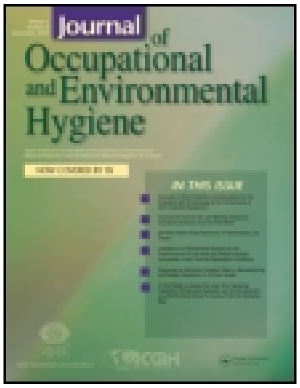

Journal of Occupational and Environmental Hygiene
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uoeh20

Determinants of Respirable Silica Exposure in Stone Countertop Fabrication: A Preliminary Study

Margaret L. Phillips [a] , David L. Johnson [a] & Andrew C. Johnson [a]

[a] Health Sciences Center, Department of Occupational and Environmental Health , University of Oklahoma , Oklahoma City , Oklahoma

Accepted author version posted online: 01 Apr 2013.Published online: 13 May 2013.

Journal of Occupational and Environmental Hygiene, 10: 368–373
ISSN: 1545-9624 print / 1545-9632 online

DOI: 10.1080/15459624.2013.789706

Determinants of Respirable Silica Exposure in Stone Countertop Fabrication: A Preliminary Study

Margaret L. Phillips, David L. Johnson, and Andrew C. Johnson
Health Sciences Center, Department of Occupational and Environmental Health, University of Oklahoma, Oklahoma City, Oklahoma

A preliminary study of personal exposure to respirable quartz was conducted in four shops that used a variety of wet and dry methods to fabricate countertops from granite and quartz-containing synthetic stone-like materials. Full-shift time-weighted average (TWA) exposures exceeded the ACGIH threshold limit value of 0.025 mg/m³ for all workers who used dry fabrication methods, even for very limited time, during any part of the work shift (n = 15 person-days). The geometric mean of exposures for workers who used dry methods extensively was about 1 mg/m³ (n = 12 person-days). Workers who operated only automated or remotely controlled stone cutting or shaping equipment had calculated TWA exposures of approximately 0.02 mg/m³ (n = 3 person-days). Task-specific geometric mean exposures for various wet and dry manual operations were ranked based on estimated concentrations extracted from multi-task partial-shift sample results using a linear algebra procedure. Limited use of dry methods was observed in shops that had previously reported using only wet methods. These results suggest that even shops that report using only wet methods might, in fact, resort to brief use of dry methods for specific operations. Therefore, there may be reason for concern over potential overexposure to respirable quartz in all stone countertop shops.

Keywords crystalline silica, determinants of exposure, granite dust, task exposure

Correspondence to: Margaret L. Phillips, University of Oklahoma, Health Sciences Center, Department of Occupational and Environmental Health, 801 Northeast 13th Street, Oklahoma City, OK 73104; e-mail: Margaret-Phillips@ouhsc.edu.

INTRODUCTION

Custom granite countertops for homes and businesses are fabricated in small shops, typically employing 10 or fewer workers, using a variety of fabrication methods.[1,2] The dangers of silicosis and lung cancer from exposure to respirable quartz in granite dust are well known to industrial hygienists.[3–7] There is also evidence that occupational silica exposure may cause kidney disease.[5,8] Exposure to granite dust can be effectively controlled.[2,9] However, despite efforts by the leading dimension stone trade association, the Marble Institute of America, to educate the industry on protection from granite dust,[10] engineering and work practice controls and respiratory protection programs in countertop shops are often inadequate.[1,11]

Use of wet methods reduces dust exposure during stone countertop fabrication.[2] However, even among shops that generally use wet methods, some dry fabrication can occur. In a recent survey of self-reported fabrication practices in granite countertop shops in Oklahoma,[1] 79% of shops reported using dry methods at least part of the time. Dry methods were used most commonly during cutting of grooves for insertion of reinforcement rods (rodding), cutting of sink openings, and shaping the edge of the countertop with a grinding tool. A survey of Marble Institute of America members found that 73% of respondents said their shops were 90 to 100% wet.[10]

The purpose of this study was to collect preliminary data on the effect of various wet and dry methods on exposure to respirable silica during stone countertop fabrication.

