Evaluating a Respirable Crystalline Silica Risk Assessment Model for the Construction Industry in Alberta

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Melanie Gorman Ng, PhD and Hugh W. Davies, PhD CIH

School of Population and Public Health
University of British Columbia

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Alberta Government

Summary

Respirable crystalline silica dust (RCS) is highly toxic and can cause the incurable lung disease silicosis and lung cancer. Silica is present in many construction materials including concrete, rock, asphalt, and gypsum. Many construction activities including cutting, grinding, drilling, and digging create RCS.

There is a demonstrated need for employers to monitor and reduce exposures to RCS on construction worksites. However, risk assessment and exposure measurement in the construction environment is complex, due to the highly dynamic nature of the work and worksites. To assist construction employers with exposure estimation and risk assessment the authors have developed a statistical exposure model for RCS exposures in construction in British Columbia (BC); the “BC silica model”. The model is derived from a database of over 4500 RCS exposure measurements from construction worksites around the world. The model is well positioned to be adapted to meet the needs of the Alberta construction industry but (i) only 4% of the observations in the database from which the model was derived were collected in Alberta, and (ii) the model had not been validated against external data. The overall aim of this project was to support adaption of the BC silica model for use in Alberta. The specific research questions were:

- What are the “common silica processes” (and related RCS controls) in the Alberta construction industry?
- What are the levels of RCS exposure associated with Alberta “common silica processes”
- Does the BC silica model generate exposure estimates that are representative of exposures that are measured in the field in Alberta?

The project consisted of three Phases.

Phase 1: Characterizing the Alberta Environment

- We conducted a survey of 7 Alberta construction industry leaders to compile a list of common silica processes (CSPs) in the Alberta construction industry
- CSP are tasks that are most likely to result in RCS exposure on Alberta construction sites.
- The industry leaders identified 36 CSPs for Alberta. Eleven of these were new Alberta CSPs that had not previously been identified in the development of the BC silica model.

Phase 2: Exposure Measurement Collection

- We conducted RCS exposure monitoring at Alberta construction worksites between September 2017 and March 2018.
- We collected 139 high-quality RCS exposure measurements with detailed supplementary information. The measurements were associated with 27 different CSPs.
- The overall geometric mean (GM) exposure level was 0.060 mg/m^3 (arithmetic mean (AM) = 0.54 mg/m^3). We observed wide variability in exposure with a geometric standard deviation (GSD) of 9.19 (arithmetic standard deviation (ASD) = 1.20 mg/m^3).

Phase 3: Data Processing and Analysis

- We used the BC silica model to generate modelled exposure estimates that corresponded to 65 of the collected RCS exposure measurements. These were used in a model validation.
- The model produces a distribution of expected exposure levels rather than a single point estimate.
- In general, modelled estimates correlated moderately well with measured observations (Pearson's r = 0.50).
- The geometric mean of the modelled estimates underestimated exposure levels 64% of the time (GM of ratios between modelled and measured exposure estimates = 0.81).
- The 95th percentile estimates were more conservative and underestimated exposure 45% of the time with a GM of ratios of 1.90.
- The 139 exposure measurements were all added to the pre-existing RCS exposure database and used to generate a new Alberta version of the silica model. This new version adds 7 new CSPs to the model, as well as a separate category for Alberta so Alberta estimates can be differentiated from BC estimates.

Key Points:

- The overall GM exposure level of 0.60 mg/m^3 is over double the Alberta occupational exposure limit for RCS (0.025 mg/m^3). Seventy-five percent of the samples were task-based and exposure levels over an entire shift would be expected to be lower; however, the data suggest that overexposure to RCS is common in the Alberta construction industry.

- The BC silica model performed well against a small dataset of Alberta exposure measurements, supporting the use of the model in Alberta. The updated Alberta silica model would be expected to perform better for Alberta exposure scenarios since it is derived from a database that includes over 80% more observations from Alberta, and it includes a coefficient that can adjust model estimates for Alberta.

- The BC Silica Control Tool will be updated by spring 2019 to incorporate the updated Alberta silica model. The Tool is currently available to all employers in British Columbia in all industries. Any Alberta employers that also operate in BC will be able to use this updated version of the Tool once it is available.

- Ongoing monitoring is encouraged. Additional RCS exposure monitoring data shared by industry could be added to the database from which the model is derived to improve the accuracy of the resulting updated models.

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List of acronyms, abbreviations

AM	Arithmetic Mean
ASD	Arithmetic Standard Deviation
ACGIH	American Conference of Governmental Industrial Hygienists
ACSA	Alberta Construction Safety Association
ARHCA	Alberta Roadbuilders & Heavy Construction Association
BC	British Columbia
BCCSA	British Columbia Construction Safety Alliance
CSP	Common Silica Process
GSD	Geometric Standard Deviation
IARC	International Agency for Research on Cancer
LOD	Limit of Detection
LPM	Liters Per Minute
Min	Minimum
Max	Maximum
Mm	Millimeters
N	Number of observations
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational Exposure Limit
RCS	Respirable Crystalline Silica
PPI	Parallel Particulate Impactor
PVC	Polyvinyl Chloride
SE	Standard Error
SiO_2	Silicon Dioxide
SME	Small and Medium Sized Enterprise
TLV	Threshold Limit Value
TWA	Time Weighted Average
US	United States
WHO	World Health Organization

Introduction

Silica Exposure

Silica (silicon dioxide, or SiO_2) is one of the most abundant minerals on earth. It is a major constituent of sand, and of many common building materials (Figure 1)

Substance	% Silica content
Brick	Up to 30
Concrete, cement, mortar	25 to 70
Tile	30-45
Sandstone, gritstone, quartzite	More than 70
Granite	Up to 30
Sand, gravel, flint	More than 70
Slate	Up to 40
Flint	More than 80

Figure 1: Percent Silica Content of Common Building Materials

In its crystalline, α-quartz form, silica is highly toxic if inhaled into the alveolar (respirable) region of the lung. This toxic form, with particles < 4 micrometers in diameter is often referred to as respirable crystalline silica or RCS. Many common operations found in the construction sector will produce fine dusts (Figure 2, Beaudry *et al,* 2013).

Common Contrcution Operations Producing Fine Dusts
Cleaning (dry sweeping and brushing, pressurized air blowing)
Drilling
Breaking and crushing
Cutting
Abrasive blasting and sand blasting
Grinding
Sanding
Excavation and digging
Hammering
Shotcreting
Mixing cement and mortar

Figure 2 Common Construction Operations that Produce Respirable Crystalline Silica (adapted from Leung, 2012)

The carcinogen surveillance program CAREX Canada has estimated that there are 380,000 workers in Canada who are exposed to respirable crystalline silica (RCS), of which approximately 54% are working in construction (CAREX Canada, 2015). By occupation, the largest exposed groups are construction trades labourers (105,000 people exposed), heavy equipment operators (41,000 people exposed), and plasterers and drywallers (34,000 people exposed). Men are much more likely to be exposed (approximately 93% of those exposed are males). Approximately 55,000 of those exposed work in Alberta.

A recent study of RCS exposures in Alberta found that overexposure to RCS is common in the construction industry. Seventy-seven percent of the exposure measurements from workers involved in construction of new commercial buildings were above the occupational exposure limit (OEL). Overexposures were also common in the other construction related sectors studied, demolition (40% > OEL) and earth moving/road building (25% > OEL) (Radnoff *et al*, 2014).

The exposure limit for RCS reflects its high toxicity; the ACGIH (American Conference of Governmental Industrial Hygienists) recommended TLV®-TWA (Threshold Limit Value – Time Weighted Average) of 0.025 mg/m^3 has been adopted in Alberta.

Health Effects of Exposure to Respirable Crystalline Silica

Inhalation exposure to RCS is linked to the several serious diseases.

Silicosis is a fibrotic lung disease (Bang *et al.*, 2015), that results from inhaled RCS particles entering lymphatic and interstitial tissues, leading to progressive fibrosis and reduction of lung volumes. Advanced disease can lead to respiratory failure and right ventricular failure. There are three widely-recognized forms. Chronic silicosis results from chronic exposure to low levels of RCS, and generally develops over decades. Acute and accelerated silicosis occur when individuals are exposed to very high levels of RCS and can occur over shorter periods (months to years).

Overall, silicosis incidence is decreasing in industrialized countries (Bang *et al.*, 2015), though silicosis incidence data are not available for Canada. In Alberta, Lappi, Radnoff and Karpluk (2014) reported a 10-year incidence based on (1) reports to Alberta Jobs, Skills, Training and Labour; (2) WCB claims, and (3) Alberta Health Services physician visits. The number of cases identified over that 10-year period were two, 33, and 861, respectively. The authors concluded that despite study limitations, the true incidence of silicosis in Alberta were likely higher than current reporting data suggested. This same conclusion was reached by Demers *el al.* (2010) who found that in BC, only 9% of silicosis cases identified between 1992 and 2007 in the BC medical system were reflected in Workers' Compensation claims data.

Respirable crystalline silica has been identified as a known human carcinogen by the World Health Organization (WHO) International Agency for Research on Cancer (IARC) because of its association with lung cancer (IARC, 2015). Recent work by the authors and colleagues at the Occupational Cancer Research Centre estimate that approximately 570 lung cancers are attributed to occupational exposure to crystalline silica each year in Canada (based on 2011 cancer statistics). This amounts to 2.4% of lung cancer cases diagnosed annually. The largest fraction of workers affected are in the construction industry (Figure 3; CAREX Canada, 2016).

