Review of Selected Literature Relevant to the Production of Natural and Engineered Stone Countertops and Adverse Health Effects

Prepared for the Natural Stone Institute (NSI)

and

International Surface Fabricators Association (ISFA)

Part 1: Stone Fabrication Inhalation Exposures: Workplace Exposure

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Foreward from NSI and ISFA

On March 25, 2016, the Occupational Safety and Health Administration (OSHA) published a final rule regulating occupational exposure to respirable crystalline silica (silica) in general industry: *29 C.F.R. § 1910.1053 Occupational Exposure to Respirable Crystalline Silica*.
{link: https://www.osha.gov/silica-crystalline/general-industry-maritime}

In 2019, the Centers for Disease Control (CDC) published a Morbidity and Mortality Weekly Report (MMWR): *Severe Silicosis in Engineered Stone Fabrication Workers — California, Colorado, Texas, and Washington, 2017–2019* which highlighted growing silicosis cases from countertop workers from multiple U.S. States. {citation link: Rose C, Heinzerling A, Patel K, et al. Severe Silicosis in Engineered Stone Fabrication Workers — California, Colorado, Texas, and Washington, 2017–2019. MMWR Morb Mortal Wkly Rep 2019;68:813–818. DOI: http://dx.doi.org/10.15585/mmwr.mm6838a1.}

The above information has prompted increased focus and research into silicosis cases and silica exposures amongst countertop workers. With a growing number of studies and reports emerging - ranging from material-specific studies, workplace exposure studies, and medical case and epidemiological studies, NSI and ISFA partnered together to employ professional services from Yale Occupational and Environmental Medicine to review available medical and scientific publications to help determine which studies are most applicable and helpful for our collective members and for the industry at large. The report that follows is a summary of the most relevant thirty-four publications available as of mid-2024.

As stated in the executive summary, a major finding of this review is the need for better exposure control and existing gaps in understanding how to best control workplace exposures. It is the hope of both NSI and ISFA that this review is helpful in providing a better understanding of materials, methods, and available controls to reduce worker exposures to RCS.

Executive Summary – Relevant Exposure Studies

Overall Summary of Findings

Thirty-four publications and documents relevant to understanding the extent of workplace respirable crystalline silica exposures (RCS) from the fabrication of engineered stone countertops are summarized in this report. The majority involved exposure monitoring in actual workplaces, followed by controlled experiments performed in either a workplace or laboratory, enclosure, or special testing chamber.

It is challenging to synthesize the exposure findings due to the substantial heterogeneity in study type and methodologies, including stone types, tooling, controls, and work environments as well as limitations in sample size, scope, and recorded details. However, several trends are apparent:

1) Workplace Silica Exposures
- The cutting, grinding, and polishing methods typically used in stone fabrication shops can generate significant concentrations of both respirable dust (RD) and RCS.
- Performed dry, fabrication processes can result in RCS exposures several orders of magnitude above the current OSHA permissible exposure limit (PEL) and action level (AL). While polishing tends to generate lower airborne concentrations than grinding, the particle sizes from polishing are frequently smaller.
- Airborne levels of respirable crystalline silica (RCS) generally correlate roughly with the crystalline silica content in the stone type being processed.
- The particle size distributions of RCS generated from processing engineered and natural stones tend to have similar profiles. However, engineered stone appears to generate higher proportions of smaller particles.

2) Non-Silica Exposures
- Processing of engineered stone results in airborne emissions of multiple different volatile organic chemicals and metals related to resin and other additives.

3) Control of Workplace Exposures
- The application of either water or local exhaust ventilation alone can significantly reduce airborne emissions of RD and RCS, typically 90% or more as compared to equivalent work performed dry. Application of dual controls (wet methods and local exhaust ventilation) resulted in the greatest reductions (96-99%) in both RD and RCS.
- However, despite such controls, some workplace exposure levels were still above OSHA's AL and some were above the PEL, with the magnitude of exceedances was generally within 10 times the PEL.
- In addition, elevated background levels of RCS (above the AL) were found in some area samples and personal samples of non-fabrication employees, indicating potential for RCS exposure to non-production employees as well as another source of exposure to fabrication employees.

This review highlights the need for better exposure control and important gaps in understanding how best to control workplace exposures related to engineered stone. Particularly relevant to NSI / ISFA member companies is the need to better understand the impact of stone type on workplace RCS exposures and also understand the effectiveness of different workplace control strategies.

Importantly, workplace exposure studies with more "controlled" and better documented workplace factors (e.g. stone type, fabrication equipment and controls) should be able to better define conditions likely to maintain RCS exposures below regulatory standards. Utilization of standard RCS sampling and analysis methods, in close collaboration with fabrication shops, would greatly facilitate and expedite such studies.

Methodology

This review includes 34 studies selected using the following approach.

While the authors were familiar with much of the published literature on engineered stone work exposures and health, an initial literature search was performed via Ovid MedlineR and Embase platforms through June 2024 using the following keyword search terms, limiting to English and human studies:

- Engineered stone OR artificial stone OR Countertops or Agglomerate / Agglomerated stone or Synthetic stone or Man-made stone OR Stone fabrication (395 studies)
  AND
- Occupational exposure OR Workplace exposure OR Industrial hygiene OR Exposure Assessment OR Occupational Health OR silica OR silicosis OR occupational disease (326,537 studies)
- Combining the above terms yielded 197 studies.

Of the 197 studies identified using these combined search terms, 28 studies focused on inhalation exposures were included in this review. Studies were excluded if they did not include some aspect of exposure assessment, either quantitative or qualitative (i.e., survey-based) or were not available in English, or only involved animals. References cited in the selected publications were reviewed to identify additional potentially relevant articles and one additional report was identified (NIOSH EPHB Report 2021).

Most of the excluded studies involved clinical studies related to engineered stone silicosis, worker surveillance studies or related reviews / commentary; these will be reviewed in later sections.

Six additional studies of interest related to silica exposures in other industries (i.e., porcelain), silica laboratory testing methods / exposure metrics, and assessment of silica toxicity are also included.

The 34 studies are organized into the following sections: Workplace exposure studies (13 studies), Experimental Studies in the workplace setting (2 studies), Experimental studies in a laboratory, enclosure, or chamber (9 studies), Selected in vitro mechanistic studies (4 studies) and Selected other studies of interest (6 studies).

Each article was critically reviewed, with a focus on aspects most relevant to NSI / ISFA membership. A brief summary of each article is provided, including methods, key findings, strengths, weaknesses and relevance to the industry.

Stone Fabrication Workplace Exposure Studies

Silica exposure during granite countertop fabrication

Study Authors / funding: Simcox N, Lofgren D, Leons J, Camp J. (University of Washington, Department of Labor and Industries)

Journal: *Applied Occupational and Environmental Hygiene, 1999*

Location / Country: Washington, USA

Study Type and Description: This case study reports on the employee exposures to respirable crystalline silica (RCS) and dust control methods at 6 granite countertop businesses in the State of Washington. The surveys and air sampling were conducted in 1997 by the State of Washington Department of Labor and Industries Consultation Group, University of Washington Field Research and Consultation Group, and State of Washington OSHA. Companies employed 3-10 workers and were considered industry representatives in that state. A total of 43 personal air samples were obtained, of which 9 were excluded as incomplete or unrepresentative. After recollection for some of the excluded samples, 37 samples were included in the final data analysis.

Key Findings:

- All of the companies visited used water-fed bridge saws to cut large slabs to begin the fabrication process, with a combination of dry and wet methods used for subsequent processes that included grinding, edging, and polishing.
- 19 personal samples were collected during dry fabrication work and 18 were collected during wet processing work.
- The majority (26/37) of sampling durations were $\geq$ 6 hours out of 8 hours shifts, with the time not sampled presumed to result in no exposure to RCS.
- RCS air sampling results (as 8-hour time weighted averages):
    - Each work site had at least 1 personal exposure 2 times or greater than the PEL in effect at the time (0.1 mg/m^3).
    - Dry processes: Mean: 0.16 to 0.49 mg/m^3; Range: <0.04 to 0.77 mg/m^3, with 12/19 (63%) of the samples collected during dry grinding also exceeding the PEL.
    - Wet processes: Mean: < 0.07 to 0.06 mg/m^3; Range: <0.02 - 0.09 mg/ m^3.
- Although dry sweeping was a common practice for clean-up, handheld power tools used without water were believed to contribute the most to exposure.
- 4/6 businesses that used dry processing methods (2 businesses had wet methods on an initial visit) were resampled after switching to wet methods and found to have a reduction in exposure following the transition.

Unique study aspects: There was a follow-up visit and sampling after a transition from dry to wet methods for 4 of the granite countertop businesses.

Conclusions of Authors: The transition to wet fabrication methods reduced granite countertop fabricators' exposure to RCS to below the state of Washington's PEL of 0.10 mg/m^3, but the exposure remained above the NIOSH recommended 0.05 mg/m^3 RCS. Employers should continue to explore methods of reducing silica exposure to as low as possible.

Other Conclusions: The mean RCS exposures by shop measured during wet processing in this study often exceeded the now-current OSHA Action Level (AL) for RCS (0.025 mg/m^3) and, in some instances, also exceeded the now-current PEL (0.05 mg/m^3).

Key Strengths and Weaknesses:
Strength:

- Three reputable groups surveyed 6 businesses within the granite stone fabrication industry and assessed RCS exposure before and after transitioning to wet methods in 4 of them.

Weakness:

- Limited details regarding specific tasks performed or the time required per task were provided. Limited information on engineering controls and use of respiratory protection was provided.

Comparison to Other Studies: This report is consistent with other studies that have shown a reduction in RCS exposure with transition from dry to wet methods (e.g., Farhang et al. 2007, Johnson et al. 2017, Cooper et al. 2015).

Relevance to the Industry: This study on fabrication of granite countertops showed that transition ot wet methods can help reduce RCS exposures but exposure levels may remain above the current OSHA action level.

Citation: Simcox, N. J., Lofgren, D., Leons, J., & Camp, J. (1999). Silica exposure during granite countertop fabrication. *Applied Occupational and Environmental Hygiene*, *14*(9), 577–582. https://doi.org/10.1080/104732299302350

OSHA compliance issues: Exposure to crystalline silica in a countertop manufacturing operation

Study Authors / funding: Fairfax R, Oberbeck R. (US Department of Labor Occupational Safety and Health Administration).

Journal: *Journal of Occupational and Environmental Hygiene, 2008*

Location / Country: Colorado, USA

Study Type and Description: This case study discusses one of the silica National Emphasis Program (NEP) inspections, conducted in 2004, at a facility that manufactured tile, granite, and marble countertops. The facility's 13 employees worked 8-hour shifts. Slabs of marble and granite were cut with a bridge saw, hand ground, polished, and buffed with pneumatic power tools, all performed using wet methods. Wet spray was used with the bridge saw, and water mist was used with a water curtain for hand pneumatic power tools. Push and pull ventilation were placed at the ends of slabs during fabrication. The wet engineering controls for the bridge saw and the hand-held power tools resulted from an earlier OSHA inspection in 1999.

4 employees (1 performing bridge cutting, and 3 performing buffing and grinding on granite and marble slabs) were sampled for respirable crystalline silica (RCS) using standard OSHA protocols and procedures. Sampling was collected for the work shift, with exposure during unsampled time assumed to be zero.

After the OSHA inspection, an outside consultant recommended controls to reduce RCS exposure, including vacuuming the work area at the end of each workday and implementing a waterfall filter with a fan directing dust towards it. The consultant also repeated personal monitoring, which showed worsening of RCS exposure with one fabricator over-exposed (results shown below in Table V). The consultant then re-evaluated the operations, adding an additional fan-powered air filtration system in the corner of the work area with two, adjustable point source vacuum extensions that the fabricators could manipulate so that the intake was located near the source of the dust generation during grinding and buffing.

Key Findings:
OSHA Inspection result (2004):

- Workers were knowledgeable about written safety and health program management, including training on hazard communications, respiratory protection, and PPE
- 2/3 of the workers performing hand grinding and buffing were wearing N-95 filtering facepiece respirators, while the other worker and bridge saw operator were not wearing any respiratory protection.

OSHA sampling results (2004):

- At the time of this work, the OSHA PEL for RCS was 0.100 mg/m^3
- 1/4 of the workers had a TWA ~4x the calculated PEL for RCS, and 2/4 had TWA's equal to the calculated PEL for RCS. The bridge saw operator was not over-exposed.

After initial abatement by an outside consultant, one fabricator remained over-exposed to RCS (>OSHA PEL).

Following further abatement (additional fan-powered air filtration system), 2006 resampling (425 minutes duration) of the 1 fabricator performing grinding and polishing found non-detectable crystalline silica (with the detection limit of 0.01 mg/m^3.)

Unique study aspects: This study was performed to ensure compliance with OSHA's recommendations from a prior inspection (1999). The follow-up inspection (2004) showed over-exposure to RCS. An outside consultant ignored the 2004 OSHA recommendations, instead suggesting different controls. Sampling conducted by the outside consultant showed continued over-exposure despite these controls. After additional controls, 2006 air sampling found no over-exposure to RCS.

Conclusions of Authors: The company was issued citations for inadequate respiratory protection, over-exposure to RCS, and lack of appropriate engineering or work practice controls. Several control interventions were needed to reduce exposure to RCS below the OSHA PEL.

Key Strengths and Weaknesses:
Strength:

- Comparative study within one facility showing that multiple controls were implemented to adequately reduce exposure to RCS. This demonstrates the importance of resampling for RCS after controls are implemented.

Weakness:

- This study included only one facility, and the sample size was small (1 sample for each of the 4 employees).

Relevance to the Industry: Follow-up sampling is essential to assess the effectiveness of implemented controls. Because exposure can vary widely between workers performing similar tasks, it is important to conduct personal air sampling on multiple workers.

Citation: Fairfax, R., & Oberbeck, B. (2008). OSHA compliance issues. Exposure to crystalline silica in a countertop manufacturing operation. *Journal of occupational and environmental hygiene*, *5*(8), D81–D85. https://doi.org/10.1080/15459620802161934

Results of inspections in health hazard industries in a region of the state of Washington

Study Author / funding: Lofgren DJ. Division of Occupational Safety and Health, Labor & Industries, Tacoma, WA

Journal: *Journal of Occupational and Environmental Hygiene*, 2008

Location / Country: Washington State, USA

Study Type and Description: This paper reviewed the results of work site safety inspections conducted by the WA Division of Occupational Safety and Health, a federally approved state OSHA program, for targeted high hazard industries from 2002 to 2007. Inspections were reportedly performed in a similar, if not identical, manner to most of those by federal OSHA, with any sampling performed in accordance with agency procedures in effect at the time. The author provides summary statistics on the number of individual work sites inspected within each industry, the health hazards assessed, frequency of violations, relative levels of worker over-exposures, and the approximate number of workers identified as overexposed.

Among the high hazard industries selected for targeted inspections were stone countertop fabricators. A total of 18 stone countertop fabrication sites were inspected during the 5-year timeframe, with personal exposures to respirable crystalline silica (RCS) and noise monitored. Limited information was provided regarding the work methods, equipment, or controls used.

Key Findings:

- Of the 18 fabrication shops inspected, the number of employees ranged from 1 to 20, with an average of 9 employees.
- Half (9) received violations for over-exposures to RCS, attributed by inspectors to a lack of adequate engineering controls:
    - Of these, all 9 sites received a violation for lacking respirator fit testing, 6 for absence of respirator training, and 3 for improper use of respirators.
    - Personal air samples (8-hour time weighted averages) documented levels ranging from 1.7 to 7.1 times the permissible exposure limit (PEL) in effect at the time (i.e., 0.100 mg/m^3.)
    - Follow-up inspections at 6 of the 9 sites found that half (3) had implemented adequate controls, 2 implemented controls after their re-inspections, and 1 had ceased operations.
- Of the 12 sites with documented over-exposures to noise, 11 (92%) received violations for not performing baseline noise monitoring, 10 (83%) for failure to have audiometric testing performed, and 5 (42%) failed to provide worker training.

Unique Study Aspects:

- High-level summary of findings based exclusively upon regulatory compliance inspections in targeted high hazard industries.

Conclusions of Author:

- The author noted poor control of health hazards across the inspected sites and the need for intervention.
- An absence of effective workplace exposure controls and overwhelming reliance on respirators for airborne exposures, and a lack of critical respiratory protection program elements, such as fit testing and training, was noted.
- Most of the inspected high hazard small employers were able to document compliance in reducing worker exposures, either before or after follow-up inspection.

Key Strengths and Weaknesses:
Strengths:
- Broad, high-level survey
- Relatively large number of work sites visited and inspected against a consistent set of regulatory compliance criteria.
- Air sampling performed by trained inspectors using standard NIOSH methods.

Weaknesses:
- The selected shops may not be representative of the industry.

Relevance to the Industry: This paper was published before the first reported cases of engineered stone silicosis. Although the stone type(s) fabricated was not specified, this study likely preceded widespread use of engineered stone and the results showed overexposure to RCS and violations of the respiratory protection standard. Of note, this study also found widespread overexposure to noise.

Citation: Lofgren DJ. Results of inspections in health hazard industries in a region of the state of Washington. *Journal of Occupational and Environmental Hygiene* 2008; 5(6):367-379.
doi: 10.1080/15459620802066133. PMID: 18409117.

Determinants of respirable silica exposure in stone countertop fabrication: A preliminary study

Study Authors / funding: Margaret L. Phillips, David L. Johnson, and Andrew C. Johnson (Health Sciences Center, Department of Occupational and Environmental Health, University of Oklahoma). Funding from University of Oklahoma Health Sciences Center and NIOSH.

Journal: *Journal of Occupational and Environmental Hygiene, 2013*

Location / Country: Oklahoma, USA

Study Type and Description: This preliminary study of personal exposure to respirable quartz was based on measurements collected from a convenience sample of four countertop fabrication shops that used a variety of wet and dry methods between November 2010 and March 2012.

Respirable dust samples were collected from workers assigned to work full days in the participating shops. Between two and four consecutive personal samples were collected to cover the entire shift, excluding mealtime breaks, and eight-hour TWA exposures for each sampled employee were calculated from consecutive partial-shift samples.

Generally, workers alternated between tasks (e.g., sawing, grinding, polishing, every 5-10 minutes or less). Sampling was not limited to a single task. Rather, an investigator took notes on the tasks performed, scoring each sample and shift using a 5-point scale according to the degree of use of wet or dry methods (all wet, mostly wet, wet & dry, mostly dry, all dry). The study authors used the "P-screen method," a linear algebra-based method, to estimate and rank task-specific exposures derived from partial-shift sample concentrations.