MATERIALS AND METHODS

Recruitment of Participants

The participating shops were a convenience sample of countertop shops in the Oklahoma City area that used a variety of fabrication methods. These ranged from small shops with as few as two fabricators using only hand-held or manually guided power tools to large shops employing 10 or more employees and using mostly large-scale automated or remotely controlled cutting and shaping equipment. Characteristics of the four participating shops and the sample collection are summarized in Table I. Sampling was conducted between November 2010 and March 2012.

Approval was secured from the University of Oklahoma Health Sciences Center Institutional Review Board prior to initiating the research, and written informed consent was obtained from shop employees who agreed to personal exposure sampling.

Sampling and Analytical Methods

Respirable dust samples were collected using 37 mm GS-3 cyclones (Model 225-100; SKC, Eighty Four, Pa.) and personal

TABLE I. Summary of Shops Sampled

Shop	Person-Days Sampled	Number of Workers Participating	Respirable Quartz Samples Collected	Month(s) When Sampled	Primary Fabrication Methods	Range of TWA Values (mg/m^3)
1	6	2	17	November	Hand tools, wet and dry	1.5–2.9
2	7	2	22	July, September, October	Bridge saw wet; hand tools, dry	0.16–3.88
3	3	2	8	June, December	Hand tools, mostly wet	0.13–1.3
4	7	5	14	March	Automated, wet	0.02–0.68
Totals	23	11	61			

sampling pumps (SKC Models 224-44XR and 224-PCXR4) at a flow rate of 2.75 L/min. At this flow rate, the 50% collection efficiency cutpoint of the cyclone occurs at an aerodynamic diameter of 4 μm. Flow rate calibration was performed using an inverted 1000 mL Kimax glass burette (Kimble-Chase, Vineland, N.J.) as a soap bubble meter. The bubble rise across a volume of 500 mL in the burette was timed to the nearest 0.01 sec using a digital stopwatch (Sport Time model; Exertec Fitness, China). In the first shop, the dust was collected on 37 mm, 5 μm pore size PVC filters (Model PVC503700; Millipore, Billerica, Mass.) that were weighed before and after sampling on a Cahn Model C-33 microbalance (Orion Research; Beverly, Mass.) to determine the respirable dust mass. The filters were loaded in clear styrene 37 mm 3-piece cassettes (SKC Model 225-3050). In the other three shops, the dust was collected using preloaded matched-weight 37 mm, 5 μm pore size PVC filter cassettes (SKC Model 224-8202). For all shops, field blanks consisting of loaded filter cassettes were transported to the sampling location, together with the sample cassettes, but were kept sealed. The matched-weight filter cassettes were analyzed gravimetrically for respirable dust using NIOSH Method 0600.[12] All respirable dust samples and a bulk sample of settled dust were analyzed for quartz using a modified version of NIOSH Method 7500, an X-ray diffraction method.[13] The laboratory performing NIOSH Methods 0600 and 7500 held current accreditation in these analytical methods from the Industrial Hygiene Laboratory Accreditation Program of AIHA®. Modifications to NIOSH Method 7500 involved (1) small changes in the procedure for preparing the suspensions of the samples and standards and redepositing them on the silver membrane filters, and (2) in lieu of the normalization of measured peak intensity, the daily use of calibration verification standards analyzed before and after each sequence of samples to validate previously established calibration curves. For the quartz analysis, the laboratory-reported limit of detection (LOD) was 0.010 mg and the lower limit of quantitation (LOQ) was 0.030 mg. The laboratory did not require submission of bulk samples to determine the mass fraction of quartz; rather, the quartz mass fraction was determined from X-ray and gravimetric analysis of the respirable dust samples themselves. One or two field blanks were analyzed for each day of sampling. The mass of quartz was below the limit of detection in 80% of field blanks. The highest reported blank mass was 0.013 mg, barely above the limit of detection. Because blank levels were below the LOQ and therefore could not be verified, sample concentrations were calculated without blank correction.