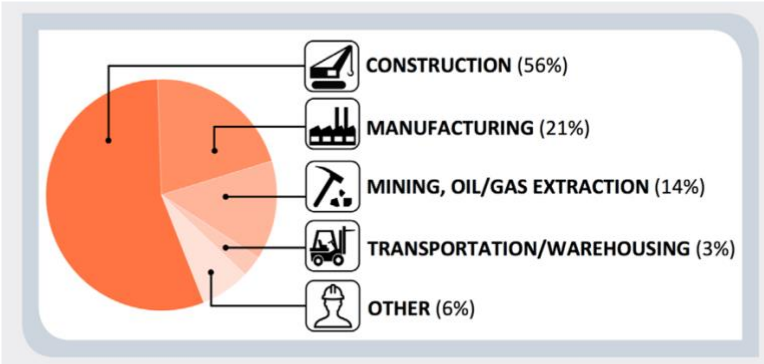

Figure 3: Distribution of by industry sector estimated lung cancer cases caused by RCS, CAREX Canada 2016

Other diseases such as chronic obstructive pulmonary disease (COPD) have also been linked to silica exposure. The association between silicosis and pulmonary tuberculosis is "well-accepted" (Jalloul & Banks, 2007). There are descriptions in the scientific literature of links between silica exposure and immune-mediated diseases such as progressive sclerotic scleroderma and rheumatoid arthritis, as well as renal complications in association with silicosis (Jalloul & Banks, 2007).

Knowledge Gaps

There is a demonstrated need for employers to reduce exposures to RCS. However, risk assessment and exposure measurement in the construction environment is complex. Construction worksites are highly dynamic, changing day-to-day as construction phases progress. Often multiple sub-trades are working side-by-side, and contractors frequently move between worksites. This can make it difficult for employers to estimate the exposure levels that might be present in their work places. Exposure measurements taken under one set of conditions may quickly become non-applicable due to the changeable nature of the work and worksite. Confounding this problem is that RCS testing is done by specialist laboratories and typically take on the order of 5-10 days to obtain a measurement; currently no direct-reading instrumentation exists.

This poses a challenge for large companies with in-house occupational health and safety staff and an even greater challenge for small and medium sized enterprises (SMEs) who do not have in-house expertise. In order for employers to keep their workers' exposures below the OEL they need to be able to quantify exposure. This allows them to compare their exposures to the OEL and, if required, select appropriate control measures, and personal protective equipment (Kromhout, 2016).

To assist construction employers in British Columbia (BC) with exposure estimation and risk assessment the authors have developed a statistical exposure model for RCS exposures in construction; the "BC silica model". The model generates evidence-based estimates of RCS exposure associated with common construction tasks using general linear regression techniques. Since the work conducted by a construction worker can vary from shift to-shift it is best to estimate exposure associated with tasks rather than job title (Beaudry *et al*, 2013). The model also estimates exposures associated with common control interventions. The model was constructed using 4550 RCS task-based exposure measurements from construction worksites around the world, but chiefly in North America and Europe. The foundation of this dataset was a database compiled by Beaudry *et al* (2013). The authors have supplemented the Beaudry *et al.,* database with data from recent peer-reviewed and grey literature, data shared from industry, data from Alberta shared by Alberta Human Services (described by Radnoff *et al*, 2014), and data from British Columbia (BC) collected by the authors in 2015.

The model was developed in partnership with the British Columbia Construction Safety Alliance (BCCSA) and with WorkSafeBC. It focused on the BC construction industry; the model was developed by liaising with a focus group of BC construction industry to create a list of 'common silica processes' (CSPs) and related control measures. CSP are tasks that are most likely to result in RCS exposure on BC construction sites. It was further tailored to BC by the collection of RCS exposure data from BC construction worksites in 2015 to (i) collect data on any CSPs that were missing from the database and (ii) increase the amount of data from BC. BCCSA have developed the model into an online application called the "Silica Control Tool" (www.silicacontroltool.com) to help their member companies with RCS risk assessment and control.

Of the 4550 observations used in the development of the model, the majority (62%) are from the United States. There are 235 observations from British Columbia and 184 from Alberta. BC and Alberta share some similarities including construction methods used, geographical proximity and a low OEL (0.025 mg/m^3). This is 50 to 75% lower than the OELs in the other North American jurisdictions represented in the database (Ontario, Quebec and the United States). The model is well positioned to be adapted to meet the needs of the Alberta construction industry, but: (i) only 7% of the observations in the database from which the model was derived were collected in BC and Alberta, and (ii) the model has not been validated against external data. We therefore aimed to increase the amount of RCS measurement data from Alberta, and validate model estimates to ensure that the exposure estimates generated are representative of exposures in these regions.

The overall aim of this project is to adapt the BC RCS exposure model for use in Alberta, and to validate the adapted model by comparing modelled exposure estimates to empirical exposure measurements collected in the field. Research questions that will be addressed by this study are:

- What are the "common silica processes" (and related RCS controls) in the Alberta construction industry?
- What are the levels of RCS exposure associated with Alberta "common silica processes"
- Does the BC silica model generate exposure estimates that are representative of exposures that are measured in the field?

Methodology

Central to our work was the concept of a "Common silica process" or CSP; these are defined as construction tasks that can generate airborne RCS dust and that are carried out hundreds or thousands of times a year across Alberta work sites. The research project comprised three phases. In phase one we characterized the CSPs and related controls found in the construction industry in Alberta. In phase two we carried out RCS exposure measurements in Alberta in order to (i) collect data on Alberta CSPs that were identified as missing from the pre-existing silica exposure database and (ii) collect exposure measurements that can be used in validation of the model. Phase three involved data processing and analysis. The Alberta CSPs and any associated data that were collected added to the model and the model was re-run to create an "Alberta silica model". The Alberta silica model estimates were then compared to the exposure measurements that were collected for validation.

PHASE 1: Characterizing the Alberta RCS Exposure Environment

We conducted an on-line questionnaire of Alberta construction industry leaders to characterize the CSPs and associated controls that are present in Alberta. The Alberta Roadbuilders & Heavy Construction Association (ARHCA) provided us with contact information for individuals from within their member organizations. We asked them to target individuals with knowledge of RCS exposure and control within the Alberta construction industry and to include representatives from different construction sectors including: (1) road work and civil engineering; (2) residential; (3) industrial; and (4) institutional and commercial construction.

The identified individuals were all contacted (email and telephone) and invited to participate. The individuals were all sent a copy of the questionnaire, and background information about the study by e-mail (Appendix A). The questionnaire included a list of the CSPs that were used in the development of the BC silica model. The participants were asked be to review this list and to use a checkmark to indicate if the CSPs were also common in Alberta. They were then asked to (i) record CSPs for Alberta that are missing from the BC list; and (ii) identify known exposure controls that are used for these CSPs. They were then given an opportunity to comment if there was anything else they thought we should know about CSPs in Alberta construction. They were given examples of the kind of factors we were interested in including regional or seasonal differences, and processes or exposure controls that will become more common in the future.

The questionnaire responses were used to compile a new version of the CSP list that incorporated the CSPs that were suggested by the participants. This list was circulated to the participants by email and they were asked to comment on the newly added CSPs.

In phase one and throughout the project, we requested existing RCS exposure data from the organizations that we interacted with. Organizations were assured that their data would be anonymized within our dataset.

PHASE 2 – Exposure Measurement Collection

In this phase we collected task-based RCS exposure measurements from Alberta construction work sites. These samples were collected for two purposes:

- Estimate exposure levels from the Alberta CSPs identified in Phase 1.
- Compare "actual" exposure levels to modelled estimates to determine whether the model estimates are representative of exposures that are measured in the field.

Exposure levels for activities identified as Alberta CSPs but that were not previously identified as BC CSPs may be available in our pre-existing database. These CSPs can be characterized in the Alberta model without collection of any additional data. However, CSPs that are not represented cannot be characterized with the model. To allow these CSPs to be added to the model we collected task-based exposure measurements for Alberta CSPs that are missing from the database.

In addition to the measurements that were taken to fill gaps in the database, we also collected task-based exposure measurements from silica processes that are already represented in the BC silica model. These measurements were collected for comparison to modelled exposure estimates.

Recruitment

Recruitment targeted worksites where either Alberta or BC CSPs were being carried out. We aimed to recruit a variety of construction companies from different sectors in order to sample a cross-section of tasks taking place in Alberta construction.

Worksites were recruited with help from the AHRCA. Our field researcher also presented to the Alberta Construction Safety Association to inform them about the project and invite member companies to participate. We targeted industry contacts that we made during Phase 1, and asked companies that we had previously worked with in BC to put us in touch with the Alberta branches of their companies.

Prior to site visits, industry contacts were provided with a list of CSPs and asked to identify worksites on which any of the CSPs were being conducted. We aimed for a breadth of tasks and an even split between new Alberta CSPs, and pre-existing BC CSPs. Once on-site, our field researcher monitored any Alberta or BC CSPs that were being conducted on the day of sampling.

Sampling Methodology

We collected personal task-based samples using two methods. The first was based on National Institute for Occupational Safety and Health (NIOSH) method 7500. This method used polyvinyl chloride (PVC) filters in aluminum cyclone sampling heads set to a flow rate of 2.5 liters per minute (LPM). We also used a high-flow rate method described by Stacey and Thorpe (2010) that uses a PVC filter in a parallel particle impactor (PPI) at a flow rate of 8 LPM. This method was used for shorter task durations to ensure that we collected a large enough volume of air to determine whether or not the exposure level was above the occupational exposure limit of 0.025 mg/m^3. Thirty-five mm polyvinyl chloride filters were used with both cyclone and PPI sampling heads. Samples from both sampling methodologies were analyzed by x-ray powder diffraction (NIOSH 7500). The worker was fitted with the sampling equipment immediately before the start of the task, and the sampling equipment was collected promptly upon task completion. Generally, the PPI method was selected for task durations ≤ 4 hours and the cyclone method was selected for durations > 4 hours. We collected 10% field blanks.