Key Findings:

- Material processed by fabricators were natural granite (2-60% quartz by volume), engineered stone (90% quartz by mass), and terrazzo (15% quartz).
- Dry methods were associated with higher respirable quartz concentrations. The five tasks associated with the highest exposures were dry sweep/brush, dry saw/cut/bore/rod, dry grind, dry polish, and wet saw/cut.
- For all shifts in which some dry fabrication was performed, the 8-hr TWA (mg/m^3) exceeded the ACGIH TLV of 0.025 mg/m^3.
- No local exhaust ventilation was observed, except for one shop that used a HEPA vacuum cleaner for certain dry cutting tasks.

Conclusions of Authors: Personal sampling results suggested that even when dry methods were used only to a limited extent, workers who fabricated countertops from granite and engineered stone were likely at high risk of exposure to respirable quartz exceeding the ACGIH TLV (0.025 mg/m^3) with a significant chance that exposure may approach or exceed the OSHA PEL.

Key Strengths and Weaknesses:

Strengths:

- The samples collected in this study were reflective of real-world conditions (e.g., frequent task alternation)

Weaknesses:

- Results are based on a small convenience sample of shops.

Comparison to Other Studies: Consistent with other studies showing that compared to wet methods, dry fabrication methods are associated with higher RCS exposures. Use of wet methods primarily may still generate exposures that approach or exceed regulatory limits.

Relevance to the Industry: Provides evidence that even limited use of dry fabrication methods likely results in respirable crystalline silica (RCS) exposures that exceed the current OSHA action level (AL) of 0.025 mg/m^3 and may approach or exceed the OSHA PEL of 0.05 mg/m^3.

Citation: Phillips ML, Johnson DL, Johnson AC. Determinants of respirable silica exposure in stone countertop fabrication: a preliminary study. *Journal of Occupational and Environmental Hygiene* 2013;10(7):368-73. doi: 10.1080/15459624.2013.789706. PMID: 23668829.

Evaluation of crystalline silica exposure during fabrication of natural and engineered stone countertops.

Study Authors / funding: Zwack LM, Victory KR, Brueck SE, Qi C. NIOSH Health Hazard Evaluation Program

Publication: *NIOSH HHE Report No. 2014-0215-3250, 2016*

Location / Country: Texas, USA

Study Type and Description: This exposure study was requested by the Texas Department of State Health Services after a worker was diagnosed with silicosis. It was conducted in 2015 at the facility where the worker was employed.

Full-shift personal air samples were collected for 36 of the 38 production employees following standard NIOSH sampling and analytical methods. Each employee worked with both natural and engineered stone (ES) during sampling; the time spent processing each stone type was not calculated. Employees were categorized by job title:

- Bridge saw
- Computer-aided design department
- CNC operator
- Comandulli Omega operator
- Comandulli Synthesis operator
- Grinder – diamond cup wheel
- Laminator
- Maintenance
- Material handler
- Office area employee
- Polisher – resin bonded disc
- Quality control/finishing
- Vanity
- Water jet cutter

In addition, a total of 28 task-based air samples were collected using higher airflow rates. Tasks sampled were polishing and grinding for durations ranging from 29 - 118 minutes, with the specific type(s) of stone used documented.

The evaluators also visually inspected the ventilation system and production area room air pressurization, reviewed previous respirable crystalline silica (RCS) sampling reports, OSHA Form 300 logs and previous spirometry results, and conducted medical interviews with 58 of 59 workers.

Key Findings:

- The quartz percent ranged from ND – 52% in full-shift respirable dust (RD) samples and was 48% and 70% in the 2 bulk dust samples. No cristobalite or tridymite was detected in any sample.
- Full-shift TWA RCS concentrations ranged from ND – 140 ug/m^3. Office area workers had ND levels. Overexposed workers were as follows:

- 4 of 4 grinders using a diamond cup wheel (range 93 – 140 ug/m^3)
- 1 of 2 laminators (31 ug/m^3)
- *The maintenance worker had extremely high RCS levels, but this was deemed inaccurate due to visible debris and observation of this worker

- Task-based sample RCS ranged from ND – 140 ug/m^3 for polishing and 50 – 140 ug/m^3 for grinding.
- Engineering controls and PPE:
    - All cutting and polishing tools and saws had water spray; the operator could control the flow rate. No dry cutting was observed.
    - No local exhaust ventilation (LEV) was used. Facility ventilation was provided by large roof exhaust fans and an open bay door at one end of the 46,000 sq. ft. building.
    - Production employees wore half-face respirators (mostly P100 filters, some organic vapor cartridges). Others wore N95 respirators when entering the production floor. They were reportedly worn properly in most cases.

Unique Study Aspects: This was a NIOSH Health Hazard Evaluation conducted in response to an employee being diagnosed with silicosis.

Conclusions of Authors:
- Workers with the job title grinding with diamond cup wheels had the highest RCS exposures and were consistently overexposed to RCS.
- Full-shift RCS exposure is largely determined by the:
    - Time spent grinding and polishing, and
    - Silica concentrations associated with each task.
- Water suppression alone was insufficient to reduce RCS exposure below the PEL in effect at the time (or the current action level or PEL).

Recommendations of Authors:
- Engineering controls:
    - Use LEV and wet methods during cutting, grinding, and polishing.
    - Negative pressure enclosure with high-efficiency air filtration for tasks with potential for high RCS exposure (grinding with diamond cup wheel).
- Administrative controls:
    - Implement a medical surveillance program and exposure monitoring following OSHA/NIOSH guidelines. Educate employees on RCS and symptoms of adverse respiratory health.
    - No dry sweeping - use wet sweeping or a HEPA-filtered vacuum for dust removal.
    - Maintain HVAC systems - timely maintenance, repairs, filter changes.
- Respiratory protection:
    - Provide users with education and training on the proper selection, use, fitting, and maintenance of respirators.

Key Strengths and Weaknesses:
Strengths:
- Real-world sampling conditions on 95% of the facility's production workers, representing 14 job titles. Sampling included personal and task-based exposures.
- Extensive workplace information was obtained, including facility ventilation, cleaning methods, previous spirometry and RCS sampling, and employee interviews.

Weaknesses:

- Sampling did not differentiate between use of natural or ES.

Relevance to the Industry: Use of wet methods alone did not reduce all RCS exposures to below the previous or current OSHA PEL and action level. The time a worker spends performing tasks with high exposures (grinding and polishing in this HHE) and the silica content of the stone can help predict RCS exposure. However, unless engineering controls can be shown to further reduce RCS exposures, respiratory protection remains necessary.

Citation: Zwack LM, Victory KR, Brueck SE, Qi C. (2016). Health hazard evaluation report: evaluation of crystalline silica exposure during fabrication of natural and engineered stone countertops. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HHE Report No. 2014-0215-3250. https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB2016103221.xhtml

Engineering control of silica dust from stone countertop fabrication and installation – Evaluation of wetting methods for grinding

Study Authors / funding: Qi C, Echt A. NIOSH Engineering and Physical Hazards Branch

Journal: *NIOSH EPHB Report No. 2021-DFSE-710, 2021*

Location / Country: USA

Study Type and Description: Exposure study conducted at a countertop fabrication facility. Respirable crystalline silica (RCS) exposures from short-term task-based grinding with three different wetting methods were assessed:

- The investigators initially evaluated personal breathing zone and area sample RCS levels while using water spray and center-feed wet methods with a handheld pneumatic grinder on engineered stone. Water flow rates on each grinder were 7.1 ± 0.4 L/min for water spray and 1.52 ± 0.05 L/min for center-feed. Sampling was paused when the worker was not grinding.
  Area samples were collected on tripods in the grinding and polishing area about 40 ft from each other and at least a few feet from any grinding or polishing activities.
- At 2 subsequent visits to the facility personal breathing zone RCS levels were evaluated while using the handheld pneumatic grinder with a combination of water spray and sheet-wetting on both natural and engineered stone. Water spray flow rate was 6.58 ± 0.03 L/min, and sheet wetting by a hose of continuous water flow across the stone surface was 15.82 ± 1.25 L/min. Sampling was continuous until the worker moved out of the range of the sheet-wetting.

All workers wore elastomeric, half-face air-purifying respirators with either P100 cartridges or combination P100 and organic vapor cartridges.
The specific natural and engineered stone products were not specified.

Key Findings:

- Short-term task-based RCS mean ± standard deviation (range) and sampling duration range
  - Water spray (n=9) = 190.4 ± 105.4 μg/m^3 (51.5 – 389.4 μg/m^3), 15 – 22.2 minutes
  - Center-feed (n=7) = 195.3 ± 168.4 μg/m^3 (93.5 – 568.5 μg/m^3), 15.4 – 21.2 minutes
  - Combination water spray and sheet-wetting (n= 10) = 33.2 ± 11.4 μg/m^3 (14.7 – 53.9 μg/m^3), 95.2 – 167.7 minutes
- Area samples RCS mean ± standard deviation (range) and sampling duration range
  - Area 1 (n=3) = 50.1 ± 29 μg/m^3 (17.6 – 73.3 μg/m^3), 167 – 178 minutes
  - Area 2 (n=3) = 44.5 ± 12.6 μg/m^3 (34.9 – 58.7 μg/m^3), 168 – 178 minutes

Unique study aspects: controlled task-based sampling comparing different wet methods in a real-world environment.

Conclusions of Authors:

- Both water spray and center-feed wetting methods performed poorly in reducing RCS exposure from grinding, likely because the water can miss the active grinding spot resulting in dry grinding. Workers grinding for a full shift would likely be exposed to 2-3x the OSHA PEL.
- Background concentrations of RCS can be high despite wet methods, which could contribute to over exposures.

- The combination of sheet-wetting and water spray was most effective at reducing RCS exposures, but this method may still result in full-shift TWAs above the OSHA PEL.

Key strengths and weaknesses:
Strength:

- Controlled study design in a fabrication facility comparing different wet methods. Sampling was paused when not actively grinding to get more accurate task-based RCS results under different wet methods.

Weakness:

- Challenging to directly compare the sheet-wetting with water spray to the other wet methods results since the sheet-wetting with water spray was conducted on both natural and engineered stone continuously and the other methods only on engineered stone and only during active grinding.

Comparison to Other Studies: Consistent with other studies that show wet methods may not be adequate to reduce RCS exposure to below the PEL (or the AL).

Relevance to the Industry: Wet methods may not reduce the RCS exposure below the PEL. However, adding sheet-wetting to water spray may be more effective than water spray or center-feed wetting alone and may reduce exposures below the PEL (not necessarily below the action level). Additionally, background RCS levels may be close to or higher than the PEL.

Citation: NIOSH [2021]. Engineering Control of Silica Dust from Stone Countertop Fabrication and Installation – Evaluation of Wetting Methods for Grinding. By Qi C, Echt A. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, *NIOSH EPHB Report No. 2021-DFSE-710.*

Occupational exposure to crystalline silica in artificial stone processing

Study Authors / funding: Salamon F, Martinelli A, Vianello L, Bizzotto R, Gottardo O, Guarnieri G, Franceschi A, Porru S, Cena L, Carrieri M (University of Padova and University of Verona in Italy, Department of Prevention in Bassano del Grappa and Padova, Italy, and West Chester University of Pennsylvania, USA).

Journal: *Journal of Occupational and Environmental Hygiene, 2021*

Location/Country: Italy

Study Type and Description: This workplace exposure study aimed to evaluate personal RCS levels in workers of artificial stone countertop shops. 51 workers from 4 separate shops were measured for an entire shift—8 hours—for RD and RCS using standardized equipment and methods. Workers' tasks were characterized as manual finishing (use of handheld tools in which the worker is close to the dust source), mechanical processing (use of stationary equipment with greater distance from the dust source), or other (such as bonding, packaging, and warehouse management). The stone material was categorized as quartz-resin stones, which were about 70 – 90% silica content by weight, and ceramic products, which were about 10 – 30% silica content by weight.

Shop A:

- 4 samples out of 6 total employees, working material was quartz-resin stones, manual finishing was done dry with extraction wall booth as an engineering control, mechanical processing was done wet with water spraying equipment

Shop B

- 9 samples out of 15 total employees, working material was quartz-resin stones, manual finishing was done dry with aspirated benches (perimeter) as an engineering control, mechanical processing was done wet with water spraying equipment

Shop C

- 29 samples out of 65 total employees, working material was quartz-resin stones, manual finishing was done wet and dry with extraction wall booths as an engineering control, mechanical processing was done wet with water spraying equipment

Shop D

- 9 samples out of 14 total employees, working material was ceramic products, manual finishing was done dry with aspirated benches (perimeter and wall) and one extraction wall booth, mechanical processing was done wet with water spraying equipment

Key Findings:

- Total sample (n=51): range = <0.3 – 98 ug/m^3, mean = 22 ug/m^3, median = 13 ug/m^3
- 1 shop (B) had all samples <25 ug/m^3, but of all 51 samples about 22% were >25 ug/m^3 and about 14% were >50 ug/m^3
- Manual finishing (median = 17 ug/m^3, range = 4 – 98 ug/m^3) was statistically significantly higher than mechanical processing (median = 12 ug/m^3, range = 4 – 54 ug/m^3) and other (median = 7 ug/m^3, range = <3 – 18 ug/m^3)
- Dry manual finishing RCS levels (n=12, median = 20 ug/m^3) were not statistically significantly higher than wet manual finishing RCS levels (n=10, median = 16 ug/m^3), but dry manual finishing

RD levels were statistically significantly higher than wet manual finishing RD levels (230 and 77 ug/m^3, respectively)

Conclusions of Authors:

- Workers can still be exposed to hazardous levels of RCS despite current preventative measures
- A combination of engineering controls, worker training, and correct PPE use along with periodic monitoring is needed for worker protection

Key strengths and weaknesses

Strengths:

- Assessed the silica content of the different stone categories
- Categorized work processes by proximity to the working surface/dust source

Weaknesses:

- No indication that the volume of work was similar among the shops for comparison or that the work in each shop was representative of a normal workday
- Wet manual finishing was all performed in 1 shop, which is likely to have less variability in methods and results when compared to dry manual finishing which was performed in all 4 shops

Comparison to Other Studies: Consistent with other studies that show local exhaust ventilation and wet methods may not prevent all hazardous RCS exposure.

Relevance to the Industry: Engineering controls such as LEV or wet methods can lower RCS exposure, but they may not prevent RCS exposure >25 or >50 ug/m^3 in a full working shift. A properly fitted and worn respirator with APF 10 would sufficiently protect workers at the levels found in this study.

Citation: Salamon, F., Martinelli, A., Vianello, L., Bizzotto, R., Gottardo, O., Guarnieri, G., Franceschi, A., Porru, S., Cena, L., & Carrieri, M. (2021). Occupational exposure to crystalline silica in artificial stone processing. *Journal of occupational and environmental hygiene*, *18*(12), 547–554. https://doi.org/10.1080/15459624.2021.1990303

Silica compliance project report

Study Authors / funding: WorkSafe WA (Government of Western Australia Department of Mines, Industry Regulation and Safety)

Location / Country: Australia

Report Description:
A silica compliance project was conducted by WorkSafe WA and included:

- workplace inspections at 150 engineered stone fabrication shops conducted between July 2018 – May 2021
- education of stone shop workers
- enforcement action
- health surveillance
- air monitoring for silica
  - 67 personal samples collected across 20 stone workshops
  - 22 personal samples collected on stone installers
- health surveillance

Key Findings:

- Air monitoring found that 25% of stone fabrication workers and 33% of installers were exposed to respirable crystalline silica (RCS) above the workplace exposure standard (WES) of 0.05 mg/m^3
- Health surveillance conducted on 365 workers identified 24 cases of silicosis
- Workers were not consistently provided with sufficient information and training on RCS hazards and appropriate control measures to reduce exposure
- Hand tools connected to water but without local exhaust ventilation (LEV) were used to grind, cut, sand and polish stone in the workshops studied
- Inadequate use of respiratory protective equipment was found

Conclusions of Authors: Silica controls in many WA stone fabrication workplaces were inadequate. Results from air monitoring highlight the need for LEV in combination with water suppression to reduce RCS exposures during engineered stone fabrication.

Key Strengths and Weaknesses:
Strength:

- Effort to characterize RCS exposure among WA stone fabrication workers and installers and document compliance with OSH regulations.

Weakness:

- The report indicated that air monitoring included 117 samples from 38 workplaces but described only 67 personal samples from 20 stone fabrication shops and 22 personal samples from installers.

Relevance to the Industry: Use of hand tools in stone fabrication shops presents a high risk of RCS overexposure despite the use of wet methods.

Citation: WorkSafe Western Australia. 2021. Silica compliance project report. Western Australia: WorkSafe Department of Mines, Industry Regulation and Safety, Government of Western Australia.

Elevated exposures to respirable crystalline silica among engineered stone fabrication workers in California, January 2019 - February 2020.

Study Authors / funding: Surasi K, Ballen B, Weinberg JL, Materna BL, Harrison R, Cummings KJ, Heinzerling A (Occupational Health Branch of the California Department of Public Health). Study funded by NIOSH.

Journal: *American Journal of Industrial Medicine, 2022*

Location / Country: California, United States

Study Type and Description: This study analyzed respirable crystalline silica (RCS) air sampling data collected as part of the Cal/OSHA Special Emphasis Program (SEP) for Occupational Exposure to Respirable Crystalline Silica (RCS), Cut Stone, and Stone Product Manufacturing.

Cal/OSHA identified 281 presumed CA workplaces where engineered stone (ES) was fabricated. From January 2019 to February 2020, Cal/OSHA initiated inspections in 106 (38%) of these worksites and, among the fabrication shops inspected, RCS personal air sampling was performed in 47 (44%). During these inspections, 44 out of 47 employers self-reported the number of employees who were exposed to RCS at their workplace.

The median number of employees with RCS exposure per shop was 5 (range 1-30). The median number of employees who underwent RCS personal air sampling per shop was 3 (range 1-6).

Personal air sampling results, sampling times, and crystalline silica forms as a percentage of respirable dust by weight were abstracted from the Cal/OSHA inspection files for those 47 shops. From that data set, 8-hr time weighted average (TWA) exposures were calculated using Cal/OSHA methods for a total of 152 workers, with exposures to RCS during the unsampled time presumed to be zero.

Cal/OSHA citations for violations of the RCS standard and respiratory protection program standard were obtained from the US Department of Labor (DOL) web portal for the 47 shops where RCS personal air sampling was conducted.

Key Findings:

- Of the 47 worksites with RCS personal air sampling data:
    - More than half, n=24 (51%), had ≥1 worker with an 8-hr TWA above the PEL. The highest exposure was > 13x the PEL.
    - Another 7 (15%) had ≥1 worker with an 8-h TWA ≥ AL but < the PEL
    - 16 (34%) had no workers with an 8-h TWA ≥ AL

- Of the 152 workers who underwent RCS personal air sampling:
    - n=38 (25%) had 8-h TWAs > PEL for RCS
        - median = 89.7 $\mu g/m^3$, range = 50.7–670.7 $\mu g/m^3$
    - n=17 (11%) had 8-h TWAs ≥ AL but below PEL
        - median = 35.2 $\mu g/m^3$, range = 25.5–47.3 $\mu g/m^3$
    - n=97 (64%) had 8-h TWAs < AL

    - median = 8.5 μg/m^3, range = 0–24.7 μg/m^3

- n=34 (72%) of the shops were cited for RCS standard violation(s)
- n=27 (57%) shops were cited for respiratory protection standard violation(s)

Unique Study Aspects: Real world conditions

Conclusions of Authors: Study findings suggest widespread overexposure to RCS among ES fabrication workers in CA. High RCS exposure levels and numerous standard violations in the shops raised concern that existing engineering, administrative, and personal protective equipment controls fail to adequately protect ES fabrication workers.

