Pergamon

PII: S0003-4878(01)00025-4

Ann. occup. Hyg., Vol. 45, No. 7, pp. 585–595, 2001
© 2001 British Occupational Hygiene Society
Published by Elsevier Science Ltd. All rights reserved
Printed in Great Britain.
0003-4878/01/$20.00

Determinants of Exposure to Respirable Quartz Dust in the Construction Industry

MIEKE E. G. L. LUMENS†* and TON SPEE‡

†*Utrecht University, Utrecht, P.O. Box* 238, 6700 *AE Wageningen, The Netherlands*; ‡*Arbouw, Postbus* 8114, 1005 *AC Amsterdam, The Netherlands*

Because most masonry building materials contain quartz and because these materials are subjected to a variety of treatments during the building process, quartz is encountered everywhere in building operations. The level of exposure to respirable quartz has been measured for some highly exposed groups of employees. At 30 construction sites personal air sampling (PAS) measurements of respirable dust and quartz have been performed and 171 samples have been taken. Both respirable dust and quartz levels were high. Respirable quartz exposures of more than ten times the Dutch limit value of 0.075 mg/m^3 TWA were common, but exposures up to 200 times the Dutch limit value were also found. The measurements were task oriented.

By statistical analysis the contribution of the different determinants to the total exposure has been identified. With this approach, directions for an effective control measures programme can be given. © 2001 British Occupational Hygiene Society. Published by Elsevier Science Ltd. All rights reserved

Keywords: quartz; silica; construction

INTRODUCTION

Dust is omnipresent at construction sites. Exposure to dust can occur during almost all activities, from excavation for the foundations up until the final sweeping before the completion of the building. Exposure to dust is very much part of everyday practice. Depending on the nature of the building material being used this dust can contain a considerable amount of silica. Crystalline free silica (silicon dioxide, SiO_2) can occur in three phases: quartz, cristobalite and tridymite. The most important and prevailing type is quartz. Reports about exposure to respirable quartz in the building industry are scarce and the problem has attracted nowhere near as much attention as exposure to respirable quartz in the mining industry and the iron and steel industry (Tomb *et al.*, 1995; Amandus *et al.*, 1995). Susi and Schneider (1995) propose a database for task-based exposure assessments in construction. Moser (1992) has determined exposure levels to respirable quartz during demolition and reconstruction of a large building. Almost 80% of 44 measurements were above the Swiss MAK of 0.15 mg/m^3. The highest levels were encountered when renovating a sandstone wall (4.7 mg/m^3) and during the milling of recesses within the building (1.2 mg/m^3). According to Riala (1988) the exposure of Finnish construction site workers to respirable quartz can be as high as 0.53 mg/m^3 during dry sweeping.

Although construction workers seem to consider exposure to dust natural and inevitable, the number of complaints, both of nuisance and of health effects, is substantial. All Dutch construction workers can, on a voluntary basis, take part in a regulatory health-monitoring programme. Results of the health monitoring are regularly analysed at a group level. The percentage of construction workers complaining about nuisance by dust is 48%, while in other industries 34% of the workers make this complaint (Anon, 1997b).

Occupational exposure to respirable quartz may cause considerable damage to the lungs, among other effects obstruction of the lungs and lung emphysema (Castranova *et al.*, 1996). Chronic exposure to high concentrations of respirable quartz may lead to silicosis (Parkes, 1985), well known from the mining industry. In Germany, where silicosis is a compensable occupational disease, 27 new compensations due

---

Received 24 May 1999; in final form 15 January 2001.

*Author to whom correspondence should be addressed.

to silicosis have been assigned in 1998 to construction workers. The number of cases of silicosis that do not lead to compensation will probably be much higher (HVBG, 1996). Hodel *et al.* (1977) described the occurrence of two cases of silicosis among construction workers. They wanted to attract attention to this previously little-recognised health hazard.

In 1996 the International Agency for Research on Cancer (IARC) reviewed recent data on the carcinogenicity of respirable quartz. As a result of this review, quartz is placed in IARC Group 1, meaning that 'there is sufficient evidence of carcinogenicity in humans' (Anon, 1997a).

The Dutch government considers respirable crystalline silica a confirmed human carcinogen (Arbeidsinspectie, 1994).

If data about exposure to respirable quartz in the construction industry are scattered, papers about control measures are even scarcer. Hallin (1993) has reported on this subject. This author determined respirable quartz exposure during a number of construction jobs. He found very marked differences between working with and without local exhaust ventilation (LEV). The highest concentration was 32.8 mg/m^3 respirable quartz when milling recesses for inserting conduits for electric cables in sand-lime bricks without LEV. The use of LEV decreases the respirable quartz exposure to an average 0.2 mg/m^3, so the exposure was still well above the Dutch limit value of 0.075 mg/m^3. Thorpe *et al.* (1999) measured the effectiveness of dust control on cut-off saws used in the construction industry. All control systems assessed, both LEV and applying water, generally reduced respirable dust levels by at least 90%. There were various factors that induced us to draw renewed attention to the exposure to respirable quartz in building.

