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Silica Dust Exposures During Selected Construction Activities

This study characterized exposure for dust-producing construction tasks. Eight common construction tasks were evaluated for quartz and respirable dust exposure by collecting 113 personal task period samples for cleanup; demolition with handheld tools; concrete cutting; concrete mixing; tuck-point grinding; surface grinding; sacking and patching concrete; and concrete floor sanding using both time-integrating filter samples and direct-reading respirable dust monitors. The geometric mean quartz concentration was 0.10 mg/m^3 (geometric standard deviation [GSD]=4.88) for all run time samples, with 71% exceeding the threshold limit value. Activities with the highest exposures were surface grinding, tuck-point grinding, and concrete demolition (GM[GSD] of 0.63[4.12], 0.22[1.94], and 0.10[2.60], respectively). Factors recorded each minute were task, tool, work area, respiratory protection and controls used, estimated cross draft, and whether anyone nearby was making dust. Factors important to exposure included tool used, work area configuration, controls employed, cross draft, and in some cases nearby dust. More protective respirators were employed as quartz concentration increased, although respiratory protection was found to be inadequate for 42% of exposures. Controls were employed for only 12% of samples. Exposures were reduced with three controls: box fan for surface grinding and floor sanding, and vacuum/shroud for surface grinding, with reductions of 57, 50, and 71%, respectively. Exposures were higher for sweeping compound, box fan for cleanup, ducted fan dilution, and wetted substrate. Construction masons and laborers are frequently overexposed to silica. The usual protection method, respirators, was not always adequate, and engineering control use was infrequent and often ineffective.

Keywords: cleanup, construction, demolition, grinding, silica exposure

APPLIED STUDIES

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Silica exposure is a primary hazard for the construction industry, but it has not been well characterized due to factors including frequent turnover of personnel and continually changing workplaces, tasks, and environmental conditions.

Silica exposure has been associated with excess disease for construction populations. More silicosis deaths were associated with construction than any other industry,[1,2] and significantly elevated mortality risk from silicosis has been observed for construction workers.[3] Pulmonary tuberculosis, known to be more prevalent among silicotics, was elevated for construction laborers[3] and a general construction population.[4] Silica exposure has been associated with lung cancer in recent years, with elevated lung cancer risk reported for construction workers by Stern,[5] Robinson,[3] Engholm,[6] Knutsson,[7] Lynge,[8] and Ng.[4] Reduced lung function also has been reported with exposure to low levels of concrete dust containing silica.[9]

Highly elevated quartz exposures have been reported for several construction activities[10–22] (see Table I) although levels appear to be conflicting from one study to the next. For most activities the sample size is small or focuses on only one or two activities. Some studies measured short term and/or concentrated dust-producing activities, whereas other studies sampled for a full shift. Full-shift samples often include numerous activities, when the target activity was only one of several activities occurring during the sampling period, making interpretation of the sample results less clear. A range of environmental conditions and process differences could also contribute to the variability seen in previous studies.

TABLE I. Quartz Exposures (mg/m³) for Construction Workers by Activity

Reference and Population	Cleaning n	Cleaning Mean (SD)	Surface Grinding n	Surface Grinding Mean (SD)
Lofgren, 1993 WA state regulatory inspections[23]			9	0.80 (0.43)
Chisholm, 1999, British construction[24]	3	0.52 (0.22)		
Riala, 1988, Finnish construction[25]	44	0.48 (UNK)		
Blute et al., 1999, U.S. highway construction[26]			3	0.01 (UNK)
Lumens, 1997, Dutch construction[27]				
Gressel et al. (Case 4), 1999, U.S. construction[10]			7	0.25 (0.27)
Case 11, 1999[11]				
Case 16, 1999[12]				
Case 17, 1999[13]				
Case 18, 1999[14]				
Case 23, 1999[15]				
Shields, 1999, OSHA construction inspections[16]	2	100% >PEL	1	>PEL

Note: UNK = unknown; SD = standard deviation; PEL = permissible exposure limit.
[A]With jackhammer or chipping gun
[B]GM and GSD

The purpose of this study was to provide a more comprehensive evaluation of exposure to silica during common dust-producing construction activities, to identify factors that are important in affecting exposure levels, and to characterize exposure for noncontinuous tasks.

METHODS

After consultation with a group of construction contractor safety directors, a list of eight activities common to many large construction projects was selected, based on frequency of occurrence and expected level of dust produced (see Appendix A). These activities were cleanup; demolition using hand tools; concrete cutting with handheld or table mount saws; concrete and mortar mixing; tuck-point grinding; surface grinding; sacking and patching concrete; and concrete floor preparation with a sandpaper disk (floor sanding).

