Journal of Occupational and Environmental Hygiene, 3: 144–152
ISSN: 1545-9624 print / 1545-9632 online
DOI: 10.1080/15459620500526552

Silica Exposure on Construction Sites: Results of an Exposure Monitoring Data Compilation Project

Mary Ellen Flanagan,[1] Noah Seixas,[1] Paul Becker,[2] Brandon Takacs,[2] and Janice Camp[1]

[1]Department of Environmental and Occupational Health Sciences, University of Washington, Seattle, Washington
[2]Safety and Health Extension, West Virginia University, Morgantown, West Virginia

To expand on the limited size and scope of construction silica exposure studies, a silica monitoring data compilation project was initiated through the American Conference of Governmental Industrial Hygienists Construction Committee. Personal silica exposure monitoring data was collected and analyzed from 13 private, research, and regulatory groups. An effort was made to collect as much detail as possible about task, tool, and environmental and control conditions so as much information as possible could be garnered. There were considerable data gaps, particularly with regulatory agency data, that represented over half of the data set. There were 1374 personal quartz samples reported with a geometric mean of 0.13 mg/m^3 and a GSD of 5.9. Descriptive statistics are reported by trade, task, tool, and data source type. Highest exposures were for abrasive blasters, surface and tuckpoint grinders, jackhammers, and rock drills. The sample period was important, with short-term samples (up to 2 hours) having considerably higher levels than midterm (2–6 hours) or longer (over 6 hours) samples. For nearly all exposure variables, a large portion of variable categories were at or over the quartz occupational exposure limit of 0.05 mg/m^3, including 8 of 8 trade, 13 of 16 task, and 12 of 16 tool categories. The respiratory protection commonly used on construction sites is often inadequate for the exposures encountered. The data variability within task and tool was very large, with some very high exposures reported for a broad spectrum of tools. Further understanding of the conditions leading to high exposures will require more detailed documentation of the sample characteristics following database design recommendations or systematic surveys of exposure in this complex industry.

Keywords construction, respirator, silica, task, tool, trade

Address correspondence to: Mary Ellen Flanagan, University of Washington, Department of Environmental and Occupational Health Sciences, 4225 Roosevelt Way NE, Suite 100, Seattle, WA 98105; e-mail: mflanaga@u.washington.edu.

Silica exposure continues to be an important hazard in the construction industry and therefore remains a concern for construction workers' health. More silicosis deaths were associated with construction than any other U.S. industry in an evaluation of 1985–1990 death certificates.(1,2) Elevated quartz exposures have been reported for several construction activities(3−10) although sample sizes are usually relatively small and scattered across a broad spectrum of construction activities.

A comprehensive study of construction related silica exposure would provide better information for assessing risk from specific activities so that controls could be targeted for most benefit. Large and comprehensive studies are very challenging in construction due to continually changing workplaces, tasks, and environmental conditions.

The American Conference of Governmental Hygienists Construction Committee initiated a silica data compilation project to obtain a larger dataset to represent as many silica dust producing construction activities as possible, determine most influential factors for predicting silica exposure, and identify strengths and weaknesses of existing data. Data was collected from public and private occupational health entities to compile more comprehensive silica exposure information for the construction industry. The database was designed with 25 variables selected for collection of more comprehensive information on exposure determinants.

METHODS

Data were solicited from organizations and agencies that have conducted air monitoring for silica on construction sites, primarily through professional organization contacts. Data from the Occupational Safety and Health Administration IMIS database does not provide the detail needed to meet the sample criteria test. All seven present and past silica SENSOR states were contacted, and 10 research or academic groups known to have an interest in construction silica exposure characterization were contacted to solicit data. Data submittal was also requested of contractors, consultants, and others present at construction sessions of conferences of the Construction Safety Council and the American Industrial Hygiene Association. All 12 parties who expressed interest at these meetings were contacted.

Thirteen organizations provided data that was entered into a data file at the University of Washington. Data were received in electronic or hard copy format with five sources providing hard copy data while the remainder submitted data electronically. For inclusion in data analysis, the following sample criteria test had to be met: a reported respirable quartz and/or respirable dust concentration, sample duration, and trade, task and/or tool associated with the sample. All data files required some recoding to meet the project's format.

The database was designed to collect as much detail as possible for variables that could be important in describing the conditions of exposure. There were 25 variables in the data set. Variables describe sample collection parameters, project conditions, and site and activity conditions. Variables with much missing data and/or poor quality data were not analyzed. These included country, SIC code, secondary and tertiary task, tool, tool model, site ventilation, and percent time doing dusty task. If the details for a variable were unavailable from the source data, the record was coded with "unreported" for that variable. If categories of a variable had fewer than eight entries, categories were combined. For example, for Trade, plumber, fabricator, painter, electrician, carpenter, drywall, and ironworker were recoded to "Other."