- The farming out of work to subcontractors is a well-known phenomenon in the building industry. The increasing rationalisation of the building process means that this phenomenon is on the increase, and there are now companies that have a single specialisation. If such specialisation concerns an occupation with a high exposure to respirable quartz, then there is a long-term exposure problem.
- In the Netherlands the Maximum Accepted Concentration (MAC) (a limit value comparable to the British OEL) for silica has been reduced from 0.150 to 0.075 mg/m^3 as from 1 May 1996.
- The Dutch government has placed respirable crystalline quartz on the list of carcinogenic substances so the EU Directive on carcinogenic substances, which was embodied in 1994 in the Dutch legislation, also applies to respirable quartz (EEC, 1990); this implies that exposure should be avoided where possible, and decreased as much as feasible where no alternative material is available.
- Despite of the large numbers of workers possibly exposed and the severe risks involved, hardly any data on exposure levels at construction sites are available.

The objectives of this study were:

- to investigate the level of silica exposure for several jobs at construction sites,
- to determine the contribution of different determinants to total exposure.

A field study was carried out, in which 171 air samples were collected. This was preceded by a literature survey, in which information was gathered about 29 occupations within the construction industry in the Netherlands, focusing on the frequency and level of respirable dust and quartz exposure.

Based on these results a ranking of occupations with a high exposure to respirable dust has been made. The current study is focused on these highly exposed employees, working as recess millers, demolition workers and inner wall constructors. Since construction job titles vary in different countries, a short description of these occupations and photos will be given.

Recess millers. Recesses are made in materials for the purpose of concealing utility lines and pipes for water and electricity. Instead of being mounted on the wall, the pipe or conduit is located inside the wall. This is neater and more practical when further finishing has to be carried out. The usual technique for making recesses is to use a recess miller (Fig. 1).

Demolition workers. Demolition here consists of the dismantling of walls, floors and ceilings, but also for example, the removal of plaster or tiles from walls. The demolition usually therefore precedes renovation and improvement. The tools used for this type of demolition are electrically or pneumatically driven jackhammers. Non-powered tools like hammers and chisels are rarely used nowadays. This study is not concerned with the demolition of complete buildings. Such work is carried out by totally different techniques such as crushing, the use of explosives or a crane. In this work the demolition experts are usually located in a cabin (Fig. 2).

Inner walls constructors. Inner walls are constructed by connecting building blocks with an adhesive. These blocks can be made of gypsum, lime sandstone or cellular concrete. These elements have to be brought to size. This can be done with a (electric) saw or with a specially designed clipper. Inner walls constructors spend about 1 h per day cutting the elements to size, the rest of the time they are actually constructing the inner walls (Fig. 3).

The construction trade has specific properties that

Fig. 1. A recess miller at work.

Fig. 2. A demolition worker.

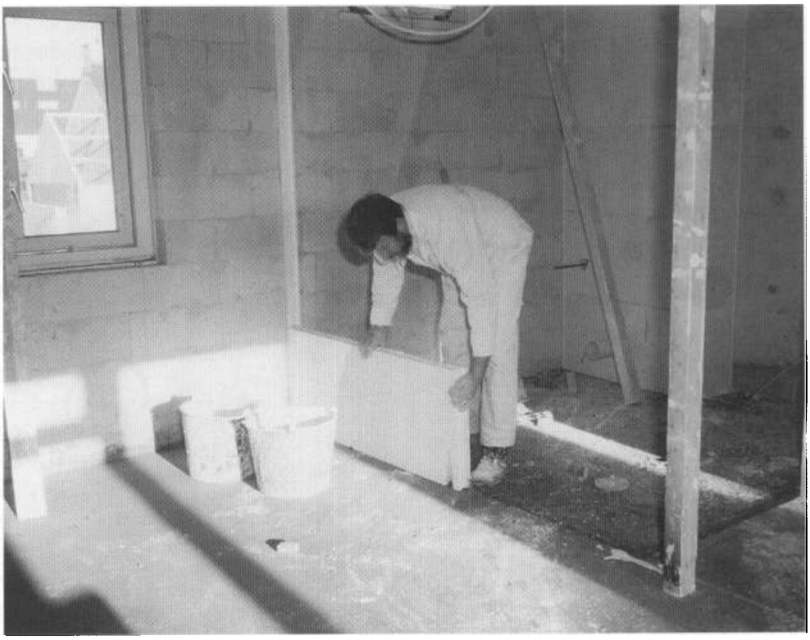

Fig. 3. Inner wall constructor.