Sampling occurred from August 2000 through January 2001 for 42 on-site days at nine large construction sites representing six contractors. Projects included five cast-in-place concrete office buildings ranging in size from three to five stories, two concrete block two story structures, one concrete tilt-up one story office building, and a major renovation of a university library.

Site days were selected primarily at the convenience of researchers, usually without advance knowledge of that day's scheduled construction activities. Volunteer subjects were recruited at the start of the shift by a referral from the foreman or during the shift as workers were observed conducting activities of interest. *Activity* is defined as the period of sampling, including ancillary functions performed in support of the activity. *Task* is used to define only the dust-producing portion of the activity.

Sample and Data Collection

Sampling was conducted for the entire activity period a worker was engaged in the target task or doing other tasks to support additional target task work. Occasionally there were large time gaps between target task occurrences when setup, cleanup, or other tasks were completed in support of the target task.

Two types of sampling devices were used. A 10-mm Dorr-Oliver nylon cyclone with polyvinyl chloride (PVC) filter calibrated at 1.7 L/min was used to measure average concentrations during full work activities. Personal DataRam (pDR) light-scattering photometers (models 1000 and 1200)[23] fitted with BGI cyclone preselectors and PVC filters and calibrated to 2.2 L/min were used to assess task-specific exposures, peak levels, and run-time averages. The pDRs were positioned with the pump in a small backpack with 12-inch silicon tubing extending from the cyclone inlet to the subject's shoulder.

Subjects were fitted with either a nylon cyclone or a pDR sampling device on each sampling day. Subjects monitored with a nylon cyclone were asked to record their tasks on a task card that delineated task, tool, respiratory protection used, work area (enclosed, inside, partially enclosed, or outside), and whether anyone nearby was making dust (Y/N). Subjects monitored with a pDR were observed by a researcher who recorded the following variables for each minute: task, tool, work area, respiratory protection used, controls employed, estimated cross draft, and whether anyone nearby was making dust.

Work area was categorized as outside, partially enclosed (not all walls and windows in place), inside, or enclosed. Examples of enclosed areas are stairwells and confined plastic enclosures. Respirators encountered included dust masks and half-face cartridge respirators. At some sites respirator protection was mandated by management during dusty operations, whereas it was a matter of worker choice at other sites. The control strategies employed varied among sites, with some sites having a much greater emphasis on controls for dust reduction than other sites. Cross draft was estimated (none, low, medium, high) using prior researcher experience and observation of visible dust as a guide. Two researchers conducted the observations and classified work area and cross draft for modeling. Although between-researcher agreement was not quantified, the researchers worked together for the first several site days and made joint decisions on classification to assure reasonable concordance on how these variables were classified.

To calibrate the three sampling devices (nylon cyclone, pDR 1000, and pDR 1200) to each other, side-by-side area samples were collected.[23,24] The three devices were placed together in a basket on a tripod with sampler inlets located within 2 inches of each other. Twenty sample sets were collected, with duration ranging from 18 to 59 min. Sampling was conducted at construction sites with samplers positioned close to operations producing moderate to high concrete dust concentrations. Each pDR instrument response was paired to its respective cyclone filter result, giving a total of 31 sample pairs. Regression analysis was conducted using

TABLE I. Extended

Tuck-Point Grinding		Saw Cutting Concrete		Drilling Concrete		Demolishing Concrete[A]	
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
6	1.35 (0.95)	2	3.73 (5.0)	3	0.22 (0.10)		
4	5.2 (1.75)	6	0.98 (1.46)	6	31.3 (47.0)	6	0.20 (0.10)
				10	0.43 (UNK)	13	0.23 (UNK)
		36	0.04 (2.6)[B]			82	1.1 (4.0)[B]
						4	0.13 (0.02)
		6	0.02 (0.01)				
		6	0.18 (0.07)				
		5	0.16 (0.17)				
15	0.98 (1.71)						
37	84% >PEL	24	50% >PEL			20	25% >PEL

the nylon cyclone sample as the dependent variable, and the resulting regression line was used to calculate adjusted respirable dust (and silica) concentrations for either run-time averages or 1-min concentrations from the pDRs.

Respirable dust samples were analyzed following National Institute for Occupational Safety and Health (NIOSH) method 600.[19] Filters were equilibrated in an environmental chamber (relative humidity 32%) for at least 2 hours before weighing on a Mettler MT-5 analytical balance with a resolution of 0.001 mg. The laboratory's limit of detection was 5.0 μg. Quartz analysis followed NIOSH method 7602,[19] using a Fourier transformed infrared spectrophotometer. The quartz limit of detection was 5.5 μg.

Analyses were conducted on run-time average dust and quartz concentrations from nylon cyclone and pDR (adjusted) results and also on the 1-min adjusted dust concentrations from the pDR.