All data sources reported some samples below the quartz and/or respirable dust limit of detection or quantification. The manner of reporting non-detects varied among data sources with some sources reporting a calculated concentration while others reported "below LOD" or "below LOQ". To standardize the non-detect data, we solicited the laboratory limit of detection and limit of quantification from each analytical laboratory and used the laboratory's limit of quantification and sample volume to calculate a sample LOQ concentration. This value was divided by 2 for entry in the data set as recommended by Hornung and Reed(11) for a skewed data set with a large portion of the data below the detection limit. Quartz was below the detection limit for 30% of personal quartz samples.

Sample year was grouped into three categories to assess time trends: 1992–1995, 1996–1998, and 1999–2002.

Quartz percentage is the respirable quartz percentage calculated for all records that reported both a respirable dust and respirable quartz concentration. No information was collected on bulk samples from substrate worked.

To assess whether workers are protected by commonly used respirators, the long-term samples (over 6 hours) from this data set were used to determine the percentage of tool users who would be protected while wearing a respirator. Protection factors of 5, 10, and 50 were used for dust mask, half-face cartridge, and full-face cartridge respirator, respectively. National Institute for Occupational Safety and Health (NIOSH) protection factor values(12) were used for cartridge respirators. The NIOSH protection factor assumes that the respirator has been fit tested assuring good fit. It is difficult to achieve a good fit with a dust mask, and our knowledge of respiratory protection programs on construction sites suggests that dust masks are rarely fit tested; therefore there is less confidence in the assumption of good fit. The NIOSH protection factor of 10 for NIOSH rated dust masks was reduced to 5 for this analysis to reflect the lack of confidence in a good fit for dust masks on construction sites. The percentage of tool users protected was calculated as a parametric exceedance factor(13) using the threshold limit value (TLV®) of 0.05 mg/m^3.

Statistical analysis utilized the statistical software SPSS 10.0. Quartz and respirable dust concentrations were generally log normally distributed so these variables were log transformed for analysis. Geometric means and geometric standard deviations were calculated to describe exposure variables.

Linear regression was run on 15 variables to identify the most influential exposure determinants. Model development was an iterative process whereby predictors (tool, task, individual source, source category, state, sample duration, quartz percentage, trade, project purpose, environment, sampling device, construction sector, quartz analytical method, controls, nearby dust source, and sample year) were added in rank order and their overall effect on the model was considered. Nonsignificant ($p > 0.05$) predictors including task, project purpose, source category, sampling device, quartz analytical method, and nearby dust source were removed from the model. Individual source and state were excluded from analysis due to overlap with construction sector.

RESULTS

Data sources included three federal or state regulatory agencies (n = 827 samples), six university or research agencies (n = 491), and four private consultants or contractors (n = 134). Samples were collected from 1992 to 2002 with 76% of samples from 1997 to 2000. There were numerous gaps from the source data with 3% of trade, 17% of task, 26% of tool, 43% of project type, 62% of environment, and 83% of control status unreported.

There were 1,630 samples that met the sample criteria test. Of these, 178 samples were area samples. Because information on the purpose and location of area sample collection was limited, these samples were eliminated from the analysis. Of the 1,452 personal samples, 1,374 reported a quartz concentration and 1,394 reported a respirable dust concentration.

Descriptive statistics for exposure variables are shown in Tables I and II. The overall geometric mean (GM) and geometric standard deviation (GSD) for personal exposures was 0.13(5.9) mg/m^3 for quartz and 1.36(5.5) mg/m^3 for respirable dust. Source is presented by sample duration category (Table I). Concentrations were higher especially for samples of $\leq$2 hours as would be expected with task sampling vs. full

TABLE I. Quartz Concentration (mg/m^3) by Data Source and Sample Duration

Source Type	Up to 2 Hours	2–6 Hours	Over 6 Hours	Total
Regulatory: GM (GSD)	0.33 (6.0) N = 206	0.13 (5.3) N = 443	0.11 (5.3) N = 114	0.16 (5.8) N = 763
Research: GM (GSD)	0.28 (3.9) N = 50	0.12 (5.2) N = 234	0.07 (6.6) N = 206	0.10 (5.9) N = 490
Private: GM (GSD)	0.20 (4.0) N = 23	0.08 (4.8) N = 54	0.05 (4.6) N = 44	0.08 (4.9) N = 121
Sample Duration Totals: GM (GSD)	0.30 (5.4) N = 279	0.12 (5.3) N = 731	0.08 (6.0) N = 364	0.13 (5.9) N = 1374

shift sampling, although it cannot be assumed that the shorter samples are task samples since the purpose of sampling is not reported for much of these data. Exposures from regulatory agency samples were higher (GM of 0.16) than research (GM of 0.10) and private (GM of 0.08) samples. Variability was high with most geometric means in the range of 4.0 to 6.0 for most trades, tasks, and tools (see Table II).