necessitate a special approach for measurements, because most of the parameters that determine the exposure are perpetually changing: building design, natural ventilation, and the amount of work to be finished in one day. Many of the tasks to be performed at construction sites take only a few hours. This means that workers often work at different places during one day, a considerable amount of time is spent preparing the work and travelling. Exposure hardly ever lasts a full eight hours working day. Moreover because of the different construction sites where employees have to work supervision at the workplace is generally limited as well as contact with co-workers, which might enable them to discuss problems and exchange solutions with respect to the exposure to respirable dust and silica. Control measures at construction sites almost exclusively are directed at personal protection devices (Reed *et al.*, 1987). The dynamics of the building industry complicate the development and application of control measures. Unfortunately, adequate 'off-the-shelf' control technology is hardly available for many construction operations (Linch *et al.*, 1994).

MATERIALS AND METHODS

Selection of construction sites

Construction sites where the research was carried out were acquired in two ways, by contacting companies listed in the telephone Yellow Pages and via the health and safety co-ordinators of several big construction companies. The selection was aimed not only at the occupations, but also at a variation in the conditions in which the jobs were carried out, e.g. variation in type of building material and level of control measures.

Measurements: task based PAS and source oriented measurements

A total of 30 construction sites were selected. Some sites were studied on more than one day. At each site employees were asked to co-operate by wearing personal air sampling equipment for some hours. The large majority of them were willing to participate in the study. Only two of them refused because they considered it too much of a fuss. Measurements were task-oriented. Because of the nature of the jobs (at different sites, ready-go-home system), the sampling time was mostly between 3 and 4 h.

In addition to the personal air-sampling, source-oriented ambient measurements were taken. A direct reading dust monitor was used both near the working environment of the worker and at the background to quantify the (relative) contributions of the different sources mentioned above.

Description of construction sites

A questionnaire and a checklist developed for this study were used to enable a qualitative description of the different workplaces where the measurements were conducted. In the questionnaire the workers at the construction sites are asked about their normal working habits, working hours, use of personal protection equipment, use of other control measures and possible improvement of the working conditions at the construction sites. The checklist was used to systematically report on factors at the workplace which might have an influence on the total exposure of the workers. Information was gathered on: type (and if available make) of building material, type and make of equipment, stage of the building process (layout, with or without glass in the windows), presence of other workers, use of LEV, good house keeping. Observations were made according to a set protocol. Reports of the weather conditions during the days of the measurements came from the nearest weather station.

Respiratory protection equipment

Respiratory protection equipment was used at 30% of the construction sites. The protection used consisted mainly of very simple disposable paper masks. In only one case was the worker wearing a filtering facepiece of P2 quality.

Sampling and analysis

Samples were collected on Millipore mixed ester filters (type RA 1.2 µm, 25 mm) using Casella cyclones as sampling heads in combination with Dupont P-2500 or Gilian Gilair pumps with a flow of 1.9 l./min. Casella cyclones collect the respirable dust fraction, which is relevant in determining exposure to respirable quartz. Filters were weighed before and after sampling with a Mettler balance (type AT 261 DeltaRange, Switzerland).

A selection of 61 of the 181 filters was sent to an external laboratory (Ascor Analyse, The Netherlands) to determine the content of respirable crystalline silica of the respirable dust. The analysis was performed by X-ray diffraction (XRD) according to NIOSH method 7500. The detection limit of this method is 10 µg/filter. The selection was done in such way that for each construction site at least two filters were analysed, representing the tasks that were performed and the building materials processed. The quartz content of these filters is considered to be representative of the filters taken under the same circumstances, and was used to calculate the quartz content of the samples taking at the same building sites working with the same building materials.

As a direct-reading aerosol monitor the MiniRAM (model PDM-3, USA) was used. This is a light scattering aerosol monitor that responds to particles in the range 0.1–10 µm. It is calibrated on Arizona Road Dust and not on 'construction' dust, so results are comparative only. The MiniRAM was connected to a data logger (Metrosonics, USA). The logged data were read into a personal computer using Metrosoft software. The results were plotted and interpreted by comparing the variation in exposure to the results of the observations made synchronously at the workplace.

All statistical analyses were performed with SAS software (SAS Institute Inc, 1994).

Determinants of exposure

One of the objectives of this study was to set priorities for control measures. In order to achieve this objective a statistical approach was used.