Analysis was conducted by Maxxam Analytics in Novi, Michigan. Maxxam is an accredited industrial hygiene laboratory by the American Industrial Hygiene Association Laboratory Accreditation Program.

The field researcher also collected contextual information to accompany each measurement. This enabled data to be added to the existing RCS exposure database, to be used in developing future versions of the silica model and, for model estimates to be generated that can be compared to the field measurement results. This contextual information was collected at the time of sampling so at that time the field researcher was 'blind' to the results of the laboratory analysis of the field measurements. The field sheet used during sampling is presented in Appendix B. The contextual information that was collected included:

1. task;
2. material;
3. tool;
4. industry sector (*e.g.* civil engineering and roadwork, commercial, residential, *etc*…);
5. project type (new construction or renovation);
6. work environment (indoors, outdoors, confined space);
7. use of controls (local exhaust ventilation, wetting, use of a closed cab, respirator); and
8. whether or not controls are integrated to the tool or are separate.

PHASE 3 – Data processing and analysis

The analytical results of the field sampling were blank corrected and results that were less than the limit of detection were replaced with the value of one half the limit of detection for analytical processing (Hornung and Reed, 1990).

All collected exposure measurements and contextual data were added to the existing RCS exposure database. The variables describing CSPs and controls were updated to include new CSPs that were added for Alberta. Descriptive statistics included histograms, skewness and kurtosis testing to determine the distribution of the measurement data.

Validation of the BC model against new Alberta measurement data

The Alberta RCS exposure measurements that represented CSPs that could be estimated by the BC silica model were compared to estimates generated with that model. The model estimates and uncertainty analysis were generated in Microsoft Excel Version 16.16.2 (Microsoft; Redmond, Washington). Model version 1.2 was used as this was the most current version of the model at the time of the analysis (October, 2018). Equation 1 was used in modelling; the model coefficients are presented in Appendix C. geometric mean (GM) and 95th percentile exposure estimates were made using an uncertainty analysis procedure.

Equation 1:

Ln(Exposure) = Equation Coefficient + Sampling Duration + CSPControl + Industry Sector + Project Type + Environment + Region

To enable assessment of model performance by task we categorized all CSPs into one of 9 task types. Measurements that were not associated with any CSPs and that did not fit into any of the task types were coded as “Other”. The task types are listed below. The task types that were assigned to each CSP are presented in the Results section.

1. Breaking;
2. Cleaning;
3. Cutting/sawing;
4. Demolition;
5. Drilling;
6. Grinding;
7. Mixing and pouring;
8. Moving and/or crushing rocks and/or earth
9. Spraying.

We compared both the GM and the 95th percentile modelled exposure estimates to measured exposure levels in a series of analyses. We calculated Pearson correlations between modelled and measured exposure estimates. This was done for the model overall, and by task type. We also calculated the ratios between modelled and measured exposure estimates. An overall model mean ratio was calculated as well as the mean ratio by task type.

It is desirable for predictive exposure models to present conservative estimates of exposure to ensure that worker health is protected. We used one-sample t-testing to test the hypothesis that the mean ratio between modelled and measured exposure levels is greater than 1.

Updating the RCS exposure model to include Alberta CSPs

The linear regression model that was developed for estimating RCS exposure (Equation 1) was re-estimated with an updated dataset which included the Alberta CSPs. This model incorporates all data collected during this study, including the data used in the validation of the BC silica model.

The variable that indicates the CSP was combined with the combined with information on engineering controls to create hybrid ‘silica process and control’ variable. This approach allows the effect of controls to be specific to the silica process, rather than applying the same controlled effect to all silica processes (as would happen if controls were included as separate variables). The same approach was used in the development of the BC silica model. The possible control statuses for each silica process were as follows:

- Uncontrolled;
- Control not specified;
- Standalone local exhaust ventilation;
- Local exhaust ventilation integrated with tool;
- Standalone water spray;

- Water spray integrated with tool;
- Local exhaust ventilation (either standalone or integrated) AND Water spray (either standalone or integrated);
- Dustbane (dust suppressant spray);
- Closed pressurized cabin.

Only CSP/control combinations for which there were more than 4 measurements were eligible for inclusion in the model.

Exposure measurement data were log transformed prior to analysis (the dependent variable). The input variables are presented in Table 1. Analysis was conducted in Intercooled Stata Version 13.1 for Mac (StataCorp; College Station, TX).

We also developed an uncertainty analysis procedure that is used to estimate uncertainty associated with model estimates in the form of 95% confidence intervals and geometric standard deviations (GSDs). This is done by generating 1000 values within the distributions defined by the coefficient and corresponding standard error (SE) for each model variable. These simulated distributions are then used to calculate 1000 modelled exposure estimates for a single scenario. The geometric mean (GM), 5^{th} and 95^{th} percentiles of these 1000 exposure estimates are taken as the GM and 95% confidence interval for the average exposure estimate.

Table 1 Variables used in predictive exposure modelling of RCS exposure during construction activities

Variable Name	Variable Type	Variable Categories
Dependent variable		
Log Exposure Measurement	Continuous	N/A
Independent (predictor) Variables		
Sampling Duration	Categorical	≤103 minutes 104 – 240 minutes 241 – 390 minutes ≥391 minutes
Industry Sector	Categorical	Civil Engineering and Roadwork Industrial, institutional and commercial Residential Testing laboratory Other/not specified
Project Type	Categorical	New Construction Renovation Other/Not Specified
Work Environment	Categorical	Indoors Outdoors Confined space Underground Not specified
Sampling Region	Categorical	Unknown United States (US) – unknown region within US US – multiple regions within US US – Northeast US – South US – Southwest US – Midwest US – West Canada East (Ontario and Quebec) British Columbia Europe Asia Alberta
CSPControl	Categorical	Variable integrates CSP and control. See Appendix D for list of CSPs.

Results

Phase 1 – Characterizing the Alberta Environment

The ARHCA provided a list of 11 construction industry leaders. Questionnaires were sent to all 11 by e-mail in May 2017. Seven of the individuals returned completed questionnaires. The seven participants each represented a separate organization. They belonged to a range of construction industry sectors including: heavy construction, roadbuilding, residential, civil, industrial/institutional and construction materials manufacturing. All of the BC CSPs were identified as Alberta CSPs by at least one of the participants. In addition, the survey participants identified the following CSPs that were not included in the list of BC CSPs:

1. asphalt jackhammering;
2. using back pack blowers to clean streets;
3. using mobile street sweeper with a rotating brush;
4. fiberglass insulation installation;
5. tile installation/repairs;
6. cutting insulation;
7. HEPA vacuum maintenance;
8. negative air handling maintenance;
9. abrasive blasting;
10. sweeping/hammering with skid steer attachments
11. construction materials job types (loader operator, truck driver, plant operator, etc…).

The survey participants did not identify any new exposure control methods that are not already included in the BC model, nor did they identify any new environmental or temporal factors that would be expected to be significant determinants needed to be added to the model. One survey participant indicated that our task-based sampling approach may not be suitable for the construction materials sector as workers in this sector are more likely to do the same activities from day to day, and thus better suited to full-shift sampling.

PHASE 2 – Exposure Measurement Collection

Recruitment

Eleven organizations participated in the field monitoring (4 of these also participated in the survey – phase 1). In total, we recruited 11 organizations to participate in the project. None of the organizations that we interacted with were able to share pre-existing RCS exposure monitoring data with the project.

Sample characteristics

Across the 11 organizations that participated in field monitoring, we conducted monitoring at 26 construction work sites. The majority of these worksites (22) were in Edmonton. Four worksites were in Calgary, one in Grande Prairie, and one in Red Deer. We also conducted monitoring at a worksite in North Vancouver, BC during project planning and training.

RCS exposure monitoring was carried out at construction worksites over a six-month period from September 20, 2017 until March 20, 2018. In total 144 exposure measurements and 19 blanks were collected. Five samples were discarded due to technical problems. The final dataset includes 139 RCS exposure measurements, 135 of which are from Alberta. These came from a variety of industry sectors and project types (Table 2). In response to the industry leader recommendation in Phase 1, we collected full-shift samples for construction materials sector activities since workers in this sector conduct the same activities day-to-day.

Table 2. Alberta Industry sectors and Project types represented by exposure monitoring

CATEGORY	NUMBER OF SAMPLES
INDUSTRY SECTOR	
CIVIL ENGINEERING AND ROADWORK	20
INDUSTRIAL, INSTITUTIONAL AND COMMERCIAL	68
RESIDENTIAL	37
AUTO REPAIR	4
CONCRETE PRE-FAB MANUFACTURING	6
PROJECT TYPE	
NEW CONSTRUCTION	54
RENOVATION	23
MANUFACTURING	54
AUTO REPAIR	4

Distribution testing indicated that the distribution of the collected exposure measurements approximated a lognormal distribution, so data were log transformed prior to analysis. The GM across all 135 measurements collected in Alberta was 0.06 mg/m^3 with a GSD of 9.19 (Table 3). Measurements ranged from 0.002 to 8.200 mg/m^3 with an arithmetic mean (AM) of 0.54 mg/m^3 (arithmetic standard deviation [ASD]= 1.20 mg/m^3).

Across the 9 task types the highest GM exposures were in breaking (GM = 0.607 mg/m^3) and cleaning (GM = 0.642 mg/m^3). The measured exposure levels are presented in Table 3, overall and by task type.

