In-Depth Survey Report

Mixing Mortar

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International Union of Bricklayers and Allied Craftworkers
Southern Ohio-Kentucky Regional Training Center

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Abstract

Background

This is the report of a field study to evaluate respirable dust and respirable crystalline silica exposures associated with the task of mixing mortar. In data presented in the Preliminary Economic Analysis for the Notice of Proposed Rulemaking for Occupational Exposure to Crystalline Silica [OSHA 2013], two results of less than the limit of detection (12 µg/m^3) and 18 µg/m^3 were reported for workers who primarily mixed fresh mortar and delivered it to other bricklayers. However, anecdotal reports from bricklayers indicated that the task could be dusty. This study was conducted to collect additional exposure data on mortar mixing.

Assessment

Task-based personal breathing zone and area air samples for respirable dust and respirable crystalline silica were collected while an apprentice bricklayer and instructors at the training center cleaned the mixer and while the apprentice bricklayer mixed a batch of lime mortar and a batch of type N mortar.

Results

In samples collected over 12 to 17 minutes, personal breathing zone sampling results for quartz ranged from less than the limit of detection while the mixer was cleaned to 0.11 mg/m^3 while lime mortar was mixed. That result is a value between the limit of detection and the limit of quantitation, which is considered a trace amount with limited confidence in its accuracy. Personal breathing zone results for respirable dust ranged from less than the limit of detection when Type N mortar was mixed to 7.8 mg/m^3 while the mixer was cleaned.

Conclusions and Recommendations

Mixing either lime mortar or Type N mortar for eight or more hours a day could generate sufficient worker exposure to require the use of an air purifying respirator that is at least as protective as a filtering facepiece respirator or half-mask respirator with N-95 filters. The respirator user must be trained and fit-tested, and the respirator must be used as part of a comprehensive respiratory protection program in accordance with the OSHA silica standard [81 Fed. Reg. 16285 (2016)]. Air sampling to characterize full-shift exposures to mortar mixing with a variety of mixes and mixing technology would determine the extent to which mortar mixing on job sites is a concern and if engineering controls should be developed for mortar mixers.

Introduction

Background for Control Technology Studies

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational Safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, EPHB has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. Examples of these completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concept techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

Background for this Study

Crystalline silica refers to a group of minerals composed of silicon and oxygen; a crystalline structure is one in which the atoms are arranged in a repeating three-dimensional pattern [Bureau of Mines 1992]. The three major forms of crystalline silica are quartz, cristobalite, and tridymite; quartz is the most common form [Bureau of Mines 1992]. Respirable crystalline silica refers to that portion of airborne crystalline silica dust that is capable of entering the gas-exchange regions of the lungs if inhaled; this includes particles with aerodynamic diameters less than approximately 10 micrometers (μm) [NIOSH 2002]. Silicosis, a fibrotic disease of the lungs, is an occupational respiratory disease caused by the inhalation and deposition of respirable crystalline silica dust [NIOSH 1986]. Silicosis is irreversible, often progressive (even after exposure has ceased), and potentially fatal. Because no effective treatment exists for silicosis, prevention through exposure control is essential. Silicosis is associated with a higher risk of tuberculosis and other lung disease [Parks et al. 1999]. Silica has been classified as a known human carcinogen by the International Agency for Research on Cancer [IARC 1997]. Occupational exposure to respirable crystalline silica has been associated with autoimmune diseases, such as rheumatoid arthritis, and kidney disease [Parks et al. 1999, Stratta et al. 2001].

Crystalline silica is a constituent of several materials commonly used in construction, including brick, block, and concrete. Many construction tasks have been associated with overexposure to dust containing crystalline silica [Chisholm 1999, Flanagan et al. 2003, Rappaport et al. 2003, Woskie et al. 2002]. Among these tasks are tuckpointing, concrete cutting, concrete grinding, abrasive blasting, and road milling [Nash and Williams 2000, Thorpe et al. 1999, Akbar-Kanzadeh and Brillhart 2002, Glindmeyer and Hammad 1988, Linch 2002, Rappaport et al. 2003].

In its Preliminary Economic Analysis and Initial Regulatory Flexibility Analysis (PEA) for the Notice of Proposed Rulemaking for Occupational Exposure to Crystalline Silica [OSHA 2013], OSHA reported two results of less than the limit of detection (LOD) (12 $\mu g/m^3$) and 18 $\mu g/m^3$, for workers who primarily mixed fresh mortar and delivered it to other bricklayers.