Generally, personal exposure is composed of the contributions of different determinants. Determinants were divided into four different categories: agents, processes or appliances, work practices and working environment and their contributions to exposure were assessed by statistical analysis. This approach is called the 'multiple source model' and is described by Buringh *et al.* (1992). Analyses of the statistical model were performed by analyses of variance within the framework of general linear models (GLM)(Draper and Smith, 1981), giving parameter estimates that indicate the contribution of the four determinants to the quartz exposure. Based on these results an estimate of exposure can be made of a work situation for which the four determinants are well described.

The determinants in their turn consist of variables on which information was gathered during the field studies. These variables were chosen because either information from earlier publications or our own workplace observations indicated their influence on the eventual exposure of the construction workers. On some of these variables quantitative information could be obtained; others had to be assessed by workplace observations. For determinants consisting of more variables, sum scores of the separate variables were made. In the regression analysis quartz exposure was the dependent variable and the determinants were the independent variables.

The four distinctive determinants are now described in further detail.

Agents: type of building material used. In the analysis a ranking of the building material is used according to its quartz content. Table 1 gives an overview of the building materials applied at the 30 construction sites under study, and their quartz content as known from literature with increasing percentage of quartz.

Processes and appliances: type of process applied, without or without use of local exhaust ventilation, make of equipment used; The influence of these variables together forms the determinant 'process/appliance'. Table 2 shows the different types of processes used with the three occupations.

Working environment: 30 construction sites were studied, varying from small apartments to large demolition sites. To standardise the influence of working environment, the layout of the building under construction is described by a number of descriptors: glass already present in the windows (0/1), presence of other workers causing extra exposure (0/1), weather conditions (rain (0/1), wind (0/1)); A sum score composed of dummy variables of these descriptors is used to assess the

Table 1. Quartz percentage of building materials[a]

Building material	This study	(1)	(2)	(3)	(4)	(5)
Gypsum	2%		1–2%	0–3.5%		
Rubble	10%					1–14%
Cellular concrete	20%	12%		44%		40%
Sand-lime stone	29%	30%		83%	30%	

[a](1) Peters *et al.* (1974); (2) Zielhuis (1990); (3) van Amelsvoort and Tjoe (1993); (4) Karlowitsch (1967); (5) Anon (1997b).

Table 2. An overview of equipment used at the 31 study construction sites

Recess milling	Double diamond saw with LEV Conventional recess miller with LEV Conventional recess miller
Inner wall construction	Specially designed clipper Electric saw
Demolition work	Fork lift truck with shovel Broom Sledgehammer Electrically or pneumatically driven jack hammer

influence of the determinant 'working environment'. The sum score, i.e. the contribution from working environment, is lowest when no glass is present in windows, no other workers are present, when it is raining and windy.

Work practices: use of personal protective equipment (ppe) and the general impression of neatness when working. Information on whether or not ppe is used and scoring of 'good housekeeping' practices on a scale of 1–3 are combined to describe the determinant 'work practice'. Adverse work practices i.e. leading to higher exposures consist of 'not wearing ppe' and 'bad housekeeping'.

RESULTS

In Tables 3 and 4 the results of the respirable dust and quartz dust determinations are summarized.

The results of the measurements of respirable dust and quartz dust for the total population and those for the three separate populations are lognormally distributed. Therefore the geometric means and standard deviations are reported. The highest respirable dust and quartz levels were found in the same sample, which was taken during demolition work. Tiles were removed from the walls with jackhammers in a confined space without natural ventilation. In recess milling the highest respirable quartz sample occurred when milling in sand lime stone with a quartz content of over 40%.

Figures 4–6 illustrate examples of dust measurements as determined by means of the MiniRAM connected to the data logger. In Fig. 4 recesses were milled in a room with glass in the windows. At 15:31 a new room is entered, and concentration drops considerably.

Figure 5 is made during the disposal of wet demolition waste. Only the surface of the waste is humid; at 15:35 the concentration rises due to the fact that the underlying dry and dusty material is scooped up. Figure 6 shows the influence of the equipment used in inner walls construction. In Fig. 6(a) a special type of clipper is used to bring the elements to the correct size. In Fig. 6(b) this is done by applying a circular saw.

Table 5 shows the results of the statistical analysis aimed at determining the influence and contribution of the four determinants to total exposure. The results of this modelling are shown to be significant for all groups of construction workers. Between groups the influence of the four determinants however differs. In principle, all determinants would be expected to contribute positively to exposure. A higher quartz content of agent used, dusty working methods, and little use of LEV, in a working environment with hardly any natural ventilation and more workers present at the workplace, and a low level of housekeeping and limited use of PPE, were expected to contribute significantly to higher quartz exposure levels. Exceptions to these results will be discussed.