Sample duration ranged from 6 to 601 minutes with a median of 219 minutes. Duration was coded into categories of less than 2 hours, 2–6 hours, and over 6 hours for analysis. For both quartz and respirable dust, the short term samples (up to 2 hours) were on average considerably high than the mid and longer term samples, with a quartz GM of 0.30 mg/m^3 for short term and 0.12 and 0.07 mg/m^3 for mid and long term categories.

For exposure controls, dust generation, and environment (Table II), levels generally follow the expected direction, although it is important to note for all three of these variables the majority of the records had missing data for these variables. For construction sector exposures were highest for residential construction and lowest for industrial/commercial projects. For project purpose, new construction projects showed lower exposure than other projects involving demolition, remodeling, and maintenance. The sampling device used for 92% of samples was either a nylon or aluminum cyclone. There was essentially no difference for these two devices. The other devices used had concentration means that varied considerably from the cyclone means, although the sample size was very small for each of these devices.

Quartz concentration trended downward over time (Table II), with a statistically significant difference between means.

The quartz content varied with the tool used (Table IV). Relatively low quartz percentages were seen for abrasive blaster and cement mixer, whereas over half the walk behind saw samples had quartz percentage of over 15%. Several tools that are used at varying substrate depths and on various silica containing materials, including surface grinder, jackhammer, and backhoe had a fairly equal distribution across all quartz percentage ranges.

Multiple regression models for ln quartz ($R^2 = 0.29$) and ln respirable dust ($R^2 = 0.22$) are shown in Table VI. For both quartz and respirable dust models, tool, trade, sample duration, environment, and controls were significant variables. In addition, Quartz%, sample year, and construction sector were also significant in the quartz model.

For tool, parameter estimates were significant or highly significant for 12 of 13 tool categories in the quartz model. For environment, as the setting is more enclosed exposure increases. Quartz% was highly significant in the quartz model and sample duration was highly significant in both models.

DISCUSSION

For all data sources, the data submitted represents samples collected from multiple construction projects. The objective for sampling (regulatory compliance, site characterization, worst case, etc.) is not known in most cases. It is also not known if the sample period encompasses the entire period of dust exposure and whether only one sample was collected on one worker for the monitored shift. Over half of the samples were obtained from federal OSHA or state plan agencies and these data tended to have fewer details recorded.

We attempted to collect data for 16 exposure determinant variables. With data coming from various sources, some with more complete data collection and retention mechanisms than others, the database has considerable data gaps. This project illustrates the importance of thorough and detailed data collection and documentation. The majority of samples collected were from regulatory sources. These sources provided much larger data sets but with much more limited detail (Table III). With improved regulatory agency databases, these data could serve as a more valuable resource for understanding exposures and contributing factors.

For source type there was a statistically significant difference between means although with modeling it was not significant. Data sources represented in this data set usually evaluated construction projects in only one or two states and for most sources projects tended to be of only one construction sector so there may be considerable overlap of state, data source, and construction sector. Source type was removed from the model for nonsignificance. State was excluded from the model due to overlap with construction sector.

