Chemical Substances and Biological Agents

Studies and Research Projects

REPORT **R-771**

Construction Workers' Exposure to Crystalline Silica

Literature Review and Analysis

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SUMMARY

Silica is one of the most prevalent inorganic compounds found in nature. As crystalline quartz, it is abundant in various minerals, including granite and sand. When materials containing crystalline silica are handled, quartz can be found as suspended dust in the air. If this dust is inhaled by workers, it can cause various respiratory tract diseases, the most serious being silicosis and lung cancer.

In the construction industry, occupational exposure to crystalline silica is common in several trades due not only to its presence in many handled materials, for example concrete, mortar and brick, but also to the processes, involving operations such as breaking, grinding or sawing. In Québec, as in other jurisdictions, the crystalline silica exposure levels in the construction industry still frequently exceed the regulatory limit values. A number of occupational diseases are compensated in this industry in Québec by the *Commission de la santé et de la sécurité du travail*.

The construction field is complex, with many trades, tasks, materials and tools that can be linked to crystalline silica exposure. Québec occupational health and safety practitioners do not have at their disposal a knowledge review that would allow preventive actions to be ranked in relation to the Québec reality in this activity sector. The production of such a portrait was the general objective of this study, with the more specific objectives being to identify the most hazardous occupations and tasks in relation to their exposure level, and to identify the various means of controlling exposure, while documenting their effectiveness and developing a relational database on silica dust exposure that compiles the literature data in a format that can be used by researchers or practitioners.

One key aspect of the method consisted of developing a database on work-related silica exposure in construction, from an exhaustive search of the international scientific literature (articles from periodicals, reports of public and private organizations, and databases). This database would associate measurement results (exposure levels) with a series of qualifying parameters, linked to the exposure and sampling conditions. This strategy was preferred to the more classic literature review method, which consists of individually analyzing the data from journal articles and synthesizing the information in tables that present each study separately, but which make the diverse data difficult to interpret. In total, of more than 500 documents, 116 were retained because they contained relevant information on exposure levels. Furthermore, 67 documents that dealt specifically with control methods were analyzed.

The exposure database associates 4251 respirable crystalline silica exposure levels with 76 parameters, mainly the occupation, task, tool, material and control methods used. The descriptive analysis of the data indicates that the most hazardous occupations in construction can be classified in three groups based on their exposure level. Underground workers (specialized labourers, pipeline labourers, surveyors and drillers) and heavy equipment operators at the controls of tunneling machines make up an initial group, exposed to levels clearly above (two to four times) the Québec regulatory value. Cement finishers, bricklayer-masons, drillers, specialized labourers and heavy equipment operators at the controls of road-milling machines represent a second group, exposed on average to levels above or close to the regulatory value. Specialized labourers (tile setters), unskilled labourers, fixed and mobile machine-tool operators,

and heavy equipment operators (other than road-milling machine and tunneling machine operators) represent a third group exposed to levels between 50–100% of the regulatory value.

The tasks and tools with the highest exposure (all more than twice the regulatory value during the duration of the task) are, in decreasing order: sawing masonry with a portable masonry saw, bush hammering, breaking pieces of masonry (chipping jackhammers on concrete or ceramic), tunnel boring (tunneling machine), and brick/stone joint grinding (tuck point grinding).

The literature review indicates that crystalline silica substitution must be encouraged when possible, but most of the time is difficult to consider in the construction industry due to its presence in numerous basic materials used. The technical means for controlling exposure, such as spraying and local exhaust ventilation, integrated into the tools, are well known and significantly reduce the concentration of crystalline silica dust in the air, with an efficiency generally exceeding 90%. However, these means do not ensure compliance, in the great majority of cases, with the exposure limit values of the different countries and organizations, and have a negative impact on performance. It is therefore recommended that the use of these technical methods be improved as much as possible, and that good practices be applied, for example by adopting certain work methods that produce less dust and by adjusting and maintaining the tools and equipment. It is recommended that respiratory protection be used in conjunction with these methods.

The present study should ultimately involve the development of plain language documents for this industry’s workers and employers that focus on the available control methods in relation to the various tasks performed and tools used. Furthermore, the occupational exposure database developed in this project should be modeled, in order to study in detail the impact of the many parameters controlling occupational crystalline silica exposure in construction. As well, the time period covered by the literature review should be extended to years prior to 1990 to make the database applicable to the retrospective evaluation of silica exposure.