Table 3 RCS Exposure Measurement Summary (mg/m^3), overall and by task type

Category	*N*	*AM*	*ASD*	*GM*	*GSD*	*Min*	*Max*
Overall	135	0.54	1.20	0.060	9.19	0.002	8.200
By Task Type							
Breaking	10	2.005	2.59	0.607	7.42	0.025	8.200
Cleaning	6	0.717	0.33	0.642	1.74	0.240	1.200
Cutting/Sawing	18	0.652	1.16	0.118	6.52	0.008	3.400
Demolition	8	0.677	0.76	0.249	5.76	0.031	2.100
Drilling	15	0.757	1.12	0.173	8.57	0.007	4.200
Grinding	25	0.731	1.45	0.086	9.00	0.007	5.700
Mixing and Pouring	15	0.119	0.27	0.027	4.80	0.005	0.980
Moving and/or Crushing	30	0.014	0.02	0.008	2.83	0.002	0.110
Other	8	0.017	0.01	0.013	2.41	0.003	0.036

N = Number of observations, AM = arithmetic mean, ASD = arithmetic standard deviation, GM = geometric mean, GSD = geometric standard deviation, Min = minimum, Max = Maximum, mg/m^3 = milligrams of RCS per cubic meter of air.

The full list of activities sampled along with summary statistics is presented in Table 4. Note that not all activities monitored were ultimately classified as CSPs. These activities were classified as either 'Other cutting', 'tunnel boring', and 'other'. The CSPs with the highest measured exposures were 'scarifying or bush hammering concrete' (GM = 1.070 mg/m^3, maximum = 8.200 mg/m^3), 'grinding concrete with a surface, angle or flat grinder' (GM = 1.405 mg/m^3, maximum = 5.700 mg/m^3). The CSPs relating to construction materials manufacturing (cement and asphalt plant workers) had the lowest measured exposures (GMs ranged from 0.003 – 0.017 mg/m^3). This is at least in part because these were full-shift exposure measurements rather than task-based measurements. Full-shift exposure measurements typically include some unexposed down time (such as breaks or low exposure activities), while task-based exposure measurements do not. The GM across all full-shift samples (N = 30) was 0.008 mg/m^3 (GSD = 2.83, AM = 0.014 mg/m^3, ASD = 0.02 mg/m^3) while the GM across all task-based samples (N = 105) was 0.107 mg/m^3 (GSD = 8.28, AM = 0.696 mg/m^3, ASD = 1.32 mg/m^3).

Table 4 RCS Exposure Measurement Summary by Activity Monitored (mg/m^3)

Activity monitored	*N*	*GM*	*GSD*	*Min*	*Max*
Cutting asphalt with walk-behind saw	1	0.035	-	-	-
Cutting concrete with saw	1	0.032	-	-	-
Coring concrete with saw	1	0.024	-	-	-
Drilling concrete with electric hammer drill	11	0.084	7.87	0.007	4.200
Grinding concrete with surface, angle or flat grinder	7	1.405	4.25	0.110	5.700
Grinding concrete with counterbalanced ceiling grinder	3	0.060	5.53	0.010	0.280
Grinding, preparing and finishing concrete – other	3	0.028	5.65	0.007	0.190
Scarifying or bush hammering (concrete)	6	1.070	8.96	0.025	8.200
Demolition (any material)	8	0.249	5.76	0.031	2.100
Sweeping (any construction area)	1			0.240	0.240
Cutting drywall	8	0.054	1.72	0.016	0.091
Sanding drywall	6	0.018	1.78	0.010	0.034
Mixing and pouring cementicious material	15	0.027	4.80	0.005	0.980
*Other cutting**	6	1.072	4.15	0.133	3.400
*Tunnel boring**	4	1.282	1.27	0.999	1.751
Cutting fiber cement board with portable saw	1	0.008	-	-	-
Loading concrete mixer	4	0.259	4.75	0.042	1.100
Walk-behind concrete grinding	6	0.033	4.35	0.007	0.200
Mobile road sweeping	5	0.782	1.36	0.580	1.200
Cement plant helper	2	0.017	1.73	0.012	0.025
Cement plant operator	4	0.003	1.26	0.002	0.004
Cement plant loader operator	6	0.008	1.94	0.003	0.022
Cement plant truck driver	8	0.009	3.28	0.003	0.045
Cement plant mechanic	1	0.026	-	-	-
Cement plant lead hand	1	0.003	-	-	-
Asphalt plant operator	3	0.013	6.69	0.003	0.110
Asphalt plant loader operator	2	0.007	4.07	0.003	0.020
Asphalt plant truck loading	2	0.005	1.10	0.004	0.005
Asphalt plant helper	1	0.010	-	-	-
*Other**	8	0.013	2.41	0.003	0.036

N = number of observations, GM = geometric mean, GSD = geometric standard deviation, Min = minimum, Max = maximum, mg/m^3 = milligrams of RCS per cubic meter of air.
* Not classified as a CSP. All other monitored activities were CSPs.

The majority of scenarios sampled (N = 83, or 61%) involved uncontrolled exposures. The most commonly encountered control method was a closed and pressurized cab (N = 22 or 16%). The closed and pressurized cabs were all used at concrete and asphalt plants. The most common controls at other construction project types was local exhaust ventilation integrated to the tool (N = 18 or 13%) and standalone water spray (N = 7 or 5 %).

PHASE 3 – Data processing and analysis

Validation of the BC model against the newly collected Alberta RCS exposure data

There were 65 exposure measurements collected for which exposure estimates could be generated using the BC silica model. These measurements comprised the validation dataset.

Overall, both GM (Pearson's r = 0.50) and 95th percentile (r = 0.50) modelled exposure estimates correlated moderately well with measured exposure levels (Table 5). The correlation between measured values and modelled estimates varied widely by task type, with two task types exhibiting negative correlations ('breaking', 'cutting and sawing'). The correlation coefficients among the other task types ranged from 0.52 – 0.93 for GM estimates, and from 0.54 – 0.93 for 95th percentile estimates. Scatter plots demonstrating the relationship between modelled and measured exposure levels are presented in Figure 4 (GM) and Figure 5 (95th percentile).

Table 5 Pearson's correlation coefficients between measured exposure levels and modelled exposure estimates, overall and by task type. Correlation coefficients for both GM and 95th percentile model estimates are presented.

Task type	**N**	**Model Estimate**	**Correlation Coefficient**
Overall	65	GM	0.50
		95th Percentile	0.50
By Task Type			
Breaking	8	GM	-0.71
		95th Percentile	-0.65
Cleaning	3	GM	0.93
		95th Percentile	0.93
Cutting and Sawing	11	GM	-0.55
		95th Percentile	-0.54
Demolition	8	GM	-
		95th Percentile	-
Drilling	11	GM	0.59
		95th Percentile	0.65
Grinding	11	GM	0.83
		95th Percentile	0.74
Mixing and Pouring	13	GM	0.52
		95th Percentile	0.54

N = Number of observations, GM = Geometric Mean

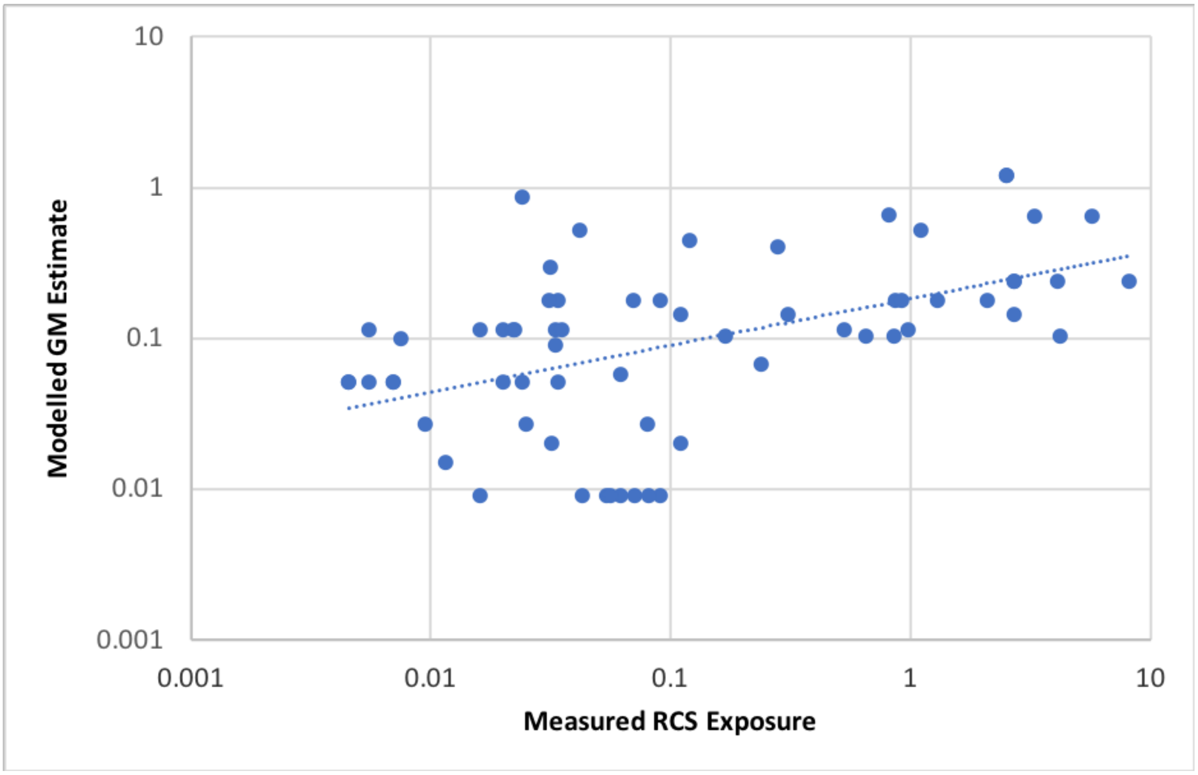

Figure 4 Scatter plot of modelled geometric mean (GM) exposure estimates (mg/m³) against measured respirable crystalline silica (RCS) exposure levels (mg/m³). r = 0.50