TABLE II. Quartz and Respirable Dust Concentrations by Exposure Variable

	Quartz (mg/m^3)		Respirable dust (mg/m^3)	
	N	**GM (GSD)**	**N**	**GM (GSD)**
Total	**1374**	**0.13 (5.9)**	**1394**	**1.36 (5.4)**
Task				
Tuckpoint grinding	101	0.60 (5.5)	97	6.05 (3.9)
Surf grinding	122	0.29 (5.0)	114	2.72 (5.9)
Cut trench/tunnel	8	0.25 (37.0)	9	15.64 (2.7)
Abrasive blasting	64	0.24 (5.0)	65	3.74 (5.9)
Drill concrete	97	0.20 (5.2)	95	1.82 (4.4)
Cut other[A]	20	0.18 (4.4)	21	1.36 (4.3)
Unreported	239	0.17 (6.9)	250	1.28 (6.0)
Hand-held demolition	226	0.14 (4.3)	228	1.63 (4.1)
Road demo	51	0.09 (3.9)	50	0.72 (2.8)
Cut concrete/brick	164	0.08 (4.0)	185	0.72 (3.8)
Other highway[B]	19	0.07 (8.0)	20	0.42 (6.8)
Hod carrier/mixing	54	0.05 (4.7)	52	1.26 (3.9)
Cleanup	61	0.05 (3.7)	62	0.66 (3.5)
Other industrial/commercial[C]	53	0.04 (2.9)	51	0.48 (4.3)
Prep/finish concrete	50	0.03 (3.4)	49	0.61 (3.9)
Heavy equipment demolition	45	0.03 (4.7)	46	0.34 (4.8)
Tool				
Tuck point grinder	102	0.61 (5.4)	98	6.36 (3.9)
Surface grinder	123	0.28 (5.1)	114	2.83 (5.6)
Abrasive blaster	56	0.24 (5.0)	56	4.44 (5.9)
Rock drill	93	0.21 (5.2)	92	1.86 (4.7)
Hand-held saw	65	0.13 (5.4)	71	1.13 (4.5)
Jackhammer/chipping gun	178	0.15 (4.1)	180	1.60 (4.1)
Unreported	360	0.14 (6.2)	378	1.19 (5.1)
Road mill	48	0.11 (3.6)	48	0.90 (2.7)
Walk behind saw	33	0.09 (3.3)	37	0.52 (3.8)
Other highway[D]	37	0.09 (4.8)	36	0.49 (6.2)
Table saw	51	0.07 (3.9)	53	0.85 (3.8)
Other industrial/commercial[E]	63	0.06 (5.3)	63	0.99 (6.0)
Concrete mixer	32	0.04 (4.0)	32	1.39 (3.9)
Broom/shovel	49	0.03 (3.6)	50	0.48 (3.5)
None	56	0.03 (3.3)	56	0.42 (4.1)
Backhoe, excavator, bulldozer, and bobcat	28	0.01 (2.6)	30	0.36 (5.3)
Trade				
Abrasive blaster	48	0.22 (5.3)	49	4.44 (5.8)
Cement finisher	229	0.16 (7.0)	217	2.01 (5.9)
Laborer	591	0.14 (5.4)	607	1.39 (4.8)
Stone/brick mason	240	0.13 (6.6)	250	1.49 (5.8)
Hod carrier	34	0.10 (4.2)	32	1.03 (4.1)
Unreported	38	0.10 (7.5)	38	0.95 (8.8)
Other[F]	92	0.10 (4.4)	96	0.75 (4.2)
Heavy equipment operator	102	0.05 (4.2)	105	0.53 (4.2)
Controls				
Isolation	16	0.17 (7.5)	13	1.68(12.3)
LEV	67	0.14 (4.9)	67	1.57 (6.6)
Unreported/other	1145	0.14 (6.1)	1158	1.45 (5.4)
Water	146	0.08 (4.4)	156	0.78 (3.9)

(Continued on next page)

TABLE II. Quartz and Respirable Dust Concentrations by Exposure Variable *(Continued)*

	Quartz (mg/m^3)		Respirable dust (mg/m^3)	
	N	GM (GSD)	N	GM (GSD)
Total	**1374**	**0.13 (5.9)**	**1394**	**1.36 (5.4)**
Nearby Dust Source				
Sometimes	124	0.17 (4.9)	122	1.55 (4.9)
Usually	77	0.13 (5.3)	77	1.77 (5.4)
Unreported	1025	0.13 (5.9)	1049	1.35 (5.5)
Rarely/never	148	0.09 (6.1)	146	1.13 (5.1)
Environment				
Confined (stairwell, corridor, tunnel)	15	0.33 (5.6)	13	5.58 (4.9)
Partially enclosed (2–4 walls)	74	0.21 (4.7)	74	2.10 (4.9)
Unreported	851	0.15 (5.6)	867	1.49 (5.3)
Enclosed (walls, roof, and windows)	160	0.12 (6.7)	163	1.52 (5.6)
Open	274	0.08 (5.8)	277	0.78 (5.2)
Construction Sector				
Unreported	591	0.17 (6.2)	612	1.58 (6.1)
Residential	24	0.14 (8.2)	24	2.53 (5.5)
Highway/bridge	294	0.13 (5.5)	291	1.09 (4.9)
Industrial/commercial	465	0.09 (5.2)	467	1.23 (4.7)
Project Purpose				
Unreported	793	0.17 (5.9)	816	1.63 (5.4)
Other[G]	341	0.10 (5.0)	342	1.25 (5.0)
New construction	240	0.07 (5.8)	236	0.83 (5.3)
Sampling Device				
Impactor	2	0.48 (1.1)	2	10.38(1.1)
BGI cyclone	68	0.36 (4.7)	68	1.97 (4.4)
Nylon cyclone	1077	0.13 (5.8)	1099	1.34 (5.3)
Aluminum cyclone	181	0.13 (6.1)	182	1.42 (6.5)
Direct-reading	37	0.08 (3.9)	37	0.92 (3.6)
Unreported	9	0.03 (3.6)	6	0.35 (2.6)
Quartz Analytical Method				
Unreported	2	0.94 (7.4)	47	0.79 (3.2)
FTIR	406	0.16 (5.5)	372	1.54 (4.6)
XRD	966	0.12 (6.0)	975	1.34 (5.8)
Sample Year				
1992–1995	107	0.23 (6.4)	114	1.49 (5.7)
1996–1998	471	0.18 (5.4)	474	1.58 (5.0)
1999–2002	796	0.09 (5.7)	806	1.22 (5.5)

[A] Cut fibrous cement board and unreported substrate.
[B] Demolition support, flagger, inspector, rock crusher, transport, and pile driver.
[C] Apply shot crete, polish stone, lay brick, hang fibrous cement board, sand drywall, transport, flagger.
[D] Vermeer saw, boring machine, compressed air, drill rig, crane, rock crusher, water truck.
[E] Vacuum cleaner, wall saw, core drill, trenching machine, compressed air, hydraulic shear, rock crusher, gunite gun, water spray.
[F] Plumber, fabricator, painter, electrician, carpenter, drywall, and iron worker.
[G] Renovation, maintenance, and demolition.