Samples were collected only on workers who were assigned to work in the shop for the full day. This eliminated workers who spent part of the day on installation crews. To prevent overloading of the filters, between two and four consecutive personal breathing zone samples were collected to cover the entire shift, excluding mealtime breaks. Eight-hour time-weighted average (TWA) exposures for each individual were calculated from the consecutive partial-shift samples.

Task Determination

In most cases, workers alternated between tasks, such as sawing, grinding, or polishing, every 5–10 min or less. It was therefore not practical to limit samples to a single task. During each sample, notes on the tasks being performed were taken continuously by an investigator. The notes stated whether each task was done wet or dry. The length of time that each task was performed was not measured. A single investigator took all the field notes. After all sample collection was completed, the same investigator who had previously taken the notes scored each sample and shift according to the degree of use of wet or dry methods, using a 5-point scale according to the relative amounts of fabrication work performed dry. The samples and shifts during which work was done entirely wet or entirely dry could be determined unambiguously from the notes. If both wet methods and dry methods are noted during a sample or across all samples in a shift, the sample or shift was scored as "mostly wet" when it was clear from the notes that dry methods were used only a fraction of the time. Similarly, a sample or shift was scored as "mostly dry" when it was clear from the notes that wet methods were used only a fraction of the time. When the predominance of either wet methods or dry methods could not be discerned from the notes, or extensive use of both methods was recorded, the sample or shift was scored as "wet and dry." No adjustment was made to the scoring for time spent on non-fabrication tasks such as moving pieces of granite.

Data Analysis

Estimates of task-specific exposures were derived from the partial-shift sample concentrations using the P-screen method, a linear algebra-based method that has been described in detail elsewhere.[14] The P-screen method is useful for extracting task-specific geometric mean (GM) exposures from data sets containing samples collected during performance of multiple tasks and can be applied in cases where task durations are unknown. Because the sample results in this study were right-skewed, the computations were performed using log-transformed concentrations to stabilize the variability. Crude estimates of time-weights for each task were created by assuming equal times for all tasks that were performed during a sample. The P-screen method was previously validated under these conditions.[14,15]

The P-screen method tends to provide biased estimates of the task-specific GM exposures, and it does not provide estimates of task-specific geometric standard deviations. Therefore, task-specific arithmetic mean exposures cannot be estimated. Furthermore, the task-specific exposure values extracted from the data should not be treated as valid estimates for exposure reconstruction or comparison with occupational exposure limits. However, the rank order of task-specific GM exposures derived using the P-screen method is reasonably accurate.[14,15] Therefore, the task-specific GM exposures obtained using the P-screen method were rounded to one significant figure and then ranked.

RESULTS

Quartz Content of Respirable Dust

Materials processed by the fabricators during the sample collection were natural granite, an engineered stone product referred to in the trade as "quartz," and terrazzo. Granite by definition can contain no less than 2% quartz and no greater than 60% quartz by volume.[16] Quartz engineered stone consists of about 90% quartz grains by mass in a polymer matrix. Terrazzo is a concrete-like material of stone, glass, and seashell fragments in a cement or polymer matrix that may contain sand as a filler. Because the composition of terrazzo can be quite diverse, a bulk sample of settled dust from dry cutting of terrazzo was collected and analyzed to determine whether it contained quartz. The bulk sample contained 15% quartz.

The mass fraction of quartz in respirable dust samples was 8–27% during fabrication with granite, 14–67% during fabrication with engineered stone, and 8–9% during fabrication with terrazzo.

