mean respirable dust level of 3.82 mg/m³, which is well above the TLV of 1.79 mg/m³. The weighted mean total dust for these workers was 25.5 mg/m³. The weighted means for the study group as a whole were 2.22 and 15.16 mg/m³ for the respirable and total dust, respectively, with a 2.1 % free-silica content for the respirable fraction. The average brickworker was thus exposed to respirable dust at a level just less than the TLV of 2.44 mg/m³, while the total dust exposure exceeded the "nuisance" value of 10 mg/m³.

Dust exposure indicators

The values in table 5 were used to construct objective dust indicators for investigating the dose-response relationships with biological variables reported elsewhere (24–26).

Continuous variables. The group mean values for the respirable and total dust concentrations in milligrams per cubic meter derived in table 5 for each job category constitute the values of the variables respirable dust, respirable dust 1, respirable dust 2, and total dust, total

dust 1, total dust 2, respectively, and represent typical dust levels (both respirable dust and total dust) in the current job and in the two previous jobs, respectively, in brickworks. The product of the variables respirable dust or total dust and length of service (in years) in the current job and in the two previous jobs yield the variables respirable dust-years or total dust-years, respirable dust 1-years or total dust 1-years, and respirable dust 2-years or total dust 2-years, and these variables represent respirable and total dust concentration-years in milligram-years per cubic meter for the three job levels. If these exposure times are summed over all the jobs in brickworks for respirable and total dust, two cumulative indicators of dust exposure time are obtained, ie, cumulative respirable dust exposure and cumulative total dust exposure.

Categorical variables. Respirable dust exposure was also used as a categorical variable. The total population was divided into tertiles on the basis of its cumulative frequency distribution. Objective dustiness, objective dustiness 1, and objective dustiness 2 correspond to the objective dustiness in the current and previous two jobs in brickworks, respectively, and have three levels corresponding to low, medium, and high exposure. They represent qualitative objective esti-

mates of current and past job dustiness. The questionnaire responses yielded three subjective indicators of dust exposure, ie, subjective dustiness, subjective dustiness 1, and subjective dustiness 2, representing current subjective dust exposure, and subjective dust exposure in the previous two jobs in brickworks, respectively. These subjective dustiness indicators have three levels corresponding to low, high, and medium dustiness in the current and past two jobs held in brickworks.

Discussion

Problems with reliable workplace information due to misinformation, sudden changes in production tempo, breakdown of technical equipment, constraints on access to workers, and other problems that were difficult to anticipate and rule out in advance gave rise

to some discrepancies in the number of samples for different dust types.

Misclassification from the assigning of job categories to wrong dustiness groupings may have resulted in an underestimation of the mean differences between the groups, and therefore in an underestimation of the dose-response relationships for respiratory health outcomes.

The shortage and high cost of monitoring equipment and laboratory services in South Africa limited the number and type of samples taken. It was not possible to perform triplicate measurements for respirable dust, total dust, and free silica for each subject. The free-silica and respirable-dust measurements were combined only at the cost of making determinations more laborious by introducing the need for elaborate filter preparation. A compromise was made when the total

Table 4. Mean dust values and hazard status by job and factory.

Workplace	Number of workplaces	Mean respirable dust (mg/m ³)	Silica hazard	Mean total dust (mg/m ³)	Dust hazard
<i>Factory 3</i>					
Drawers	6	2.332	Yes	26.018	Yes
Driers	5	0.865	No	7.365	No
Firemen	3	0.972	No	4.059	No
Offsetters	4	1.079	No	6.562	No
Preparation average	5	1.958	Yes	14.969	Yes
Box feeder	1	3.886	Yes	25.445	Yes
Forklift driver	1	2.259	Yes	10.414	Yes
Mixer operator	1	0.868	No	1.963	No
Pan operator	1	1.388	No	22.081	Yes
Panel operator	1	1.408	No	—	—
<i>Factory 4</i>					
Offsetters	4	0.673	No	3.748	No
Preparation average	7	2.458	Yes	16.675	Yes
Box feeder	1	6.089	Yes	45.490	Yes
Cleaner	4	1.917	Yes	13.916	Yes
Driver	1	1.508	No	8.066	No
Panel operator	1	1.941	Yes	10.264	Yes
<i>Factory 1</i>					
Clamp setter	2	0.399	No	15.196	Yes
Downdraughts	9	2.266	Yes	24.431	Yes
Hoffmanns	13	11.108	Yes	66.163	Yes
Driers	6	1.184	No	6.401	No
Firemen	5	1.180	No	4.965	No
Flu cleaners	4	9.099	Yes	40.267	Yes
Preparation	5	3.011	Yes	21.495	Yes
Box feeder	1	3.251	Yes	—	—
Cleaner	1	—	—	21.495	Yes
Operators	3	3.011	Yes	—	—
Offsetter	8	1.044	No	—	—
Burnt rockface conveyor	3	0.678	No	3.315	No
Burnt rockface operator	6	3.109	Yes	22.372	Yes
Green rockface	2	1.405	Yes	16.487	Yes

Table 5. Average dust exposure levels and free-silica content by dust exposure group. (TLV = threshold limit value)

Exposure group	Number of samples	Respirable dust (mg/m ³)	Free silica (%)	Silica TLV (mg/m ³)	Silica hazard	Total dust (mg/m ³)	Dust hazard
High	46	7	3.2	1.9	Yes	42	Yes
Medium	80	2	3.9	1.7	Yes	16	Yes
Low	142	1	0.7	3.7	No	6	No

dust concentration was determined in that the non-respirable fraction was collected from the cyclone holder. Although some dust may have adhered to the walls of the container after being emptied, there is no reason why this procedure should significantly underestimate the weight of dust any more than dust adhering to the inner walls of the filter holder underestimates the respirable dust concentration. Given the fact that a standard procedure was followed throughout, these determinations could, at worst, be slight systematic underestimates. The inability to test for tridymite and cristobalite may have resulted in an underestimation of the silica hazard.

In cases in which the total dust level exceeded 10 mg/m³, there was almost always a silica hazard as well (table 4). With regard to this particular industry, therefore, a strong case could be made for using total dust estimations as a screening procedure in future monitoring programs. These tests would be the cheapest option, as the use of cyclones would not be necessary and more time-consuming and multiple gravimetric measurements would be circumvented. The ability to dispense with X-ray diffraction analysis would result in substantial savings in time and cost. This and other simple screening devices for free silica based on the respirable dust level (27) may have particular preventive application in countries with less-developed resources, if an initial validation of the test has been performed for the situation to be screened on a routine basis.

The overall levels of dustiness measured in this study were not exceptional. They were lower than previous levels recorded in similar brickworks in South Africa.³ What is interesting however is that the ratios (1:2:7) between the levels for the different dustiness groups in the factories were all similar. The mean respirable dust levels in brickworks in Great Britain (1) and Canada (2) were similar to those found in this study. The percentages of free silica were probably similar in Great Britain, but appeared to be higher in Canada and the United States (4, 7). They may however be similar in that problems with the analytical method resulted in an almost certain upward bias for both the Canadian and American results. They are very similar to percentages in a Polish red brick study (10). These results, taken together with the lack of preventive action at the workplace, indicate the existence of both general and silica dust hazards.

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