Other conclusions: It is unclear how widespread overexposure is; 64% of workers who underwent RCS personal air sampling had 8-hr TWA < AL, and close to half of shops had no worker RCS exposures above PEL.

Key Strengths and Weaknesses:
Strength:
- Systematic effort to characterize RCS exposures in CA ES fabrication workers and document compliance with RCS and respiratory protection standards.

Weaknesses:
- RCS air sampling performed on 1 day and fabrication shops were notified in advance. Therefore, the measured RCS exposure levels may under-represent exposures.
- For the shops with ≥ 1 worker with exposure > PEL, it is not known how many of the samples exceeded the PEL.
- Limited information regarding engineering controls or respiratory protection use.

Comparison to Other Studies:
- Findings are consistent with those reported by Weller et al. (2024).

Relevance to the Industry:
- More than half the shops sampled had ≥ 1 worker with RCS exposure > the PEL, and 25% of the workers across all shops had exposures > PEL.
- >70% shops received citations for violations of the Cal/OSHA RCS and respiratory protection standards.
- A significant number of fabrication shops need assistance to reduce RCS exposures and increase compliance with existing Cal and federal OSHA regulations.

Citation: Surasi, K., Ballen, B., Weinberg, J. L., Materna, B. L., Harrison, R., Cummings, K. J., & Heinzerling, A. (2022). Elevated exposures to respirable crystalline silica among engineered stone fabrication workers in California, January 2019 - February 2020. *American Journal of Industrial Medicine*, *65*(9), 701–707. https://doi.org/10.1002/ajim.23416

Respirable silica dust exposure of migrant workers informing regulatory intervention in engineered stone fabrication

Study Authors / funding: Seneviratne M, Shankar K, Cantrell P, Nand A. (SafeWork NSW, Australia)

Journal: *Safety and Health at Work*, *2024*

Location / Country: Sydney, Australia

Study Type and Description: Exposure study of respirable crystalline silica (RCS) in engineered stone benchtop fabricating shops in 2017. 6 shops were randomly chosen from a public listing. 3 shops had <10 workers, 2 shops had 10-24 workers, and 1 shop had 25-99 workers. In total, 34 workers (all male migrants) had personal air samples collected for full shifts of about 6 hours duration. The workers were categorized as 1 of 3 exposure groups:

- EG1: Wet Cutting (n=8) – cutting slabs with bridge saw, water jet, or CNC routers
- EG2: Dry Finishing (n=6) – preparing slabs for lamination or finished edges using hand-held dry power tools with diamond blades or grinders with water spray bottles or sponges for wetting
- EG3: Wet Finishing (n=20) – polishers using water-fed pneumatic hand tools or larger wet polishing machines

Wet Cutting with continuous water was performed at all 6 shops, and most of these workers did not wear any respiratory protection. Dry Finishing was performed at 4/6 shops, and wet finishing was performed at the other 2 shops. Finishing workers generally wore disposable masks or half-face masks with filter cartridges. All shops used pedestal fans for dust control; 3 used local exhaust ventilation, but at least 2/3 were deemed ineffective for unsuitable designs or overloaded filters. No off-site installation work was performed during sampling.

Key Findings:

- 79% of 34 workers sampled had RCS levels above the Australian Workplace Exposure Standard (WES) of 100 ug/m^3 TWA-8 hours
- Overall RCS exposure ranged from about <40 – 1,420 ug/m^3
  - Wet Cutting range - about <40 – 260 ug/m^3 (lowest)
  - Wet Finishing range - about <40 – 580 ug/m^3 with an outlier of about 1,340 ug/m^3 in which the worker used a high-pressure water-fed pneumatic grinder
  - Dry Finishing range - about <40 – 1,420 ug/m^3 (highest)
- Those who used hand-held power tools for dry finishing were exposed to 7 – 14 times the WES
- Lack of basic occupational health services in all shops: no health monitoring, air monitoring, fit testing for respiratory protection, or knowledge of RCS and its associated health effects

Unique study aspects: Randomly selected shops in 2017 prior to regulatory intervention on banning dry cutting tasks or engineered stone.

Conclusions of Authors:

- Results are generalizable to over 100 engineered stone fabrication facilities in the Sydney area based on processes and work practices, shop size, and worker demographics.

- Recognizing the multiple factors of work-related health outcomes, including demographics and socioeconomic factors can help guide intervention programs.

Key strengths and weaknesses

Strengths:

- Exposure groups provided an easy comparison across job categories

Weaknesses:

- Unknown how many samples from each exposure group was > WES or how many samples from each shop

Comparison to Other Studies: Consistent with other studies that show dry methods expose workers to higher levels of RCS than wet methods, but wet methods do not necessarily keep exposure lower than the regulatory limit.

Relevance to the Industry: Tasks with wet methods showed a lower exposure than dry finishing, in most cases. However, wet method tasks still overexposed many workers.

Citation: Seneviratne, M., Shankar, K., Cantrell, P., & Nand, A. (2024). Respirable Silica Dust Exposure of Migrant Workers Informing Regulatory Intervention in Engineered Stone Fabrication. *Safety and health at work*, *15*(1), 96–101. https://doi.org/10.1016/j.shaw.2024.01.003

An assessment of worker exposure to respirable dust and crystalline silica in workshops fabricating engineered stone.

Study Authors / funding: Weller M, Clemence D, Lau A, Rawlings M, Robertson A, Sankaran B.
From SafeWork NSW, the Australian workplace health and safety regulator (governmental agency)

Journal: *Annals of Work Exposures and Health*, *2024*

Location / Country: New South Wales, Australia

Study Type and Description: This exposure study was conducted between June 2022 and April 2023 in 30 stone fabrication shops in the Sydney, Australia metropolitan area that were randomly selected out of the approximately 200 shops known to be in operation. The included shops processed engineered stone (ES) exclusively or in combination with natural stone (porcelain and marble), with exact mixtures of stone processed per shop unknown; 1 shop processed only quartzite. Participation in this study was NOT voluntary.

Measurements of respirable dust (RD) and respirable crystalline silica (RCS) were taken by personal air samples (n=123 across 27 shops; 3 shops were excluded because only marble was processed on the day of sampling). To estimate 8-hr TWA personal exposures, sampling durations were a minimum of 75% of workers' full shifts, with similar exposure during unsampled time presumed.

Workers' primary tasks (5 to 8 hours of a work shift) were identified and included:

- Semi-automated bridge saw
- Semi-automated edge polisher
- Semi-automated router
- Semi-automated miter saw
- Pneumatic hand polishing only
- Pneumatic hand grinding/cutting and polishing
- Hand laminating
- Other (variety of tasks, each for shorter periods)

In addition, 34 area samples were collected across 20 of the shops.

No dry fabricating was observed at any shop, although the details of the wet methods used were not described in detail.

Key Findings:

- The mean number of workers per shop was 4.
- The ratio of geometric means (GMs) for RCS to RD from personal air samples ranged from 0.31 to 0.56.
- RCS air sampling results (all reported as 8-hr TWA's):

Primary Task	Operating Mode	Sample Size (n)	GM	GSD	95th Percentile
All samples pooled	Mix	123	0.034	2.7	0.174
Bridgesaw	Semi-Automated	30	0.039	3.2	0.26
Edge polisher	Semi-Automated	6	0.018	2.4	0.072

Router / water jet	Semi-Automated	7	0.022	2.6	0.105
Miter saw	Semi-Automated	4	0.047	2.7	0.24
Hand polishing	Manual	23	0.036	2.4	0.154
Hand grinding, cutting, & polishing	Manual	7	0.062	2.4	0.26
Hand laminating	Manual	23	0.032	2.3	0.130
Other activities	Manual	21	0.033	2.9	0.192

- The lowest RCS exposures were in operators of semi-automated edge polishers and routers / water jets.
- Workers using pneumatic hand tools for grinding, cutting, and polishing had the highest RCS exposures, with the single highest level for this task (0.23 mg/m^3) reportedly occurring from work inside a booth.
- At the shop-level:
    - only 4 shops (14.8%) had all worker RCS exposures below the OSHA action level (AL) of 0.025 mg/m^3.
    - 8 shops (29.6%) had 1 or more workers with RCS exposures between OSHA's AL and the permissible exposure limit (PEL) of 0.05 mg/m^3.
    - 15 shops (55.6%) had 1 or more workers with RCS exposures above OSHA's PEL.
- The RCS exposures for the area samples had a GM = 0.016 mg/m^3. Area samples for half of the shops were higher than the OSHA AL of 0.025 mg/m^3, indicating significant background exposures to RCS.
- In the 1 shop fabricating only quartzite (n=5 worker samples), RCS exposures were surprisingly low (GM = 0.014 $mg/\ m^3$) given that quartzite can contain high levels of quartz, raising questions about the specific operations and control methods employed in this shop.

Conclusions of Authors:
- Compared to prior literature on RCS exposure levels where work largely occurred dry, the wet fabrication methods used by shops in this study substantially reduced RCS exposure levels.
- However, despite the use of wet methods, some workers remain exposed above the Australian Worker Exposure Limit (WEL) and OSHA PEL of 0.05 mg/m^3, making respiratory protection necessary for those exposures until additional control methods are implemented.
- Class P2 or N95 respirators, providing an assigned protection factor (APF) of 10, will provide adequate protection for workers who are clean-shaven, properly trained, and fit tested.

Key Strengths and Weaknesses:
Strengths:
- Large representative sample of ES workers across 27 different shops
- Tasks included manual hand operations and semi-automated machinery
- SafeWork NSW conducted both the data collection and analysis
- Paper provides an excellent summary of other similar studies

Weaknesses:
- Presumption of comparable exposures during balance of unsampled work shift times may have biased results towards higher estimates of exposure in some shops (the authors considered this impact negligible to overall analysis).
- Unclear how many individual personal samples were above the WEL / OSHA PEL for RCS

- Specific mixture of stone types processed during each sampling campaign was not provided

Comparison to Other Studies:

- Similar to reports from the United States (Surasi, et al. (2022), Lofgren (2008)), Australian stone fabrication shops tend to be very small businesses
- The finding that workers using pneumatic hand tools for grinding, cutting, and polishing had the highest RCS exposure concurs with findings reported by multiple authors, including Qi and Lo (2016) and Qi and Echt (2016).
- Similar to the findings of Surasi et al (2022), >50% of the workshops studied had 1 or more workers exposed to RCS above the OSHA PEL.

Relevance to the Industry: Even with the use of wet methods, slightly more than half of the shops had 1 or more worker exposures to RCS above the OSHA PEL. While the findings support conclusions that operators of automated / semi-automated tools have lower RCS exposures than those using hand tools, some workplace exposures still exceeded regulatory limits. The finding that half of the shops had area samples exceeding the OSHA AL suggests more widespread RCS exposures that could potentially impact non-production workers and require better controls.

Citation: Weller, M., Clemence, D., Lau, A., Rawlings, M., Robertson, A., & Sankaran, B. (2024). An assessment of worker exposure to respirable dust and crystalline silica in workshops fabricating engineered stone. *Annals of Work Exposures and Health*, *68*(2), 170–179. https://doi.org/10.1093/annweh/wxad072

Workplace Questionnaire Surveys

Prevalence of dry methods in granite countertop fabrication in Oklahoma

Study Authors / Funding: Phillips M and Johnson A (Department of Occupational and Environmental Health, University of Oklahoma). Funding: University of Oklahoma Health Sciences Center and NIOSH Training Grant

Journal: *Journal of Occupational and Environmental Hygiene, 2012*

Location / Country: Oklahoma, USA

Study Type and Description: The purpose of this questionnaire and observational study was to estimate the prevalence of exposure control methods in granite countertop fabricators in Oklahoma to assess the number of workers at risk for crystalline silica over-exposure in this industry. Granite fabrication shops in the Oklahoma City, Tulsa, and Lawton metropolitan areas that performed their own granite fabrication were identified. A 13-item questionnaire was administered via on-site survey or over the phone to 47 fabricating shops. The questionnaire gathered the following information:

- Equipment used in the fabrication step of initial cuts, edge grinding, edge profiling, polishing, cutting of grooves for rodding and cutting of sink opening,
- Degree to which tasks were performed with wet or dry methods,
- Whether the shop had a respiratory protection program with fit testing,
- Types of personal protection equipment used,
- How dust was cleaned up,
- Ventilation in the work area,
- Number of countertops fabricated, i.e., daily, weekly, monthly, or yearly,
- Number of fabricators and average length employed.

Descriptions of equipment and methods were based upon direct observations during on-site surveys, a review of vendor catalogs and websites, and discussions with employees.

Key Findings:

- Countertop shops were small businesses. The number of workers per shop ranged from 1-23, with the majority having fewer than 10 employees. Length of employment ranged from 1-25 years (mean 6 years).
- Production rates of countertops also ranged widely, from approximately 8 per year to 120 per month with a median of 24 per month. Fabrication shops with CNC machines produced more countertops.
- For initial cuts of granite slabs: 34 shops (72%) used a bridge saw, 8 (17%) shops used a rail saw, 3 shops (6%) used handheld stone saws and 2 shops (4%) used CNC machines exclusively.
- 43 shops (91%) always performed initial cuts with wet methods, 3 shops (6%) would usually perform initial cuts with a wet method and 1 shop (2%) always performed initial cuts with a dry method using a hand-held saw.
- 13 shops (28%) performed edge grinding (7 shops (15%) with edge grinding machines, 3 shops (6%) with handheld grinders and 3 shops (6%) with both). 15% of all shops performed edge grinding with dry methods most of the time.
- For edge profiling, 24 shops use a stone router exclusively, 11 shops (23%) used handheld grinders, 3 shops (6%) used both routers and handheld grinders and 9 shops (19%) use CNC machines. 17% of all shops performed edge profiling using a dry method most of the time.

- For polishing, 39 shops (83%) used handheld tools (with water feed or operated wet using a sponge), 6 shops (13%) used CNC machines, and 1 shop (2%) which used both. 37 shops (79%) performed polishing with only or mostly wet methods, 3 shops (6%) performed polishing using half wet and half dry methods, and 7 (15%) performed polishing using only or mostly dry methods.
- 41 shops (87%) cut grooves for installing reinforcing rods (i.e., rodding) with handheld tools and 1 shop (2%) performed it with CNC machines. 5 shops (11%) did not perform the rodding process at all. 29 shops (62%) reported only using dry methods, 2 shops (4%) reported using half wet and half dry methods, 11 shops (23%) reported using only wet methods.
- For cutting sink openings, 29 shops (62%) reported handheld saws, 11 shops (23%) used CNC machines and 7 shops (15%) used specialized radial arm saws. 21 shops (45%) always used dry methods and 26 shops (55%) always used wet methods.
- Overall: 10 shops (21%) reported always using wet methods for stone fabrication processes, 1 shop (2%) reported using always dry methods, and 31 shops (66%) reported using a mixture of both.
- All 47 shops (100%) reported some type of respiratory protection, but none performed fit testing in accordance with OSHA. Full face and half face respirators (N95, P100) were reported but most reported only providing dust masks.
- Reported methods for cleanup included washing, sweeping, blowing dust out of the shop, and vacuum cleaning. 78% of those using entirely wet fabrication methods reported wet cleanup while only 31% of those who did not use entirely wet methods reported wet clean up.
- All 47 shops (100%) reported using ceiling or exhaust fans of various types, but only 4 shops (9%) used a dust collection / suppression system, with 1 shop (2%) using a shop vacuum held near the point of operation.

Conclusions of Authors:

- Granite countertop fabrication using dry methods was a regular practice in 2011 and used most often for edge profiling, cutting grooves for reinforcing rods, and cutting sink openings.
- Bridge saw cutting was widely used but limited to cutting granite slabs into smaller pieces.
- CNC machines were used only in 28% of shops.
- 90% of workers were employed for less than 10 years, which is shorter than the typical latency period for silicosis to be diagnosed.
- Extrapolating to the national population, the authors conservatively estimated at least 36,000 workers employed in the fabrication of granite countertops in the United States
- Increased awareness and use of effective dust control measures is needed in the granite countertop industry.

Key Strengths and Weaknesses

Strength:

- Survey of representative granite stone countertop fabricators as of 2011, gathering relevant information on work tasks, wet versus dry processes, and use of respiratory protection.

Weaknesses:

- Based on self-reporting from shop representatives.
- Lacked specific question on the use of local exhaust ventilation.

Comparison to Other Studies: Similar to a report by Lofgren (2008) that summarized inspection findings from stone countertop shops in Washington State, indicating an absence of OSHA-compliant respirator fit testing.

Relevance to the Industry: This study helped characterize the granite stone fabrication industry as of 2011, highlighting that although most shops used a combination of wet and dry processing methods, many still used some degree of dry processing.

Citation: Phillips, M. L., & Johnson, A. C. (2012). Prevalence of dry methods in granite countertop fabrication in Oklahoma. *Journal of Occupational and Environmental Hygiene*, *9*(7), 437–442. https://doi.org/10.1080/15459624.2012.684549

Self-reported silica exposures and workplace protections among engineered stone fabrication workers in California

Study Authors / funding: Spiegel A, Cummings K, Flattery J, Harrison R, Heinzerling A. (Thomas Jefferson University, California Department of Health)

Journal: *American Journal of Industrial Medicine, 2022*

Location / Country: California, USA

Study Type and Description: This study evaluated worker responses to a questionnaire administered by Cal/OHSA after inspections of 106 California-based fabrication workshops between November 2019 and March 2020. The questionnaire was given to a sample of workers to assess common work tasks, their perceived exposures to silica dust, workplace protections, and utilization of mandated medical surveillance.

Key Findings:
- 92 workers from 33 inspected facilities completed the questionnaire
- 36 (39%) workers reported Spanish as their preferred language
- Median work tenure at their current facility was 3.8 years (Interquartile range (IQR) 1-13.3 years)
- 84 (91%) workers reported performing tasks that can generate respirable crystalline silica (RCS) (cutting, grinding, laminating, or polishing), with 26% reporting sometimes using dry methods for these tasks
- 69 (75%) workers reported wearing a respirator (40% disposable filtering facepiece respirator, 63% half-face elastomeric respirator) for >30 days within the previous 12 months.
- 18 (20%) workers reported that they had completed respirator fit testing within the previous 12 months.
- 63 (68%) workers reported that their employer did not share the results of any silica air monitoring.
- 5 (5%) workers reported that their employer had sent them or their co-workers for required silica medical examinations.