Plant and Process Description

A mortar mixer was used inside the training center for this project (Figure 1). An apprentice bricklayer and trainers cleaned the mixer. Then, the apprentice bricklayer mixed two batches of mortar while air samples were collected to assess his exposures to respirable dust and respirable crystalline silica. The apprentice wore a full-face air-purifying respirator (3M, St. Paul, MN) with P-100 filters, safety glasses, ear plugs, work gloves, work boots, and a hardhat.

The first batch of mortar consisted of a 50-pound (lb) bag of lime (Ivory autoclaved finish lime, Graymont Dolime (OH), Inc., Genoa, OH), approximately 21 shovelfuls of sand, and water to mix. The second batch of mortar included 1, 70-lb bag of Type-N masonry cement (Custom Color, Lehigh Hanson, Irving, TX), and water to mix.

Occupational Exposure Limits and Health Effects

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH investigators use mandatory and recommended occupational exposure limits (OELs) when evaluating chemical, physical, and biological agents in the workplace. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Combined effects are often not considered in the OEL. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus can increase the overall exposure. Finally, OELs may change over the years as new information on the toxic effects of an agent become available.

Most OELs are expressed as a time-weighted average (TWA) exposure. A TWA exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended short-term exposure limit (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

In the U.S., OELs have been established by Federal agencies, professional organizations, state and local governments, and other entities. The U.S. Department of Labor OSHA Permissible Exposure Limits (PELs) [CFR 2003] are occupational exposure limits that are legally enforceable in covered workplaces under the Occupational Safety and Health Act. NIOSH recommendations are based on a critical review of the scientific and technical information available on the prevalence of health effects, the existence of safety and health risks, and the adequacy of methods to identify and control hazards [NIOSH 1992]. They have been developed using a weight of evidence approach and formal peer review process. Other OELs that are commonly used and cited in the U.S. include the Threshold Limit Values (TLVs®) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH®), a professional organization [ACGIH 2015]. ACGIH TLVs are considered voluntary guidelines for use by industrial hygienists and others trained in this discipline “to assist in the control of health hazards.” Workplace Environmental Exposure Levels (WEELs®) are recommended OELs developed by the American Industrial Hygiene Association (AIHA®), another professional organization. WEELs have been established for some chemicals “when no other legal or authoritative limits exist.” [AIHA 2007].

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91–596, sec. 5(a)(1)]. Thus, employers are required to comply with OSHA PELs. Some hazardous agents do not have PELs, however, and for others, the PELs do not reflect the most current health-based information. Thus, NIOSH investigators encourage employers to consider the other OELs in making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminating or minimizing identified workplace hazards. This includes, in preferential order, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation) (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection).

Crystalline Silica Exposure Limits

When dust controls are not used or maintained or proper practices are not followed, respirable crystalline silica exposures can exceed the NIOSH REL, the OSHA PEL, or the ACGIH TLV. NIOSH recommends an exposure limit for respirable crystalline silica of 0.05 mg/m^3 as a daily TWA determined during a full-shift sample for up to a 10-hr workday during a 40-hr workweek to reduce the risk of developing silicosis, lung cancer, and other adverse health effects [NIOSH 2002]. When substituting less hazardous materials for crystalline silica (where feasible) and source controls cannot keep exposures below the NIOSH REL, NIOSH also recommends minimizing the risk of illness that remains for workers exposed at the REL by using appropriate respiratory protection, and by making medical examinations available to exposed workers [NIOSH 2002]. In cases of simultaneous exposure to more than one form of crystalline silica, the concentration of free silica in air can be expressed as micrograms of free silica per cubic meter of air sampled (µg/m^3) [NIOSH 1975].

$$\mu\mathrm{g\,SiO_2/m^3} = \frac{\mu\mathrm{g\,Q} + \mu\mathrm{g\,C} + \mu\mathrm{g\,T} + \mu\mathrm{g\,P}}{\mathrm{V}} \qquad (1)$$

Where Q is quartz, C is cristobalite, and T is tridymite, P is “other polymorphs”, and V is sampled air volume.