Respirable Quartz Exposure

Quartz was detected in amounts above the LOD and the field blank values in all respirable dust samples. Ten samples had measured amounts of quartz below the LOQ of 0.030 mg. The laboratory reported these amounts as unverified values. All 10 samples were collected on workers performing tasks mostly or entirely wet. Nine of the ten sample concentrations calculated from reported sample masses that were below the LOQ did not exceed 0.04 mg/m^3; all of these samples were collected during use of automated or remotely controlled equipment. One sample concentration of 0.081 mg/m^3 was calculated based on an unverified sample mass of 0.014 mg, which was barely above the LOD, collected over 62 min during wet polishing and washing. Concentrations calculated from samples with quartz masses at or above the LOQ were all greater than 0.05 mg/m^3.

The distribution of respirable quartz concentrations in the 61 partial-shift samples collected is shown in Figure 1. Ten samples were collected on workers performing tasks entirely wet. The GM concentration in this subset was 0.060 mg/m^3; the two highest concentrations (0.38 mg/m^3 and 0.77 mg/m^3) were found when another worker was performing dry work nearby. The GM concentration was 0.065 mg/m^3 for samples collected during operations that were done predominantly wet but included very limited use of dry methods (n = 7). The subsets of samples collected during operations with extensive use of both wet and dry methods (n = 5), predominantly dry operations (n = 12), and entirely dry operations (n = 27) each had a GM of about 1.2 mg/m^3. Among the samples collected on workers performing tasks entirely dry, the lowest concentrations were found when the worker spent significant

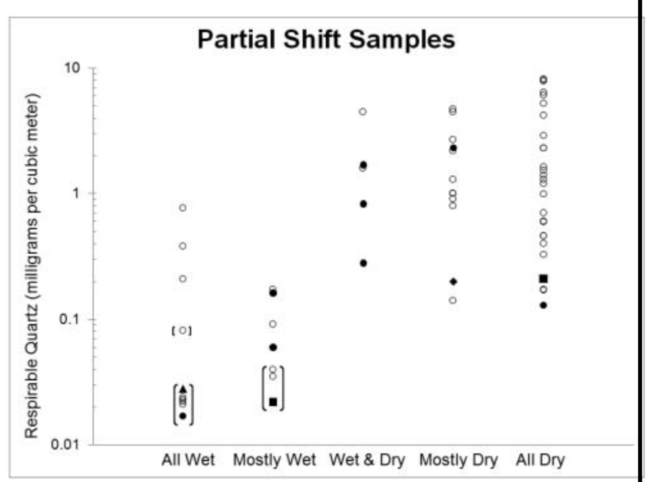

FIGURE 1. Distribution of personal breathing zone exposures (mg/m^3) to respirable quartz in partial-shift samples in relation to the relative amount of fabrication work performed using wet methods or dry methods during the sample collection. Number of samples: 10-All Wet, 7- Mostly Wet, 5-Wet & Dry, 12-Mostly Dry, 27-All Dry. Open circles: granite fabrication only. Solid circles: engineered stone only. Solid square: terrazzo only. Solid diamond: granite and terrazzo. Solid triangle: granite and engineered stone. Exposure data points in brackets were calculated from reported sample masses that were below the lower limit of quantitation.

TABLE II. Computed Task Exposure Ranking and Task Frequency in 50 Multitask Partial-Shift Samples Involving Only Manually Guided Tools

Computed Exposure Ranking	Task and Frequency
1 (highest exposure)	Dry sweep/brush (5)
2	Dry saw/cut/bore/rod (20)
3	Dry grind (41)
4	Dry polish (19)
5	Wet saw/cut (10)
6	Wet polish (13)
7	Blow off dust with compressed air (5)
8	Move/wrap/load materials (11)
9	Wash down floors/counters (3)
10	Wet grind (2), wet routing (5)
11 (lowest exposure)	Pneumatic chisel (3)