Unique Study Aspects: Questionnaire data from a selected group of fabrication workers.

Conclusions of Authors:
- Findings support the need for improved workplace protections and the enforcement of existing OSHA silica regulations.
- Although most workers reported wearing respirators, few workers reported that they had fit testing; unfitted respirators are unlikely to provide adequate protection against RCS.
- Few workers were aware of RCS monitoring results performed in their workplace.
- These results were consistent with prior reviews of Cal/OHSA citations.

Key Strengths and Weaknesses:

Strengths:
- A relatively large number workplaces (33) were included in this study.
- The questionnaire was developed in collaboration with the California Department of Health and provided in 2 different languages.

Weaknesses:

- It is unclear how representative of the industry the included shops are.

Comparison to Other Studies:
Similar results to those found in a study by Tustin et al., 2022.

Relevance to the Industry:
This study provides a summary of selected CA stone fabrication workers' questionnaire responses to an Cal/OSHA administered questionnaire. The results suggest that improvements are needed in the stone fabrication industry, including engineering controls, OSHA-compliant respiratory protection programs, and medical surveillance.

Citation: Spiegel, A., Cummings, K. J., Flattery, J., Harrison, R., & Heinzerling, A. (2022). Self-reported silica exposures and workplace protections among engineered stone fabrication workers in California. *American Journal of Industrial Medicine*, *65*(12), 1022–1024. https://doi.org/10.1002/ajim.23432

Experimental Studies - Workplace Setting

An evaluation of on-tool shrouds for controlling respirable crystalline silica in restoration stone work

Study Authors / funding: Healy, C. B., Coggins, M. A., Van Tongeren, M., MacCalman, L., & McGowan, P. Funded by the Commissioners for Public Works in Ireland as part of a research PhD at the National University of Ireland, Galway.

Journal: *Annals of Occupational Hygiene, 2014*

Location / Country: Ireland

Study Type and Description: The study examined the effectiveness of 4 commercially available shrouds at reducing respirable crystalline silica (RCS) levels when used by restoration stone workers to grind sandstone with typical tools and techniques. Grinding sandstone was carried out using 5-inch angle grinders (a FLEX grinder and Hilti grinder) with 6 different grinding wheels, both with and without a shroud.

The four shrouds were chosen by experienced stoneworkers based on practicality of design. Shrouds that could not be modified to expose the tip of the grinding wheel were rejected. Four configurations of shrouds were tested: 1) a FLEX grinder equipped with a shroud manufactured by FLEX (steel with a diameter of 13.5 cm), 2) a FLEX grinder with a Dust Muzzle shroud (polypropylene with a diameter of 15 cm), 3) a FLEX grinder equipped with a Dustie shroud (flexible lightweight plastic), and 4) a Hilti shroud equipped with a shroud manufactured by Hilti. A Nederman vacuum unit equipped with a HEPA filter was used for the three configurations that used the FLEX grinder, and the Hilti angle grinder used a Hilti portable jobsite vacuum.

The FLEX grinder was equipped with five different grinding wheels: a 10 cm Diamond Teck cup grinder operating at 4000 rpm, a Diamond Teck 12.2 cm Multi-cutter wheel operating at 4500 rpm, a FLEX 10 cm coarse grade disc operating at 2000 rpm, a Bavaria Corundum 10 cm grinding ring grit 30 operating at 4000 rpm, and a Bavaria Corundum grinding point operating at 3000 rpm.

The study was conducted over three trials in a stone workshop in Ireland. The workplace consisted of a rotating stone masonry bench with the capability of accommodating on-tool local exhaust ventilation systems. One experienced stoneworker participated in two of the trials, and another participated in the third. The stoneworkers wore respiratory protection during the trials.

In trial one, sandstone was shaped to fabricate and assemble a sandstone fireplace. In the second and third trial, a sandstone window jamb (the vertical parts forming the sides of a window frame) were constructed.

Evaluation of the effectiveness of shrouds at reducing airborne respirable dust (RD) and RCS was assessed by measuring personal exposures to respirable dust (RD) and respirable crystalline silica (RCS). RD was measured with direct reading datalogging equipment, while RCS was measured with personal air sampling pumps and cyclones following methods similar to those specified by NIOSH. For the FLEX grinding tool, measurements were taken using the grinding tool without a shroud and with each of the 3 shrouds. Tests involving the FLEX grinding tool also recorded the type of grinding wheel used. Measurements for the Hilti tool were taken with and without its accompanying shroud. Measurement duration was 15 minutes with a shroud and 10 minutes without a shroud. Personal RD samples were collected using a cyclone attached to the worker's lapel, and photometric sampling was collected in the worker breathing zone using a personal aerosol monitor.

As the RD and RCS data were approximately log normally distributed, the geometric mean and geometric standard deviation were calculated. The student's t-test was used to investigate if there were statistically significant differences. The study authors also investigated the impact of using different grinding wheels on RD concentrations, carrying out linear regression using the log transformed photometric data as the dependent variable, and, after adjusting for the presence or absence of a shroud, using the grinding wheel and shroud type as the independent variable.

Worker feedback on the use of shrouds was also recorded, as none of the workers had used any of these dust shrouds before.

Key Findings:
The crystalline silica content of the sandstone was approximately 50%. Generally, the investigators found that the concentrations of RD were reduced by an order of magnitude (92% reduction in geometric mean) when compared to use of the grinders without a shroud. Use of any shroud demonstrated similar reductions in RD concentrations (range = 90-93% reduction) and a 99% reduction in RCS (range = 97-99% reduction by shroud type). While the type of grinding wheel without a shroud was associated with differences in dust generated, there was no appreciable difference with use of any type of grinding wheel with a shroud.

Notably, workers indicated that the grinders were easier to use without shrouds, particularly when working with sandstone due to improved visibility. Additionally, modifications were required to equip the FLEX grinder with the Dust Muzzle shroud and the Dustie shroud to expose the tip of the grinding wheel and to ensure fit. Worker feedback indicated that the Dustie shroud performed best in terms of practicality. The Hilti tool operated at too high of an RPM for restoration stonework.

The study authors also found that mobile vacuum units required frequent filter replacement in comparison to a stationary unit.

Unique Study Aspects: Few studies have investigated RD and RCS levels associated with shrouds outside of the construction sector and when working with a material other than concrete. This is also one of the few studies to investigate the effectiveness of shrouds at reducing RD and RCS levels while grinding stone with a 5-inch grinder. Restoration stoneworkers regularly use different grinding tools and grinding wheels unique to their trade.

Conclusions of Authors: Shrouds are an effective engineering control for reducing RD and RCS concentrations while grinding sandstone for restoration stonework. The authors emphasize the importance of worker feedback when implementing exposure controls. The authors note that use of shrouds can still expose workers to RCS above European SCOEL permissible limits (equivalent to OSHA's current PEL), particularly when used in uncontrolled environments.

Key Strengths and Weaknesses:
Strength:
- Strong study with large numbers of samples that quantify the degree to which an on-tool shroud can reduce RD and RCS concentrations.

Weakness:

- Only studied the effectiveness of one form of engineering control, concluding that use of a LEV shroud alone is insufficient to reduce RCS exposure levels below the current PEL.

Relevance to the Industry:
Informs the industry in crafting recommendations for potential use of engineering controls, with the limitation that use of an LEV shroud alone is likely insufficient to ensure compliance with applicable regulation.

Citation: Healy, C. B., Coggins, M. A., Van Tongeren, M., MacCalman, L., & McGowan, P. (2014). An evaluation of on-tool shrouds for controlling respirable crystalline silica in restoration stone work. *The Annals of occupational hygiene*, *58*(9), 1155–1167. https://doi.org/10.1093/annhyg/meu069

Evaluating silicosis risk: Assessing dust constitution and influence of water as a primary prevention measure in cutting and polishing of silica agglomerates, granite and marble.

Study Authors / Funding: Martínez-González, D., Carballo-Menéndez, M., Guzmán-Taveras, R., Quero-Martínez, A., & Fernández-Tena, A from the Instituto Nacional de Silicosis, Spain. This study received no specific funding from any agency.

Journal: *Environmental Research, 2024, Online ahead of print*

Location / Country: Spain

Study Type and Description: This experimental study measured airborne concentrations of respirable dust (RD) and respirable crystalline silica (RCS) generated during dry and wet cutting and dry polishing of two forms of natural stone (NS) and one artificial stone (AS) product. The NS materials were Pink Porrino granite (42% quartz) and White Macael marble (< 2% quartz), while the AS was a manufactured product (Silestone) containing 80.8% quartz and 16.5% cristobalite. Work was performed in an existing marble fabrication shop, by one worker. Dust generated during the tasks was measured by personal air sampling (similar but not identical to NIOSH Methods for RD and RCS), along with real-time direct reading instrumentation for particle sizing. Individual tasks were of short duration, ranging from 6 to 25 minutes each.

Key Findings:

- Dry cutting produced the highest levels of RD and RCS for all stone types, with the application of water reducing levels by approximately 90%.
- Dry polishing produced consistently lower RD levels than dry cutting. Wet polishing was also performed but the results were too low for the laboratory to quantity above the detection limit.
- While granite produced the highest RD levels under all test conditions, RCS levels were consistently higher from the Silestone product. The marble contained essentially no silica and therefore did not generate appreciable amounts of RCS.
- Smaller particles, particularly those less than 0.5 µm, were predominantly produced during dry machining of granite and the AS material, with statistically-significantly elevated concentrations of RCS generated in processes involving the AS compared to granite and marble.

Unique Study Aspects: Studied RD and RCS generated during actual work conditions, although the tasks performed were of short duration.

Conclusions of Authors: Dry cutting and dry polishing procedures in marble, AS, and granite generated higher RD concentration than wet methods. Smaller particles, particularly those less than 0.5 µm, were predominantly produced during dry machining of granite and the AS material. These smaller particles likely have higher pathogenic potential due to their higher probability of reaching pulmonary interstitial tissue.

Processing of AS consistently generated higher concentrations of RCS as compared to granite and marble, especially with dry work methods. The presence of cristobalite in AS-generated dust was also noted, reflecting a composition that included both quartz and cristobalite. The authors concluded that AS has a higher pathogenic potential than previously recognized, and that the use of water alone is insufficient to control RCS exposures during AS processing. They further noted that this is of particular importance in home installation work where any final trimming or processing largely occurs dry.

Key Strengths and Weaknesses:
Strengths:

- Relatively large number of replicate samples collected for each task, control, and stone type.
- Multiple sampling methods employed.

Weaknesses:

- The concentrations of RD and RCS generated during wet polishing using water injection on all 3 materials were too low to be accurately quantified by the laboratory. Longer sampling periods and/or use of a sampling method with a higher airflow rate would be appropriate.
- Limited details about the tools or water injection method were provided.
- The very low levels of quartz found during dry polishing of marble were not explained by the authors, although they may have resulted from the abrasives used in polishing.

Comparison to Other Studies: These results were consistent with recent reports by multiple authors, including Hall et al. (2022), Thompson and Qi (2023), and others.

Relevance to the Industry: This study reinforces the benefit of water injection during cutting and polishing stone to reduce the concentrations of RD but provides additional evidence that wet work alone may be insufficient to adequately control RCS exposures during AS processing.

Citation: Martínez-González, D., Carballo-Menéndez, M., Guzmán-Taveras, R., Quero-Martínez, A., & Fernández-Tena, A. (2024). Evaluating silicosis risk: Assessing dust constitution and influence of water as a primary prevention measure in cutting and polishing of silica agglomerates, granite and marble. *Environmental Research*, 118773. https://doi.org/10.1016/j.envres.2024.118773

Experimental Studies - Lab, Enclosure, and Chamber Tests

Crystalline silica dust and respirable particulate matter during indoor concrete grinding – wet grinding and ventilated grinding compared with uncontrolled conventional grinding.

Study Authors / funding: Akbar-Khanzadeh, F., Milz S, Ames A, Susi PP, Bisesi M, Khuder SA, Akbar-Khanzadeh M. University of Toledo Health Science Campus (Toledo, OH) and Center to Protect Workers' Rights (Washington, DC) (NIOSH-funded)

Journal: *Journal of Occupational and Environmental Hygiene, 2007*

Location / Country: USA

Study Type and Description: This controlled study evaluated the effectiveness of 3 engineering controls in reducing respirable dust (RD) and respirable crystalline silica (RCS) exposures during concrete grinding. The tests were performed with hand-held angle grinders equipped with diamond grinding wheels ranging from 4.5 to 7-inches in diameter. The controls evaluated were general room exhaust ventilation, local exhaust ventilation directly through the grinder, and a field-adapted wet method; open-air grinding was used as uncontrolled comparison.

The tests were performed by a single experienced worker inside an indoor enclosed room, which could provide general exhaust ventilation at the rate of approximately 40 room air changes per hour. All tests were performed on concrete samples with the same origin, with bulk samples showing an average silica content of 26% (as quartz).

Uncontrolled open-air grinding was performed with Makita and Black & Decker grinders, wet grinding was performed with the same Makita grinder with a field-adapted hose for delivering water, and local exhaust ventilation was evaluated using a Hilti brand angle grinder designed for use with a dry type shop vacuum. Water was delivered during wet grinding at the rate of approximately 3 L/min (= 0.8 gal/min), which the operator identified as an optimum delivery rate for keeping the concrete surface wet during grinding but preventing water splash. Local exhaust ventilation through the Hilti grinder to the shop vacuum was provided at about 50 L/sec (=106 ft^3/min or CFM).

The following combinations of grinding and dust controls were evaluated:

- Both with and without general room ventilation:
  - Uncontrolled open-air grinding
  - Grinding with water
  - Grinding with local exhaust ventilation

Measurements of RD and RCS were made with personal air samples using standard industrial hygiene air sampling pumps, cyclones, and filters per NIOSH Methods 0600 and 7500, with analyses reportedly conducted by an accredited analytical laboratory. The only area samples collected were from outside of the enclosure to confirm that make-up air introduced into the room did not contain appreciable concentrations of either RD or RCS.

Personal air samples were collected as paired side-by-side samples on the left side of the operator's breathing zone, with each combination of grinding and control replicated at least 2 times. Sampling sessions ranged in duration from 5 to 161 mins including breaks, with active grinding occurring on average 70% of the time. Results were reported as time-weighted averages over the duration of each combination of test sessions. Percent reductions in exposures to RD and RCS were computed from uncontrolled conventional grinding.

Key Findings:

- RD and RCS concentrations were below the analytical limits of detection for the outdoor air samples, all field blanks, and 3 personal air samples collected during local exhaust ventilation control testing.
- The GM was consistently (slightly) lower than the AM, suggesting skewed distributions towards log-normal, the more common distribution in most occupational and environmental sampling studies.
- Personal exposure monitoring showed:
    - Uncontrolled open-air grinding (without any room-level exhaust ventilation) produced the highest RD and RCS concentrations (mg/m^3: Mean = 86, GM = 75.5, Range = 43.0 – 147). At these high concentrations, less than 1 minute of exposure would result in an 8-hour TWA exposure exceeding OSHA's PEL of 0.05 mg/m^3.
    - Room-level exhaust ventilation alone lowered the average RD and RCS concentrations by about 3-fold, but those differences were not significant.
    - The application of water or local exhaust ventilation resulted in significantly reduced RD and RCS exposures, ranging from 96 – 99%$^+$ as compared with uncontrolled grinding (with or without general room exhaust). Although local exhaust ventilation consistently resulted in RD and RCS concentrations lower than those produced during wet grinding, those differences were not significant.
- Despite the large reductions in RD and RCS exposure from the use of water or tool-connected local exhaust ventilation, all samples were above the current OSHA action level of 0.025 $mg/m^{3\ TWA\text{-}8\text{-}h}$.

Unique Study Aspects:

- Controlled environment study comparing readily accessible control methods on commonly used and sized hand-operated angle grinders.

Conclusions of Authors:

- This work reinforced findings from other studies confirming the general effectiveness of wet methods and especially the application of local exhaust ventilation through grinding tools.

- Relative to uncontrolled concrete grinding, the constant water flow system reduced RCS and RD exposures by 98.2% and 97.6%, respectively; the application of through-tool local exhaust reduced those exposures even more (99.7% and 99.6%, respectively).

- The use of wet or through-tool local exhaust control methods - with or without room-level exhaust ventilation – resulted in personal exposures above the OSHA action level of 0.025 $mg/m^{3\ TWA\text{-}8\text{-}h}$, with all samples collected from wet grinding well above the OSHA permissible exposure limit of 0.05 $mg/m^{3\ TWA\text{-}8\text{-}h}$. Presuming relatively high work-to-rest ratio regimens, such as those used in this study, respiratory protection remains necessary even with the application of water or local exhaust ventilation controls.

Key Strengths and Weaknesses:

Strengths:

- Controlled indoor work environment.
- Well-described testing and sampling methods

- Relatively large sample sizes

Weaknesses:

- Different grinders and grinder wheel diameters were used for different control combinations, and limited information on the diamond grinding wheels was provided.
- Despite relatively large sample sizes, the short duration of sampling precluded documentation that non-detectable samples were below the action level.

Comparison to Other Studies:

- The study was consistent with multiple other published works reporting the general efficacy of local exhaust ventilation and wet methods at reducing RD and RCS from silica-rich substrates.

Relevance to the Industry: Although concrete was used as the substrate in this study and not natural or engineered stone, the work here reaffirms the very high levels of RD and RCS emitted during dry concrete grinding, and the significant reductions that wet and local exhaust dust control measures can provide. However, even with such high reduction rates, respiratory protection remains necessary to effectively lower personal exposures below the PEL and AL.

Considering the maximum RCS exposures from each test combination, of the control methods evaluated in this study, only through-tool local exhaust ventilation sufficiently reduced personal exposures enough to enable use of respirators with an assigned protection factor (APF) of 10 (i.e., half-face HEPA or N95 filtering facepieces). The at-tool wet method resulted in higher personal exposures, for which more protective respirators would be required (i.e., upgrading to a full-face respirator (HEPA filtered) or a tight-fitting high-APF powered air purifying respirator (HEPA filtered).

Citation: Akbar-Khanzadeh, F., Milz, S., Ames, A., Susi, P. P., Bisesi, M., Khuder, S. A., & Akbar-Khanzadeh, M. (2007). Crystalline Silica Dust and Respirable Particulate Matter During Indoor Concrete Grinding—Wet Grinding and Ventilated Grinding Compared with Uncontrolled Conventional Grinding. *Journal of Occupational and Environmental Hygiene*, 4(10), 770–779. https://doi.org/10.1080/15459620701569708

Effectiveness of dust control methods for crystalline silica and respirable suspended particulate matter exposure during manual concrete surface grinding.