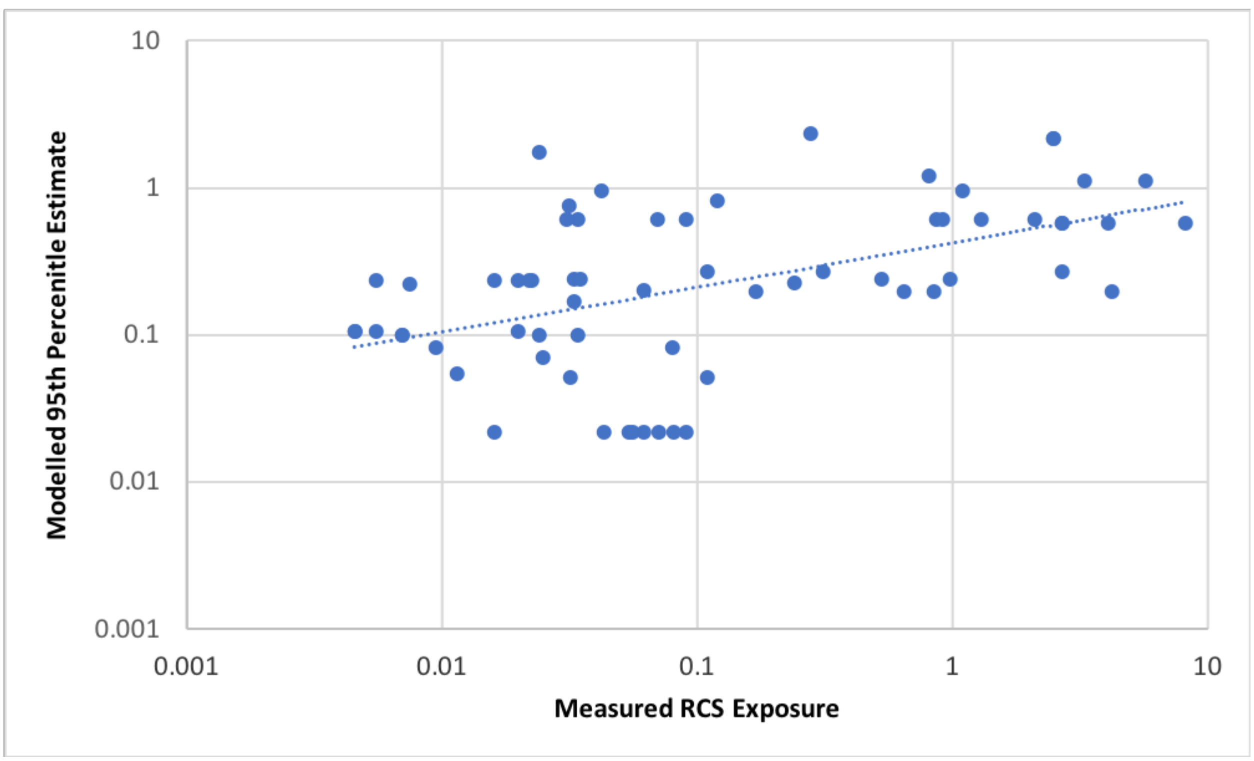

Figure 5 Scatter plot of modelled 95th percentile exposure estimates (mg/m³) against measured respirable crystalline silica (RCS) exposure levels (mg/m³). r = 0.50

The ratios between modelled and measured exposure were calculated and the distributions of the calculated ratios approximated a log-normal distribution, so data were log-transformed prior to analysis. The calculated ratios are summarized, both overall and by task type, in Table 6. On average, the GM modelled exposure estimates underestimated exposure (GM of ratio = 0.81) while the 95th percentile modelled exposure estimates overestimated exposure (GM of ratio = 1.90). One-sided t-testing indicated that the true GM for the ratio between 95th percentile modelled exposure and the measured exposure estimates was significantly likely to be >1 ($p = 0.003$). The modelled estimates were greater than the measured exposure levels 46% of the time for the GM model estimates, and 55% of the time for the 95th percentile model estimates.

A similar pattern was seen across the task types with the model GM typically underestimating exposure and the model 95th percentile overestimating exposure, with the exception of mixing and pouring, in which both estimates typically overestimated exposure. In t-testing the GM ratios were not significantly greater than 1 in any of the analysis by task-type; this is likely due to the small sample sizes.

Table 6 Ratios between modelled and measured exposure levels for both GM and 95th percentile model estimates and the number of observations for which the ratio>1

TASK TYPE	N	MODEL ESTIMATE	RATIO BETWEEN MODELLED AND MEASURED EXPOSURE ESTIMATES				P * (RATIO>1)	N>1
			GM	GSD	Min	Max		
OVERALL	65	GM	0.81	6.32	0.02	35.71	0.816	30
		95th Percentile	1.90	6.29	0.05	72.42	*0.003*	36
BY TASK TYPE								
BREAKING	8	GM	0.35	8.55	0.03	12.43	0.894	2
		95th Percentile	0.74	7.58	0.07	22.98	0.656	3
CLEANING	3	GM	0.70	2.25	0.28	1.30	0.738	1
		95th Percentile	2.45	2.32	0.95	4.78	0.104	2
CUTTING/SAWING	11	GM	0.59	9.13	0.10	35.71	0.778	3
		95th Percentile	1.40	8.74	0.24	72.42	0.308	4
DEMOLITION	8	GM	0.72	5.76	0.09	5.81	0.691	4
		95th Percentile	2.45	5.76	0.29	19.68	0.095	4
DRILLING	11	GM	0.63	5.83	0.02	7.29	0.798	5
		95th Percentile	1.31	5.85	0.05	14.14	0.313	7
GRINDING	11	GM	0.51	3.57	0.05	2.84	0.944	4
		95th Percentile	1.13	4.36	0.10	8.63	0.392	5
MIXING AND POURING	13	GM	3.63	4.53	0.12	20.91	*0.005*	11
		95th Percentile	7.50	4.50	0.24	42.55	*0.0002*	11

N = Number of observations, GM = geometric mean, GSD = geometric standard deviation, Min = minimum, Max = maximum
* P-values are from one-sample t-tests testing the hypothesis that the GM of the ratios is >1.

Updating the RCS exposure model to include Alberta CSPs

A new version of the silica model – the Alberta Silica Model, was generated using Equation 1 and using the entire silica database which was updated to include the Alberta data collected in this study.

The inclusion of the new data enabled the addition of the following 7 new CSPs to the model:

- abrasive blasting;
- mobile road sweeping;
- cement plant operator;
- cement plant loader operator;
- cement plant truck driver;
- sanding Drywall;
- walk-behind concrete grinding.

'Abrasive blasting', 'mobile road sweeping', and the cement plant activities were Alberta CSPS that were identified by the questionnaire participants. 'Sanding drywall' and 'walk-behind concrete grinding' were CSPs that were identified during the creation of the BC model that we had not yet been able to include due to a lack of available data.

We also separated "BC" and "Alberta" in the region variable so the model now includes a coefficient specifically for Alberta. In general, exposure levels in Alberta are higher than in BC. In the model of the log-transformed data the coefficient for BC is -0.520 (SE = 0.17) and the coefficient for Alberta is -0.365 (SE = 0.17).

The full Alberta silica model with all model coefficients and SEs is presented in Appendix D.

Discussion

Strengths

To our knowledge, this is the first survey of primarily task-based RCS exposure in the Alberta construction industry. We collected 139 high-quality RCS exposure measurements with detailed supplementary information, 135 of these were from Alberta. These data are challenging and time consuming to collect in the construction industry. The fast-paced, highly dynamic nature of the work makes it difficult to predict when and where CSPs of interest will be taking place.

We validated the BC silica model against Alberta RCS exposure data. The modelled exposure estimates correlated moderately well with measured exposure measurements, and 95th percentile modelled exposure estimates overestimated exposure levels on average (GM of ratio of modelled to measured = 1.90). In the validation, 95th percentile model estimates were conservative 55% of the time with a geometric mean ratio of modelled to measured exposure of 1.90. This model performance is encouraging and supports the use of the model for RCS risk assessment in Alberta.

The model performed well when compared to validation studies of other predictive exposure models. This is particularly encouraging since the model is focused on a single material and industry. Predictive exposure models typically estimate exposure levels for a variety of materials and industries so large variabilities in exposure levels are expected. For example, The Dermal Exposure Assessment Method (DREAM) is a model for estimating dermal exposure to liquids, vapours and powders. The model was validated against dermal exposure measurement data with values ranging up to 10 orders of magnitude. Correlations within individual substances (including pesticides, metal working fluids and organic solvents) were inconsistent and ranged from 0.13 to 1.0. The model was unable to differentiate between tasks for which dermal exposure levels differed by less than half an order of magnitude) (van Wendel de Joode *et al.*, 2005).

A European study of five predictive exposure assessment models in common use in the European Union found that the Pearson's correlation coefficient between modelled and measured exposures ranged from <0.4 to 0.7. None of these models can be used for estimating exposure to respirable dust. All are intended to be conservative and only underestimated exposures 3 – 21% of the time. (van Tongeren *et al,* 2017). When compared to measured data the BC silica model compares favourably to the European models with a correlation coefficient of 0.50. The model is less conservative than the European models, but it was built to provide realistic estimates for control selection purposes while the European models were intended to be protective to screen work scenarios for further assessment.

We also developed an updated version of the silica model for Alberta. This version includes the additional 139 measurements, new variables for Alberta CSPs, and a new region category to differentiate Alberta from BC. The updated Alberta silica model is based on a dataset that includes nearly double the number of measurements from Alberta that were used in the BC silica model (from N = 166 from Alberta, to N = 305). The model indicated that RCS exposure levels in Alberta were generally higher than in BC. In the BC silica model Alberta and BC were combined in one category "Western Canada" so the same exposure estimates were made for BC and Alberta. In the new model they will be separate, so the estimates will be more accurately adjusted for regional differences and may be less likely to underestimate exposure.