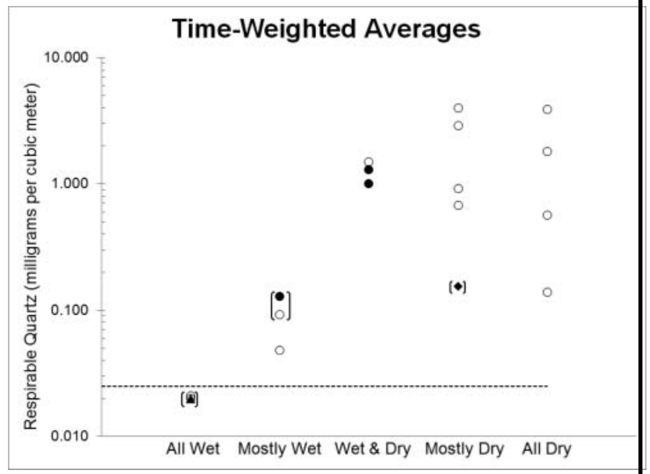

FIGURE 2. Distribution of 8-hr TWA (mg/m^3) to respirable quartz in relation to the relative amount of fabrication work performed using wet methods or dry methods throughout the shift. The TLV is indicated by the horizontal dotted line at 0.025 mg/m^3. Number of shifts represented: 3-All Wet, 3-Mostly Wet, 3-Wet & Dry, 5-Mostly Dry, 4-All Dry. Open circles: granite fabrication only. Solid circles: engineered stone only. Solid diamond: granite and terrazzo. Solid triangle: granite and engineered stone. Data points in brackets included contributions from partial-shift sample concentrations calculated from reported sample masses that were below the lower limit of quantitation.

portions of time on non-fabrication tasks such as moving pieces of granite around the shop.

To rank task-specific GM exposures, the P-screen method[14] was used to analyze data from 50 partial-shift samples, aggregated across all four shops, in which only manually guided tools were used. Samples that were collected during operation of an automated or remotely controlled machine (bridge saw, automated edge shaping machine, or computer numerical control machine) were excluded from this analysis. Twelve manual tasks, including wet and dry methods, were identified from the field notes. Wet routing, wet grinding, and use of compressed air to blow off dust tended to occur together in samples from one shop, but otherwise, there were no significant collinearities among manual tasks in this data set. The rank order of the estimated task-specific GM exposures is presented in Table II. There was one tie in rank among the 12 manual tasks. The tasks with the highest estimated exposures were dry sweeping, dry sawing/cutting, and dry grinding. Pneumatic chiseling, wet grinding, and wet routing had the lowest estimated exposures.

Due to pump failures (3 person-days) and one abbreviated workday of less than 5 hr (2 person-days), a total of 18 full-shift TWA exposures could be calculated from the partial-shift samples collected during 23 person-days of sampling. The distribution of these full-shift TWA exposures is shown in Figure 2. The ranges of TWA exposures found in each shop are provided in Table I. In all shifts in which some dry fabrication work was performed, the time-weighted average exposure exceeded the threshold limit value (TLV®)[17] of 0.025 mg/m^3. All dry fabrication work was performed with hand-held tools such as angle grinders and concave disc cutters, or hand-guided tools such as worm-drive circular saws. Three full-shift TWA exposures in the narrow range 0.020–0.021 mg/m^3 were calculated on workers who spent the whole shift operating either a bridge saw or an automated edge shaping machine, both of which were operated under continuous water stream with the operator standing some distance away. It should be noted, however, these exposures were calculated entirely from sample results that were below the LOQ of the analytical method. The GM of TWA exposures was 0.083 mg/m^3 for workers performing mostly wet operations with very limited use of dry methods (n = 3), 1.2 mg/m^3 for workers using both wet and dry methods extensively (n = 3), 1.0 mg/m^3 for workers performing predominantly dry operations (n = 5), and 0.87 mg/m^3 for workers performing entirely dry operations (n = 4). Two TWA exposures calculated for workers performing mostly wet operations and one TWA exposure calculated for a worker performing mostly dry operations included a small contribution from partial-shift sample results that were below the LOQ of the analytical method.