Study Authors / funding: Akbar-Khanzadeh, F, Milz SA, Wagner CD, Bisesi MS, Ames, AL, Khuder S, Susi P, Akbar-Khanzadeh M. University of Toledo Health Science Campus (Toledo, OH), and Center to Protect Workers' Rights, The Center for Construction Research and Training (Silver Spring, MD) (NIOSH-funded)

Journal: *Journal of Occupational and Environmental Hygiene*, 2010

Location / Country: USA

Study Type and Description: This controlled study expanded upon previous work published by the same research group in 2007. This work corrected several weaknesses in the earlier publication by increasing the number of samples and durations of some activities and standardized grinding tools for testing. The goal of this work was to further evaluate the effectiveness of ventilation (general room and local tool exhaust) and wet methods in reducing exposures to respirable dust (RD) and respirable crystalline silica (RCS) during concrete grinding. It also included an assessment of exposures and controls from grinding in both the horizontal and vertical orientation. The tests were performed with 3 different sized hand-held angle grinders equipped with diamond grinding wheels ranging from 4 to 7-inches in diameter, as well as with a device designed specifically for concrete grinding with integral dust collection features. The controls evaluated were general room exhaust ventilation, local exhaust ventilation directly at or through each of the grinders, and a field-adapted wet method; uncontrolled open-air grinding was used to establish worst-case baseline exposures for comparing control methods.

The tests were performed by a single experienced worker inside an indoor enclosed room, capable of providing general room exhaust ventilation at the rate of 62 room air changes per hour (about 50% higher than in their previous study). All tests were performed on concrete samples collected from the same origin, with bulk samples containing an average crystalline silica content of 29% (as quartz, range = 11 – 43%).

Each of the grinding tools was used to establish exposures from uncontrolled open-air grinding as well as with the different controls applied. The 3 hand-held angle grinders were fitted with an aftermarket shroud for connection to various exhaust devices to evaluate effectiveness of local exhaust ventilation; these same grinders were also field fitted to a source of water for evaluating wet method dust controls. The specific concrete grinding tool was tested only with local exhaust ventilation.

The following combinations of grinding activities and dust controls were evaluated:

- General and no general room ventilation
- Concrete slab in horizontal and vertical orientation
- Varying sized grinding tools and diamond grinding wheels / cups (4, 4.5, 5, and 7" diameter)
- Different dust control methods:
    - None - uncontrolled open-air grinding
    - Room-level general exhaust ventilation
    - Local tool-level exhaust with 2 types of HEPA vacuums and 1 common shop-vacuum
    - Wet grinding with operator- and researcher-adjusted water flow rates

Measurements of RD and RCS during these activities were made with personal and area air samples using standard industrial hygiene air sampling pumps, cyclones, and filters per NIOSH Methods 0600 and 7500, with all samples analyzed by an accredited analytical lab.

Personal air samples were collected as paired side-by-side samples, but in this study the samples were collected with one sample on each side (left / right) of the operator's breathing zone rather than on the same side. Each combination of grinding activity and control method was replicated at least 3 times, with some as many as 14 times, for a total of 336 personal samples. Sampling sessions ranged from 5 to 90 mins in duration including breaks, with active grinding occurring on average 76% of the time during sampling sessions.

Area samples (n = 177) were collected approximately 2 m (6.6 ft) from the operator. Outdoor area air samples were also collected to establish background air levels of RD and RCS and for quality assurance purposes.

Results were reported as time-weighted averages over the duration of each test session (not over an entire 8-hour workday). Percent reductions in exposures to RD and RCS were computed from uncontrolled conventional grinding.

Key Findings:

- Of the 336 combined personal samples collected, 100 (~ 30%) were below their limits of detection (51% from local exhaust ventilation control samples, 9.8% from wet method samples, and 1.3% from uncontrolled grinding samples (the latter caused by short sampling time)).
- Paired personal exposure samples (left and right side of operator's breathing zone) were significantly different only for uncontrolled grinding activities, suggesting a strong directionality of emitted dust and/or closer proximity of the operator based upon handedness.
- Area samples were statistically lower than personal air samples.
- No statistical differences were observed between the specific concrete grinding tool with inherent local exhaust dust collection and the hand-held angle grinders fitted with aftermarket shrouds.
- Of the sources of local exhaust ventilation, the common shop vacuum performed less effectively than the 2 other types of vacuums designed for heavy dust and concrete work.
- Grinding with concrete in a vertical vs. horizontal position (to simulate wall work) generated non-significantly higher RCS and RD levels.
- Personal exposure monitoring showed:
    - Uncontrolled open-air grinding (without any room-level exhaust ventilation) again produced the highest average personal RD and RCS concentrations (142 – 359 mg/m^3 for RD and 23.6 – 55.3 mg/m^3 for RCS). At these high concentrations, 1 minute or less exposure to concrete dust generated during uncontrolled work would result in an 8-hour TWA exposure exceeding OSHA's PEL of 0.05 mg/m^3.
    - The application of room-level exhaust ventilation alone significantly reduced concentrations of both RD (70.2%) and RCS (66%).
    - The application of water or local exhaust ventilation resulted in significantly reduced RD and RCS exposures, ranging from 93 – 99^+% as compared with uncontrolled grinding (with or without general room exhaust). Compared with the wet method, local exhaust ventilation produced significantly lower exposures to both RD and RCS.
    - Despite the high levels in RD and RCS reduction from the use of water or local exhaust ventilation, all task-based exposures remained above the OSHA action level of 0.025 $mg/m^3_{TWA\text{-}8\text{-}h}$.

Unique Study Aspects:

- Controlled testing environment, task-based study comparing readily available control methods on commonly used and sized hand-operated angle grinders.

Conclusions of Authors:

- This work reinforced findings from other studies that general room-level ventilation, locally exhausted tools, and wet grinding methods reduced exposures to RCS and RD with concrete substrates. However, no combination of factors or control methods reduced the 8-hr exposure level for crystalline silica to below the recommended criterion of 0.025 mg/m^3, requiring further refinement in engineering controls, administrative controls, or the use of respirators.

- Based upon these results, the authors identified likely respiratory protection requirements for a range of work: rest regimens over the course of a typical 8-hour work shift. None of the work: rest ratios eliminated the need for respiratory protection during uncontrolled grinding, and only the lowest ratio (10% work: 90% rest) was predicted to eliminate the need for respiratory protection during any of the local exhaust or wet methods of control.

Key Strengths and Weaknesses:

Strengths:

- Controlled indoor work environment.
- Well-described testing and sampling methods
- Large sample sizes

Weaknesses:

- The short duration of sampling precluded documentation that non-detectable samples were below the action level.
- As acknowledged by the authors, differences in concrete removal rates between grinders and grinding wheels is an uncontrolled variable in this study.
- The shortened presentation of data made it difficult to interpret the reductions achieved by the control methods or identify extreme exposure values.
- The work: rest regimen analysis was based upon OSHA's previous silica PEL (0.100 mg/m^3), a now-outdated limit. Insufficient information was provided to recalculate based on OSHA's current silica PEL (0.050 mg/m^3).

Comparison to Other Studies:

- The study was consistent with multiple published works reporting the ability of local exhaust ventilation and wet methods to reduce RD and RCS from silica-rich substrates (although values remained above the Action Limit)

Relevance to the Industry: The study reaffirmed that very high levels of RD and RCS are emitted during dry grinding, and that both wet and local exhaust ventilation dust control measures, as well as high room-level exhaust ventilation rates, can provide significant reductions in personal and area exposures. However, even with these high emission reduction rates, respiratory protection remains necessary to effectively lower personal exposures below the PEL and AL for all but the shortest activities.

Tools with local exhaust ventilation produced significantly lower personal exposures than wet methods alone, potentially challenging the long-standing primary reliance on water in the stone fabrication industry.

As the authors also document, the use of water creates hazards with electrically powered tools, for which GFCI-protection is essential or switching entirely to pneumatically powered tools.

The rapid failure of commonly available shop vacuums highlights that only vacuums designed for such use should be procured.

Citation: Akbar-Khanzadeh, F., Milz, S. A., Wagner, C. D., Bisesi, M. S., Ames, A. L., Khuder, S., … Akbar-Khanzadeh, M. (2010). Effectiveness of Dust Control Methods for Crystalline Silica and Respirable Suspended Particulate Matter Exposure During Manual Concrete Surface Grinding. *Journal of Occupational and Environmental Hygiene*, *7*(12), 700–711. https://doi.org/10.1080/15459624.2010.527552

Respirable silica dust suppression during artificial stone countertop cutting.

Study Authors / funding: Cooper J, Johnson D, Phillips M. (University of Oklahoma College of Public Health). Funded by a NIOSH training grant and the University of Oklahoma Health Sciences Center Vice President for Research

Journal: *The Annals of Occupational Hygiene, 2015*

Location / Country: Oklahoma, USA

Study Type and Description: This study compared respirable silica dust exposure during simulated stone countertop cutting with a handheld circular saw under different wet controls. A slab of 85% quartz-based artificial stone was cut with 27 successive cuts using a worm-drive circular saw mounted on a roller bridge within an outdoor tent. The tent was unventilated and sealed, and airflow was controlled during trials.

The different wet control combinations used were:

- Wet blade only (add-on water line directs a stream of water at the saw blade's front edge during cutting)
- Wet blade plus an additional water line to provide a thin water curtain to the blade's cutting path.
- Wet blade plus local exhaust ventilation (LEV) via a cowl mounted to the guard surrounding the wetted saw blade, placing it 2.5-5 cm from the cutting zone. A HEPA-filtered vacuum was used to provide the local exhaust.

4 trials for each of the 3 scenarios and 1 trial of dry cutting was performed.

A single breathing zone respirable dust (RD) sample was collected for each trial. The mean duration of the trials was 29.9 minutes (range 26.5 - 32.9 minutes)

Key Findings: (the means and SEMs reported in Table 2 for RCS are incorrect: we notified the author and we re-calculated the correct means noted below*)

- The dry-cutting trial had the highest RD concentration, at 69.9 mg/m^3, and the highest respirable crystalline silica (RCS) concentration, at 44.37 mg/m^3.
- Trials for wetted blades only had a mean RD concentration of 4.934 mg/m^3 and a mean RCS concentration of 2.87 mg/m^3.*
- Trials for wetted blades with water curtains had a mean RD concentration of 3.813 mg/m3 (23% lower compared to wetted blades only) and a mean RCS concentration of 2.16 mg/m^3.*
- Trials for wetted blades with LEV had the lowest mean RD concentration of 0.604 mg/m3 (92% lower compared to wetted blades only) and the lowest mean RCS concentration at 0.25 mg/m^3. *

Conclusions of Authors:

- Wetted blade cutting resulted in a 10-fold reduction in RD and RCS exposure compared to dry cutting. An additional 10-fold reduction was observed when using wet blade cutting plus LEV.
- A water curtain plus wet blade cutting appeared to reduce RD and RCS exposure compared to a wet blade alone, but the difference was not statistically significant.
- Adding LEV to wet blade cutting with a handheld circular saw appears to be an effective, simple, low-cost control for reducing RCS exposure during stone countertop fabrication.

Other Conclusions: The means and SEMs reported in Table 2 for RCS are incorrect. Using data from the individual trials, the correctly calculated means are 2.87 mg/m^3, 2.16 mg/m^3, 0.25 mg/m^3 for wetted blade only, wetted blade plus water curtain, and wetted blade plus LEV, respectively, supporting the conclusion that wetted blade plus LEV results in a 10-fold reduction in RCS compared to wetted blade only.

Key Strengths and Weaknesses:
Strength:
- This was an experimental study with a good comparison in a controlled environment. There were repeated trials for each combination of engineering controls.

Weakness:
- Only 1 trial of dry cutting was performed. An additive combination, i.e., wetted blade, water curtain, and LEV, was not performed to determine what the additive effect of these controls might be.

Comparison to Other Studies: The study's finding of decreased RD exposure using wet engineering control during stone cutting/fabrication is consistent with previous and later reports (e.g., Yasui et al. 2003, Pocock 2012, Beaudry et al. 2013).

Relevance to the Industry: There is clear evidence for reducing RD and RCS exposure with wet blade use compared to dry cutting and an additive effect when LEV is used with wet blade cutting. When possible, the addition of LEV to wet blade cutting should be encouraged.

Citation: Cooper, J. H., Johnson, D. L., & Phillips, M. L. (2015). Respirable silica dust suppression during artificial stone countertop cutting. *The Annals of occupational hygiene*, *59*(1), 122–126. https://doi.org/10.1093/annhyg/meu083

Experimental evaluation of respirable dust and crystalline silica controls during simulated performance of stone countertop fabrication tasks with powered hand tools

Study Authors / funding: Johnson DL, Phillips ML, Qi C, Van AT, Hawley DA. (University of Oklahoma College of Public Health and NIOSH). Study funded in part by NIOSH.

Journal: *Annals of work exposures and health, 2017*

Location / Country: USA

Study Type and Description: This study was conducted to evaluate the efficacy of wetting methods and on-tool local exhaust ventilation (LEV) in reducing operator exposure to respirable dust (RD) and respirable crystalline silica (RCS) during powered hand tool use on an engineered stone countertop. All experiments, except for one set, were conducted in an unventilated, enclosed shelter (about 100 sq. ft with a peaked top) using one type of a 2-cm thick engineered stone containing > 85% quartz. Between trials, the shelter was opened to allow dust to dissipate, and the stone slab was hosed, vacuumed, or wet wiped.

Tasks performed:

- Edge grinding with a diamond cup wheel
    - Trials with water-spray wetting and LEV, water-spray wetting and no LEV, sheet-flow-wetting and LEV, sheet-flow-wetting and no LEV
- Edge grinding with a silicon carbide abrasive wheel
    - Trials dry with LEV, dry with no LEV, with sheet-flow-wetting and LEV, with sheet-flow-wetting and no LEV
- Edge polishing
    - Trials with center-feed-wetting and LEV, center-feed-wetting and no LEV, sheet-flow-wetting and LEV, sheet-flow-wetting and no LEV
- Blade cutting with a diamond cutting blade
    - Trials dry with LEV, dry with no LEV, with sheet-flow-wetting and LEV, with sheet-flow-wetting and no LEV
- Core drilling with a diamond core bit
    - Trials dry with LEV, dry with no LEV, with a water ring

Aerosol concentrations in the breathing zone were measured for all experiments and for background concentrations between trials. Personal breathing zone measurements for RD and RCS were sampled and analyzed using standard NIOSH methods and an AIHA-accredited laboratory.

Seven experiments were conducted and consisted of one or two tasks with trials of various controls for each task. The order of trials was randomized for 5 of 7 experiments, and the set of trials within each experiment were replicated 3 - 6 times.

Key Findings: mg/m^3

- Edge grinding with a diamond cup wheel (RCS in mg/m^3):
    - Sheet-flow-wetting with no LEV: GM = 2.115; range 1.520 - 2.621
    - Sheet-flow-wetting with LEV: GM – 1.128; range 0.907 - 1.484
        - Adding LEV to sheet-flow-wetting *decreased* RCS by about 50%.

  - Water-spray-wetting with no LEV: GM = 0.434; range 0.261 – 0.571
  - Water-spray-wetting with LEV: GM = 2.988; range = 2.084–6.223
    - Adding LEV to water-spray-wetting *increased* RCS almost 700%.
- Edge grinding with silicon carbide abrasive wheel (RCS in mg/m^3):
  - Dry grinding with no LEV: GM = 4.819; range = 1.749–8.738 (reference)
  - Sheet-flow-wetting alone: GM = 2.249; range = 1.161–4.436 (-50%)
  - LEV alone: GM = 0.767; range = 0.198–1.830 (-85%)
  - Sheet-flow-wetting and LEV: GM = 0.248; range = 0.160–0.496 (-95%)
- Blade cutting (RD in mg/m^3):
  - Dry cutting with no LEV: GM = 4.332; range = 3.415–6.240 (reference)
  - LEV alone: GM = 3.203; range = 1.951–6.722 (-26%)
  - Sheet-flow-wetting alone: GM = 2.075; range = 0.968–5.904 (-52%)
  - LEV and sheet-flow-wetting: GM = 1.212; range =0. 525–2.408 (-72%)
- Edge polishing (RD):
  - All RCS levels were below the limit of quantification (LOQ) (about 0.160 mg/m^3) and aerosol measurements were not significantly above background levels (about 0.73 mg/m^3)
- Core drilling (RD):
  - Not statistically significant above the background (about 0.063 mg/m^3) for any trial.

Unique Study Aspects: Controlled experiments conducted in a 110 sq ft enclosed shelter outdoors, not a workplace, using only 1 stone type.

Conclusions of Authors:
- During grinding and cutting, the combination of LEV and sheet-flow-wetting was more effective than either method alone. LEV alone was more effective than sheet-flow-wetting alone during silicon-carbide wheel grinding, whereas, sheet-flow-wetting alone was more effective than LEV alone during blade cutting.
- Low levels of cristobalite was found in some samples of the silicon-carbide wheel grinding, which the authors attributed as likely derived from the grinding wheel itself.

Key Strengths and Weaknesses:
Strengths:
- Controlled variability by using only one type of engineered stone, only one operator for every task in the study, and performing standardized tasks (duration, length/angle of grinding and polishing, cutting depths)
- Relatively large sample size, with repeated trials.

Weaknesses:
- Equipment: different sampling equipment was used for experiment 1 and experiments 3 and 4, and it was unclear if the aerosol monitor was calibrated to the measured aerosol, which may have led to an underestimation of the true RD.
- The short duration of some tasks (1-3 minutes) limited analysis.

Comparison to Other Studies:
- Generally, the combination of wet methods and LEV reduce RD/RCS concentrations more than either alone. However, the water-spray and LEV results during cup wheel grinding contradicted this. As an explanation, the authors suggest water droplets formed by water-spraying, as compared to sheet-

wetting, and the location of the LEV in association with the water-spray source, may reduce the effectiveness of wetting in lowering RD/RCS exposure. Additionally, the small, enclosed space used for testing may have favored collection of dust in droplets from water-spray-wetting compared to low flow sheet-flow-wetting.

Relevance to Industry: This study was not designed to replicate real-world working conditions with respect to the enclosed environment and duration of tasks. However, engineering controls were shown to reduce RCS concentrations up to 95% during some tasks. Grinding and cutting should be priority areas for interventions based on their high generation of RCS as compared to polishing and drilling tasks.

Citation: Johnson, D. L., Phillips, M. L., Qi, C., Van, A. T., & Hawley, D. A. (2017). Experimental Evaluation of Respirable Dust and Crystalline Silica Controls During Simulated Performance of Stone Countertop Fabrication Tasks With Powered Hand Tools. *Annals of work exposures and health*, *61*(6), 711–723. https://doi.org/10.1093/annweh/wxx040

Characterization of silica exposure during manufacturing of artificial stone countertops.