Table 3. Personal respirable dust concentrations at construction sites (in mg/m^3)[a]

	N	Min	Max	GM	GSD
Total population	171	n.d.	298.8	5.2	3.8
Recess millers	53	n.d.	18.9	3.1	2.7
Inner wall constructors	36	0.2	10.6	2.1	2.9
Demolition workers	82	0.5	298.8	10.8	3.5

[a]GM: geometric mean; GSD: geometric standard deviation; n.d.: not detectable.

Table 4. Personal respirable quartz dust concentration at 30 construction sites (in mg/m^3)[a]

	N	Min	Max	GM	GSD
Total population	171	n.d.	35.9	0.5	5.6
Recess millers	53	n.d.	6.9	0.7	3.3
Inner wall constructors	36	n.d.	0.2	0.04	2.6
Demolition workers	82	n.d.	35.9	1.1	4.0

[a] GM: geometric mean; GSD: geometric standard deviation; n.d.: not detectable, below detection limit.

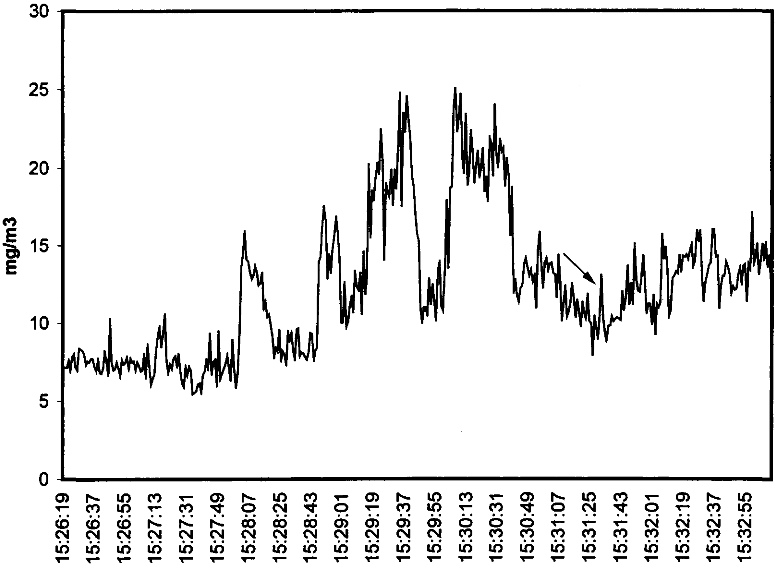

Fig. 4. Miniram results for recess milling in glass-closed room, at ↘ a new room is entered.

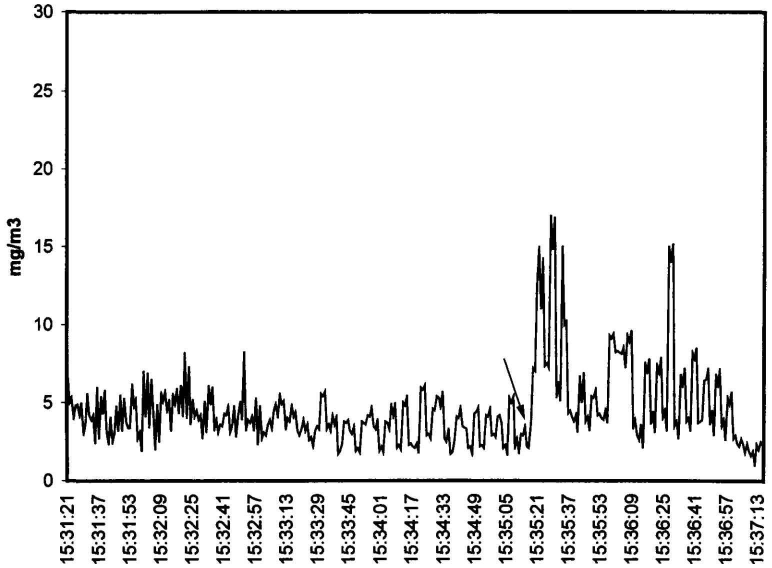

Fig. 5. Miniram results for disposal of wet demolition waste, at ↘ increase of level due to dry inner material.