Accuracy of Self-Reported Fabrication Practices

In the previous survey of fabrication methods,[1] Shop 3 and Shop 4 had reported that all fabrication steps were performed entirely wet. However, during sample collection, some use of dry methods was observed in these shops. In Shop 3, wet methods were used as much as possible, but corners of rectangular openings were bored out with finger bits, and curved portions of sink openings were cut dry with a concave disc saw. During this dry cutting, an assistant held the hose of a HEPA vacuum cleaner near the point of operation of the tool, capturing part of the dust plume. In Shop 4, sink openings with curved portions were cut out and polished on a computer numerical control (CNC) machine under a water stream. However, in the case of rectangular openings, the straight edges were cut on a CNC machine, and a worker then briefly used a hand-held saw, without a water feed, to make the final cuts of about 3–4 cm at each corner to release the opening. Grinding and polishing of countertop corners and some sink edges were also performed dry in Shop 4.

Shop 2 had reported in the survey that sink openings and polishing were done entirely wet, and edge profiling was done with a combination of wet and dry methods. During 5 days of sampling in Shop 2, it was observed that edge profiling and cutting of sink openings were done entirely dry. Polishing with coarse pads was performed dry; when the fabricator progressed to polishing with finer pads, he used a sponge to wet the surface of the stone.

It was previously reported that bridge saws were used only for cutting granite pieces into the desired dimensions.[1] However, in Shop 4, the bridge saw was also used to cut the approximately 1.25 cm wide by 1.5 cm deep grooves for reinforcing rods. This cutting was performed with a specialized blade under a water stream. The bridge saw was remotely controlled by the operator.

The ventilation practices observed during sampling in all four shops were consistent with those reported by the shops in the survey.[1] Aside from the use of the HEPA vacuum cleaner in the one shop as described above, no attempt at local exhaust ventilation was observed. All shops used fans for general ventilation. During the warm months (March–September), shop doors were kept open throughout the shift to provide natural dilution ventilation. During sample collection in the cooler months (October–December), doors were kept closed during part or all of the shift when outside temperatures were too cold for comfort.

DISCUSSION

Though based on sampling in only a small number of workplaces, the results of this study provide evidence that whenever dry methods are used, even for limited periods, there is a high likelihood that full-shift TWA exposure to respirable quartz could exceed the TLV of 0.025 mg/m^3, and a significant chance that exposure may approach or exceed the effective permissible exposure limit (PEL) of 0.1 mg/m^3 established by the Occupational Safety and Health Administration (OSHA).[18] Respirable dust samples in this study were collected with a 50% cut point of 4 μm in accordance with the ACGIH® criteria for collection of the respirable fraction,[17] rather than the 3.5 μm cut point required for determination of compliance with the OSHA PEL for respirable dust.[18] Full-shift TWA exposures were below the TLV only for workers who operated automated or remote-controlled equipment entirely wet for the entire shift. Even for these workers, the TWA exposure level of approximately 0.02 mg/m^3, calculated from detected quartz mass below the LOQ, was not far below the TLV.

Estimates of task-specific GM exposure for manual tasks performed by countertop fabricators were extracted from the data set of mostly multitask partial-shift sample concentrations using a linear algebra method (the P-screen method), which is suitable for data sets where task durations are not known.[14] Although the estimates obtained by this method are subject to bias, they are useful for identifying which tasks involve the highest exposure.[15] Estimates of GM exposures obtained from log-transformed data by multiple regression, using task occurrence as a dichotomous predictor variable in the absence of information on task duration, would have been prone to similar bias.[15]