Study Authors / funding: Carrieri M, Guzzardo C, Farcas D, Cena LG. University of Padua (Italy), West Chester University of Pennsylvania, West Virginia University, and Windjammer Environmental, Washington, DC (funded by an internal WCU research award and grant)

Journal: *International Journal of Environmental Research and Public Health, 2020*

Location / Country: USA

Study Type and Description: This controlled laboratory study evaluated dust emissions from the cutting and grinding of 3 types of artificial stone and one granite sample. The goal was to evaluate the airborne concentrations, particle sizes, and mineral content of respirable dust (RD) and respirable crystalline silica (RCS) during short duration cutting / grinding, with the work performed inside a modified glove box enclosure measuring 132 x 163 x 61 cm.

A common style of hand-held angle grinder equipped with a 4" diameter diamond stone cutting blade was used within the enclosure to actively cut / grind the sample substrates for 7 to 14 minutes, with 3 replicates for each stone type. The enclosure, grinder, and blade were cleaned between runs and the chamber purged with HEPA filtered make-up air. In addition, the grinder and blade were replaced with new units between stone types. No dust control measures were evaluated.

Three forms of artificial stone and 1 natural stone (granite) were tested:

Stone Type	**Primary Constituents (as reported by suppliers)**
Artificial Stone A	Inorganic mineral fillers (sand, cristobalite, silicon, glass, quartz, and ceramic particles (85-95%)), polyester resin (5-15%), additives and pigments (<5%)
Artificial Stone B	Quartz (>85%), resin and pigments (<15%)
Artificial Stone C	Aluminosilicate silicas (< 11%), zircon (variable %'s), inorganic pigments (<7%), with the material cured by high temperature sintering
Granite	No information provided

Measurements of airborne dusts generated during grinding and cutting were made by air sampling inside the enclosure using direct reading instruments for respirable dust as well as traditional industrial hygiene methods (i.e., NIOSH methods with a sampling pump, size-fractioning cyclone, and PVC membrane filter). The direct reading instruments were used to characterize particle numbers and mass concentrations. The industrial hygiene samples measured RD and RCS, with analysis by an accredited analytical lab.

Key Findings:

- Due to the use of a small, enclosed test chamber, grinding and cutting resulted in very high RD and RCS concentrations, regardless of the measurement method. However, the results from the direct reading instruments were not comparable to those collected by the traditional industrial hygiene method, with those from direct reading instruments about 2 orders of magnitude higher than those by the pump and cyclone methods.

- Of the 3 minerals that comprise "silica", only quartz was detected. Average % quartz ranged from 51.4 to 53.6% for artificial stones A and B, about 8% for the natural granite sample, and 4.4% for the (reportedly low silica-containing) artificial stone C.
- For the measurements collected by the industrial hygiene method:
    - RD ranged from about 83 to 430 mg/m^3, with the granite stone producing the highest levels, significantly higher than the 3 artificial stone samples.
    - The highest RCS levels were from artificial stone samples A and B (mean = 50.8 and 47.7 mg/m^3 respectively), followed by granite (mean = 33.5 mg/m^3). Artificial stone C generated the lowest RCS levels, with a mean about an order of magnitude lower (3.7 mg/m^3), reflecting the lower bulk silica composition and potentially the annealing effect from high temperature sintering during its manufacture.
- Particle size distributions varied:
    - By number of particles, artificial stones A and B showed bimodal distributions, with peaks at about 0.03 and 0.3 um, while artificial stone C and granite showed largely mono-modal peaks at about 0.3 um.

Unique Study Aspects:
- Highly controlled testing environment.
- Scanning electron microscopy analysis of particles, coupled with size fractioning instrumentation.

Conclusions of Authors:
- Dust generated from cutting and grinding of 2 artificial stone products contained elevated proportions of nanoparticles, with a greater potential impact on health.
- While no observations were reported from actual countertop fabrication facilities, the authors also concluded that:
    - Standard control methods and personal protective equipment should be re-evaluated.
    - Grinding and polishing activities result in layers of dust on all surfaces, and that these depositions are subject to resuspension from foot and equipment traffic.
    - Dust control should be provided at the tool and workstation levels through a combination of local exhaust ventilation, downdraft tables, and water jet sprays.
    - Floor drainage systems should be installed to enable rinsing and cleaning before wet dusts dry.
    - Use of respiratory protection when cutting and grinding both natural and artificial stone is recommended.
    - High silica content artificial stone products pose a substantial health risk when subjected to manipulations like those used in this study.

Key Strengths and Weaknesses

Strengths:
- Controlled experimental design within an enclosed chamber with different types of stones, using the same grinder.
- Well-described testing and sampling methods overall (with one caveat, see *Weaknesses*, below)
- Triplicate samples per substrate

Weaknesses:
- The paper interchangeably described the angle grinder work as involving "cutting", "grinding", and "polishing", making it unclear the exact nature of work activities. However, all work

reportedly occurred with the same make / model grinder and same size and type of diamond blade.

- Direct reading instrument results were consistently much higher (by several orders of magnitude) than those reported by standard NIOSH methods involving cyclone and filter sampling, an anomaly that was not explained or discussed by the authors.
- Analysis for crystalline silica by x-ray diffraction (XRD) was reported as by NIOSH Method 7400, a method used for analyzing fibers by phase contract microscopy, not XRD, which for silica is NIOSH Method 7500. While this is likely a typographical error, it raises questions regarding attention to detail.

Comparison to Other Studies:

- The study was consistent with multiple published works reporting the high levels of RD and RCS generated during cutting and grinding of silica-rich natural and artificial stone substrates.

Relevance to the Industry: The artificial stone samples containing the highest levels of silica (A and B) generated significant fractions of much smaller size (nanometer-scale) particles by number than the natural granite and the low-silica artificial stone tested. While the majority (by mass) of airborne dusts from all samples were much larger in size, the abundance of ultrafine particulates from some substrates may help explain their higher relative toxicity.

Citation: Carrieri, M., Guzzardo, C., Farcas, D., & Cena, L. G. (2020). Characterization of Silica Exposure during Manufacturing of Artificial Stone Countertops. *International Journal of Environmental Research and Public Health,* 17(12), 4489. https://www.mdpi.com/1660-4601/17/12/4489

Characterizing and comparing emissions of dust, respirable crystalline silica, and volatile organic compounds from natural and artificial stones.

Study Authors / funding: Hall S, Stacey P, Pengelly I, Stagg S, Saunders J, Hambling S (Science Division, Field Operative Directorate, Health and Safety Executive, UK)

Journal: *Annals of Work Exposures and Health*, *2022*

Location / Country: United Kingdom

Study Type and Description: This exposure study aimed to determine differences in the emission profiles generated from natural and engineered stone. Nineteen stone samples (12 resin engineered stones, 3 sintered engineered stones, 1 “ceramic” engineered stone, and 3 natural stones (1 sandstone, 1 granite, 1 marble) were crushed, ground, and milled to generate fine dust powders which were used to quantify crystalline and non-crystalline composition. Pyrolysis and heating (combined with GC-MS and thermal desorption methods) were used to determine resin composition and VOC emissions.

To characterize the emissions when cutting and polishing, 5 of 19 stones (1 sandstone, 1 granite, 2 engineered, and 1 sintered) were placed inside a dust tunnel and cut and polished using mounted electric hand tools with a moving table. Air samples were collected downstream of the task to assess particle size and composition and also VOCs. Real-time particle size distributions (from 10 nm – 35 um) were determined by aerosol spectrometry, and a thermal camera was used to evaluate the temperature.

Key Findings:

- Different stones contained highly variable amounts of crystalline silica (i.e., quartz, cristobalite, tridymite).
- The engineered stones contained different resins, most commonly polyester-styrene (9/12), but also acrylic (1/12), polyethylene terephthalate (1/12), and epoxy (1/12).
- Total VOC emissions were highly variable in quantity (ranging from non-detectable to 20.53 μg/g); specific VOCs included phthalic anhydride, C9-carboxylic acid, acetone, styrene, methyl acetate, and heptane isomers.
- The mass of dust generated was higher, and particle size was larger, during cutting versus polishing stone, regardless of stone type.
- For both cutting and polishing, the higher the level of crystalline silica in the bulk material, the higher the level of silica in dust emissions.

Unique study aspects:

- Extensive characterization of 12 engineered stone products.
- For 5 stones (2 natural, 2 engineered, 1 sintered) an experimental chamber design was used to assess mineral and VOC emissions during dry cutting and polishing, with comparison to bulk analyses.

Conclusions of Authors:

- Cutting versus polishing stone and stones with higher silica content generate higher RCS exposures.
- When working with stone with higher levels of silica, existing controls may not be adequate.

Key Strengths and Weaknesses:
Strengths:

- Extensive analysis and characterization of the 19 different stones, including 12 engineered stones using established methods by experienced investigators.
- Analyzed particles sizes and masses.

Weakness:

- A limited number of samples (5 of 19) were evaluated in the test chamber.

Comparison to Other Studies:
Greater information is provided regarding the content of the different stones compared to most studies. Consistent with other studies demonstrating that higher exposures occur with cutting versus polishing, and that higher crystalline silica content bulk materials generate higher RCS levels.

Relevance to the Industry:

- Workers are exposed to higher concentrations of RCS when cutting versus polishing stone, regardless of stone type.
- Polishing, however, can generate smaller sized particles, which could increase toxicity.
- Higher crystalline silica content stones generally produce higher RCS emissions during cutting and polishing.
- A variety of different resins are used in engineered stone, which can off-gas different types and concentrations of VOCs.

Citation: Hall, S., Stacey, P., Pengelly, I., Stagg, S., Saunders, J., & Hambling, S. (2022). Characterizing and Comparing Emissions of Dust, Respirable Crystalline Silica, and Volatile Organic Compounds from Natural and Artificial Stones. *Annals of work exposures and health*, *66*(2), 139–149. https://doi.org/10.1093/annweh/wxab055

Characterisation of dust emissions from machines engineered stones to understand the hazard for accelerated silicosis

Study Authors / funding: Ramkissoon C, Gaskin S, Thredgold L, Hall T, Rowett S, Gun R. (University of Adelaide, Government of South Australia – Safework SA)

Journal: *Scientific Reports, 2022*

Location / Country: Australia

Study Type and Description: This study explored the physical and chemical characteristics of respirable dust (RD) emissions from cutting 12 types of engineered stones (ES) compared with 3 natural stones (white marble, white and black granite). Each of the stones was dry cut inside a small enclosure using an angle grinder. RD was collected with a cyclone or impactors and analyzed for particle size and surface electrical charges (zeta potential) shortly after collection to avoid sample aggregation / agglomeration. Dust samples were stored in cool, dry conditions until analysis for mineral composition (x-ray diffraction), resin content (thermogravimetric), particle morphology (scanning electron microscopy), and elemental composition (x-ray fluorescence spectrometry). The specific surface area was based on settled dust because there was an insufficient sample in respirable fraction.

Key Findings:

- RD emissions from ES contained >80% crystalline silica (both quartz and cristobalite), 2 stones had only quartz (>90%), and the majority had quartz ranging from 42%-88%. In stone with low quartz content (<25%), cristobalite was the major mineral.
- Natural stones had lower quartz in RD: 30% for black granite, 11% for white marble, and 3.6% for white granite.
- Resin content for ES types ranged from 8% to 20%.
- Particle size of RD generated with dry cutting ES was very fine (<1 µm), with >90% between 190 nm and 825 nm. Natural stones had similar mean particle sizes ranging from 503-634 nm.
- ES had a high variability of zeta potential but generally was higher compared to natural stones (-29.9 $\pm$ 0.62 mV vs -15.2 $\pm$ 0.80 mV)
- ES particles had more irregular borders, sharp edges, and fractures along the surface as compared to the natural stones.
- The specific surface areas of ES types were highly variable but higher than those of natural stones.
- The elemental content of natural stone RD emission was higher than that of ES.
- RD emission from ES contained trace amounts (<0.1% wt) of Cu, P, S, Ni, Co, Cr, Sn, Zr, and Cl, minor amounts (<1%wt) of Fe, Ca, Mg, and K. Several ES samples had Ca, Mg, Na, and Ti elemental levels greater than 1%.

Conclusions of Authors:

- ES generated dust containing a high concentration of very fine particles, predominantly quartz and cristobalite, with the potential to detrimentally-impact respiratory health.
- RD generated from different ES types varied significantly in chemical properties, including crystalline silica, resin content, and surface charge.
- RD emission from natural stones were significantly different from ES, with lower silica content, smaller surface areas, and generally lower particle surface charges.

Key Strengths and Weaknesses:
Strengths:
- 12 different ES types chosen for their popularity
- 3 different natural stones and a reference high-purity quartz

Weaknesses:
- Specific surface area measurements were performed on settled dust rather than air-collected samples used for mineralogy and resin analyses.

Comparison to Other Studies:
This study's results were consistent with two other studies (Ramkissoon et al. 2023 and Ramkissoon et al. 2024). Resin results were like those reported by Carrieri et al. (2020), and particle size results were similar to those of Pavan et al. (2016).

Relevance to the Industry: There is variability in the crystalline silica, elements, and resin content of different ES types, which may differentially impact respiratory health. Dusts generated from machining ES contains ultrafine particles, predominantly quartz and cristobalite.

Citation: Ramkissoon, C., Gaskin, S., Thredgold, L., Hall, T., Rowett, S., & Gun, R. (2022). Characterisation of dust emissions from machined engineered stones to understand the hazard for accelerated silicosis. *Scientific Reports*, *12*(1), 4351. https://doi.org/10.1038/s41598-022-08378-8

Engineered stone fabrication work releases volatile organic compounds classified as lung irritants

Study Authors / funding: Ramkissoon C, Gaskin S, Hall T, Pisaniello D, Zosky G. (University of Adelaide, University of Tasmania). Funded by the Medical Research Future Fund.

Journal: *Annals of Work Exposures and Health, 2023*

Location / Country: Australia

Study Type and Description:
This study evaluated the organic composition of airborne dust generated from dry cutting of 12 different engineered stone (ES) products. The work was performed inside a small enclosure, and the respirable dusts (RD) generated were collected by standard air sampling techniques for subsequent laboratory analysis to determine mineral content, resin fractions, and organic chemical content. The ES product with the highest organic content was further analyzed for 73 volatile organic chemicals (VOCs).

Key Findings:
- The ES samples generated RD containing 8.6%-20% resin and 80%-91% respirable crystalline silica (RCS, in both quartz and cristobalite forms).
- The most abundant and ubiquitous organic compound identified was phthalic anhydride (26-85% of total organic compound), a known respiratory sensitizer that can cause occupational asthma.
- Benzaldehyde (4%-22%) and styrene (2%-6%) were also found in all samples.
- Propylene glycol, benzoic acid, acetophenone, phenol, and squalene were observed in some ES samples.
- Additional testing on 1 ES sample resulted in emissions of phthalic anhydride, styrene, toluene, benzene, ethylbenzene, and acetone above their respective detection limits. Of particular note, phthalic anhydride was detected at 0.32 mg/m^3, significantly higher than the ACGIH short-term exposure limit (STEL) of 0.005 mg/m^3 and their 8-hour time weighted average (TWA) limit of 0.002 mg/m^3.

Conclusions of Authors:
- Active dry fabrication work on ES can generate VOCs. One ES generated significantly elevated emissions of phthalic anhydride, a recognized dermal and respiratory irritant and sensitizer.
- Concurrent assessment for VOCs and RCS may be warranted for a more comprehensive understanding of workplace exposure among ES fabricators.

Key Strengths and Weaknesses:
Strengths:
- 12 different ES types were tested.

Weakness:
- Only 1 ES - the product with the highest resin content - was analyzed in more detail for VOCs.
- Samples were only cut dry. Since many shops use wet methods of dust control, information about the interaction of these emissions and water would be informative.

Comparison to Other Studies:

Studies by Leon-Jimenez et al. (2021) and Hall et al. (2021) showed a similar composition of VOC.

Relevance to the Industry: There is variability in RCS and resin content of various ES types. The VOCs were generally low, except for phthalic anhydride which was significantly higher than ACGIH's recommended exposure limits. It is important to understand the composition of each ES product being fabricated to better understand the risks to health and guidelines for regulatory compliance.

Citation: Ramkissoon, C., Gaskin, S., Hall, T., Pisaniello, D., & Zosky, G. (2023). Engineered stone fabrication work releases volatile organic compounds classified as lung irritants. *Annals of Work Exposures and Health*, *67*(2), 288–293. https://doi.org/10.1093/annweh/wxac068

Characterization of the emissions and crystalline silica content of airborne dust generated from grinding natural and engineered stones

Study Authors / funding: Thompson, D and C. Qi (CDC, NIOSH. Funded by NIOSH / CDC)

Journal: *Annals of Work Exposures and Health, 2023*

Location / Country: NIOSH, Cincinnati, USA

Study Type and Description: This was a controlled experiment designed to characterize the airborne dust and respirable crystalline silica (RCS) generated from grinding engineered (ES) and natural stone under laboratory conditions. Four samples were evaluated: 3 ES products and 1 natural stone (a granite). Two of the ES products consisted of a polymer resin matrix embedded with crystalline silica (50 to 90%) while the third product was composed of recycled glass (amorphous silica) in a cement matrix that contained no crystalline silica; the granite had an estimated crystalline silica content of 72%.

The study used a handheld pneumatic angle grinder equipped with a 10-cm diameter, coarse diamond grinding cup wheel to grind the stone samples. The work was performed inside a small, enclosed chamber. Air samples were collected by several methods to measure total and respirable dust and RCS generation rates as well as crystalline silica content. Real-time particle size distributions were also measured with direct reading instrumentation. Settled bulk dusts from the interior of the chamber were also analyzed.

Key Findings:

- The granite sample generated more dust (total and respirable) per unit volume of material removed than any of the ES products. However, the normalized generation rate of RCS was correlated with the crystalline silica content of each stone, with the ES containing the highest proportion resulting in the highest airborne RCS levels.
- All stone types generated similar trimodal lognormal number-weighted particle size distributions during grinding, suggesting dust formation from grinding is a similar process even across different stone types.
- For the stones containing crystalline silica, the highest normalized RCS generation rates occurred with particles ranging in diameter from 3.2 - 5.6 um.
- Bulk dust, RD, and total dust samples from each stone type contained comparable proportions of crystalline silica, suggesting that the RCS content in bulk dust can be representative of that in airborne RD generated during grinding.

Unique Study Aspects:

- Specifically examined the task of dry grinding under controlled laboratory conditions.
- Used the normalized generation rate (the mass of emissions generated per unit of volume removed from the workpiece) as a metric for characterizing emissions from the subtractive process of grinding, allowing for direct comparison between different stone types.
- Examined size-classified dust generated from dry grinding.

Conclusions of Authors:

The mechanical process of dust formation from grinding stones appeared similar for the granite and ES products examined, suggesting that the same engineering control measures are applicable across many stone types. The crystalline silica content of bulk dust was generally representative of that in RD generated during grinding, potentially making bulk dust analysis a useful predictor of airborne RCS. Manufacturing and adopting ES products with lower crystalline silica formulations may lower or eliminate RCS health risks. Removing particles in the respirable sized range should be prioritized.