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ACRONYMS AND ABBREVIATIONS

AAEV: Adjusted average exposure value
ACGIH: American Conference of Governmental Industrial Hygienists
AIHA: American Industrial Hygiene Association
AM: Arithmetic mean
ASTM: American Society for Testing and Materials
BGBAU: *Berufsgenossenschaft der Bauwirtschaft* (Building industry occupational health and safety insurance association)
BGIA: *Berufsgenossenschaftliches Institut für Arbeitsschutz* (Institute for occupational safety and health)
BIOSIS: Biosciences Information Service
BPW: Building and Public Works
CISDOC: Bibliographic database of the International Occupational Safety and Health Information Centre
COLCHIC: COLlecte des données recueillies par les laboratoires de CHimie de l'Inrs et des Cram
COSH: Commission for Occupational Safety and Health
Cram: *Caisse régionale d'assurance maladie* (Regional health insurance fund)
CSST: *Commission de la santé et de la sécurité du travail* (Québec workers' compensation board)
DB: Database
EMBASE: Excerpta Medica Database
ERG: Eastern Research Group
GM: Geometric mean
GSD: Geometric standard deviation
HSE: Health and Safety Executive
HSELINE: Health and Safety Executive on Line
IAPA: Industrial Accident Prevention Association
IARC: International Agency for Research on Cancer
ILO: International Labour Office
INRS: *Institut national de recherche et de sécurité*
InVS: *Institut de veille sanitaire*
IRSST: *Institut de recherche Robert-Sauvé en santé et en sécurité du travail*
LD: Limit of detection
Max: Highest value
MDHS: Method for the Determination of Hazardous Substances
Min: Lowest value
mppcf: Million particles per cubic foot
n: Number of measurements
NAICS: North American Industry Classification System
NA: Not applicable
NEDB: National Exposure Database
NIOSH: National Institute for Occupational Safety and Health
NIOSHTIC: National Institute for Occupational Safety and Health Technical Information Center
NS: Not specified

nS: Number of studies
OEBD : Occupational exposure database
OEL : Occupational Exposure Limit
OEMD: Occupational exposure measurement database
OSHA: Occupational Safety and Health Administration
P25: 25th percentile
P75: 75th percentile
P90: 90th percentile
PEV: Permissible exposure value
PNOS: Particles Not Otherwise Specified
PVC: Polyvinyl chloride
ROHS: Regulation respecting occupational health and safety
TLV: Threshold Limit Value
TWA: Time-Weighted Average
TWAEV: Time-weighted average exposure value
WHO: World Health Organization

1. INTRODUCTION

For more than ten years, the Construction Action Plan of the *Commission de la santé et de la sécurité du travail* (CSST) has sought to reduce the major hazards in the building and public works sector (BPW). Every year, the revised action plan targets specific hazards and identifies new issues. The 2007 Plan marked the beginning of targeted interventions, during work (other than sand blasting) likely to produce crystalline silica (quartz) dust in poorly ventilated spaces and without source control methods and appropriate respiratory protection [1]. The specific issue of sand blasting is excluded from this report, having already been addressed in studies for this industry [2, 3, 4, 5, 6].

A study by the public health department of the *Agence de la santé et des services sociaux de Montréal* carried out in the BPW sector in 2002-2003 confirms an overexposure situation, with close to 50% of the 120 measurements during construction work exceeding the permissible exposure value in the *Regulation respecting occupational health and safety* (ROHS) [7].

The public health department’s observations regarding risk assessment, exposure, and exposure control seem to be confirmed by a preliminary analysis of the scientific literature. Researchers in the Netherlands [8, 9] concluded that many construction workers are exposed to crystalline silica concentrations that exceed the national exposure limit value of 0.075 mg/m³, that these workers are at high risk of contracting silicosis, that there is a significant lack globally in the number and quality of exposure measurements, and that the effectiveness of the control measures is not well known. A British study [10] arrived at the same conclusions. Researchers in the United States [11] compiled 1374 breathing zone quartz concentration results for construction workers. They produced a database documenting the task, the tools used, the occupation, the degree of confinement of the premises, the construction sector, the purpose or reason for the construction site, the exposure control methods, and the sampling and analysis techniques. They concluded that worker exposure to crystalline silica on construction sites is high or extremely high, that exposure controls are rarely used and often ineffective, and that there is a clear need for additional research in order to better characterize the hazardous tasks and prevention strategies.