For samples below the analytical detection limit, the detection limit divided by the square root of 2 was used as the value for all data analysis.[20] All data were lognormally transformed before analysis, because the data were generally lognormally distributed. Geometric means, geometric standard deviations, and parametric exceedance fractions[27] were used for summary statistics in run time average and 1-min data sets. The parametric exceedance fraction was selected over the actual exceedance fraction, because the actual exceedance fraction is extremely unstable for a small sample size,[10] and the intent was to exploit the material in this data set to the maximum extent.

The determinants of exposure concentrations were assessed using multiple linear regression modeling for 1-min concentrations for the three activities that had at least six sampling sessions: surface grinding, hand demolition, and cleanup. Factors were added to the model stepwise and included if the coefficients were significant ($p<.05$).

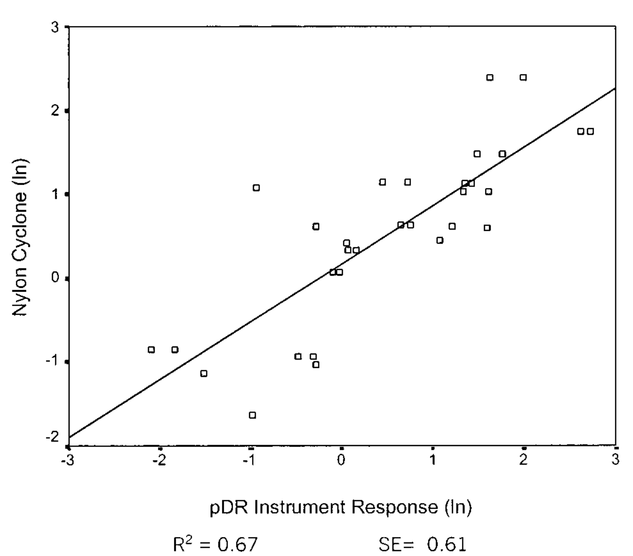

FIGURE 1. Nylon cyclone versus pDR concentrations

RESULTS

For the side-by-side area samples (Figure 1), no difference was observed between the two pDR results, and a clear linear relationship (on the log scale) was observed between the nylon cyclone and pDR results. The R^2 was .67, the standard error was 0.61, and the observed regression line was

$$\ln(\text{nylon cyclone}) = 0.1714 + 0.6932 \times \ln(\text{pDR})$$

This relationship was used to adjust the pDR-derived concentrations to be comparable with the standard nylon cyclone values. Part of the residual variation may derive from particle distribution in various tasks. Thorpe and Walsh found in a controlled study that the monitor to cyclone ratio varied somewhat with stone particle size with ratios of 0.91–0.97 at 4 μm and 1.12–1.22 for 6.4 μm.[18] The present calibration study, which occurred under field conditions, is valid because it was done under conditions observed in the study, despite the increased variability that may occur.

Respirable dust and quartz run-time average concentrations by activity are presented in Table II. There were 113 samples collected, representing eight activities and one "mixed" activity category. Sample duration averaged 202 (standard deviation=97) min. The highest exposures were during surface grinding and tuck-point grinding, and the lowest exposures were for cleanup and sacking/patching concrete. Mixed samples may be elevated due to amount of surface grinding represented in these samples. Although geometric means for respirable dust were substantially less than the American Conference of Governmental Industrial Hygienists threshold limit value (TLV®) of 3.0 mg/m³, 34% of the sample distribution would be expected to exceed the respirable dust TLV of 3 mg/m³.

The geometric mean quartz concentration was 0.11 (geometric

TABLE II. Respirable Dust and Quartz Run-Time Averages (mg/m³)[A]

Usual Trade	Activity	n	Duration (min) Mean (SD)	Respirable Dust GM (GSD)	Respirable Dust TLV Exceed %	Quartz GM (GSD)	Quartz TLV Exceed %	Quartz % Mean (SD)	% Quartz Samples <LOD
Laborer	cleanup	11	226 (68)	0.55 (1.82)	5	0.03 (2.79)	50	6.0 (4.0)	36
Laborer	hand demolition	14	215 (77)	0.96 (2.18)	21	0.10 (2.60)	88	13.2 (8.0)	7
Brick mason	concrete cutting	15	285 (118)	0.76 (2.14)	14	0.07 (2.78)	77	12.4 (8.9)	7
Brick mason	concrete mixing	9	262 (98)	0.91 (1.70)	13	0.02 (1.99)	20	2.2 (1.5)	56
Brick mason	tuck-point grinding	12	128 (25)	2.25 (2.10)	54	0.22 (1.94)	100	12.2 (11.8)	0
Cement finisher	surface grinding	23	146 (87)	6.17 (3.16)	84	0.63 (4.12)	100	11.7 (5.9)	0
Cement finisher	sack and patch concrete	13	219 (104)	0.40 (2.01)	3	0.03 (2.22)	40	11.0 (12.6)	54
Cement finisher	concrete floor sanding	9	184 (52)	0.63 (1.73)	7	0.07 (2.62)	80	21.0 (27.6)	33
Cement finisher	mixed[B]	7	227 (118)	2.66 (5.47)	72	0.22 (3.93)	97	10.7 (9.4)	0
Total		113	205 (99)	1.25 (3.95)	34	0.11 (5.21)	75	11.3 (11.5)	19