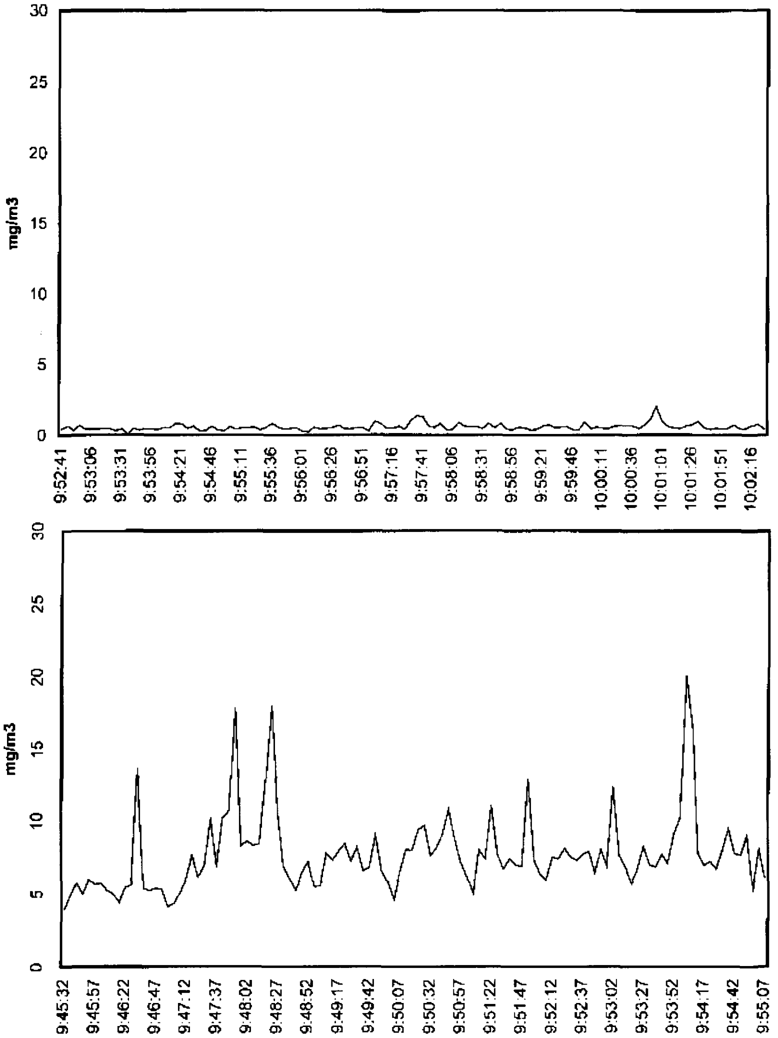

Fig. 6. (a) Miniram results for inner wall construction using clippers. (b) Miniram results for inner wall construction using circular saw.

Table 5. Regression coefficients (and their *P*-values) of regression analysis on the multiple source model, with personal respirable quartz concentration as dependent variable

	Total population	Recess millers	Inner walls constructors	Demolition workers
Agents	0.12	0.14	0.05	−0.05
	(0.007)	(0.02)	(0.02)	(0.78)
Process/appliances	0.27	0.15	0.59	0.61
	(0.001)	(0.003)	(0.04)	(0.001)
Working environment	0.08	0.03	−0.28	−0.15
	(0.17)	(0.71)	(0.04)	(0.23)
Work practice	−0.03	−0.45	0.12	0.61
	(0.81)	(0.02)	(0.57)	(0.14)
R^2 (explained variance)	0.74	0.64	0.65	0.82
$P>F$	(0.001)	(0.001)	(0.001)	(0.001)

DISCUSSION

General

As the measurements are performed in a large variety of construction sites, construction materials, working conditions and external conditions the respirable quartz levels are considered representative for the three occupations under study. The construction sites were selected by thorough discussions with construction experts, to create a picture of the everyday practice for these occupations.

Due to the nature of the jobs (task based), the average measuring time did not cover a full workday. However, even if exposure during the remaining part of the working day were zero, average respirable quartz levels would be too high.

The average level of exposure to respirable quartz is higher than the Dutch limit value of 0.075 mg/m^3. Demolition workers and recess millers are especially at health risk due to their exposure.

As the large standard deviation indicates, variation between workplaces is large. A number of factors prove to have a negative or positive influence on the level of exposure. For instance, in a building with glass in the windows the average concentration was 0.8 mg/m^3, in open buildings quartz dust exposure was 0.2 mg/m^3. An LEV system directly connected to a recess miller reduces the concentration from an average 1.0 mg/m^3 to about 0.3 mg/m^3 quartz dust. However, even in case of this control measure the average exposure is still too high.

Workplace visits checklists and personal interviews made clear that dust at the construction site is regarded as unavoidable by those concerned. On the building sites almost no one is aware of the potential health hazards of respirable (quartz) dust. This is probably the reason why only limited measures are taken to reduce dust occurrence and dispersion. Measures to reduce the exposure have been taken in a number of cases, but these do not lead to an acceptable exposure level.

The influence of determinants

The results of the personal measurements indicate the need for control measures, which can be applied most effectively, when the main determinants of exposure are known.

In order to assess the contribution of the different determinants to the total exposure the 'multiple source model' is applied. The results of the statistical analyses show that the model can explain up to about 80% of the variation in the respirable quartz exposure, depending on the occupation investigated.

