ORIGINAL ARTICLE

Mortality in the UK industrial silica sand industry: 1. Assessment of exposure to respirable crystalline silica

T P Brown, L Rushton

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See end of article for authors' affiliations

Correspondence to: Dr T P Brown, Medical Research Council Institute for Environment and Health, 94 Regent Road, Leicester LE1 7DD, UK; tpb3@le.ac.uk

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Aims: To develop a job-exposure matrix (JEM) from personal and static respirable crystalline silica (RCS) measurements in UK industrial silica sand workers.

Methods: A total of 2429 personal and 583 static RCS dust samples were collected using cyclone samplers at seven UK quarries between 1978 and 2000. These data were combined, and analysis of variance using general linear models was used to evaluate the effect of quarry, job, and year on RCS concentrations, and facilitate the creation of five quarry and three time categories with similar exposure levels by comparing the least-square GM RCS concentrations.

Results: The overall geometric mean (GM) RCS concentration was 0.09 mg/m^3 (geometric standard deviation 3.9). Silica flour and dry job categories tended to have the highest RCS exposure and 13.3% of all samples exceeded the UK maximum exposure level of 0.3 mg/m^3. RCS levels generally decreased over time.

Conclusions: Data have been collected and used to develop a JEM for UK industrial silica sand workers between 1978 and 2000. Although there were some limitations in the data and certain assumptions were made, the use of available data to estimate exposure quantitatively is an improvement over the use of qualitative and surrogate measures of exposure. The continual collection of dust measurements in the industry is essential to facilitate the exploration of exposure-response relations that may exist between silica and silicosis, lung cancer, and other diseases.

The health consequences of exposure to respirable crystalline silica (RCS) are well documented in many industries; in addition to silicosis, RCS has been associated with lung cancer,[1] non-malignant respiratory disease,[2] non-malignant renal disease,[3] and autoimmune disease.[4] However, there have been no studies published of silica sand workers in the UK. The silica sand industry is engaged in quarrying and refining a product of high silica content and at quarries where silica flour and cristobalite are produced. Thus the possible respiratory risk may be higher than in other quarrying industries. During 1986 the UK Health and Safety Executive (HSE) assembled a cohort of 4749 individuals who had ever been employed at seven quarries owned by a large UK industrial sand company, but did not collect any exposure data. An analysis of mortality was undertaken in 1991[5] but never published. Before a reanalysis of mortality was undertaken, the Institute for Environment and Health was asked to collect data on exposure measurements of silica dust. This paper describes the development of a job-exposure matrix from personal and static RCS dust samples collected between 1978 and 2000.

METHODS

Historical personal and static RCS measurements, between 1978 and 2000, were obtained from company records. Personal measurements were collected using a cyclone sampler that was attached to the subject's chest, while for static samples the sampler was placed in the vicinity of the subject's workplace. From the occupational hygiene records it was clear that not all the cohort members were involved when sampling took place. However, normally all operatives in a particular category on a single shift were fitted with personal samplers. Measurements were carried out as part of a routine sampling programme at various times of the year, and the number of samples taken varied from year to year. The timing and quantity of samples taken each year did not reflect any pattern. Filters from the cyclones were analysed gravimetrically. Silica content was measured by Fourier transform infrared spectrophotometer until 1996–97, and then by *x* ray diffractometry. All samples had been collected over time periods greater than four hours and RCS concentrations calculated as 8-hour time weighted averages. The only other change in the methodology of sample collection/analysis was in 1997 when the flow rate on the cyclone samplers was increased from 1.9 to 2.2 l/min, to take into account the implementation of the CEN 481 standard on size fraction definitions for measurement of airborne particles.[6] Seven samples were excluded from the dataset because they were documented as having been from surveys investigating unusual dust levels and not part of the routine monitoring programme. A total of 2429 personal and 583 static respirable crystalline silica (RCS) samples were obtained. The personal and static data were combined into a single dataset, since no significant differences were found ($p > 0.05$) between the two measurements across quarries, jobs, and years. For example (personal versus static): silica flour, 0.29 mg/m^3 *v* 0.27 mg/m^3; dry/other, 0.21 mg/m^3 *v* 0.26 mg/m^3.

The introduction of personal protective equipment by the company was not well documented. From the experience of employees, respiratory masks were not worn before 1973, except during exceptionally dusty tasks, and their use was not made compulsory until a few years later. However, their use was intermittent, and even current employees on occasions removed them when the working conditions got hot and uncomfortable. The respirable dust measurements did not take account of whether the individual was wearing a mask or not.