[A]Cyclone and pDR filter concentrations; pDR respirable dust concentrations adjusted
[B]Includes mixture of surface grinding (6 of 7 samples), patching, cleanup, demolition

standard deviation [GSD]=5.21) mg/m³ with 75% of the run-time average quartz concentration distribution exceeding the quartz TLV of 0.05 mg/m³. For five of the eight activities more than half the sample distribution exceeded the quartz TLV. Quartz, as a percentage of the respirable dust samples, ranged from 2.2 to 21.0% depending on activity.

Respiratory protection use was assessed with quartz data because respirator decisions would normally be based on quartz exposure. As quartz exposure increased, greater respiratory protection was employed, with geometric means (GMs) of 0.03, 0.12, and 0.20 mg/m³, respectively, for no respirator, dust mask, and cartridge respirator (Table III). When no respirator was used, the TLV was exceeded for 46% of samples. When dust mask and cartridge respirators were used (respirator protection factor of 5 for dust mask and 10 for cartridge), concentrations exceeded the respirator's protection concentration for 43% dust mask samples and 38% of cartridge respirator samples. For higher exposure activities (tuck-point grinding and surface grinding) respirators were always used, with a preference for cartridge respirators. Laborers and brick masons tended to favor no respirators or dust masks, whereas cartridge respirators were more common among cement finishers.

Dust control methods were employed rather infrequently, with only 12% of samples using some form of control, including water, area fans, ducted fan exhaust, and sweeping compound.

Surface grinding was the activity with the highest exposures (Table II). Grinding samples included work with 4.5 and 7-inch grinding wheels, and both abrasive grinding (for finer finishing work) and diamond wheels (for more aggressive rough grinding). Quartz exposures when the 4.5-inch grinders were used were 33% less than exposures for 7-inch grinders, and exposures when the abrasive wheel was used were 60% less than exposures when the diamond wheel was employed.

The 1-min average data set offers the opportunity to look at exposures during only the target task or during the full activity sample period, including nontarget tasks. Table IV summarizes adjusted respirable dust exposure for each activity by task and tool (when appropriate). There were 39 sampling sessions conducted to collect 6365 min of data with an overall GM of 0.66 mg/m³ (GSD=3.07). The highest GMs were for tuck-point grinding and surface grinding, the lowest for sacking/patching and floor sanding. For some activities (tuck-point grinding, cleanup, demolition) the subject worked at the target task for most of the sampling session; other activities (concrete mixing, concrete cutting, floor sanding) involved much more time on support tasks than the target task. Some activities showed little difference in exposure between target and nontarget tasks (cleanup, sacking/patching, and floor sanding), and others showed clearly elevated exposure during the target task (grinding, demolition, cutting, and mixing). For

TABLE III. Quartz Run-Time Concentrations by Activity and Respirator Use (mg/m³)

Activity	No Respirator N	No Respirator GM (GSD)	No Respirator % Exceed TLV[A]	Dust Mask N	Dust Mask GM (GSD)	Dust Mask % Exceed w/PF[A]	Half-Mask Cartridge N	Half-Mask Cartridge GM (GSD)	Half-Mask Cartridge % Exceed w/PF[A]
Cleanup	9	0.03 (2.14)	57	1	0.04 (—)	[B]	1	0.01 (—)	[B]
Hand demolition	3	0.07 (3.07)	90	6	0.07 (2.40)	35	5	0.19 (2.27)	44
Concrete cutting	10	0.05 (2.19)	72	4	0.09 (3.74)	59	1	0.39 (—)	[B]
Concrete mixing	6	0.01 (1.80)	17	3	0.02 (2.18)	32	0	—	—
Tuck-point grinding	0	—	—	3	0.30 (2.49)	87	9	0.20 (1.81)	26
Surface grinding	0	—	—	7	0.48 (7.45)	95	16	0.70 (3.10)	76
Sack and patch	4	0.03 (1.78)	54	4	0.03 (1.54)	5	5	0.02 (3.39)	18
Floor sand concrete	1	0.06 (—)	[B]	2	0.10 (1.11)	<43	6	0.06 (3.24)	27
Mixed activities	1	0.03 (—)	[B]	5	0.26 (3.32)	78	1	0.69 (—)	[B]
Total	34	0.03 (2.50)	46	35	0.12 (4.67)	43	44	0.20 (5.00)	38