Several publications, including those of Tjoe Nij *et al*., Beamer *et al*, Thorpe *et al*. and Akbar-Khanzadeh *et al*. [12-15] evaluated the effectiveness of specific exposure control methods on construction sites. They found that this type of study is complex due to the large number of parameters that must be evaluated, that control methods can reduce exposure, but that, in order to reach a level below the permissible exposure values, a combination of several means of protection must be used.

The construction sector is complex: many different tasks, mobility of the labour force, short-term nature of the construction sites, and the many parameters that have an impact on worker exposure to crystalline silica. A summary of the knowledge on the exposure levels associated with the occupations and hazardous tasks would be desirable. It would allow better planning of the interventions required to prevent silicosis and the other silica-related diseases in construction workers and would identify the most hazardous occupations and tasks that should be given priority.

2. OCCUPATIONAL HEALTH PROBLEMS AND RESEARCH OBJECTIVES

Occupational exposure to crystalline silica is a universal problem. The World Health Organization (WHO) in conjunction with the International Labour Office (ILO) has been managing since 1995 a *Global Program for the Elimination of Silicosis*, while NIOSH in the United States initiated a program in 2005 called *Elimination of Silicosis in the Americas* [16]. The European Union recognized the importance of this issue in several industry sectors, including BPW, by publishing in 2006 in its official journal a good practices guide for handling crystalline silica and products containing it [17].

Prolonged exposure to respirable dust containing crystalline silica may cause silicosis, a lung disease characterized by progressive fibrosis of the lungs [18]. Also, the International Agency for Research on Cancer (IARC) has classified crystalline silica (quartz or cristobalite) as a human carcinogen (group 1) when it is inhaled in the work environment [19]. The ACGIH [20] and the Québec *Regulation respecting occupational health and safety* (ROHS) [21] classify quartz as a suspected human carcinogen. In March 2009, IARC reaffirmed the carcinogenicity of crystalline silica (group 1) [22].

Crystalline silica is a major component of many construction materials, the most common being sand, cement, stone, brick and mortar. Construction workers can be exposed to respirable crystalline silica during activities such as the demolition of masonry structures or other concrete structures, the crushing, loading, transport and unloading of rocks, and the removal of dusts of concrete, stone or sand by dry sweeping or compressed air blowing [23]. Crystalline silica can also be present in asphalts, roof coverings, composite materials, and joint compounds for wallboard, paint, plaster, caulking material, mastic, etc. [24]. Construction work can therefore pose a risk for lung diseases such as silicosis and lung cancer for some workers.

Peters *et al*. recently estimated that a total of 71000 Québec workers have been exposed to crystalline silica, all industries combined. More specifically for the construction industry, they report that 30000 workers would be exposed for specialized contractors (NAICS[1] 238), 11000 in the construction of buildings (NAICS 236), 3900 in heavy and civil engineering construction (NAICS 237), and 1,100 in highway, street and bridge construction (NAICS 2373) [25]. The CSST statistics department counted, in the BPW sector, 19 compensated deaths registered between 1995 and 2009 related to silica exposure [26]. According to other statistical data from 1995 to 2007, the CSST counted 12 cases of silicosis in the BPW sector, among a total of 194 cases of lung diseases compensated in this sector [27].

The general objective of this project was to provide Québec occupational health and safety practitioners with a knowledge summary enabling them to better identify the preventive actions relating to crystalline silica exposure in the construction industry. The specific objectives of this study were to:

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[1] North American Industry Classification System, industry 23, Construction: http://stds.statcan.gc.ca/naics-scian/2002/ts-rt-eng.asp?criteria=23

1. Identify the most hazardous occupations and tasks in the construction industry according to the Québec situation in terms of their exposure level (excluding sand blasting);
2. Identify the different methods for controlling crystalline silica exposure in the construction industry and to document their effectiveness;
3. Develop a relational database of crystalline silica dust exposure measurements in the construction industry, compiling literature data in a format that can be used by practitioners and researchers.