This project also contributed to knowledge transfer and awareness of the dangers of RCS exposure in Alberta. By conducting field work and site recruitment for the project we engaged in knowledge transfer about the health effect of RCS exposure, the ways in which exposure can occur in the construction industry, and some of the methods of reducing exposure levels.

Limitations

The primary limitation in this study stemmed from challenges with recruitment. We conducted our monitoring campaign between September 2017 and March 2017. This was partly due to project timelines and field researcher availability, and party intended to capture some of the climatic differences between BC and Alberta winters. We aimed to collect measurements during autumn, winter and spring. Unfortunately, snow arrived early in October in 2017 and persisted in to March 2018 so the majority of our sampling was conducted during winter conditions. While construction work does continue through the winter, some activities (for example road building) were limited. This restricted the availability of worksites eligible to participate in the study and ultimately made recruitment challenging. We initially aimed to collect up to 300 RCS samples and were unable to reach this sample size. Due to the weather conditions during the sampling period we were also unable to sample some of the Alberta CSPs identified by the focus group participants including asphalt jackhammering, using back pack blowers to clean streets, and sweeping/hammering with skid steer attachments.

When conducting occupational hygiene research, researchers remain independent from regulatory authorities so that companies can be assured that the information collected will be used for research purposes only and will not lead to further inspections or actions by the regulator. For this reason, we did not foster a connection to Alberta Labour Occupational Health and Safety regulators for the purposes of this study. However, we did notice that some companies were reluctant to participate because they were uncertain that the local regulator would endorse an RCS monitoring tool for construction. In BC WorkSafeBC has trained regulatory inspectors in appropriate uses of the Silica Control Tool and employers are encouraged to use it to create exposure control plans. Similar regulator buy-in in Alberta could encourage participation of worksites in future RCS monitoring campaigns.

Due to the difficulties with recruitment we had a small sample size for our validation dataset (N = 65). As a result, we compared individual exposure measurements to model estimates. There is considerable variability in occupational exposure levels within a work activity, and even within an individual worker from day to day (Kromhout *et al*, 1993). This is likely to be particularly true in construction where workers are working on different worksites, alongside different trades, and potentially with different materials day-to-day. We have observed large variability within our sampling data with an overall GSD of 9.2. Given the wide variability in exposure levels, a single point measurement may not be representative. The model estimates are based on multiple measurements (at least 4 per CSP/Control combination) and may be more representative than a single on-site measurement. It may be more appropriate to compare GM exposure measurements from the same exposure scenario to model estimates in validation but given our relatively small sample size this was not possible.

Knowledge Translation

We identified three potential audiences for knowledge translation efforts:

- Exposure scientists (e.g. conferences, peer-reviewed papers)

- Alberta industry (e.g. industry conferences and industry association meetings)
- Alberta employers and employees.

Current KT Work

During the study period we engaged all three audiences through presentations given by either the investigators (Dr.'s Melanie Gorman-Ng and Hugh Davies, or the staff occupational hygienist, Mr. Aaron Birch). Because the study was still ongoing, these presentations focused on the general hazard posed by exposure to RCS in construction, as well as the study design, methods and progress. Ten presentations were given; these were:

Presentation to Exposure Scientists

1. Gorman Ng Melanie; Adaption of the Silica Control Tool model for Alberta, Canadian Association for Research on Work and Health Conference; Vancouver, October 2018
2. Gorman Ng Melanie; Implementation and Continued Development of the Silica Control Tool, Poster at the X2018 Conference, Manchester UK, October, 2018

Presentations to Alberta Industry

3. Davies, HW; Reducing Silica Exposure in the BC Construction Industry, Quarry Tech Conference, Calgary
4. Davies, HW; Reducing Silica Exposure in the BC Construction Industry, Canadian Association of Petroleum Producers, Hygiene Technical Committee, Calgary
5. Birch, A; Alberta Roadbuilders and Heavy Construction Association (ARHCA), Edmonton
6. Birch, A; Alberta Construction Safety Association (ACSA) , Edmonton
7. Birch, A; Canadian Home Builders Association (Edmonton chapter), Edmonton

Presentations at Construction Employers and Employees

8. Birch, A; Alberta Employer 1
9. Birch, A; Alberta Employer 2
10. Birch, A; Alberta Employer 3

In addition, all worksites who participated in monitoring (N=26) would have been informed about the nature and objectives of the study as part of their recruitment, and received copies of the exposure data obtained at their worksites. As well, several Alberta agencies/companies[1] were provided with access to the BC version of the silica controls tool to explore its potential.

Planned KT Work

As the project has now concluded, we are in a position to continue the project Knowledge Translation efforts, with an emphasis on the results of the study. Working with our industrial partner in Alberta, we will again identify opportunities in our three target audiences. This could include:

[1] Canadian Association of Petroleum Producers (CAPP), Rock to Road | Crane & Hoist Canada, Alberta Labour, Govt of Alberta, Western Foundations & Construction Service Inc., JVDriver

Presentation to Exposure Scientists

- Preparation of scientific manuscript for publication in 2019; target journal, Journal of Occupational and Environmental Hygiene

Presentations to Alberta Industry and Construction Employers and Employees

- We will apply to present at the 2019 Alberta Construction Safety Association (ACSA) annual meeting

In addition, we will continue to work with the BC Construction Safety Alliance to make the existing BC-based Silica Control Tool ready for roll-out to Alberta worksites in a timely manner should the province or its construction sector decide to adopt the tool.

Conclusion

This study aimed to characterize RCS exposure in the Alberta construction industry both to assess the suitability of the BC silica model for Alberta, and to create an updated version of the model for Alberta. We conducted a survey of Alberta construction industry leaders to compile a list of CSPs in Alberta construction. This list included all of the CSPs that had been previously identified for BC and 11 additional CSPs. We collected 139 RCS exposure measurements associated with 27 different CSPs. The overall GM exposure level was 0.060 mg/m^3. We observed wide variability in exposure with a GSD of 9.2. We generated modelled exposure estimates with the BC silica model for 65 of the collected measurements. These were used in a model validation. In general, the GM and 95th percentile modelled estimates correlated moderately well with measured observations (Pearson's r = 0.50 for both). The GM model estimates underestimated exposure levels 64% of the time (GM of ratios between modelled and measured exposure estimates = 0.81). The 95th percentile estimates were more conservative and overestimated exposure 55% of the time with a GM of ratios of 1.90. The 139 exposure measurements were all added to the pre-existing RCS exposure database and used to generate a new Alberta version of the silica model. This new version adds 7 new CSPs to the model, as well as a separate category for Alberta so Alberta estimates can be differentiated from BC estimates.

All of the newly identified CSPs from the industry leader questionnaire are also conducted in British Columbia, but were not identified by BC employers as priorities for sampling. Consequently, the newly added CSPs will also be useful for BC industry. In order for the model to be useful for the Alberta industry it was important to get this input on Alberta needs and priorities.

The BC silica model performed well against a small dataset of Alberta exposure measurements, supporting the use of the model in Alberta. The updated Alberta silica model would be expected to perform better for Alberta exposure scenarios since it is derived from a database that includes over 80% more observations from Alberta, and it includes a coefficient that can adjust model estimates for Alberta. It is important to note that the validation compared individual exposure measurements to GM and 95th percentile exposure estimates based on a database of 4708 exposure measurements. There is significant variability in exposure levels both between workers, and within individual workers over time. The individual exposure measurements may not be indicative of true GM or 95th percentile exposure for the individual worker. Over multiple days, weeks, or months, the true exposure level may regress toward the model estimate. This could be evaluated in future studies by comparing multiple measurements within multiple scenarios to modelled exposure estimates.

The BC Silica Control Tool is an online application that was built using the BC silica model. It allows users to enter information about their worksites and work activities and use the BC silica model to generate exposure estimates and create exposure control plans. The BC Silica Control Tool was launched in May 2017 and as of October 18, 2018 it has over 1300 registered users. The tool has been used to generate over 1500 exposure estimates and exposure control plans. The tool includes a feedback interface so that users can report exposure scenarios that they are interested in that are not included in the tool. This prompts exposure monitoring and model updates. It also encourages the BC construction industry to participate in exposure monitoring and data sharing. It enables exposure monitoring data to be useful beyond a one-time compliance assessment. A similar approach is feasible in Alberta and could be implemented immediately with the updated Alberta silica model as a basis. The BC Silica Control Tool will be updated by spring 2019 to incorporate the Alberta silica model. The Tool is currently available to all employers in British Columbia in all industries. Any Alberta employers that also operate in BC will be able to use this updated version of the Tool once it is available.

Ongoing exposure monitoring is necessary to ensure that the model is applicable to current industry conditions. In BC, monitoring has continued both in response to user requests and to collect data on CSPs that are underrepresented in the database. Since the May 2017 launch, two updates to the Tool have been made to with updated versions of the model that incorporated newly collected data. Ongoing monitoring would also be beneficial if the Alberta silica model were to be used in Alberta. This ongoing monitoring could collect additional data on the CSPs that we were not able to monitor in this study, and increase the amount of current Alberta data in the database. Adding additional data to the database from which the model is derived will improve the accuracy of the resulting updated models.

We are currently working on a research project funded by Manitoba Research and Workplace Innovation to collect RCS exposure measurements within the Manitoba construction industry so that the silica model can be adapted for use in Manitoba. There is potential for this approach to be continued in additional jurisdictions beyond BC, Alberta and Manitoba to characterize local RCS exposure in the construction industry and develop customizable versions of the silica model. In addition to the customization of the silica model for additional jurisdictions, it would be possible to develop similar models for other exposure agents (such as lead, noise or wood dust) and other industries.