[A]Percentage of exposures exceeding the TLV and protection factor (PF) for specified respirator (dust mask PF = 5 and half-mask cartridge PF = 10)
[B]GSD needed to calculated percentage unprotected

TABLE IV. One-Minute Adjusted Respirable Dust Concentrations (mg/m³)

Activity	No. of Sampling Sessions	Minutes Sampled	Respirable Dust GM (GSD)	% of Time at Target Task
Cleanup	6	1222	0.66 (1.80)	59
Task: Cleanup		715	0.73 (1.85)	
Concrete demolition		10	0.78 (1.15)	
Other		497	0.56 (1.68)	
Tool: Broom		385	0.73 (1.91)	
Shovel		267	0.76 (1.73)	
Backpack blower		13	1.24 (2.11)	
Chipping gun		10	0.78 (1.15)	
Demolition w/handheld power tools	7	967	0.71 (3.37)	51
Task: Concrete demolition		489	0.99 (3.68)	
Cleanup		169	0.50 (2.89)	
Other		309	0.51 (2.67)	
Tool: Jackhammer		23	0.27 (1.86)	
Chipping gun		118	0.55 (2.67)	
Rivet buster		279	1.09 (4.03)	
Sledgehammer		69	2.73 (1.59)	
Shovel		84	0.61 (2.97)	
Broom		40	0.67 (2.30)	
Vacuum cleaner		25	0.22 (2.66)	
Concrete cutting	4	425	0.88 (2.05)	31
Task: Concrete cutting		132	1.71 (1.94)	
Other		293	0.66 (1.68)	
Tool: Handheld saw (dry)		9	1.64 (2.23)	
Table mount saw (wet or dry)		125	1.47 (2.21)	
Walk behind slab saw (wet)		23	1.01 (1.61)	
Concrete mixing[A]	3	726	0.57 (1.83)	11
Task: Concrete/mortar mixing		78	1.19 (2.09)	
Other		648	0.52 (1.68)	
Tuck-point grinding[A]	3	321	1.44 (3.35)	69
Task: Grinding		220	1.96 (3.11)	
Other		101	0.73 (2.98)	
Surface grinding[A]	8	1272	1.01 (3.75)	40
Task: Grinding		515	3.02 (2.71)	
Cleanup		69	0.65 (1.67)	
Other		688	0.46 (2.64)	
Sack and patch concrete	2	376	0.32 (2.14)	37
Task: Sack and patch		139	0.40 (2.10)	
Other		237	0.28 (2.11)	
Floor sand concrete[A]	4	686	0.20 (2.77)	18
Task: Floor sanding		125	0.31 (2.47)	
Cleanup		90	0.24 (2.50)	
Concrete mixing		20	0.53 (2.84)	
Other		451	0.16 (2.72)	
Mixed tasks	2	370	1.10 (2.47)	—
Task: Surface grinding		34	8.11 (2.17)	
Cleanup		46	1.10 (1.43)	
Concrete demolition		35	2.30 (2.61)	
Concrete mixing		13	1.35 (1.70)	
Sack and patch		134	0.68 (1.40)	
Other		108	0.82 (1.72)	
Total	39	6365	0.66 (3.07)	—

[A]Only one primary tool—same as primary task

cleanup, one tool, the backpack blower, generated higher exposures than other hand tools. For demolition the rivet buster and sledgehammer produced the highest exposures, and for concrete cutting the handheld and table saws were higher than the slab saw with water control.

Several measures to control dust levels were observed during sampling for the 1-min data set, including the following.

- A sweeping compound was used to control dust during sweeping. This compound, composed of dyed sawdust, sand, and mineral oil, is broadcast over the floor before sweeping. With the

TABLE V. Effect of Controls on Adjusted Respirable Dust Exposure (mg/m³)

	None		Sweeping Compound		Box Fan		Ducted Fan Dilution		Local Exhaust Vent		Wetted Substrate	
Task	n	GM (GSD)	n	GM (GSD)	n	GM (GSD)	n	GM (GSD)	n	GM (GSD)	n	GM (GSD)
Cleanup inside	595	0.63 (2.04)	46	0.79 (1.59)	162	0.74 (2.42)	52	1.09 (1.79)	—	—	—	—
Demolition inside	45	1.81 (2.06)	—	—	—	—	152	1.92 (2.14)	—	—	—	—
Tuck-point grinding outside	93	1.47 (2.08)	—	—	—	—	—	—	—	—	127	2.42 (3.73)
Surface grinding inside	47	6.27 (2.44)	—	—	73	2.71 (2.39)	—	—	—	—	—	—
Surface grinding outside	154	4.87 (2.41)	—	—	—	—	—	—	73	1.42 (2.49)	—	—
Floor sanding inside	70	0.42 (2.44)	—	—	55	0.21 (2.13)	—	—	—	—	—	—

sweeping action, the dry dust tends to adhere to the oil-impregnated particles rather than become airborne. The amount of compound used and the uniformity of distribution are likely important factors in its effectiveness.