Abbreviations: GM, geometric mean; GSD, geometric standard deviation; JEM, job-exposure matrix; MEL, maximum exposure limit; RCS, respirable crystalline silica; RPE, respiratory protective equipment

Main messages

- A job-exposure matrix was developed for the study of mortality among UK industrial silica sand workers.
- There were some data limitations and assumptions had to be made about the exposures of some job categories. These assumptions and the developed matrix should be explored by sensitivity analysis of any dose-response relations.
- The continual collection of dust measurements is essential to facilitate the exploration of dose-response relations between silica exposure and the incidence/mortality of silicosis, lung cancer, and other diseases.

Policy implications

- A job-exposure matrix was developed to study the relation between crystalline silica exposure and mortality among UK industrial silica sand workers. The study will add to the literature on the relation between respirable crystalline silica exposure, silicosis, lung cancer, and other diseases.
- The uncertainties in the matrix exposure estimates will hinder the establishment of occupational exposure limits on the basis of exposure-response relations, if any, identified through use of this matrix.

Other sources of dust measurements were also sought. Data for the same period held by the Silica and Moulding Sands Association (SAMSA) and collected by the HSE's Inspectorate of Mines and Quarries at the time the original study was set up were also obtained. These data were crosschecked against data already held; most were found to be duplicates. However, an additional 24 measurements were found for quarry 6 from the HSE database. A further 67 measurements were also found, but could not be converted to RCS exposure concentrations, because data on the sample silica content were missing.

In the original cohort one of 16 job categories had been assigned to each individual. However, dust measurements were only available for 12 of these (table 1); none were found for brickworks/drivers, brickworks/wet and brickworks/dry workers, and office workers. These were assumed to have similar exposures to other drivers, other wet process workers, other dry/dryer workers, and site management, respectively, at the same quarry.

Too few samples were available to estimate RCS exposure for each job-quarry-year cell within the JEM ($n = 2576$). Existing data were therefore used to facilitate the grouping of similar categories of quarry and time periods. Analysis of variance using general linear models was used to evaluate the effect of quarry, job, and year on RCS concentrations. These models were used to estimate mean exposure levels for:

- Each quarry, taking account of variation in jobs and time period
- Each job, taking account of variation in quarries and time period
- Each year, taking account of variation in jobs and quarries.

These are referred to as adjusted means. The grouping of similar quarries was accomplished by comparing the least-square geometric mean RCS concentrations, adjusted by job and year (using t test) of the quarries and grouping those with similar means. The groupings attempted to maximise the similarity of the GM RCS concentrations of quarries within a group, while maximising the difference between groups. The GM RCS concentrations for quarries within a category were more closely related than quarry concentrations outside their category. A similar process was used to group years, but not job categories, as they already comprised specific job titles and were thought to be distinctive. The seven quarries were thus combined into five categories (A–E) and time into three categories (1978–85, 1986–94, and 1995–2000) (table 1) to give a total of 180 quarry-job-year categories.

Even though the groupings were collapsed from 2576 combinations to 180, there were still some combinations for which data were missing ($n = 52$), and these were job categories that experienced minimal exposure (HGV drivers, workshop, other drivers, site maintenance, and management). For these, the overall quarry mean was multiplied by the overall time period mean and the result divided by the overall mean for the job. Four of the job/quarry/time cells were created from static measurements only and 120 from personal measurements only. Static measurements were not carried out on HGV drivers and site maintenance workers.

RESULTS

Table 1 presents means and standard deviations of the log transformed RCS measurements for each quarry, job category, and year grouping. Those jobs with the highest exposure to RCS (dry areas and silica flour) were monitored more than the others (for example, wet process, sand winners, drivers, maintenance, management), and 15% of the samples from these job categories exceeded the UK maximum exposure level (MEL) of 0.3 mg/m^3; 88% of the samples that exceeded the MEL were from these job categories. A total of 1235 (41.0%) samples were less than 0.05 mg/m^3, with 483 (14.4%) 0.01 mg/m^3 or less. The overall geometric mean RCS concentration was 0.09 mg/m^3 (GSD 3.9), and the highest concentration was 13.97 mg/m^3.

The number of samples collected, GMs, and maximum RCS concentrations varied considerably across all quarries. A significant proportion of the samples from quarries 4, 6, and 7 exceeded the current maximum exposure limit (MEL) of 0.3 mg/m^3.