The current OSHA PEL for respirable crystalline silica is 0.05 mg/m^3 for daily 8-hr TWA exposures [81 Fed. Reg. 16285 (2016)].

The ACGIH TLV for ɑ-quartz and cristobalite (respirable fraction) is 0.025 mg/m^3 [ACGIH 2015] as a daily 8-hr TWA. The TLV is intended to mitigate the risk of pulmonary fibrosis and lung cancer.

Methodology

Personal breathing zone (PBZ) and area air samples for respirable dust and respirable crystalline silica were collected while an apprentice bricklayer cleaned the mixer and mixed two batches of mortar inside the training center.

Personal breathing zone air samples for respirable particulate were collected at a flow rate of 9 liters/minute (L/min) using a battery-powered sampling pump (Leland Legacy sampling pump, SKC, Inc., Eighty-Four, PA) calibrated before and after sampling. A sampling pump was clipped to the apprentice’s belt (Figure 2). The pump was connected via Tygon® tubing fitting to a pre-weighed, 47-mm diameter, 5-micron (µm) pore-size polyvinyl chloride (PVC) filter supported by a backup pad in a three-piece conductive filter cassette sealed with a cellulose shrink band (in accordance with NIOSH Methods 0600 and 7500) [NIOSH 1998, NIOSH 2003]. The front cover of the cassette was removed and the cassette was attached to a respirable dust cyclone (BGI GK 4.162 cyclone, MesaLabs, Butler, NJ). At a flow rate of 9 L/min, the GK 4.162 cyclone has a 50% cut point of (D_{50}) of 3.91 µm, and conforms to the respirable sampling convention at flow rates between 8.5 and 9.5 liters per minute [HSL 2012]. D_{50} is the aerodynamic diameter of the particle at which penetration into the cyclone declines to 50% [Vincent 2007]. The cyclone was clipped to the apprentice's sweatshirt near his head and neck within the breathing zone (Figure 2). Area samples were collected using the same sampling method, except that the sampling pump and cyclone were placed in holders mounted atop two tripods at about breathing zone height (60 inches). The tripod on the left was approximately 5 feet (ft) from the mixer, as shown in Figure 1. The tripod on the right was approximately 3 ft away. A bulk sample of dust was also collected in accordance with NIOSH Method 7500 [NIOSH 2003].

Figure 1 - Mortar Mixer Inside Training Center, Showing Area Sampler Locations

The filter samples were analyzed for respirable particulates according to NIOSH Method 0600 [NIOSH 1998]. The PVC filters were allowed to equilibrate for a minimum of two hours before weighing. A static neutralizer was placed in front of the balance and each filter was passed over this device before weighing. The filters were weighed on a balance (model MT5, Mettler-Toledo, LLC, Columbus, OH). The limit of detection (LOD) was 20 µg/sample. The limit of quantitation (LOQ) was 79 µg/sample.

Samples were prepared and analyzed for respirable crystalline silica according to NIOSH Method 7500 [NIOSH 2003]. Each filter was removed from the cassette and folded two times into a quarter pie-shaped pocket to contain the particulate inside. A drop of 2-propanol (IPA) was added to the inside of the cassette lid and the back side of the sample filter was used to wipe the interior of the sampling cassette. The filters were placed into individual disposable borosilicate glass test tubes. The filters were dissolved by addition of 7 mL of tetrahydrofuran (THF) to each sample tube. The samples were mixed by vortex. The sample tubes were covered with aluminum foil and placed in an ultrasonic bath for ten minutes. The sample suspensions were transferred to silver-membrane filters, as described: First, a silver-membrane filter was placed in the vacuum filtration unit. Next, 2 mL of THF solvent was placed onto the filter. The sample suspension was vortexed and immediately added onto the silver membrane filter. The sample tube was rinsed with three separate portions of 2 mL THF. Each rinse was added to the sample on top of the silver membrane filter. Finally, vacuum was applied to deposit the sample suspension onto the filter. The silver-membrane filter was transferred to an aluminum sample plate and placed in the automated sample changer for analysis by X-ray diffraction. The LOD for quartz on a 47-mm PVC 5 µm filter was 5 µg/sample. The LOQ was 17 µg/sample.

In this sample set, the maximum air sample volume collected was 173 L. At the LOD for quartz of 5 µg/sample, the minimum detectable quartz concentration was 0.029 mg/m^3, slightly more than half the NIOSH REL of 0.05 mg/m^3. The minimum quantifiable quartz concentration at the LOQ of 17 µg/sample was 0.098 mg/m^3.