- A box fan was positioned in a work area with the intent of creating a cross draft to carry dust-laden air from the area. The position of the fan relative to dust generating activities varied greatly.
- An interior space was ventilated by a large exhaust fan and 12-inch diameter duct, exhausting outside the building. Sometimes the space was isolated from adjacent spaces using plastic sheeting, whereas at other times there was no isolation. The duct was sometimes located close the dust generating source.
- A surface grinder with a shroud surrounding the disk was connected to a vacuum with high efficiency particulate air filter.
- Grout (substrate) to be ground was wetted with a hose prior to tuck-point grinding.

A task without controls is compared with the same task with controls in the same type of work area (inside, outside, etc.) in Table V. GMs were reduced for surface grinding or floor sanding inside when a box fan was in use (2.71 versus 6.27 mg/m³, and 0.21 versus 0.42 mg/m³, respectively), and for surface grinding outside when local exhaust ventilation was in use (1.42 versus 4.87 mg/m³). Sweeping compound, box fan for cleanup, ducted fan dilution, and wetted substrate produced higher exposures than the comparable task without dust control. It may be that control strategies were employed only when high exposures were anticipated, so increased exposures while using controls does not necessarily suggest that exposures increased with the use of these controls.

The three activities for which data were collected during at least six sampling sessions were modeled to identify which factors had most effect on exposure. For the surface grinding task, the tool, work area, cross draft, and controls were all highly significant

TABLE VI. Exposure Determinant Models for Surface Grinding

Activity	n	β	SE
Surface grinding—R^2 = .61			
Intercept		−1.54[A]	0.10
Task			
Surface grinding	515	1.86[A]	0.15
Cleanup	69	0.79[A]	0.12
Other (baseline)	688	—	—
Grinder style:			
Abrasive	285	−0.38[B]	0.15
Diamond	195	0.43[C]	0.16
Unknown or none	792	—	—
Work area:			
Enclosed	56	1.55	0.86
Inside	391	0.32[A]	0.08
Partially enclosed	351	0.21[C]	0.07
Outside (baseline)	574	—	—
Cross draft:			
High	30	−0.38	0.25
Medium	423	1.16[A]	0.09
Low	669	1.01[A]	0.09
None (baseline)	150	—	—
Controls:			
Box fan	142	−0.77[A]	0.11
Ducted fan dilution	56	0.24	0.84
Local exhaust vent.	75	−0.94[A]	0.12
None (baseline)	999	—	—

[A]$p \leq .001$
[B]$p \leq .05$
[C]$p \leq .01$

TABLE VII. Exposure Determinant Model for Concrete Demolition

Activity	n	β	SE
Concrete demolition—R^2 = .35			
Intercept		−1.50[A]	0.10
Task:			
Concrete demo	489	0.56[A]	0.16
Cleanup	169	−1.03[A]	0.24
Other (baseline)	309	—	—
Tool:			
Broom	40	1.12[A]	0.29
Shovel	84	0.86[A]	0.26
Chipping gun	118	−0.65[A]	0.19
Rivet buster	279	0.35	0.18
Jack hammer	23	−1.48[A]	0.26
Sledgehammer	69	[B]	—
Vacuum cleaner	25	0.63[C]	0.32
None (baseline)	329	—	—
Work area:			
Enclosed	50	0.99[A]	0.21
Inside	378	0.85[A]	0.12
Partially enclosed	259	−0.74[A]	0.12
Outside (baseline)	280	—	—
Cross draft:			
Medium	599	1.12[A]	0.12
Low	140	0.38[C]	0.18
None (baseline)	228	—	—

[A]$p \leq .001$
[B]Parameter set to zero because it is redundant
[C]$p \leq .05$

TABLE VIII. Exposure Determinant Model for Cleanup

Activity	n	β	SE
Cleanup—R^2 = .14			
Intercept		−0.83[A]	0.09
Tool:			
Broom	392	0.25[A]	0.04
Shovel	267	0.09	0.05
Backpack blower	13	0.94[A]	0.17
Chipping gun	10	0.37[B]	0.18
None (baseline)	547	—	—
Work area:			
Inside	1002	0.44[A]	0.06
Outside (baseline)	220	—	—
Cross draft:			
Medium	84	0.33[A]	0.09
Low	460	0.22[A]	0.05
None (baseline)	678	—	—
Nearby dust generation:			
No	944	−0.22[A]	0.06
Yes (baseline)	278	—	—

[A]$p \leq .001$
[B]$p \leq .05$

($p < .001$) and had an R^2 of .61 (Table VI). For concrete demolition the model produced an R^2 of .35 (Table VII), with task, tool, work area, and cross draft being highly significant ($p < .001$). For cleanup the R^2 was .14 (Table VIII) with tool, work area, cross draft, and nearby dust generation being highly significant ($p < .001$).