The statistical model as it is applied in this study is most appropriate for the occupation of recess millers and inner walls constructors. For these job titles the four determinants are best described, and important parameters at the workplace could be easily attributed to one of the four determinants. For demolition workers the contribution of the determinants of this 'multiple source model' is less evident. A further quantification of the determinants, e.g. better quantification of quartz content in the different types of demolition debris may improve the model for these workers.

As to the contribution of the four separate determinants the following can be concluded.

Not surprisingly the *agent*, i.e. the type of building material and its quartz content are an important factor in the exposure to respirable quartz. This is most prominent for the recess millers. In this occupational group, building material is well defined, certainly compared to the demolition workers, who almost always work in a mixed dust environment. Recess millers usually know the type of building material they were milling, because the choice of their grinding wheel depends on the hardness of the material. The quartz content of the building material may vary from about 0% in gypsum to 40% for sand lime. Moreover, at most construction sites recess milling produces most respirable dust, so the personal exposure of the millers predominantly can be attributed to the quartz content of the construction material. Demolition workers usually work with a mixture of building materials. This makes it difficult to investigate the influence of the material on respirable quartz exposure. Inner walls constructors know the type and make of elements they are joining to construct inner walls. Since however the respirable dust emission with this task is not very high, the quartz exposure may be due to the activities of other construction workers. The model therefore indicates that the influence of the agent is strong in determining the respirable quartz exposure of recess millers, less strong for the inner walls constructors and absent for the demolition workers.

With regard to the contribution of the *process and equipment* used, the results also indicate differences between the three selected occupations. For demolition workers, a significant influence is detected: when considering the large variety in tasks and materials used in this occupation, ranging from using hand held jack hammers for removing small remnants of stone (average quartz exposure of 3.8 mg/m^3) to using a small bulldozer to push over walls (quartz exposure about 0.2 mg/m^3), the predominant factor is obvious. The variation in respirable dust emission between these extremes is clearly visible.

To a certain extent this also applies to the recess millers. The way they perform their tasks varies from using 'conventional' recess millers to using diamond saws with LEV. The use of either of these methods has large implications for the respirable dust exposure and quartz exposure. In case of conventional recess milling average respirable quartz levels are 2.4 mg/m^3, with diamond sawing 0.7 mg/m^3.

For inner walls constructors, two different types of equipment are used to bring the elements to the correct size. The elements can either be sawn or cut, leading to exposures of 0.06 mg/m^3 for sawing and 0.02 mg/m^3 quartz dust when using the clipper. The influence of these methods is clearly visible in the results of the modelling.

The determinant described as *working environment* is composed of a number of parameters. Considering the large variety of building and construction sites it will be clear that, in comparison with agents and processes, the variation in the working environment is almost unlimited. Its influence is different for the occupation groups studied. No influence is found for recess millers and demolition workers. In inner walls construction a significant negative contribution of the working environment is found. This would imply that working with closed windows and several colleagues around leads to a lower exposure. The probable explanation for this finding is that in these cases inner walls constructors tend to go outside to perform the dustiest task, i.e. the sawing of the elements. Recess millers and demolishers do not have this possibility.

In this study *work practices* are described by the investigation of neatness by a checklist and the use of respiratory protection equipment (RPE). The use of RPE is considered an indicator for a positive attitude towards safe working. In this case RPE is not considered to have a direct influence on the personal exposure as measured. We did not place the sampling head inside the RPE. The use of RPE is only included in the determinant 'work practice' as an indicator of awareness of the hazard of respirable quartz dust, as a potential contributor to safer work practices. This may explain the negative regression coefficient found in the group of recess millers: personal protection equipment might be used only in the worst conditions, leading to the highest exposure levels. The results of this statistical model are partly supported by the results of the direct reading instrument with data logger, which enabled us to investigate the contributions of the separate determinants.

Calculations based on this model have yielded relevant information on the contributions of the four determinants. This information can be used to order and prioritise these determinants to their individual contribution on personal exposure. When designing control measures for high exposure situations or occupations it is important to determine what type of control measures on what determinant will have the highest influence. The model shows a different hierarchy for the three occupations.

For each occupation the problem of high respirable quartz dust exposures can now be tackled in a structured way.

CONCLUSIONS

Under the present conditions the exposure limit for respirable quartz exposure is frequently exceeded for several jobs in the construction industry. The statistical model used in this investigation has yielded information on the influence of different factors on the level of the exposure. As the contributions made by the determinants become clearer, a more systematic approach can be followed to formulating corrective preventive measures.

The most important conclusion however is that there is a clear need to raise the awareness to the hazard of high exposure to respirable quartz dust in the construction industry.

Acknowledgements—This project has been financed by employers' and employees' organisations in the building industry and by the Dutch government. We would like to thank the employees and employers of the construction firms for their kind co-operation. Furthermore we want to thank Martijn van Amelsfort, Andrea Schipper, Sonja Sol, Hendrik Jan Janssen and Rimke Kerkhoff, who performed a large part of the field measurements.