Key Strengths and Weaknesses:
Strengths:

- Use of the normalized generation rate of RCS which allows for comparison across studies.
- Size-classification of airborne dusts.
- Multiple analytical methods compared.

Weaknesses:

- Only one natural stone and 3 ES products were examined.
- Sampling losses associated with specific measurement instruments, particularly the MOUDI (estimated to exceed 10% for particles with aerodynamic diameters > 10%) may affect calculation of the normalized generation rate.

Comparison to Other Studies: Findings that the crystalline silica content in RD collected during grinding is equivalent to that of bulk material / bulk dust samples reinforce similar findings by Hall et. al. (2022).

Relevance to the Industry: This study supports the position that products with lower crystalline silica content will likely reduce RCS exposure to stoneworkers while grinding.

Citation: Thompson, D., & Qi, C. (2023). Characterization of the emissions and crystalline silica content of airborne dust generated from grinding natural and engineered stones. *Annals of Work Exposures and Health*, *67*(2), 266–280. https://doi.org/10.1093/annweh/wxac070

Selected In Vitro Mechanistic Studies

Abrasion of artificial stones as a new cause of an ancient disease. Physicochemical features and cellular response

Study Authors / funding: Pavan C, Polimeni M, Tomatis M, Corazzari I, Turci F, Ghigo D, Fubini B. (University of Torino). Funded by the Italian Workers' Compensation Authority of Piemonte and the Local Health Authority of Firenze, Italy.

Journal: *Toxicological Sciences, 2016*

Location/Country: Turin, Italy

Study Type and Description:
This study aimed to explore the physicochemical properties and the in-vitro biological reactivity that could be relevant to the reported high pathogenicity of engineered stone dust, including the generation of free radicals. Samples collected from different companies that specialize in manufacturing quartz conglomerates were obtained. Samples were collected after 2 different tasks: dry cutting with a grinding machine and wet cutting with a circular saw or pantograph. All samples were tested for chemical composition and oxidative reactivity, but only 1 dry and 1 wet sample were tested for particle size, morphology, and cellular response. A portion of wet or dry cut samples was ground for 1 hour to simulate the abrasion of material. Dust was collected and tested at different intervals of time to determine aging effects on free radical release. A reference quartz was used as a positive control, and synthetic amorphous silica was used as a negative control.

Morphology was determined by scanning electron microscopy, and particle size was determined by flow particle image analysis. The surface area was determined by the BET method. Elemental composition was determined by micro-x-ray florescence spectroscopy. Free radicals were detected using electron paramagnetic resonance spectroscopy with spin-trapping techniques. Residual volatiles were analyzed using thermogravimetric analysis coupled with Fourier-transformed infrared spectroscopy with GCMS. Hemolysis assessments were performed on human erythrocytes exposed to different concentrations of dust suspended in sodium chloride solutions. Human bronchial cells and murine alveolar macrophages were exposed to different dust particles for different durations and assessed for cytotoxicity (leakage of LDH), morphology (optical microscopy), PCR analysis for quantification of human E-cadherin, vimentin, alpha-smooth muscle actin, and house-keeping gene ribosomal subunit protein S14.

Key Findings:

- Dust generated by wet and dry processing of both reference quartz and artificial stone, had irregular shapes and sharp edges.
- 90% of all particles had an average diameter <4 µm; dry cutting resulted in slightly finer dust than wet cutting, and artificial stone was coarser than the reference quartz.
- Artificial stone dust contained varying amounts of metals such as Fe, Cu, Zn and Al.
- Artificial stone dust showed a high potential to generate HO- radical, but decreased over time, and after 60 minutes was about the same as reference quartz.
- Artificial stone dust obtained by wet processing did not generate carboxyl radicals, whereas dry processing produced highly reactive dust (10x more than reference quartz)
- Human bronchial epithelial cells exposed to artificial stone dust did not show hemolytic activities or cytotoxic effects, but after resin removal through heat treatment and grinding, hemolytic activity and cytotoxicity was documented.

- Human bronchial epithelial cells exposed to artificial stone dust samples showed gene expression profiles consistent with fibrotic pathways and suppression of protective mechanisms.

Conclusions of Authors:
- Artificial stone dust may be an activator of fibrotic markers
- Artificial stone workers are at risk of exposure to highly reactive and potentially fibrogenic dusts of respirable size, and these dusts are more reactive when freshly cut.

Key Strengths and Weaknesses:
Strength:
- Multiple in vitro tests to assess potential pathogenic mechanisms.

Weakness:
- It is unclear if the samples were obtained from 1 artificial stone or multiple stones.
- Significance of the in vitro findings is unclear.

Relevance to the Industry:
This study highlights that processing artificial stone generates free radicals that become less reactive with time. The dust generated may act through multiple pathogenic pathways.

Citation: Pavan, C., Polimeni, M., Tomatis, M., Corazzari, I., Turci, F., Ghigo, D., & Fubini, B. (2016). Editor's Highlight: Abrasion of Artificial Stones as a New Cause of an Ancient Disease. Physicochemical Features and Cellular Responses. *Toxicological sciences: an official journal of the Society of Toxicology*, *153*(1), 4–17. https://doi.org/10.1093/toxsci/kfw101

Metal ion release from engineered stone dust in artificial lysosomal fluid – variation with time and stone type

Study Authors / funding: Maharjan P, Crea J, Tkaczuk M, Gaskin S, Pisaniello D. (Adelaide Exposure Science and Health, School of Public Health, University of Adelaide). Funded by the SA Mining and Quarrying OHS Committee.

Journal: *International Journal of Environmental Research and Public Health, 2021*

Location / Country: Adelaide, South Australia

Study Type and Description: The potential role played by resin and metal ions in the development of lung disease from exposure to engineered stone (ES) dust has not been well studied. Elemental components of ES, such as metal ions, are potentially important contributors to lung toxicity, primarily due to their ability to produce reactive oxygen species. The purpose of this preliminary study was to understand the variability in solubility across engineered stone (ES) types and the time trend of metal ion release in artificial lysosomal fluid (ALF) simulating the intracellular acidic intracellular environment of lung macrophage lysosomes.

Ten samples of engineered stone from 5 different manufacturers, selected based on consumer popularity, color, and design were obtained. Each sample was cut, crushed, and comminuted to generate fine dust for analysis. Dust was mixed with ALF containing pyruvate, citric acid and glycine and sampled at various time points (1 week, 2 weeks, 4 weeks, 8 weeks). A blank containing no engineering stone dust was used as control. Sample aliquots were sent to a commercial lab to perform elemental analysis of metal ions including Iron, Manganese, Aluminum and Titanium. The brightness of uncut ES was measured using normal overhead fluorescent lighting and captured with a luminance meter. Silica content of the dust was also determined.

Key Findings:

- The metal concentration of four elements – aluminum (60-250 mg/kg), titanium (4-10 mg/kg), manganese (1-63 mg/kg), and iron (30-3800 mg/kg) - was reported. Iron and Manganese had significant variability in solubility and release from ALF. Aluminum was more abundant in ALF but less variability in solubility. Vanadium, arsenic, nickel, copper, chromium, and antimony were below the limit of detection. Tungsten and cobalt were not included as these could be introduced as contaminants during stone dust generation using tungsten carbide.
- All metal ions in ALF in the blank (no ES) were below the level of practical quantification.
- Silica Content:
  - 5/10 samples contained $\geq$ 90% Quartz, with the other 5 samples ranging from 19%-89% quartz.
  - 4/10 samples contained albite (2%-7%), 1/10 contained magnetite (0.8%), 2/10 contained rutile (2%-4%) and 4/10 contained cristobalite (23%-47%)
  - 8/10 had quartz as the main crystalline mineral species and 2/10 had Cristobalite as the main crystalline mineral species.

Conclusions of Authors:

- There is substantial variability in silica content and metal ion release from ES dust in a simulated lung cell environment.

- Metal ion release and time trends for metal release varied by ES type and by metal ion. No speciation of metals was performed.
- Metals and mineral presence in ES were generally consistent with SDS sheets but SDSs do not provide proportionate information on elemental constituents.
- Further investigation of the toxicological properties of ES dust is needed.

Key Strengths and Weaknesses:
Strength:

- 10 different ES samples from 5 different manufacturers were used.

Weaknesses:

- There was no discussion about other factors such as pigment analysis or resin analysis.
- Study used bulk samples, not air sampling.

Relevance to the Industry: It is important to understand the uniqueness of ES and how varied the composition of each ES may be, including mineral composites and metal constituents. Quartz may not be the main crystalline mineral in all ES types. It is important to note the type of ES being used.

Citation: Maharjan, P., Crea, J., Tkaczuk, M., Gaskin, S., & Pisaniello, D. (2021). Metal Ion Release from Engineered Stone Dust in Artificial Lysosomal Fluid-Variation with Time and Stone Type. *International journal of environmental research and public health*, *18*(12), 6391. https://doi.org/10.3390/ijerph18126391

Rapid assessment of oxidative damage potential: A comparative study of engineered stone dusts using a deoxyguanosine assay

Study Authors / funding: Leigh Thredgold, Chandnee Ramkissoon, Chellan Kumarasamy, Richard Gun, Shelley Rowett, and Sharyn Gaskin (University of Adelaide / SafeWork South Australia). Funded by an Insurance and Care NSW (iCare) Dust Disease Board Focus Grant.

Journal: *International Journal of Environmental Research and Public Health, 2022*

Location / Country: Adelaide, Australia.

Study Type and Description: This was a controlled experiment in which the oxidative damage potential of engineered stone (ES) dust was assessed using a deoxyguanosine assay. The deoxyguanosine assay is a well-accepted in vitro method that uses reactive oxygen species-mediated hydroxylation of 2'-doxyguanosine to 8-hydroxy-2'-deoxyguanosine (8-OH-dG) as an indicator of oxidative DNA damage. By applying freshly generated ES dust to a cell-free in vitro deoxyguanosine assay, the study authors sought to make a comparative assessment of the oxidative damage potential across different stone materials and to determine if there was any difference in reactivity between airborne respirable dust and dust that had settled onto workplace surfaces.

12 ES samples, selected for study based on the highest volume of sales in Australia, and 3 natural stone samples were studied. For comparative purposes, 2 additional materials were tested – a respirable crystalline silica (RCS) reference material and "Hebel," a common concrete building material. The physicochemical properties differed by mineral content, resin for ES, mean particle size, and elemental composition. An angle grinder with a diamond blade was used to perform zip cuts on each stone to generate sufficient stone dust for analysis. Dust sampling was conducted for 15 minutes per sample and samples of settled dust were collected from surfaces after each cutting event.

The deoxyguanosine assay involved the suspension of five milligrams of dust in 3.8 mL of 0.1 M phosphate buffered saline, to which 1 mL of 0.2. M hydrogen peroxide and 0.01 M 2'-deoxyguanosine was added. Assay samples were incubated on an orbital saker in the dark with caps removed to facilitate air exchange for 60 minutes, and then all samples were filtered prior to analysis. All samples were analyzed with a negative control. This assay was performed for all engineered and natural stone samples as well as for settled dust aged for 1, 7, 14, and 21 days. Analysis of 8-OH-dG was performed by liquid chromatography.

Results of the assay were expressed as ug of 8-OH-dG generated per 10^5 dG for each stone sample. Differenced between aged samples were analyzed via one-way ANOVA with Duncan post hoc tests. Unpaired t-tests were used to assess differences between respirable and settled dust fraction of identical stone samples.

Key Findings:

- Physicochemical properties of stone dust:
    - All respirable ES dust contained high silica content, ranging from 47.2%-91% compared with natural stone dust, which ranged from 3.5% to 30.1%.
    - ES dust contained between 8.62% and 20.0% resin.
    - Hebel contained 5.9% silica.

  - Respirable dust (RD) particle size ranged between 200 and 715 nm in diameter.
- Oxidative Damage Potential of Freshly Generated Stone Dust:
  - Generally, RD from freshly cut engineered stone gave high assay values.
  - Two of the three natural stone samples gave low reactivity values while a third was on par with the ES samples.
  - The building material, Hebel, had low reactivity.
  - There was a large, statistically significant difference in oxidative potential between respirable and settled dust fractions for all materials tested, particularly noticeable in ES samples (in general, airborne respirable dusts were 3x more reactive than dust settled on surfaces).
  - No correlation between resin content and dust reactivity was observed.
- Effect of Stone Dust Aging:
  - The settled fraction of stone dust for 4 ES types and 1 natural stone was collected and stored open to the atmosphere up to 21 days prior to application to the deoxyguanosine assay.
  - None of the ES dusts exhibited a significant gain or loss in reactivity or oxidative damage potential.
  - The 1 natural stone dust sample exhibited a 28% drop in reactivity across the aging timeframe that was statistically significant.

Unique Study Aspects: This study evaluated the relative reactivity of airborne respirable and settled ES dusts and compared them with natural stone dusts via a deoxyguanosine assay.

Conclusions of Authors: The study authors conclude that respirable ES dust exhibits high overall reactivity and potential to cause oxidative damage. ES dust displayed higher reactivity than two out of three natural stones and the common building material, Hebel. Smaller dust particles are more reactive. Settled ES dusts maintain their reactivity over a 21-day period.

Key Strengths and Weaknesses:
Strength:
- Controlled experiment directly examining the reactivity of ES dust.

Weakness:
- Only three natural stones chosen for comparison to 12 ES types.

Comparison to Other Studies: This is one of a growing number of studies investigating pathogenic mechanisms of engineered stone.

Relevance to the Industry: Limited applicability when informing control measures. Differentiates engineered stone versus natural stone in terms of reactivity/oxidative damage potential in controlled laboratory experiments.

Citation: Thredgold, L., Ramkissoon, C., Kumarasamy, C., Gun, R., Rowett, S., & Gaskin, S. (2022). Rapid Assessment of Oxidative Damage Potential: A Comparative Study of Engineered Stone Dusts Using a Deoxyguanosine Assay. *International Journal of Environmental Research and Public Health*, *19*(10), 6221. https://doi.org/10.3390/ijerph19106221

Understanding the pathogenesis of engineered stone-associated silicosis: The effect of particle chemistry on the lung cell response.

Study Authors / funding: Ramkissoon C, Song Y, Yen S, Southam K, Page S, Pisaniello D, Gaskin S, Zosky G. (University of Adelaide, University of Tasmania). Funded by the Medical Research Future Fund

Journal: *Respirology*, *2024*

Location / Country: Australia

Study Type and Description: This study aimed to provide a comprehensive dataset on engineered stone (ES) dust samples' physical and chemical characteristics and link them to lung cell response. Respirable dust (RD) was obtained from 50 different ES types varying in color, pattern, and design from 5 suppliers (including 3 reduced-Si products), 2 granite stones, 1 marble stone, and 2 alternative building materials (autoclaved aerated concrete and ultracompact surface sintered material). Dust was generated with zip cuts by an angle grinder with a diamond blade inside a Perspex glove cabinet and analyzed for mineralogy, morphology, metals, resin, particle size and charge. Using air dust samples, crystalline silica, resin content, and dust size fraction were determined. The elemental composition was determined using total settled dust fraction by x-ray fluorescence (XRF) spectrometry.

The study focused on 2 cellular processes related to lung injury: cell death and inflammation. Human alveolar epithelial cells were cultured and exposed to dust particles, with positive control being standard silica and negative control without silica. A lactate dehydrogenase assay was performed to evaluate cytotoxicity, and ELISA assays were used to assess extracellular cytokine production. Adjustment was made for non-specific binding of secreted protein with binding experiments in a cell-free system. Each exposure experiment was performed 8 times with new generations of dust and cells for each trial.

Key Findings:

- Crystalline silica content ranged from 36% to 74% of ES emissions. Quartz was usually the dominant from of silica, but some ES types contained up to 30% cristobalite.
- 2/3 reduced-Si products contained ~30% crystalline silica (1 with 22% Quartz, 1 with 25% cristobalite), and the other reduced-Si product contained 7% crystalline silica.
- Crystalline silica content ranged from 20% to 26% of granite and 10% of marble stone emissions, with quartz being the most dominant.
- Aerated concrete material had 22% crystalline silica, and sintered mineral material had 15% crystalline silica.
- The average resin content of engineered stones was similar (15 + 0.6%), and there was no resin in natural stone or alternative building materials.
- Actively cutting stones using an angle grinder generated fine particles (<600 nm). ES's average particle size was 495 nm (273nm-665nm). The alternative building material's average particle size was 642nm (634nm-651nm). The natural stone's average particle size was 545nm (485nm-633nm). 2/3 reduced-Si stones generated ultrafine particles (<100nm) predominantly.
- Morphology analysis shows agglomeration of ultrafine particles with irregular shapes, sharp edges, and fractures along the surface.
- Cutting ES generated ultrafine particles consisting mainly of crystalline silica but also contained titanium, copper, cobalt, and iron.

- The elemental content of ES, natural stones, and alternative building materials had a wide range of various metals, including Iron, Aluminum, Calcium, and Titanium. Magnesium and Manganese
- IL-8 levels were higher with exposure to 15 ES samples but not with natural stone, standard silica, or alternative building materials. There were significant differences in cytotoxicity and levels of IL-6 and TNF-α in all samples.

Conclusions of Authors:

- There was an association between the quartz content of particles and macrophage inflammatory response; high levels of silica is one contributing factor to disease severity though not the only contributing factor to adverse lung cell response.
- Cobalt and Aluminum were strongly associated with THP-1 cytotoxicity, highlighting the potential importance of non-silica elements in causing adverse lung responses.
- ES has high levels of crystalline silica but produces larger particles, while reduced-Si stone has lower silica content but produces finer particles.
- ES dust was more potent in inducing cytotoxicity and pro-inflammatory response in epithelial cells, while standard silica was more potent for macrophages.
- Some of the highest inflammatory responses were seen in non-engineered stone, highlighting that other non-silica and inorganic components may strongly contribute to adverse lung response.

Key Strengths and Weaknesses:

Strengths:

- large sample of ES type (50) and a comparison to natural stone (marble and granite), 2 alternative building materials, and standard silica.
- New alveolar epithelial cell cultures with new dust generation were used in each trial.

Weaknesses:

- There was only 1 marble stone and 2 natural stone for comparison. Analysis of a greater number of natural stones would have been beneficial.
- Dust was generated with a single type of task (cutting stone).

Comparison to Other Studies:

This is one of a growing number of studies investigating pathogenic mechanisms of engineered stone.

Relevance to the Industry:

There is a large variation in the crystalline silica content of ES, natural stones, reduced-Si stones, and aerated concrete building materials, with a large variation in the non-silica components. High levels of RCS dust during ES processing likely contributes to lung disease severity. Fabrication of ES with high crystalline silica content generated larger particles than natural stone. The smallest particle sizes were generated when working with reduced-Si stone. Particle size may contribute to risk of adverse lung response. This study also highlighted the potential importance of non-silica components that may contribute to adverse lung responses.