TABLE III. Unreported Factors by Data Source

Data Source	N	Controls	Environment	Near by Dust	Construction Sector
Private	134	55%	7%	49%	0%
Research	544	75%	25%	50%	1%
Regulatory	774	94%	99%	99%	82%

Note: Percentage of all records missing.

TABLE IV. Respirable Quartz Percentage by Tool Used

		Respirable Quartz Percentage Range			
Tool	**N**	**0–5%**	**6–10%**	**11–15%**	**Over 15%**
Tuckpoint grinder	102	7 (8%)	40 (44%)	32 (35%)	12 (13%)
Surface grinder	123	13 (11%)	44 (38%)	28 (25%)	30 (26%)
Abrasive blaster	56	21 (50%)	7 (18%)	2 (5%)	12 (29%)
Rock drill	93	6 (7%)	29 (32%)	21 (23%)	34 (38%)
Hand-held saw	65	6 (10%)	12 (20%)	25 (41%)	18 (29%)
Jackhammer	178	32 (19%)	42 (25%)	36 (22%)	55 (33%)
Road mill	48	2 (4%)	16 (33%)	12 (25%)	48 (38%)
Walk behind saw	33	2 (6%)	7 (22%)	5 (16%)	18 (56%)
Table saw	51	11 (23%)	16 (33%)	11 (23%)	10 (21%)
Concrete mixer	32	16 (55%)	6 (21%)	4 (14%)	3 (10%)
Backhoe, excavator, bulldozer, bobcat	28	6 (25%)	5 (21%)	4 (17%)	9 (37%)
Broom/shovel	49	7 (16%)	23 (53%)	6 (14%)	7 (17%)

Ideally, all exposure sampling would be conducted for a full shift when comparison is made with a full shift occupational standard. In construction it is frequently not feasible to characterize exposure with full shift sampling because tasks can change often within a shift. Even regulatory samples collected in this database were, more often than not, partial shift samples. There is considerable difference in exposure level reported for shorter vs. longer sample durations. Confidence in this interpretation is strengthened because this trend is sustained for all data source types. The higher exposures at shorter duration found in this data set suggest that short term samples are more likely to be continuous dusty operations and perhaps task samples, although this cannot be concluded with the information available.

It was encouraging to see a downward trend in exposure over the period represented in this data set although quartz exposure for the most recent period (1999–2002) was still almost twice the TLV.

As tool and task are defined in this database, they often overlap. Frequently the tool used and task performed are describing the same construction activity. This is why task dropped out of multiple regression modeling. When designing a data collection scheme for construction, tool may be a more descriptive variable than task, with less uncertainty about interpretation of category definitions.

For trade, task, and tool, (Table II) exposures generally agree with levels reported in the literature.(3−10) For trade, abrasive blasting was the highest quartz exposure followed by cement finisher, laborer, and stone/brick mason. It was unexpected that for both task and tool, the highest quartz exposure was tuck point grinding, followed by surface grinding, both exceeding abrasive blasting which is commonly considered an extremely high exposure.

For abrasive blasting, practices vary with air samples collected both inside and outside of the blasting hood. The GM abrasive blasting exposure was considerably lower than sand blasting concentrations outside the hood reported by Linch.(14) Information on blasting medium was not collected in this dataset. In the last decade several alternative nonsilica blasting agents have been introduced.(15) Some of these agents may have been used during some of the abrasive blasting sampling in this dataset. Unreported information on these factors limit confidence in the abrasive blasting results.

The range of exposures for any tool or task is extremely broad–spanning 3 or 4 orders of magnitude for most tasks and tools. This wide range means that using any measure of central tendency to represent an activity could seriously underestimate exposures in some cases. For this data set, 13% of all quartz samples were over 1.0 mg/m^3 or 20 times the TLV. These extremely high exposures represented 9 of 12 tools and less than half were abrasive blasting or grinding samples, those activities one might expect to produce extreme exposures.

The heterogenous nature of construction silica exposure has been recently documented by Nij et al(16) and Rappaport et al.(6) Rappaport et al found that between worker variance tended to be much greater than within worker variance when looking at activities for four trades. Nij et al found that differences in the material worked explained most differences in between worker variance in a study of 8 construction tasks.