REFERENCES

Anon. IARC monographs on the evaluation of the carcinogenic risks to humans: silica, some silicates, coal dust and paramid fibrils, vol. 68. Lyon: IARC, 1997.

Anon. Bedrijfstakatlas: arbeid en gezondheid in de bouwnijverheid (Branch atlas: work and health in the construction industry), Scientific ed. Amsterdam: Arbouw, 1997.

Amandus HE, Shy C, Castellan RM, Blair A, Heineman EF. Silicosis and lung cancer among workers in the North Carolina dusty trades. Scand J Work Envir Hlth 1995;21(Suppl. 2):81–4.

van Amelsvoort L, Tjoe Ny E. Arbeidsomstandigheden in de Bouw, in het bijzonder (silica) stofblootstelling; een literatuuroverzicht [Working conditions in the construction trade, with regard to (silica) dust exposure: a literature review] Wageningen, Department of Air Quality Landbouwuniversiteit, internal report IV-187, March 1993 [in Dutch].

Arbeidsinspectie. Werken met kankerverwekkende stoffen en processen (Working with carcinogenic agents and processes) [P-187, in Dutch], SDU, Den Haag, The Netherlands, 1994.

Buringh E, Noy D, Pouwels H, Swuste P. A systematic implementation of control measures for airborne contaminants in workplace air. Staub Reinhalt Luft 1992;52:347–51.

Castranova V *et al.*. Silica and silica induced lung diseases. Boca Raton (FL): CRC Press, 1996.

Draper N, Smith H. Applied regression analysis, 2nd ed. New York: John Wiley and Sons Inc, 1981.

EEC. European Directive 90/394/EEC: directive on carcinogenic substances. Official Journal of the European Communities, L-374, 1990.

Hallin N. Occurrence of quartz in the construction sector, an investigation of the occurrence of quartz dust in connection with various operations in the construction sector. Bygghalsan 1993.

Hodel T, Schegel H, Ruttner JR. Backstein- und Betonbohrersilikose (Brick and concrete drillers silicosis). Schweiz med Wsch 1977;107:1896–9.

HVBG (Hauptverband der gewerbliche Berufsgenossenschaften). Geschafts- und Rechnungsergebnisse der gewerblichen Berufsgenossenschaften '95, (Business and numerical results of industrial accident assurances, in German) HVBG Sankt Augustin, 1996.

Karlowitsch L. Gesundheitschadeliche Staube bei der Natursteinverarbeitung, Betonsteinherstellung and Verarbeitung (Dusts adverse to health in the processing of natural stone and manufacturing and processing of concrete stone). Moderne Unfallverhutung 1967;12:80–6 [in German].

Linch KD, Groce DW, Cocalis JC, Parker JE. Silica exposure surveillance in the construction industry. In: Proceedings of the Second International Symposium on Silica, Silicosis and Cancer, October 1993, San Francisco, Western Consortium for Public Health, 1994.

Moser HA. Staubgefaehrdung bei Arbeiten im Hochbau (Risk of dust exposure when working at construction sites). Staub 1992;52:163–7.

Parkes WR. Occupational lung disorders. London: Butterworths, 1985.

Peters T, Mumenthaler T, Jenni JP. Mineralogische und technologische Untersuchungen an Ziegeltonen aus der Molasse der NE Schweiz (Mineralogical and technological research on clays in the Molasse rocks of NE Switzerland). Schw Mineral Petrof Mitteil 52 [in German].

Reed LD, Lenhart SW, Stephenson RL, Allender JR. Workplace evaluation of a disposable respirator in a dusty environment. Appl Ind Hyg 1987;2:53–6.

Riala R. Dust and quartz exposure of Finnish construction site cleaners. Ann Occup Hyg 1988;32:215–20.

Susi P, Schneider S. Database needs for a task-based exposure assessment model for construction. Appl Occup Envir Hyg 1995;10:394–9.

Thorpe A, Ritchie AS, Gibson MJ, Brown RC. Measurements of the effectiveness of dust control on cut-off saws used in the construction industry. Ann Occup Hyg 1999;43:443–56.

Tomb TF, Gero AJ, Kogut J. Analysis of quartz exposure data obtained from underground and surface coal mining operations. Appl Occup Envir Hyg 1995;10:1019–27.

Zielhuis RL. Fijn hinderlijk stof; gezondheidskundige aspecten van bijlage 3 bij de National MAC lijst 1989 (Nuisance dust; health based aspects of annex 3 of the Dutch national OEL list 1989), DGA, Den Haag, RA 9/90 [in Dutch].