DISCUSSION

Using traditional respirable sampling techniques, elevated quartz exposures were documented for most activities for the period sampled. Through the use of data logging monitors, noncontinuous tasks could be evaluated both for the task exposure and the larger period containing nontarget tasks. The monitors also offered the ability to characterize the portion of time a target task occurred for specific activities.

The percentage of time spent performing the target task varied among activities (Table III), from 11% for hod carriers doing concrete mixing to 69% for restoration masons doing tuck-point grinding. Some activities with relatively low respirable dust concentrations, such as concrete cutting and mixing (0.88 and 0.57 mg/m^3, respectively), had task concentrations that were two times higher (1.71 and 1.19 mg/m^3, respectively). If a job required continuous cutting or mixing, exposures could be considerably higher than suggested by the activity concentration.

Quartz concentrations reported in this study (Table II) were in general agreement with concentrations found in other U.S. construction studies[10–19,27] but were lower than those found in European studies.[20–22] Some of this variance may be due to differences in methods used.

There were several limitations in the methods used in the present study. Because sampling was not full-shift, comparison with any full-shift standard may overestimate standard exceedances. The contractors that agreed to participate in this study were leaders in promoting health and safety in construction. There may be greater implementation of respirator use and other controls on their sites than a typical site. It was assumed that respirators, when used, were used continually over the course of the sampling period. Respirators may sometimes have been used intermittently, producing an overestimation of respiratory protection. It also was assumed that respirators all fit properly. Respirator fit was probably variable, particularly for dust masks, which are difficult to fit-test.[28–30] Although this was not assessed in the study, casual inquiry regarding respirator fit-testing suggests that it is very infrequent on construction sites, especially for dust masks. When respirators do not fit well, protection is underestimated. The comparison of dust exposure with and without control strategies in a variety of circumstances is a crude comparison method. Exposures that warrant control application may initially be more elevated than exposures for which control treatments were not employed. If control technologies were employed for the highest exposures only, then the comparison would underestimate the effects of controls observed. Statistical models used did not account for serial correlation, which may result in reduced standard errors. However, this simplification should not affect the observed coefficients.

Modeling identified factors of importance to exposure and was most successful at explaining variability when the dust cloud was more concentrated (grinding). For all activities modeled, task and work area were highly significant. Exposure increased with increasing cross draft. Cross-draft estimation was a crude metric. Cross-draft direction was not recorded, and this may be a more important variable than cross-draft velocity for operator exposure. Nearby dust generation was significant only for cleanup, when personal exposure was from a more disperse dust cloud.

For surface grinding, grinder diameter was an important exposure factor, with exposures for 4.5-inch grinder being 33% less than 7-inch grinder exposures. Rotation rate varied with the two grinder sizes (6000 rpm for 7-inch and 10,000 rpm for 4.5-inch), with both grinders having a tip speed of approximately 11,000 ft/min. Although tip speed remained constant, the grinder surface area was probably an important factor, with surface area of 0.27 ft^2 for 7-inch and 0.11 ft^2 for the 4.5-inch grinder.

Because both grinder size and wheel type were important, the choice of grinder size and wheel could be part of a plan to limit quartz exposure, especially when the space is enclosed or other workers are positioned near grinding operations.

Protection was inadequate with use of respiratory protection nearly half the time, and higher levels of respiratory protection involve respirators that are more expensive and require greater maintenance (powered air-purifying or supplied air), which bolsters the argument for greater use of engineering controls. Another important reason for promoting engineering controls is that respirators do not protect nearby workers. Use of controls may allow dust-producing activities to be scheduled in the same area where other trades are working—a strong incentive for an industry in which production schedule maintenance is very important.

CONCLUSIONS

Quartz exposure was elevated in some cases for all activities, with five of the eight activities having GMs exceeding the TLV (surface grinding, tuck-point grinding, demolition, concrete cutting, and floor sanding). Exposures were highest for surface grinding, which had a GM 12 times the TLV. For some activities the dust-generating task tended to be continuous, whereas for others dusty tasks were more often intermittent.

The degree of enclosure for the work area, tool used, and cross draft were important predictors of exposure. For surface grinding the wheel diameter and type affected exposure. This information can be used to select work practices that reduce silica exposure.