Not surprisingly, dry cutting, dry grinding, and dry sweeping were identified as the highest exposure tasks. Dry polishing, wet polishing, wet sawing, use of compressed air to blow dust off surfaces, moving of countertop pieces, and washing down surfaces with water were in the middle tier of estimated exposure. Use of a pneumatic chisel, use of a stone router with water feed, and wet grinding were in the lowest tier of estimated exposure. The pneumatic chisel was used to chip pieces about 2 cm wide and 0.5 cm deep off the edge of a countertop, creating a rough-hewn look. This was performed dry. For each chip, the chisel bit was carefully positioned on the granite and then activated with a foot pedal to strike the stone. A small puff of dust was released with the chip. Given the low intensity of aerosol generation in this task, it is not surprising that it fell in the low-exposure tier. Stone routing and grinding both involve shaping the edge of the stone piece with a high-speed rotating wheel. The low exposure computed for wet grinding and wet routing was not surprising since high speed stone grinding using a water-fed grinder is quite effective in reducing operator exposures, compared with dry methods.[2] The result that measured respirable dust exposures were less for wet grinding and wet routing than wet polishing was consistent with the observation by Sirianni et al.[19] that grinding produces relatively more coarse particles compared with polishing, which produces more small and mid-sized particles. Overall, the task-specific exposure rankings obtained from the P-screen method appear plausible and are potentially useful for setting priorities for follow-up, including single task sampling and possible interventions to reduce exposure.[15]

Because very few samples were collected during work in which only wet methods with hand tools are used, the data in this study did not provide much information on the adequacy of wet methods for controlling dust exposure from hand-held power tools. Also, partial-shift samples collected during use of automated or remotely controlled stone-working machines tended to have respirable quartz mass below the limit of quantitation, making comparison of results to the TLV uncertain. Full-shift samples should be used to better evaluate the exposure of workers whose predominant job assignment is operation of such machines.

Based on observation of fabrication practices during the sample collection, the use of dry methods appeared to be underreported in the previous survey of countertop shops.[1] Shops 3 and 4 had previously reported using exclusively wet methods but in the present study they used dry methods part of the time, especially during cutting of sink openings. Apparently, even the expensive and sophisticated CNC machines used in one of these shops could not cut certain shapes completely in a single wet process.

By definition, true granite may contain up to 60% of the mineral quartz by volume.[16] The engineered stone product known as quartz contains about 90% quartz by mass or 80% quartz by volume. In this study, the quartz content of respirable dust from fabrication of engineered quartz countertops tended to be higher than the quartz content of respirable granite dust. However, controlling for the relative amount of dry fabrication used during each sample, it is evident from inspection of Figures 1 and 2 that exposures to respirable quartz from engineered stone were not generally higher than exposures to respirable quartz from granite.

In the absence of dust collection systems, the countertop shops observed in this study relied on natural ventilation from open doors to dilute the aerosol generated by work operations. The potential effect of room volume, sizes and configurations of exterior openings, and closed doors during cold weather were not evaluated in this study, given the small number of shops and sampling days.

CONCLUSION

The personal sampling results from this study suggest that workers who fabricate countertops from granite and from quartz-based engineered stone are at high risk of full-shift TWA exposure to respirable quartz above the TLV even if dry methods are used only to a limited extent. Many shops report using dry methods at least part of the time,[1,10] and as observed in this study, even shops that report using only wet methods might in fact resort to brief use of dry methods for specific operations. Therefore, there may be reason for concern about potential overexposure to respirable quartz in all stone countertop shops. Furthermore, countertop fabricators who use dry methods extensively on granite or other quartz-rich materials are likely to have full-shift TWA exposures in excess of the current OSHA PEL, which is less protective than the TLV.

Further research is needed to better characterize exposures when exclusively wet methods are used in stone countertop fabrication. The feasibility and effectiveness of local exhaust ventilation in countertop fabrication should also be evaluated.

ACKNOWLEDGMENTS

This research was supported by a seed grant from the University of Oklahoma Health Sciences Center Vice President for Research and by NIOSH Training Grant 5T01OH0086 14. The authors thank Linda Kincaid for donation of preloaded filter cassettes; Kim Graziano, Anthony Banks, and Ishita Tejani for assistance in sample collection; and the owners and employees of the participating shops for their cooperation in this study.