A bulk sample was prepared and analyzed following NIOSH Method 7500 [NIOSH 2003], as noted. The sample was collected from dropped sand and mortar near the base of the mixer.

Approximately 1 gram of sample was ground to a fine powder using a mortar and pestle. The ground powder was wet sieved through a 10 µm sieve using 2-propanol. The alcohol was evaporated in a drying oven. Approximately 2 mg of sieved-dried sample was weighed into a 15-mL test tube. Approximately 10 mL of 2-propanol was added into the test tube to create a suspension. The test tube was placed in an ultrasonic bath for about 10 minutes until agglomerated particles were broken up. The sample suspension was vortexed and immediately re-deposited onto a 25-mm diameter silver membrane filter, as follows: First, a silver membrane filter was placed in the vacuum filtration unit. Next, 2 mL of 2-propanol was added into the filtration funnel, followed by the sample suspension and test tube rinses. Finally, vacuum was applied to re-deposit the suspension onto the filter. The silver membrane filter was transferred to an aluminum sample plate and placed in the automated sample changer for analysis by X-ray diffraction. The LOD for quartz was 0.2% by weight. The LOQ was 0.62%.

Control Technology

No control technology was in place.

Results

The bulk sample contained 41% quartz. Respirable dust and quartz results are reported in Table 1, below. Personal breathing zone sampling results for quartz ranged from less than the limit of detection, while the mixer was cleaned, to 0.11 mg/m^3 while lime mortar (batch 1) was mixed. Personal breathing zone results for respirable dust ranged from less than the limit of detection, when Type N mortar was mixed (batch 2), to 7.8 mg/m^3 while the mixer was cleaned.

Table 1 – Air Sampling Results

Activity	Sample Location	Duration (minutes)	Volume (L)	Respirable Quartz Concentration (mg/m^3)	Respirable Dust Concentration (mg/m^3)
Cleaning	left	19	173	ND	ND
Cleaning	right	19	171	ND	ND
Batch 1	left	15	137	(0.053)	ND
Batch 1	right	16	144	(0.051)	0.60
Batch 2	left	11	100	(0.061)	1.5
Batch 2	right	09	81	ND	4.6
Cleaning	personal	17	155	ND	7.8
Batch 1	personal	14	127	(0.11)	2.3
Batch 2	personal	12	109	(0.063)	ND

ND indicates a result less than the LOD, which was 5 µg/sample for quartz and 20 µg/sample for respirable dust. Concentrations in parentheses were calculated from results between the quartz LOD 5 µg/sample and quartz LOQ of 17 µg/sample. The values in parentheses should be regarded as trace values with limited confidence in their accuracy.

Conclusions and Recommendations

The quartz results reported here were between the limit of detection and the limit of quantitation. While their actual quantitative values are uncertain, these results suggest that the actual exposures associated with mixing either type of mortar for eight or more hours a day may result in exposures that require an air purifying respirator that is at least as protective as a filtering facepiece or half-mask respirator with N-95 filters. Under such a scenario, the worker must be fit-tested and trained and the respirator used as part of a comprehensive respiratory protection program in accordance with the OSHA silica standard [81 Fed. Reg. 16285 (2016)]. In this study, apprentices are trained, fit-tested, and medically qualified as part of their employer's respiratory protection program. An evaluation of that program is beyond the scope of this study.

Air sampling to characterize full-shift exposures to mortar mixing with a variety of mixes and mixing technologies would determine whether or not mortar mixing on job sites is a concern and if engineering controls should be developed for mortar mixers. Air sampling results outdoors will probably be lower than those recorded here, especially on windy days when the wind blows the dust away from the worker's breathing zone. This may explain the differences between the results in this report and those reported in the OSHA Preliminary Economic Analysis of less than the LOD (12 µg/m^3) and 18 µg/m^3. If an engineering control was desired to control fugitive dusts during mortar mixing, a dust control could likely be devised that consisted of a slot hood, duct, fan, and dust collector. The fan could potentially be driven by the mixer motor.

References

81 Fed. Reg. 16285 [2016]. Occupational Safety and Health Administration: Occupational Exposure to Respirable Crystalline Silica; Final Rule. (To be codified at 29 CFR 1910, 1915, and 1926).