Respiratory protection was used about 70% of the time, and more protective respirators were generally worn as exposures increased, although respiratory protection was often inadequate. Half-face cartridge respirators, the respirator worn when high exposures were expected, did not provide adequate protection 38% of the time they were worn.

Engineering controls were encountered infrequently; only 12% of samples used any protective measures other than respirators. When controls were used, exposures were lower for box fan for surface grinding, box fan for floor sanding, and vacuum/shroud for surface grinding, with reductions of 57, 50, and 71%, respectively. These reductions for surface grinding would not reduce exposures below the TLV. For other controls employed, including sweeping compound, box fan for cleanup, ducted fan dilution, and wetted substrate, exposures were higher than for the comparable task without dust control. However, there is some uncertainty about the effectiveness of controls, because the circumstances may have varied for controlled versus uncontrolled exposures.

Exposures were often high, and respirators were not always protective enough. Use of controls was infrequent and usually did not control exposures below the TLV. Effective engineering controls should be promoted on construction sites. Research to assess the effectiveness of available controls is needed to assist the industry in identifying effective controls and reducing exposures.

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APPENDIX A: DESCRIPTION OF SAMPLED ACTIVITIES

FIGURE 1. Cleanup: Cleanup involved the removal of construction debris, particularly settled dust, using brooms, shovels, and occasionally a backpack blower. There was often frequent interruption of the cleanup task to move obstructions out of the way.

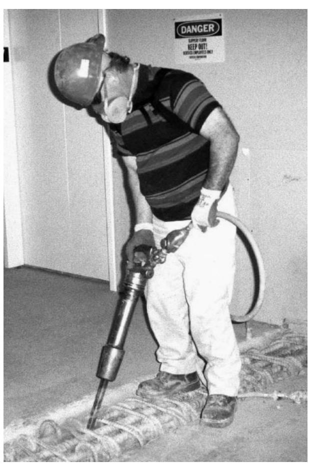

FIGURE 2. Hand Demoltion: Handheld concrete demolition involved the use of a small jackhammer or reciprocating gun with interchangeble chipping or rivet busting head to remove excess concrete from overpours, splashovers or when concrete forms did not meet.

FIGURE 3. Concrete Cutting: Concrete block was cut using a handheld gasoline or a table-mounted masonry saw. The handheld saw was always used outside, and cutting was intermittent and always dry, whereas the table-mounted saw was used both inside and outside on scaffolding, usually cutting with at least some water spray to the blade and sometimes continuously for several hours.

FIGURE 4. Concrete Mixing: Concrete, mortar, and grout are mixed, usually by the hod carrier on a brick mason crew. Typically mortar was mixed 3–4 times in a shift, with each session taking about 10 minutes. On two occasions, grout could not be delivered to the site and it was hand mixed, resulting in a fairly continuous period of mixing.

FIGURE 5. **Tuck-Point Grinding: During masonry wall renovation, tuck-point grinding removes old mortar from between bricks, using a right-angle grinder. Usually, grinding occurs for half a shift and "tuck pointing" e.g. replacement of mortar, occurs for the remainder of the shift.**

FIGURE 6. **Surface Grinding: Rough walls, floors, and support columns were leveled using the flat surface of a 4.5 or 7 inch diameter surface grinder with an abrasive or diamond disk. At times this process takes an entire shift, while many times it was employed for only a small area or intermixed with patching.**

FIGURE 7. **Sack and Patch Concrete: Sacking is a finishing process for fine cement surfaces, to fill small pin holes and other imperfections. It involves applying a wet cementatious slurry with a rag, followed by application of very fine, dry, usually 100% silica sand using a handheld burlap sack material. It is often done in conjunction with other patching tasks, although it was sampled in this study only when done separately from other types of patching tasks.**

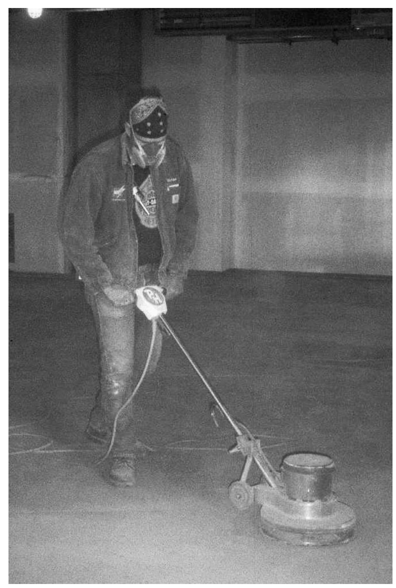

FIGURE 8. **Floor Sanding: Floor sanding is a finishing process for smoothing cementatious floor underlayment products. The floor sander was a 16 inch diameter sandpaper disk and is operated from a standing position. This process was interrupted frequently to move obstructions out of the way.**