There are other factors that are also very important to exposure. The degree of work area enclosure, the presence and degree of natural ventilation, adjacent dusty activities, and the continuous vs. intermittent nature of the dusty task are all potentially important factors. Environment was identified as important in multiple regression modeling of these data. Flanagan et al(7) and Akbar-Khanzadeh and Brillhart(17) were able to document the importance of these factors for some construction activities. More work is needed to describe the factors that produce variability, with a focus on identifying situations that result in the highest exposures so they can be targeted for control.

TABLE V. Exposure Determinant Models for Quartz and Respirable Dust Exposure

	LnQuartz–$R^2 = 0.29$		**LnRespirable Dust–$R^2 = 0.22$**	
	β	**SE**	β	**SE**
Intercept	−4.21*	0.50	−0.75	0.49
Tool				
Tuck point grinder	3.54*	0.40	2.84*	0.38
Surface grinder	2.28*	0.39	1.36*	0.37
Abrasive/sand blaster	1.68**	0.59	1.39**	0.59
Hand-held saw	1.65*	0.39	0.80**	0.37
Table top saw	1.38**	0.42	0.79**	0.40
Jackhammer/chipping gun	1.41*	0.36	0.84**	0.34
Walk behind saw	1.11**	0.44	0.01	0.42
Rock drill	1.52*	0.37	0.89**	0.35
Concrete mixer	0.94**	0.44	1.30**	0.43
Road mill	1.41*	0.38	0.64**	0.36
Unreported	1.28*	0.36	0.61**	0.34
Other—industrial/commercial	0.71***	0.38	0.37	0.36
Other—highway/bridge	0.44	0.41	−0.33	0.39
None	0.22	0.40	−0.32	0.38
Broom/shovel	0.14	0.40	−0.34	0.38
Backhoe/excavator/dosier/bobcat	—		—	
Trade				
Abrasive blaster	0.61	0.55	0.84	0.52
Laborer	0.45***	0.21	0.39**	0.20
Finish mason	0.36	0.25	0.53	0.24
Hod carrier	−0.01	0.35	−0.16	0.35
Unreported	−0.38	0.34	−0.14	0.33
Stone mason	−0.23	0.25	−0.28	0.25
Other	−0.22	0.27	−0.08	0.27
Heavy equipment operator	—		—	
Sample Duration (min)	−0.01*	0.00	−0.01*	0.00
Environment				
Confined (stairwell, corridor, tunnel)	0.94**	0.46	1.41**	0.46
Unreported	0.29**	0.14	0.41**	0.14
Partially enclosed (2–4 walls)	0.60**	0.21	0.64**	0.21
Enclosed (walls, roof, and windows)	0.56**	0.16	0.76*	0.16
Open	—		—	
Construction Sector				
Highway/bridge	0.39	0.37	0.47	0.38
Industrial/commercial	−0.11	0.36	−0.10	0.36
Unreported	0.06	0.37	0.08	0.37
Residential	—		—	
Controls				
Isolate	0.62	0.46	0.54	0.46
Unreported/other	0.25	0.16	0.06***	0.15
LEV	−0.61**	0.27	−0.53**	0.26
Water	—		—	
Sample Year				
1992–1995	0.52**	0.18	0.21	0.17
1996–1998	0.30**	0.10	0.15	0.10
1999–2002	—		—	
Quartz%	2.08*	0.29		

Note: Parameter set to zero because it is redundant. Dependent Variable, ln of conc. (mg/m^3) *$p \leq .001$; **$p \leq .05$; ***$p \leq .1$.

Quartz % means were significantly different by construction sector. Differences in construction techniques and to some extent the concrete composition could explain this difference. All concrete contains three components: a cement and water mixture known as paste (containing little or no silica); sand (almost always a silica base); and aggregate rock (with silica content depending on the rock source). For industrial projects the composition is approximately 30% paste, 30% sand, and 40% aggregate by volume. Highway projects may contain a somewhat smaller proportion of paste and larger proportion of aggregate. Highways are built on a crushed rock support layer, potentially creating silica dust during hauling and dumping. Highway projects are usually scheduled during warmer weather when soil and materials are dry, whereas industrial projects continue through most seasons, including wetter weather. As concrete is finished, the sand and aggregate are pushed into lower layers and the paste rises to the top creating a smooth surface. On industrial sites the concrete mixture is often worked longer to produce a finer finish and more of the paste containing little or no silica is at the surface. As tools are used to cut, break, or finish the concrete, the tools' abrading or cutting action and the depth of intrusion into the slab will affect the respirable quartz content of the dust generated.

Quartz Percent was calculated from the respirable air sample. Information was not collected on the substrate worked and no bulk sampling was included in this dataset. Contractors are interested in a simple sampling strategy and have expressed an interest in collecting bulk samples to assess a quartz hazard. Since there may be differences in silica content through the depth of a slab, and the demolition or construction activity will likely affect the particle size distribution of the dust, bulk samples offer only a crude measure for assessing a respirable silica hazard.