The Manitoba research project also includes an update to the model structure to include Bayesian statistics. This will improve the way in which the model integrates new exposure data with older data, and will improve the uncertainty analysis approach within the model by allowing the estimation of probabilities of overexposure.

In 2019 we aim to submit a scientific manuscript describing the findings of this study to the Journal of Occupational and Environmental Hygiene. We will also apply to present our findings at the Alberta Construction Safety Association (ACSA) annual meeting. The Silica Control Tool acts as a form of knowledge translation as users who interact with the tool are provided with educational information about RCS exposure and control, and become more knowledgeable about the exposure levels associated with different CSPs and controls. We continue to support its development and would do so if it, or a similar tool, were adopted by the Alberta construction industry.

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Appendices

Appendix A. Industry Leader Questionnaire and Background Information

You have been asked to complete this questionnaire because of your knowledge of the local construction industry in Alberta.

We are trying to learn about the typical work activities in the Alberta construction industry that could generate respirable crystalline silica (RCS) exposure above the occupational exposure limit (0.025 mg/m^3). We call these activities **common silica processes (CSPs).**

In British Columbia we have identified 25 CSPs. These are listed in Table 1. The task, tool and material for each CSP are also listed. The BC Silica Control Tool has been developed around these CSPs. The tool aims to be able to estimate RCS exposure for each CSP. We would like to identify the CSPs in Alberta so that we can update our model to estimate exposure for CSPs in the Alberta construction industry.

Please complete the following steps to help us identify the CSPs in Alberta.

1. Please place a check mark beside each CSP in Table 1 that is also a CSP in Alberta (pages 2 – 3)

2. List any additional CSPs that are common in Alberta but that are missing from Table 1 and, if known, provide information on the common exposure reduction methods used (Pages 4 - 5).

3. Please provide any further information that you think we should know about CSPs in the Alberta construction industry.

Please complete, scan if necessary and return to hugh.davies@ubc.ca

Step 1: Please place a check mark in the "Alberta CSP" column if the CSP is also common in Alberta

Table 1: Common Silica Processes in British Columbia

Material	Task	Tool	CSP	Alberta CSP?
Asphalt	Cutting	Walk behind saw	Cutting asphalt with walk behind saw	
	Milling	Milling machine	Milling asphalt with milling machine	
Concrete masonry unit	Cutting	Table saw	Cutting with table saw	
	Cutting	Powered saw	Cutting with gas powered saw	
Concrete	Cutting	Powered saw	Cutting concrete with saw	
	Coring	Coring machine	Coring concrete	
	Drilling	Electric hammer drill	Drilling concrete with electric hammer drill	
	Grinding	Surface, angle, right angle or flat grinder	Grinding concrete with angle grinder	
	Grinding	Counterbalanced ceiling grinder	Grinding concrete with counterbalanced ceiling grinder	
	Scarifying	Bush hammer	Scarifying or bush hammering	
	Breaking	Jackhammer	Jackhammering	
Various	Demolition	Multiple	Demolition	
	Sweeping	Brush	Sweeping	

Table 1 Continued: Common Silica Processes in British Columbia

Material	**Task**	**Tool**	**CSP**	**Alberta CSP?**
Shot-crete	Spraying	Shot-crete	Shotcreting	
Ceramic tiles	Cutting	Powered saw	Cutting ceramic tiles with powered tile saw	
Rock/Sand/Earth	Manual moving	Shovel, sometimes with wheelbarrow	Manual moving of rock/sand/earth	
	Mechanized moving	Heavy equipment (backhoe, excavator, bobcat, etc…)	Mechanized moving of rock/sand/earth	
	Crushing	Crusher	Crushing/processing of rock/sand/earth	
Marble/Granite	Cutting	Powered saw	Cutting marble/granite with powered saw	
Drywall	Cutting	Saw	Cutting drywall	
	Grinding	Sander	Grinding drywall	
Cementicious material	Mixing and pouring	Mortar or concrete mixer	Mixing and pouring of cementicious material	
	Loading	Concrete mixer truck	Loading concrete mixer truck	
Mortar	Tuck point grinding	Tuck point grinder	Tuck point grinding	
Fiber cement board	Cutting	Portable saw	Cutting fiber cement board with portable saw	

Step 2: Please list any additional CSPs that are common in Alberta but that are missing from Table 1. Please also provide information on exposure controls used to reduce exposure (if known). Place a check in the wetting and/or exhaust ventilation columns if these are used for the CSP. If another exposure control method is used, please specify.

CSP	Known exposure controls		
	Wetting?	**Exhaust Ventilation?**	**Other (please specify)**

Step 3: Please comment below if there is anything else that you think we should know about common silica processes in Alberta construction (for example: regional or seasonal differences, processes or exposure controls that will become more common in the future, etc..)

Appendix B: Field Data Collection Form

Field Form Observation Sheet
Site Location:
Date:
Sample ID:
Common Silica Process (CSP):
Worker Job Title:
Shift Length:
Task Duration: Regular Task Duration: How many times task takes place during a normal shift:
General Observations/Comments:
Engineering Controls in place: YES or NO (circle one) - Sample for the CSP is "controlled" or "uncontrolled" (circle one)
Engineering Controls Description and Observations (i.e., water used, or general LEV, or LEV on tool - make/model/description/age):
Sub-Tasks Observed during the CSP:
Materials Involved in CSP:
Materials MSDS Available: YES or NO (circle one); If YES, silica %:
Tools Used (make/model/description):
PPE Worn/Used:
Work environment: Temperature: 0C Precipitation: NO Pressure: NA Wind: NO Indoors / Outdoors (circle one)
Environment/Work Area Description (indoors/outdoors, confined space, enclosed, partial, etc…):
Construction type: New build or Renovation (circle one)
Site Category: Residential Industrial Institutional/Commercial Civil/Roadwork Other:
Outside Temperature: Precipitation: Pressure: Wind:
Photos taken: Yes or No Photo ID (if applicable):
Environmental Conditions/Observations:

Appendix C: BC Silica Model Version 1.2

This model is derived from a database of over 4500 RCS exposure measurements and is intended to be used as part of an algorithm for predicting RCS exposure levels associated with construction work activities in order to aid selection of appropriate control strategies.

Equation for Exposure:

Ln(Exposure) = Equation Coefficient + Sampling Duration + CSPControl + Industry Sector + Project type + Environment + Region

To obtain the 'average' exposure estimate, add up the appropriate coefficients for each of the above variables. All variables are categorical. The possible categories and the associated values that would be entered to the equation are outlined below.

The coefficient and standard error (average and standard deviation) for each variable and category are listed below.

Equation Coefficent

Possible Categories	Average	Standard Error
N/A	-2.607	0.20

Sampling Duration:

Possible Categories	Average	Standard Error
0 (0.32 – 103 minutes)	0.00	
1 (104-240 minutes)	-0.656	0.09
2 (241 – 390 minutes)	-0.742	0.09
3 (>390 minutes)	-0.964	0.09

CSPControl:

Possible Categories CSP	Control	Average	Standard Error
Cutting asphalt with walk-behind saw	Uncontrolled**	1.562	1.46
	EV on Tool	0.562	1.46
	Any EV+ Any Wetting	0.288	0.74
Milling asphalt with milling machine	Uncontrolled	0.100	0.25
	EV on tool	-0.318	0.22
	Standalone Water spray	-0.595	0.61

	Water spray on tool	-0.353	0.24
	Any EV + Any Wetting	-0.836	0.26
Concrete ceiling grinding	Uncontrolled	1.796	1.03
	EV on tool	-0.926	0.61
Cutting concrete masonry unit with table saw	Uncontrolled	3.759	1.03
	Standalone EV	1.599	1.03
	Water spray on tool	0.848	0.66
	Any EV + Any Wetting	-2.916	1.45
Cutting concrete masonry unit with portable saw	Uncontrolled	3.419	0.67
	EV on tool	0.816	0.67
	Water spray on tool	1.350	0.67
Cutting concrete with saw	Uncontrolled	2.315	0.27
	EV on tool	1.357	0.45
	Water spray on tool	0.070	0.34
Coring Concrete	Uncontrolled**	2.315	0.27
	Water spray on tool	-0.647	0.53
Grinding concrete with surface, angle or flat grinder	Uncontrolled	2.676	0.23
	EV on tool	0.789	0.21
	Standalone Water spray	1.461	0.52
	Water spray on tool	0.791	0.58
Scarifying or bush hammering concrete	Uncontrolled	1.140	0.43
	Water spray on tool	0.086	0.61
Demolition	Uncontrolled	0.864	0.73
	Standalone Water spray	-1.405	0.56
	Any EV + Any Wetting	0.456	0.24
Sweeping	Uncontrolled	-0.158	0.66
	Standalone Water spray	-0.355	0.55
	Dustbane	-1.467	0.75
Shot-creting	Uncontrolled	0.288	0.44
	Standalone Water spray	-1.279	0.20
Manual moving of small rocks, soil etc	Uncontrolled	-0.003	0.43
Mechanized moving of small rocks, soil etc	Uncontrolled	-0.584	0.30
	Standalone Water spray	-0.015	0.37
Crushing and processing rock/sand/earth	Uncontrolled	-0.009	0.45
	Standalone Water spray	0.827	0.66
Cutting marble/granite	Uncontrolled	1.844	1.03
	Standalone EV	-0.338	0.53
	Standalone Water spray	2.190	1.46
	Water spray on tool	0.240	0.56