REFERENCES

1. **Phillips, M.L., and A.C. Johnson:** Prevalence of dry methods in granite countertop fabrication in Oklahoma. *J. Occup. Environ. Hyg. 9*:437–442 (2012).
2. **Simcox, N.J., D. Lofgren, J. Leons, and J. Camp:** Silica exposure during granite countertop fabrication. *Appl. Occup. Environ. Hyg. 14*:577–582 (1999).
3. **Hamilton, A.:** *Exploring the Dangerous Trades.* Boston, Mass.: Northeastern University Press, 1985.
4. **Rosner, D., and G. Markowitz:** *Deadly Dust Silicosis and the Politics of Occupational Disease in Twentieth Century America*. Princeton, N.J.: Princeton University Press, 1991.
5. **National Institute for Occupational Safety and Health (NIOSH)**: *Health Effects of Occupational Exposure to Respirable Crystalline Silica*. DHHS (NIOSH) Pub. No. 2002-129. Cincinnati, Ohio: NIOSH, 2002.
6. **Graham, W.G.B., J. Costello, and P.M. Vacek:** Vermont granite mortality study: An update with an emphasis on lung cancer. *J. Occup. Environ. Med. 46*:459–466 (2004).
7. **Attfield, M.D., and J. Costello:** Quantitative exposure-response for silica dust and lung cancer in Vermont granite workers. *Am. J. Ind. Med. 45*:129–138 (2004).
8. **Steenland, K.:** One agent, many diseases: Exposure-response data and comparative risks of different outcomes following silica exposure. *Am. J.* Ind Med. *48*:16–23 (2005).
9. **Wickman, A.R., and P.J. Middendorf:** An evaluation of compliance with occupational exposure limits for crystalline silica in ten Georgia granite sheds. *Appl. Occup. Environ. Hyg. 17*:424–429 (2002).
10. **Marble Institute of America**: *Silicosis: An Industry Guide to Awareness and Prevention*. Cleveland, Ohio: Marble Institute of America, 2008.
11. **Lofgren, D.J.:** Result of inspections in health hazard industries in a region of the state of Washington. *J. Occup. Environ. Hyg. 5*:367–379 (2008).
12. **National Institute for Occupational Safety and Health (NIOSH):** Method 0600. Particulates not otherwise regulated, respirable. In *NIOSH Manual of Analytical Methods (NMAM)*, 2003.
13. **National Institute for Occupational Safety and Health (NIOSH):** Method 7500. Silica, crystalline, by XRD (filter deposition). In *NIOSH Manual of Analytical Methods (NMAM)*, 2003.
14. **Phillips, M.L., and N.A. Esmen:** Computational method for ranking task-specific exposures using multi-task time-weighted average samples. *Ann. Occup. Hyg. 43*:201–213 (1999).
15. **Phillips, M.L., N.A. Esmen, and J. Costantino:** The reliability of multiple regression and an alternative method for extracting task-specific exposure estimates from time-weighted average data. *Appl. Occup. Environ. Hyg. 16*:56–65 (2001).
16. **Winter, J.D.:** *An Introduction to Igneous and Metamorphic Petrology*. Upper Saddle River, N.J.: Pearson Prentice Hall, 2010.
17. **ACGIH:** *TLVs and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices*. Cincinnati, Ohio: ACGIH, 2012.
18. "Air Contaminants. Table Z-3 Mineral Dusts" *Code of Federal Regulations Title 29*, Part 1910.1000, 1997.
19. **Sirianni, G., H.D. Hosgood, M.D. Slade, and J. Borak:** Particle size distribution and particle size-related crystalline silica content in granite quarry dust. *J. Occup. Environ. Hyg. 5*:279–285 (2008).