Figure 1 shows the change in GM RCS measurements and number of samples taken by year; there is a steady decline over the years. Between 1978 and 1985 just under 20% of samples were not in compliance with the current MEL standard. However, the proportion of samples exceeding the MEL has reduced to below 10%.

DISCUSSION

The historical RCS exposure in the UK industrial sand industry from 1978 to 2000 showed a large quarry effect. These differences, to some extent, reflect how the sand is deposited, extracted, and processed at each quarry. In other studies of industrial sand workers[7 8] similar variations between quarries and plants have been observed. Unadjusted geometric means in US sand workers were observed to be between 0.026 mg/m^3[7] and 0.042 mg/m^3,[8] of samples taken between 1974–96 and 1974–98, respectively. Although exposure levels in this study (0.09 mg/m^3) are higher than in other studies of sand workers over approximately the same time period, they are much lower than in other industries where workers are exposed to silica.[9 10]

Measurements also showed a clear job effect. The highest exposed jobs tended to be those that were in dustier environments—that is, those exposed to silica flour and the dry job categories (dry/dryer, dry/bagger, dry/other). Other

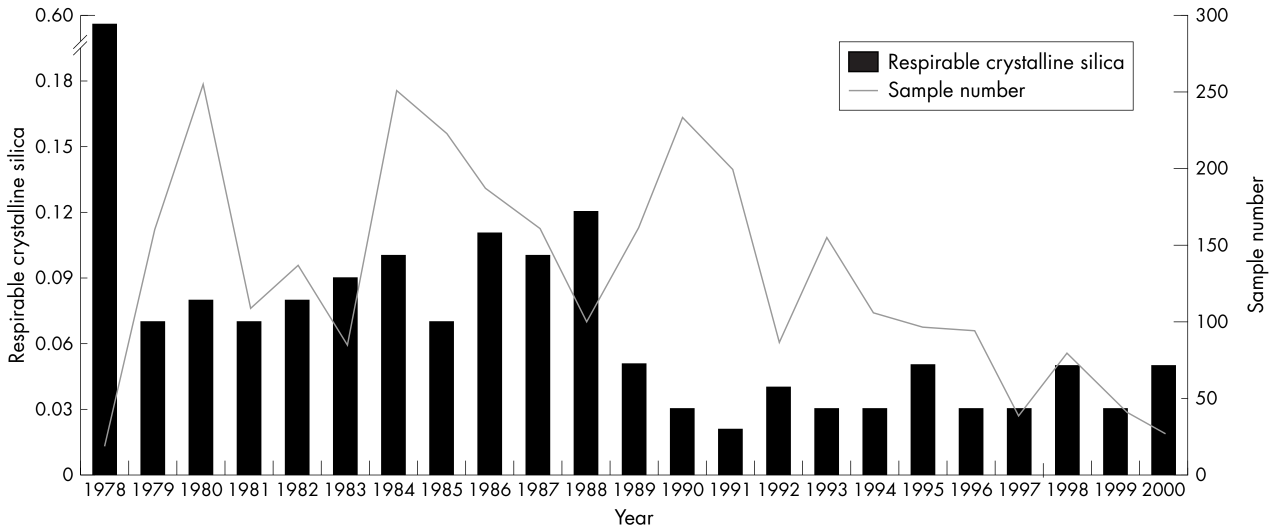

Figure 1 Geometric mean respirable crystalline silica measurements (mg/m^3) and number of sample measurements by year.

studies of sand workers have also shown a wide variation in exposures between different jobs,[7 8] similar jobs receiving similar levels of RCS exposure.

Levels generally decreased over time (fig 1), a pattern seen in the sand industry worldwide,[7 8 11] although the decrease was not linear and varied between quarry and job category, probably reflecting the introduction of dust control measures at each quarry. Current exposure levels are slightly higher although generally below the regulatory exposure limit.

Combining the static and personal measurements into a single dataset may have introduced bias to the estimates of exposure in the JEM. Personal samples have been found to be generally higher in concentration than static (area or stationary) samples because of people being closer to the source of exposure and spending more time within the source location, or in the emission pathway.[12 13] However, when static samples are taken at the source location or in the emission pathway they are similar to the values reported for personal samples,[14 15] and in some incidents may measure a higher concentration.[12 16] In the majority of other studies static measurements have usually been dust counts, which have then been converted to respirable mass concentrations, using a variety of conversion factors derived from parallel count/respirable mass measurements.[8] In this study the same sampling methodology was used for both static and personal samples—that is, using cyclone samplers, over long

Table 1 Number of respirable crystalline silica samples collected, adjusted and unadjusted geometric means (GM) and standard deviations (GSD), maximum level, and percentage exceeding the maximum exposure level by job, quarry, and year group