	Any EV+ Any Wetting	-1.963	0.74
Mixing and pouring cementicious material	Uncontrolled	0.335	0.36
Tuckpoint Grinding	Uncontrolled	3.109	0.22
	Standalone EV	-2.346	0.74
	EV on tool	0.598	0.16
	Standalone Water spray	1.899	0.73
	Water spray on tool	1.322	0.45
Breaking concrete with jackhammer	Uncontrolled	0.722	0.30
	EV on tool	0.423	0.46
	Standalone Water spray	2.151	0.85
	Water spray on tool	-1.549	0.48
Cutting fiber cement board with portable saw	Uncontrolled	0.584	0.37
	EV on tool	-0.732	0.32
Loading concrete mixer	Uncontrolled	0.116	0.61
	Any EV + Any Wetting	-0.600	0.66
Drilling concrete with hammer drill	Uncontrolled	0.223	0.29
	EV on tool	-1.037	0.53
	Water spray on tool	-0.478	0.66
	Standalone water spray	2.049	0.84
Cutting Drywall	Uncontrolled	-2.033	0.49
Crushing Concrete	Uncontrolled	-2.433	1.03
Cutting concrete with walk-behind saw	Uncontrolled	2.315	0.27
	Water spray on tool	-0.042	0.31
	Standalone water spray	-2.077	0.48
Chipping concrete	Uncontrolled	2.067	0.25
	Standalone water spray	1.746	0.60
	Water spray on tool	-0.155	0.85
Mixing gypsum	Uncontrolled	-1.414	1.04
Concrete breaking with excavator	Uncontrolled	0.013	0.66
	Standalone water spray	-0.639	1.03
Asphalt breaking with excavator	Uncontrolled**	0.013	0.66
	Standalone water spray	-1.675	1.03
Rock Drilling with drilling machine	Uncontrolled	0.530	1.03
	EV on tool	0.754	0.52
	Any EV + Any Wetting	-0.035	1.03

Industry Sector:

Possible Categories	Value if selected	SE
Civil engineering and roadwork	0	
Industrial, institutional and commercial	0.237	0.10
Residential	0.403	0.18
Testing laboratory	1.026	0.19

Other/not specified	0.227	0.11

Project Type:

Possible Categories	Value if selected	
New Construction	0	
Renovation	0.306	0.10
Other/Not specified	0.397	0.10

In Out:

Possible Categories	Value if selected	
Indoors	0	
Outdoors	-0.483	0.08
Confined Space	0.508	0.26
Not specified	-0.225	0.11

Region:

Possible Categories	Value if selected	
US Multiple Regions	0.818	0.15
US Northeast	0.787	0.16
US South	0.615	0.21
US Southwest	1.247	0.27
US Midwest	0.069	0.17
US West	0.384	0.18
Canada East	0.036	0.18
Canada West	-0.514	0.15
Europe	0.355	0.14
Asia	-0.927	0.43

Appendix D: Alberta Silica Model

This model is derived from a database of over 4500 RCS exposure measurements and is intended to be used as part of an algorithm for predicting RCS exposure levels associated with construction work activities in order to aid selection of appropriate control strategies. It is an update to the BC Silica Model that incorporates 139 new RCS measurements, 135 of which were collected from Alberta construction sites.

Equation for Exposure:

Ln(Exposure) = Equation Coefficient + Sampling Duration + CSPControl + Industry Sector + Project type + Environment + Region

To obtain the 'average' exposure estimate, add up the appropriate coefficients for each of the above variables. All variables are categorical. The possible categories and the associated values that would be entered to the equation are outlined below.

The coefficient and standard error (average and standard deviation) for each variable and category are listed below.

Equation Coefficent

Possible Categories	Average	Standard Error
N/A	-2.643	0.20

Sampling Duration:

Possible Categories	Average	Standard Error
0 (0.32 – 103 minutes)	0.00	
1 (104-240 minutes)	-0.668	0.09
2 (241 – 390 minutes)	-0.752	0.09
3 (>390 minutes)	-0.965	0.09

CSPControl:

Possible Categories CSP	Control	Average	Standard Error
Cutting asphalt with walk-behind saw	Uncontrolled**	1.562	1.46
	Exhaust Venilation (EV) on Tool	0.652	1.46
	Any EV + Any Wetting	0.336	0.75
Milling asphalt with milling machine	Uncontrolled	0.121	0.25
	EV on tool	-0.290	0.22

	Standalone sater spray	-0.574	0.61
	Water spray on tool	-0.308	0.24
	Any EV + Any Wetting	-0.812	0.26
Concrete ceiling grinding	Uncontrolled	1.592	0.85
	EV on tool	-0.988	0.52
Cutting concrete masonry unit with table saw	Uncontrolled	3.752	1.03
	Standalone EV	1.601	1.04
	Water spray on tool	0.837	0.66
	Any EV + Any Wetting	-2.914	1.45
Cutting concrete masonry unit with portable saw	Uncontrolled	3.470	0.67
	EV on tool	0.867	0.67
	Water spray on tool	1.401	0.67
Cutting concrete with saw	Uncontrolled	2.345	0.27
	EV on tool	1.206	0.43
	Water spray on tool	0.0096	0.34
Coring Concrete	Uncontrolled	-1.308	1.46
	Water spray on tool	-0.777	0.48
Grinding concrete with surface, angle or flat grinder	Uncontrolled	2.817	0.22
	EV on tool	0.864	0.21
	Standalone Water spray	1.485	0.53
	Water spray on tool	0.870	0.59
Scarifying or bush hammering concrete	Uncontrolled	1.835	0.38
	Water spray on tool	0.161	0.61
Demolition	Uncontrolled	0.993	0.44
	Standalone Water spray	-1.349	0.56
	Any EV + Any Wetting	0.555	0.24
Sweeping	Uncontrolled	0.119	0.56
	Standalone Water spray	-0.304	0.56
	Dustbane	-1.460	0.68
Shotcreting	Uncontrolled	0.310	0.44
	Standalone Water spray	-1.255	0.21
Manual moving of small rocks, soil etc	Uncontrolled	0.042	0.43
Mechanized moving of small rocks, soil etc	Uncontrolled	-0.597	0.31
	Standalone Water spray	0.079	0.38
Crushing and processing rock/sand/earth	Uncontrolled	-0.004	0.45
	Standalone Water spray	0.918	0.66
Cutting marble/granite	Uncontrolled	1.948	1.03
	Standalone EV	-0.295	0.53
	Water spray on tool	0.262	0.56

	Any EV+ Any Wetting	-1.940	0.74
Mixing and pouring cementicious material	Uncontrolled	-0.244	0.28
Tuckpoint Grinding	Uncontrolled	3.133	0.22
	Standalone EV	-2.404	0.75
	EV on tool	0.631	0.16
	Standalone Water spray	1.926	0.73
	Water spray on tool	1.372	0.45
Breaking concrete with jackhammer	Uncontrolled	0.786	0.30
	EV on tool	0.501	0.46
	Standalone Water spray	2.094	0.85
	Water spray on tool	-1.495	0.48
Abrasive blasting	Uncontrolled	0.793	0.38
	Standalone Water spray	-0.498	0.74
	Water spray on tool	0.387	0.47
Cutting fiber cement board with portable saw	Uncontrolled	0.329	0.36
	EV on tool	-0.815	0.32
Loading concrete mixer	Uncontrolled	0.176	0.62
	Any EV + Any Wetting	-0.540	0.67
Drilling concrete with hammer drill	Uncontrolled	0.268	0.26
	EV on tool	-0.884	0.46
	Water spray on tool	-0.419	0.67
	Water spray	2.072	0.85
Cutting Drywall	Uncontrolled	-1.348	0.38
Sanding Drywall	Uncontrolled	-1.363	0.68
Crushing Concrete	Uncontrolled	-2.433	1.03
Cutting concrete with walk-behind saw	Uncontrolled	2.315*	0.27
	Water spray on tool	-0.017	0.31
	Standalone water spray	-2.081	0.48
	EV + Wetting	1.595	1.04
Chipping concrete	Uncontrolled	2.015	0.24
	Standalone water spray	1.753	0.61
	Water spray on tool	-0.121	0.85
Mixing gypsum	Uncontrolled	-1.515	1.04
Walk-behind concrete grinding	EV on Tool	-0.919	0.63
Mobile road sweeping	Uncontrolled	2.442	0.67
Concrete breaking with excavator	Uncontrolled	0.059	0.66
	Standalone water spray	-0.598	1.04
Asphalt breaking with excavator	Uncontrolled**	0.013	0.66
	Standalone water spray	-1.666	1.04
Rock Drilling with drilling machine	Uncontrolled	0.561	1.03
	EV on tool	0.780	0.53
	Any EV + Any Wetting	0.588	1.46
Cement Plant Operator	Closed Pressurized Cab	-2.627	0.74
Cement Plant Loader Operator	Closed Pressurized Cab	-1.230	0.61

Cement Plant Truck Driver	Closed Pressurized Cab	-1.890	0.67

Industry Sector:

Possible Categories	Value if selected	SE
Civil engineering and roadwork	0	
Industrial, institutional and commercial	0.267	0.10
Residential	0.516	0.17
Testing laboratory	1.061	0.19
Other/not specified	0.220	0.11

Project Type:

Possible Categories	Value if selected	
New Construction	0	
Renovation	0.280	0.10
Other/Not specified	0.320	0.10

In Out:

Possible Categories	Value if selected	
Indoors	0	
Outdoors	-0.453	0.08
Confined Space	0.554	0.26
Not specified	-0.160	0.11

Region:

Possible Categories	Value if selected	
US Multiple Regions	0.847	0.15
US Northeast	0.784	0.16
US South	0.604	0.21
US Southwest	1.107	0.26
US Midwest	0.068	0.17
US West	0.430	0.18
Canada East	0.086	0.18
British Columbia	-0.520	0.17
Alberta	-0.365	0.17

Europe	0.377	0.14
Asia	-0.870	0.43