Citation: Ramkissoon C, Song Y, Yen S, Southam K, Page S, Pisaniello D, et al. Understanding the pathogenesis of engineered stone-associated silicosis: The effect of particle chemistry on the lung cell response. *Respirology*. 2024; 29(3): 217–227. https://doi.org/10.1111/resp.14625

Selected Other Studies of Interest

Assessment of exposure in epidemiological studies: the example of silica dust.

Study Authors / funding: Dahmann D, Taeger D, Kappler M, Büchte S, Morfeld P, Brüning T, Pesch B. Institut an der Ruhr-Universitat Bochum, Institut fur Arbeitswissenschaften der RAG Aktiengesellschaft, Dortmund, and Institut fur Arbeits- and Sozialmedizin der Universitat zu Koln, Germany. (No funding information listed)

Journal: *Journal of Exposure Science and Environmental Epidemiology*, 2008

Location / Country: Germany

Study Type and Description: This older paper reviews potential uncertainties in assessing exposure to respirable crystalline silica (RCS) in occupational settings, with a goal to improve the exposure estimates used in epidemiological studies. The authors focus on three primary areas necessary to accurately characterize exposure:

- Agent (RCS) and respirable dust (RD)
- Characterization of the occupational setting (job title, job tasks, use of personal protective equipment, application of other protective measures, duration in job)
- Air sampling methods (measurement strategy, type of measurement, measurement metric, data points, averaging procedure, sample size)

Key Findings:

- "Silica" is not a single mineral but a term that collectively describes various forms of silicon dioxide. The specific mineral composition, size, and form(s) of silica are important to document as they can provide additional information on the potential health hazards of dust in the workplace. Data on potential co-existing hazardous substances should also be addressed.
- Sampling and analytical methods for measuring airborne RD and RCS have changed over time, making comparisons between studies difficult. Use of recognized standard sampling and analytical methods are therefore important.
- Since most air sampling is performed for regulatory compliance rather than epidemiological studies, and occupational exposure limits have changed over time, compliance-driven measurements may differ from those collected in more random surveys; care in interpretation is important.

Conclusions of Authors: Failure to determine the mineral composition of airborne dusts, describe the work setting and controls, or use consistent, standard sampling and analysis methods can lead to inaccurate exposure estimates that can bias epidemiological study findings.

Relevance to the Industry: When assessing workplace RD and RCS exposures, standardized sampling and analytic methods should be used and the work setting, job task(s), and materials processed should be well documented.

Citation: Dahmann D, Taeger D, Kappler M, Büchte S, Morfeld P, Brüning T, Pesch B. Assessment of exposure in epidemiological studies: the example of silica dust. *Journal of Exposure Science and Environmental Epidemiolology*. 2008 Sep;18(5):452-61. doi: 10.1038/sj.jes.7500636.

Quantitative crystalline silica exposure assessment for a historical cohort epidemiologic study in the German porcelain industry

Study Authors / funding: Birk, T., Guldner, K., Mundt, K. A., Dahmann, D., Adams, R. C., & Parsons, W. Project sponsors: the Berufsgenossenschaftder keramischen und Glas-Industrie (BGGK, now VBG), the Steinbruchs-Berufsgenossenschaft (StBG), and by EUROSIL, the European Association of Industrial Silica Producers, with additional support from other trade associations and individual companies.

Journal: *Journal of Occupational and Environmental Hygiene, 2010*

Location/Country: Germany

Study Type and Description: This was a longitudinal quantitative exposure assessment of silica exposure among an occupational cohort of 18,000 German porcelain workers from 94 porcelain plants followed for an average of 19 years. Exposure assessment was based on individual work history records and over 8000 historical industrial hygiene measurements from 1954-2006 obtained from the former German ceramic and glass professional association, BGGK (now VBG).
The study authors converted historic dust and silica measurements into modern units. To account for process and equipment improvements over time, six "Similar exposure groups" (SEGs) were created based on more than 100 work area codes, job tasks and process descriptors: preparation, forming, drying, firing preparation, firing, and finishing. All exposure data were standardized to (mg/m3) respirable silica as an 8-hour time-weighted average (TWA) and the data were combined to generate an industry-wide exposure assessment. Most data were based on static (area) sampling, and 6% of measurements were from personal sampling. A job exposure matrix (JEM) was constructed for the six primary SEGs over time.

Key Findings:
Of the six primary SEGs, materials preparation was associated with higher crystalline silica exposure compared with the other areas. For all SEGs, there was a generally monotonic decline in respirable crystalline silica exposure over time. Overall, 40% of the cohort accumulated less than 0.5 mg/m3-years. Approximately one-third of cohort members accumulated exposures greater than 1 mg/m3-years.

Individuals first employed prior to 1960 had a much higher (5 to 8-fold) exposure to crystalline silica compared with those hired after 1960. Exposures prior to 1975 routinely exceeded German and US occupational exposure limits. Cumulative exposures correlated with decade of hire and age.

Unique study aspects: This was the largest epidemiologic study of crystalline silica exposure outside of China and the first in the porcelain industry with large numbers of usable workplace exposure monitoring results.

Conclusions of Authors: The study authors report that quantitative exposure estimates based on these data can be used to evaluate exposure response relationship between crystalline silica exposure and risk of silicosis and other diseases.

Other conclusions: The study authors present exposure assessment data over time and do not present data related to risk of silicosis.

Key strengths and weaknesses:

Strength:

- Large cohort study. Detailed and sound methodology for conversion factors.

Weakness:

- Most relevant to the German porcelain industry.

Comparison to Other Studies: More extensive longitudinal exposure assessment than most studies.

Relevance to the Industry: Can inform development of a JEM relevant to respirable crystalline silica exposure related to countertop fabrication with engineered stone.

Citation: Birk, T., Guldner, K., Mundt, K. A., Dahmann, D., Adams, R. C., & Parsons, W. (2010). Quantitative Crystalline Silica Exposure Assessment for a Historical Cohort Epidemiologic Study in the German Porcelain Industry. *Journal of Occupational and Environmental Hygiene*, *7*(9), 516–528. https://doi.org/10.1080/15459624.2010.487789

Silica exposure assessment in a mortality study of Vermont granite workers

Study Authors / funding: Verma DK, Vacek PM, des Tombe K, Finkelstein M, Branch B, Gibbs GW, Graham WG. University affiliated (McMaster, Vermont, Alberta) with one associated with Safety Health Environment International Consultants Corp. Supported by the Crystalline Silica Panel of the American Chemistry Council (ACC) through a contract with University of Vermont.

Journal: *Journal of Occupational and Environmental Hygiene, 2011*

Location / Country: Vermont, USA

Study Type and Description: Retrospective exposure assessment of respirable dust (RD) and respirable crystalline silica (RCS) in Vermont granite industry workers to create a job exposure matrix (JEM). The authors gathered exposure data covering the period 1924 – 2004, which included 5,204 individual exposures.

The data was categorized into 2 groups - shed and quarry - and similar jobs were grouped into classes resulting in 562 jobs forming 22 job classes with the assistance of industry experts.

- Bit Grinder
- Blacksmith
- Boxer
- Carver
- Channel Bar
- Crane
- Cutter
- Draftsman
- Driller
- Foreman
- Grinder
- Jackhammer
- Laborer
- Lumper
- Maintenance
- Quarry
- Office Worker
- Polisher
- Sandblaster
- Sawyer
- Shed
- Surfacer

Additionally, 3 time periods were established as benchmarks for dustiness:

- Period 1: <1940, pre-dust control (1938: dust standard of < 10 mppcf was set in Vermont)
- Period 2: 1940 – 1949, transition period
- Period 3: >1950, post-dust control (dust control technology applied)

The authors selected 11% as the fraction of free silica in respirable dust for the Vermont granite industry based on previous studies and previous Vermont data. Their own database (n=987) showed an average of 10.2% with a range of 1.0 - 76%. They also used the conversion factor of 10 mppcg = 0.1 mg/m^3, which is the equation recommended by OSHA, to convert older data that was measured with impingers.

RCS mean concentrations for each job class by year were calculated using the combination of personal and area samples. Number of samples for each job type varied greatly from 1 sample in the 80-year period (bit grinder) to 1,900 samples (cutter). And multiple methods—imputation, interpolation, extrapolation—were used for missing data.

Key Findings: mg/m^3 (reported in the paper) has been converted to ug/m^3

- RCS exposure has decreased over time from for all job classes included in the study except for draftsman and office workers, who had minimal exposures. The authors used the Period 1 values of draftsman and office workers for all their time periods since they were generally not exposed to shed or quarry.

- RCS exposure during Period 1 was highest in Drillers (1.07 mg/m^3 with a range of 0.01 - 1.07 mg/m^3). RCS exposure during Period 3 was highest in Laborers (0.10 mg/m^3 with a range of 0.01 - 0.10 mg/m^3 but all values were extrapolated data).

Unique Study Aspects: This paper describes the creation of a job exposure matrix (JEM) for Vermont granite workers for RD and RCS using retrospective exposure samples from 1924 – 2004 (98% of samples were obtained 1925 – 1984). The JEM was then used in an epidemiologic study assessing mortality in Vermont granite workers.

Conclusions of Authors: This new JEM can be useful for future studies of Vermont granite workers, particularly for adverse health outcomes or mortality.

Other Conclusions: If one agrees with the authors' TWA assumptions, conversion factors, and methods and justifications for interpolation and extrapolation, then the JEM could be useful for RD and RCS exposures for certain job classes.

Key Strengths and Weaknesses:

Strengths:

- Similar to but more robust than previous job-based estimates of exposure in these granite workers in number of measurements and the time period covered.

Weaknesses:

- Exposure measurements from impingers (usually task-based samples < 30 minutes) were used as the TWA, which is very likely to have overestimated those exposures (about 60% of all measurements in the study and mostly prior to 1972).

- Many data points were calculated using various mathematical methods rather than being actual measurements, including Period 2 (1940-1949) and some entire job classes for certain time periods.

Relevance to Industry: A JEM for the countertop industry could possibly guide which job classes to prioritize with interventions or that might not need respiratory protection. After implementation of controls in 1950, exposures for 14 out of 22 job classes were at or above the current OSHA PEL.

Citation: Verma, D. K., Vacek, P. M., des Tombe, K., Finkelstein, M., Branch, B., Gibbs, G. W., & Graham, W. G. (2011). Silica exposure assessment in a mortality study of Vermont granite workers. *Journal of Occupational and Environmental Hygiene*, *8*(2), 71–79. https://doi.org/10.1080/15459624.2011.543409

Risk evaluation and exposure control of mineral dust containing free crystalline silica: a study case at a quarry in the Recife Metropolitan Area

Study Authors / funding: Mario Lira, E. Kohlman Rabbani , Beda Barkokébas Junior, Eliane Lago (Civil Engineering Postgraduate Program, University of Pernambuco, Brazil). No funding information provided.

Journal: *Work, 2012*

Location / Country: Recife, State of Pernambuco, Brazil

Study Type and Description: This study was conducted in 2009 at an aggregate stone quarry in the Recife Metropolitan Area of Brazil. The principal goal of the work was to determine quarry workers' exposure to respirable dust (RD) and respirable crystalline silica (RCS), as part of a larger corporate risk assessment to evaluate compliance with local requirements.

The study authors collected a limited number of personal air samples for RD and RCS, following NIOSH methods. RD and RCS data by quarry activity are presented, but limited details on work operations, equipment, and protective work practices are provided. "Risk factor" scores that compare the RD concentration with ACGIH TLVs are presented but poorly explained. The authors also administered a checklist-based survey to assess the company's compliance with applicable regulations.

Key Findings:

- Personal exposures to RD ranged from 0.204 - 6.611 mg/m^3, and those for RCS ranged from 0.038 - 1.589 mg/m^3, with the highest reported from the primary crusher operator.
- All of the RCS results exceeded the OSHA Action Level, and all but 1 exceeded the OSHA PEL.
- Operations at this aggregate quarry were determined to be out of compliance with applicable standards based on the survey administered.

Unique Study Aspects: Limited data on a single quarry in Recife, Brazil.

Conclusions of Authors: The authors concluded that their findings confirmed unhealthy conditions at the quarry site and that Brazilian standards are inadequate.

Key Strengths and Weaknesses:
Strengths: None
Weaknesses:

- Failure to describe the mineralogical composition of the stone being quarried and crushed.
- Lack of sufficient methodological detail, including incomplete description of sampling methods.
- Limited sample size (n=12 total) and absence of replicates.
- Over-interpretation of limited data.

Relevance to the Industry: This article is of minimal utility to the industry.

Citation: Lira, M., Kohlman Rabbani, E., Barkokébas Junior, B., & Lago, E. (2012). Risk evaluation and exposure control of mineral dust containing free crystalline silica: a study case at a quarry in the Recife Metropolitan Area. *Work*, *41 Suppl 1*, 3109–3116. https://doi.org/10.3233/WOR-2012-0570-3109

What do safety data sheets for artificial stone products tell us about composition? A comparative analysis with physicochemical data

Study Authors / funding: Kumarasamy C, Pisaniello D, Gaskin S, Hall T. (Curtin University, University of Adelaide) Funding support from the South Australia Mining and Quarrying OHS Committee.

Journal: *Annals of Work Exposures and Health, 2022*

Location / Country: Australia

Study Type and Description: The aim of this study was to identify the compositional differences between artificial stone (AS) from various suppliers and compare them to SDS-reported values. Only organic resin containing AS types were examined. Twenty-five AS samples from 6 suppliers were chosen based on consumer popularity, color, and design. Using laboratory conditions, each AS was initially cut with a wet diamond blade saw, crushed with a tungsten carbide jaw crusher, and comminuted to the mid-point size distribution of 10-18 μm to obtain bulk samples. External National Association of Testing Authorities, Australia (NATA)-accredited laboratories assessed the physico-chemical properties of the AS samples, excluding organic resin. Absolute metal content was determined by X-ray fluorescence (XRF) and crystalline mineral content was determined by X-ray diffraction (XRD), with a precision value at 0.001% and 1% by weight, respectively. The organic resin content for the samples was determined by weight loss after heating (calcination) to 600°C, with a precision of 0.5% by weight. Results were compared to the SDS obtained from the supplier.

Key Findings:
- There was significant variability between reported constituents, with little consistency in SDSs from different suppliers.
- Quartz and Cristobalite were reported separately by 1 supplier, combined by 2 suppliers, and the cristobalite content was not reported by 3 suppliers.
- Despite unusually wide ranges in the concentration of minerals per the SDSs, the bulk sample analysis showed higher quartz and cristobalite contents (outside the range reported on the SDS) in several AS samples tested.
- Quartz bulk sample testing ranges between 10% and 99%, and cristobalite between 0.3% and 90%.
- There was also variability in the report of metals (2 reported only titanium, while the others did not report any metals). Still, testing showed the presence of these metals (iron, aluminum, manganese, chromium, copper, nickel, cobalt, and lead).
- Although only 2 AS suppliers reported organic resin content, polyester resin was found in all AS samples with content ranging from 8.9% to 14.6%.

Conclusions of Authors:
- SDSs contained limited information about the mineralogical and metallic composition of AS, with significant variability from actual bulk analysis results.
- Improvements in SDS preparation could help bridge gaps in communicating accurate health and safety information to users.

Key Strengths and Weaknesses:
Strengths:
- A large variety of AS samples were tested (n=25) from 6 suppliers

- AS samples were assessed using multiple analytical methods to provide comprehensive information on their mineral and metal components

Weaknesses:

- Analysis was performed on bulk samples only; the study did not address the composition of dusts generated during various AS fabrication processes.

Comparison to Other Studies: One of the few studies to assess the accuracy of SDSs for engineered stone.

Relevance to the Industry:

- The accuracy and completeness of information provided in SDSs for AS can vary widely, so reliance on that information alone should be avoided.
- AS typically contains more than just silica, including various resins and metals that frequently are not adequately described in SDSs.

Citation: Kumarasamy, C., Pisaniello, D., Gaskin, S., & Hall, T. (2022). What Do Safety Data Sheets for Artificial Stone Products Tell Us About Composition? A Comparative Analysis with Physicochemical Data. *Annals of Work Exposures and Health*, *66*(7), 937-945. https://doi.org/10.1093/annweh/wxac020

Caution on using tetrahydrofuran for processing crystalline silica samples from engineered stone for XRD analysis

Study Authors / Funding : Qi C, Thompson D, Feng A. (NIOSH, CDC). Funding through NIOSH / CDC.

Journal: *Annals of Work Exposure and Health, 2022*

Location / Country: Cincinnati, OH, USA

Study Type and Description: This laboratory study evaluated two different methods of sample preparation used in the determination of silica content in natural and engineered stone (ES). Samples of granite (30% quartz) and an ES (14% quartz, 46% cristobalite) were each mechanically ground inside a small test chamber. Representative air samples were collected during the work for subsequent analysis following standard NIOSH Methods 0600 and 7500. The samples were split for the laboratory analysis component, with one group prepared using traditional tetrahydrofuran dissolution and the other ashed in a muffle furnace. All samples were then subjected to standard x-ray diffraction analysis for mineral content.

Key Findings:
- For the granite samples, a similar crystalline silica content was found using both the muffle furnace ashing and tetrahydrofuran dissolution steps. However, for the ES samples, the traditional tetrahydrofuran dissolution step resulted in substantially lower crystalline silica content compared to muffle furnace ashing .

Unique Study Aspects: Specific study identifying a potential systematic bias in the laboratory method for analyzing silica minerals.

Conclusions of Authors:
- Using tetrahydrofuran dissolution methods to analyze ES samples for silica can result in artificially lower quantification of crystalline silica as compared to muffle furnace ashing due to the reaction between resin(s) in ES and tetrahydrofuran.

- When conducting assessments of worker exposures to silica in countertop fabrication, either muffle furnace or RF plasma ashing should be used as the preferred processing method for ES samples to produce more accurate quantification of crystalline silica.

Key Strengths and Weaknesses:
Strengths:
- Well-controlled study with multiple samples for each experiment design (stone type and duration of grinding).
- Samples were obtained from the same task, limiting the potential for differences in the grinding method between samples.

Weaknesses:
- The study only included 1 type of granite and 1 engineered stone. No analysis could be made about confounding variables, including resin type, minerals within the resin, or the content or distribution of the different crystalline silica polymorphs.

- RF plasma ashing was not performed for comparison to tetrahydrofuran dissolution and muffle furnace ashing.

Relevance to the Industry:
This study highlights the importance of standardized methods and uniform analysis for reliable and comparable silica air monitoring results and cautions against using tetrahydrofuran dissolution as the processing method to analyze ES samples. Documentation of where samples were analyzed and the method used are important for accurate assessment.

Citation: Qi, C., Thompson, D., & Amy Feng, H. (2022). Caution on using tetrahydrofuran for processing crystalline silica samples from engineered stone for XRD analysis. *Annals of Work Exposures and Health*, *66*(9), 1210–1214. https://doi.org/10.1093/annweh/wxac063

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