	Number of samples (%)	Adjusted GM (mg/m^3) (GSD)	Unadjusted GM (mg/m^3) (GSD)	Maximum (mg/m^3)	% >MEL
Job category					
Sand winner	207 (6.9)	0.09 (3.8)	0.06 (5.0)	1.17	10.6
Wet process	141 (4.7)	0.05 (3.6)	0.04 (4.2)	0.73	3.5
Dry, dryer	572 (19.0)	0.08 (4.0)	0.09 (3.6)	4.10	15.0
Dry, bagger	461 (15.3)	0.11 (4.0)	0.10 (3.4)	13.97	16.5
Dry, other	513 (17.0)	0.11 (4.4)	0.11 (4.0)	9.05	12.5
Laboratory technician	234 (7.8)	0.07 (3.6)	0.06 (3.6)	0.96	6.0
Driver, HGV	11 (0.4)	0.04 (3.4)	0.08 (2.4)	0.24	
Driver, other	19 (0.6)	0.04 (3.4)	0.04 (6.4)	1.68	5.3
Site maintenance	55 (1.8)	0.05 (3.5)	0.04 (4.3)	1.65	7.3
Workshop	4 (0.1)	0.03 (3.3)	0.02 (3.7)	0.16	
Site management	30 (1.0)	0.03 (3.4)	0.02 (3.2)	0.30	3.3
Silica flour	765 (25.4)	0.10 (5.9)	0.13 (3.1)	12.01	16.6
Quarry (group)					
1 (A)	159 (5.3)	0.05 (4.1)	0.05 (4.7)	1.87	3.1
2 (B)	70 (2.3)	0.05 (3.8)	0.03 (4.1)	1.17	5.7
3 (B)	347 (11.5)	0.05 (6.2)	0.06 (4.3)	13.97	8.1
4 (C)	415 (13.8)	0.06 (7.0)	0.08 (4.5)	9.05	11.1
5 (D)	308 (10.2)	0.07 (5.7)	0.07 (3.7)	2.98	9.1
6 (D)	1045 (34.7)	0.06 (14.4)	0.10 (3.2)	8.84	13.2
7 (E)	668 (22.2)	0.10 (9.0)	0.14 (3.7)	12.01	22.6
Year group					
1978–1985	1240 (41.2)	0.08 (17.9)	0.13 (3.2)	7.29	19.4
1986–1994	1388 (46.1)	0.05 (19.0)	0.08 (4.3)	12.01	8.8
1995–2000	384 (12.7)	0.04 (6.0)	0.06 (4.0)	13.97	9.9
Total	3012 (100.0)		0.09 (3.9)	13.97	13.3

GM, geometric mean; GSD, geometric standard deviation; MEL, maximum exposure limit 0.30 mg/m^3.
Brickworks/wet, brickworks/dry, brickworks/drivers, and office workers assumed to have similar exposures to wet process, dry/dryers, dry/others, and site management.

time periods during a normal working shift period. These practices and the fact that static dust levels were similar to levels obtained from personal measurements, led us to combine personal and static measurements into a single dataset.

Analyses of the samples were mainly undertaken by the company's own laboratories using FTIS until 1996 and XRD thereafter. This change could possibly have affected the detection of RCS in the samples, and partly explain why levels in the last time period (1995–2000) were greater than the previous period (1986–94). However, a recent study of the performance of laboratories by the UK Health and Safety Laboratory under the UK Workplace Analysis Scheme for Proficiency (WASP) showed a good correlation between the two methods.[17]

Various engineering control measures to reduce dust exposure have been introduced by the company over the years. However, it was not clear when these measures were introduced at each quarry, although their effect on dust levels would be reflected in the JEM. However, the exposure assessment does not take into account the use of respiratory protective equipment (RPE), for example, dust masks. Data are not available on the use of RPE, either the type or effectiveness, or working practices, especially historically and at all quarries. RPE do not provide 100% protection against exposure to dust, but depending on the protection factor can substantially reduce the amount of respirable dust reaching the lungs. Therefore, if used regularly RPE could have impacted on the exposure assessment and hence the values within the JEM, but only on those dustier jobs requiring its use for long periods, for example, baggers.