On average, silica exposures on construction sites need to be reduced. For exposure by task, 12 of 15 categories and for tool 12 of 16 categories are at or in exceedance of the TLV. Controls are needed, whether it be provided by respiratory protection or engineering controls. In a recent study with some use of dust masks and half face cartridge respirators on commercial construction sites,(7) the respirator choice was frequently inadequate for the exposure encountered. If engineering controls were already appropriately employed, the high exposures found in this data set would not be occurring.

Only long-term or "full shift" samples were analyzed for comparison with a full-shift exposure limit. Adequate respiratory protection is defined as exposure below the TLV inside the respirator considering the protection factor of a given respirator. The percentage of tool users protected was calculated using the long term (over 6 hours) samples for 10 tools. For all tools except backhoe/excavator, working without a respirator would usually result in some overexpsoures, with about half of cement mixer operators overexposed without a respirator (Figure 1) and even more for most other tools. As the level of respiratory protection increases, more tool users are protected, although even with a full face respirator, only 73% of tuckpoint grinders, 87% of surface grinders and 90% of rock drillers would have adequate respiratory protection.

The use of a positive pressure abrasive blasting helmet is generally recognized as the appropriate protective gear for abrasive blasters. It is interesting that this level of protection is unusual for grinding and drilling, but it appears from Figure 1 that a positive pressure respirator would be the appropriate choice, for at least some grinding and drilling activities.

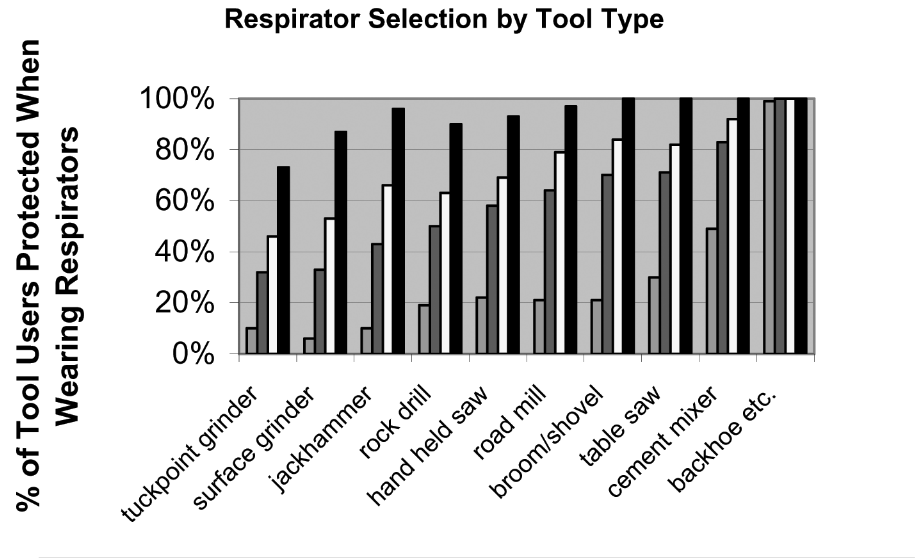

FIGURE 1. Percentage of tool users who would be protected if wearing respirators (all samples >6 hours duration)

The Control categories are fairly crude in describing the different control options attempted at different construction sites. "Water" represents a wide range of controls involving the use of water from occasional wetting before beginning a task to a fine mist continuously applied at the point of operation. Often it was difficult to categorize a control any more precisely than "water" because the descriptive notes were limited. The same was true of ventilation and isolation. More thorough record keeping is critical for better understanding the importance of controls and a more rigorous approach will provide more robust results. Even with these limitations, concentrations were lower with local exhaust ventilation than when water was applied for dust control. When no control mechanism was reported, concentrations were higher than when water was applied. Not surprisingly, the highest concentrations were for the isolation category. Isolation of very dusty activities by curtaining off or otherwise separating it, often in a small space, is used to control exposure to nearby workers. In this more enclosed environment the worker generating the dust is likely to have greater exposure.

Although these data suggest dust controls have not been widely adopted, effective control options have been identified in several recent studies.(6,16–19) It is now the industry's challenge to implement these controls more rigorously and perhaps in combination with personal protective equipment and administrative controls.

CONCLUSIONS

This compilation database is much larger than any of the construction data sets previously reported in the literature. Exposure levels generally agree with studies previously reported and the larger sample size offers more confidence for characterizing silica construction exposures although there are considerable limitations with the quality of these data.

Silica exposures on construction sites are on average high and can be extremely high. This is true for a broad spectrum of tools and construction activities. The controls typically used do not adequately protect workers who are engaged in these dust generating activities. More research is needed to identify the factors that produce the highest exposures so that strategies can be identified to target and control them.