ACGIH [2015]. 2015 TLVs® and BEIs®: threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

AIHA [2007]. 2007 Emergency Response Planning Guidelines (ERPG) & Workplace Environmental Exposure Levels (WEEL) Handbook. Fairfax, VA: American Industrial Hygiene Association.

Akbar-Khanzadeh F, Brillhart RL [2002]. Respirable crystalline silica dust exposure during concrete finishing (grinding) using hand-held grinders in the construction industry. Ann Occup Hyg 46:341-346.

Bureau of Mines [1992]. Crystalline silica primer. Washington, DC: U.S. Department of the Interior, Bureau of Mines, Branch of Industrial Minerals, Special Publication.

CFR [2003]. 29 CFR 1910.1000. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

Chisholm J [1999]. Respirable dust and respirable silica concentrations from construction activities. Indoor Built Environ 8:94-106.

Flanagan ME, Seixas N, Majar M, Camp J, Morgan M [2003]. Silica dust exposures during selected construction activities. AIHA Journal 64:319-328.

Glindmeyer HW, Hammad YY [1988]. Contributing factors to sandblasters' silicosis: inadequate respiratory protection equipment and standards. J Occup Med. 30:917-921.

HSL [2012]. Evaluation of the penetration characteristics of a high flow rate personal cyclone sampler for NIOSH. Report ECM/2011/03. Buxton, UK: Health and Safety Laboratory.

IARC [1997]. Silica. In: IARC monographs on the evaluation of the carcinogenic risk of chemicals to humans. Vol 68: silica and some silicates. Lyon: International Agency for Research on Cancer.

Linch, KD [2002]. Respirable concrete dust-silicosis hazard in the construction industry. Appl Occup Environ Hyg, 17:209-221.

Nash NT, Williams DR [2000]. Occupational exposure to crystalline silica during tuckpointing and the use of engineering controls. Appl Occup Environ Hyg, 15:8–10.

NIOSH [1975]. Criteria for a recommended standard – Occupational exposure to crystalline silica. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, HEW Publication No. (NIOSH) 75-120.

NIOSH [1986]. Occupational respiratory diseases. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 86-102.

NIOSH [1992]. Recommendations for occupational safety and health: compendium of policy documents and statements. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 92-100.

NIOSH [1998]. Particulates not otherwise regulated, respirable. NIOSH Manual of Analytical Methods (NMAM®), 4th ed., 2nd Supplement, Schlecht, P.C. & O'Connor, P.F. Eds. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 98-119.

NIOSH [2002]. NIOSH Hazard Review: Health Effects of Occupational Exposure to Respirable Crystalline Silica. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2002-129.

NIOSH [2003]. Silica, crystalline, by XRD (filter redeposition). NIOSH Manual of Analytical Methods (NMAM®), 4th ed., 3rd Supplement, Schlecht, P.C. & O'Connor, P.F. Eds. Cincinnati, OH: U.S. Department of Health and Human Services, Public

Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2003-154.

OSHA [2013]. Preliminary economic analysis and initial regulatory flexibility analysis. Supporting document for the notice of proposed rulemaking for occupational exposure to crystalline silica. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration.

Parks CG, Conrad K, Cooper GS [1999]. Occupational exposure to crystalline silica and autoimmune disease. Environmental Health Perspectives 107, Supplement 5: 793-802.

Rappaport SM, Goldberg M, Susi P, Herrick RF [2003]. Excessive exposure to silica in the U.S. construction industry. Ann Occup Hyg 47:111-122.

Stratta P, Canavese C, Messuerotti A, Fenoglio I, Fubini B [2001]. Silica and renal diseases: no longer a problem in the 21st century? J Nephrol 14: 228-247.

Thorpe A, Ritchie AS, Gibson MJ, Brown RC [1999]. Measurements of the effectiveness of dust control on cut-off saws used in the construction industry. Ann Occup Hyg 43:443-456.

Vincent JH [2007]. Aerosol sampling. Chichester, West Sussex, England: John Wiley&Sons, Ltd. Pp. 203.

Woskie SR, Kalil A, Bello D, Virji MA [2002]. Exposures to quartz, diesel, dust, and welding fumes during heavy and highway construction. AIHA Journal 63:447-457.

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