The JEM has been developed from measurements of total RCS. It does not take into account particle numbers and surface area per microgram of silica, surface chemistry, or presence of other minerals, factors that vary widely in dusts produced from different industrial processes using different source materials, and affect biological activity.[18–20]

Summary

In this study we obtained a large quantity of measurements of respirable crystalline silica from seven quarries in the UK industrial silica sand industry. These data have been used to develop a job-exposure matrix for the years 1978 to 2000. There are limitations in the data and a number of assumptions were made, but these are common to those encountered in any attempt to estimate historical exposures. The use of available data to estimate exposure quantitatively and develop a job/quarry/time exposure matrix, however, is a considerable improvement over the use of qualitative and surrogate measures of cumulative exposure, for example, duration of exposure. There are few other published studies on silica measurements of sand quarrying in Europe and these results thus are an important addition to those published from the USA.[7,8] The continual collection of dust measurements in the industry is essential to facilitate the exploration of exposure-response relations that may exist between silica and silicosis, lung cancer, and other diseases.

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Authors' affiliations

T P Brown, L Rushton, Medical Research Council Institute for Environment and Health, Leicester, UK

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REFERENCES

1 **IARC**. *Silica, some silicates, coal dust and para-aramid fibrils.* Lyon: International Agency for Research on Cancer, 1997.
2 **American Thoracic Society**. Adverse effects of crystalline silica exposure. *Am J Respir Crit Care Med* 1997;**155**:761–8.
3 **Calvert GM**, Steenland K, Palu S. End-stage renal disease among silica-exposed gold miners: a new method for assessing incidence among epidemiologic cohorts. *JAMA* 1997;**277**:1219–23.
4 **Steenland K**, Goldsmith DF. Silica exposure and autoimmune diseases. *Am J Ind Med* 1995;**28**:603–8.
5 **Benn RT**, Hutchings SJ, Thomas PG, *et al.* Mortality of workers in the silica sand industry. Unpublished results, 1991.
6 EN 481. *Workplace atmospheres: size fraction definitions for measurement of airborne particles in the workplace.* Brussels: Comite Europeen de Normalisation (CEN) standard EN 481, 1993.
7 **Sanderson WT**, Steenland K, Deddens JA. Historical respirable quartz exposures of industrial sand workers: 1946–1996. *Am J Ind Med* 2000;**38**:389–98.
8 **Rando RJ**, Shi R, Hughes JM, *et al.* Cohort mortality study of North American industrial sand workers. III. Estimation of past and present exposures to respirable crystalline silica. *Ann Occup Hyg* 2001;**45**:209–16.
9 **Koskela RS**, Klockars M, Laurent H, *et al.* Silica dust exposure and lung cancer. *Scand J Work Environ Health* 1994;**20**:407–16.
10 **Checkoway H**, Heyer NJ, Seixas NS, *et al.* Dose-response associations of silica with nonmalignant respiratory disease and lung cancer mortality in the diatomaceous earth industry. *Am J Epidemiol* 1997;**145**:680–8.
11 **Davies LST**, Robertson A. *Evaluation and comparison of personal dust and quartz exposure measurements from the UK and German silica producers industry*. Edinburgh: Institute of Occupational Medicine, 1998.
12 **Leung P-L**, Harrison RM. Evaluation of personal exposure to monoparometric hydrocarbons. *Occup Environ Med* 1998;**55**:249–57.
13 **Lange JH**, Kuhn BD, Thomulka KW, *et al.* A study of matched area and personal airborne asbestos samples: evaluation for relationship and distribution. *Indoor and Built Environment* 2000;**9**:192–200.
14 **Corn M**. Assessment and control of environmental exposure. *J Allergy Clin Immunol* 1983;**72**:231–41.
15 **Lange JH**. A statistical evaluation of asbestos air concentrations. *Indoor and Built Environment* 1999;**8**:293–303.
16 **Lange JH**, Lange PR, Reinhard TK, *et al.* A study of personal and area airborne asbestos concentrations during asbestos abatement: a statistical evaluation of fibre concentration data. *Ann Occup Hyg* 1996;**40**:449–66.
17 **Stacey P**, Tylee B, Bard D, *et al.* The performance of laboratories analysing quartz in the Workplace Analysis Scheme for Proficiency (WASP). *Ann Occup Hyg* 2003;**47**:269–77.
18 **Donaldson K**, Borm PJA. The quartz hazard: a variable entity. *Ann Occup Hyg* 1998;**42**:287–94.
19 **Fubini B**. Surface chemistry and quartz hazard. *Ann Occup Hyg* 1998;**42**:521–30.
20 **HSE**. *Working Group on the Assessment of Toxic Chemicals (WATCH). Crystalline silica: Phase 1.* London: Health & Safety Executive, 2001.