ACKNOWLEDGEMENTS

All organizations that provided data for this project are gratefully acknowledged for their contributions. They include John Dimos and the Construction Safety Council, Alan Echt and Ken Linch of NIOSH, Steve Eversmeyer of Marine Environmental Testing, Mark Goldberg of Hunter College–City University of New York, Scott Knowlon of Cianbro Corporation, Jeff Leons and Al Lemon of the Washington Department of Labor and Industry, Kermit McCarthy of Oregon OSHA, Venetia Runnion of the Clayton Group Services Seattle office, Charles Shields of the Aurora, IL OSHA office, Don Schill of the New Jersey Department of Health, Pam Susi of the Center to Protect Workers Rights, and the University of Washington.

Support for data analysis was provided under NIOSH Contract 2002-Q-0048.

REFERENCES

1. **National Institute for Occupational Safety and Health:** *Work-Related Lung Disease Surveillance Report 1999.* Cincinnati, OH: NIOSH (1999).
2. **Bang, K.M., R. Althouse, J. Kim, S. Game, and R. Castellan:** Silicosis mortality surveillance in the United States, 1968–1990. *Appl. Occup. Environ. Hyg. 12*:1070–1074 (1995).
3. **Blute, N.A., S.R. Woskie, and C.A. Greenspan:** Exposure characterization for highway construction Part 1: Cut and cover and tunnel finish stages. *Appl. Occup. Environ. Hyg. 14*:632–641 (1999).
4. **Lofgren, D.J.:** Silica exposure for concrete workers and masons. *Appl. Occup. Environ. Hyg. 8*:832–836 (1993).
5. **Linch, K., W. Miller, R. Althouse, D. Groce, and J. Hale:** Surveillance of respirable crystalline silica dust using OSHA compliance data (1979–1995). *Am. Jour. Ind. Med. 34*:547–558 (1998).
6. **Rappaport, S., M. Goldberg, P. Susi, and R. Herrick:** Excessive exposure to silica in the U.S. construction industry. *Ann. Occup. Hyg. 47*(2):111–122 (2003).
7. **Flanagan, M.E., N. Seixas, M. Majar, J. Camp, and M. Morgan:** Silica dust exposures during selected construction activities. *Am. Ind. Hyg. J. 64*:319–328 (2003).
8. **Riala, R.:** Dust and quartz exposure of Finnish construction site cleaners. *Ann. Occup. Hyg. 32*:215–220 (1988).
9. **Thorpe, A., A. Ritchie, M. Gibson, and R. Brown:** Measurements of the effectiveness of dust control on cut-off saws used in the construction industry. *Ann. Occup. Hyg. 43*:443–456 (1999).
10. **Woskie, S., A. Kalil, D. Bello, and M. Virji:** Exposures to quartz, diesel, dust, and welding fumes during heavy and highway construction. *Am. Ind. Hyg. J. 63*:447–457 (2002).
11. **Hornung, R.W., and L.D. Reed:** Estimation of average concentration in the presence of nondetectable values. *Appl. Occup. Environ. Hyg. 5*:46–51 ((1990).
12. *NIOSH Respirator Selection Logic 2004* Cincinnati, OH. NIOSH Publication No. 2005-100 (2005).
13. **Rappaport, S.M.:** The rules of the game: An analysis of OSHA's enforcement strategy. *Am. J. Ind. Med. 6*:291–303. (1984).
14. **Linch, K.:** Respirable concrete dust–silicosis hazard in the construction industry. *Appl. Occup. Environ. Hyg. 17*:209–221 (2002).
15. **Porter, D, A. Hubbs, V. Robinson, L. Battelli, M. Greskevitch, M. Barger, D. Landsittel, W. Jones, and V. Castravova:** Comparative pulmonary toxicity of blasting sand and five substitute abrasive blasting agents. *J. Toxicol. Environ. Health A. 65*(16):1121–1140 (2002).
16. **Nij, E., D. Hohr, P. Borm, I. Burstyn, J. Spierings, F. Steffens, M. Lumens, T. Spee, and D. Heederik:** Variability in quartz exposure in the construction industry: Implications for assessing exposure-response relations. *J. Occup. Environ. Hyg. 1*:191–198 (2004).
17. **Akbar-Khanzadeh, F., and R. Brillhart:** Respirable crystalline silica dust exposure during concrete finishing (grinding) using hand-held grinders in the construction industry. *Ann. Occup. Hyg. 46*(3):341–346 (2002).
18. **Croteau, G., S. Guffey, M. Flanagan, and N. Seixas:** The effect of local exhaust ventilation controls on dust exposures during concrete cutting and grinding activities. *Am. Ind. Hyg. J. 63*:458–467 (2002).
19. **Croteau, G., M. Flanagan, J. Camp, and N. Seixas:** The efficacy of local exhaust ventilation for controlling dust exposures during concrete surface grinding. *Ann. Occup. Hyg.* (2004).
20. **Echt, A., K. Sieber, E. Jones, D. Schill, D. Lefkowitz, J. Sugar, and K. Hoffner:** Control of respirable dust and crystalline silica from breaking concrete with a jackhammer. *Appl. Occup. Environ. Hyg. 18*:491–495 (2003).