3. METHODOLOGY

To fulfill the above-mentioned three objectives, this work is based on an exhaustive compilation of the international scientific literature and on its interpretation in the context of the Québec work environment. One key aspect involved the development of an occupational exposure measurement database (OEMD) compiling all of the measurements related to crystalline silica in construction, originating from various existing literature sources (sections 3.1 to 3.5). This OEMD was based on the occupational exposure database (OEDB) model, such as COLCHIC [28] and NEDB [29], developed by various public organizations from measurements taken in workplaces under their jurisdiction. These databases associate measurement results (exposure levels) with a series of predetermined qualitative parameters, related to the exposure and sampling conditions [30]. These databases can then be analyzed to link the exposure levels to various parameters.

The strategy of creating an OEMD was preferred over the more classic literature review process which consists of individually analyzing the data sources and synthesizing the information in tables presenting the data from each study separately, but these data are difficult to interpret due to their heterogeneity [31]. The descriptive statistics presented in this report are the result of an analysis of the OEMD, in relation to the parameters adapted to the Québec construction industry (section 3.6).

However, regarding the identification and evaluation of exposure control methods, the methodology (section 3.7) has been based on a classic critical analysis of the literature sources specifically dealing with this topic. The focus is on source control methods. Respiratory protection is mentioned, but the choice and use of respiratory protective equipment are not discussed in detail, given the variety of the situations and regulatory contexts.

3.1 Search for sources of exposure data

The systematic search of the scientific and technical literature focused on publications since 1990. Different bibliographical databases were consulted to identify the primary source materials dealing with crystalline silica exposure and the means of controlling this exposure. These included: Medline/PubMed, Toxline, PolTox (up to December 2001), Current Contents, HSELINE, NIOSHTIC, EMBASE, Chemical Abstracts, CISDOC (ILO), INRS, Scirus, BIOSIS and CANADIANA.

In addition, three organizations that have already developed occupational exposure databases for crystalline silica in construction were contacted: the ACGIH in the United States, the InVS in France, and Berufsgenossenschaft der Bauwirtschaft (BGBAU) in Germany.

3.2 Document selection

All of the data sources underwent a screening process following an initial review:

1. Elimination of all sources of data not relevant to the construction environment. Some data sources, for example the mining and agriculture sectors, were retained because the

discussion of certain occupations, such as those related to the preparation of access roads, is very comparable to that of the same occupations in construction.

2. Elimination of all data sources whose subject did not involve the exposure levels for dust containing crystalline silica or control methods for reducing exposure. These included epidemiological studies and other studies aiming to compare the efficiency of the sampling or instrumental analytical methods.

3. Elimination of all data sources in languages other than French or English, from which sufficient information could not be gathered to characterize the exposure levels presented.

4. Elimination of all data sources not meeting the scientific quality and relevance criteria: methodological quality, relevance to the Québec work environment, sufficient description of occupations and tasks, documentation of the type of sampling, description and effectiveness of technical exposure control methods, representativeness of the samples, description of the environmental conditions, and the type of material used at the time of the exposure assessment.

The data sources were then classified according to whether they contained only exposure data, only information on the control methods, with or without quantitative measurements, or information on both subjects.

3.3 Development of an exposure measurement database

The documentation gathered was studied and coded according to a data input template allowing standardization of the exposure value data and the parameters describing this exposure, including the control methods.

3.3.1 Selection of parameters

Rajan *et al*. [30] as well as the joint committee of the ACGIH and the American Industrial Hygiene Association (AIHA) [32] each proposed a series of parameters for the quantitative measurements in order to prepare exposure databases. The list of these parameters is too exhaustive for a database produced from the existing documentation, which was not necessarily written in compliance with their recommendations. The final list of parameters retained to construct our data input template is therefore based on these two documents, on an article by Flanagan *et al*. [11], on the database transmitted by the InVS [33], and on recommendations by Gillen and Echt of NIOSH [34].

3.3.2 Québec adaptation of certain parameters

To represent the Québec context, four parameters were specifically coded: the occupation title, the task, the tool, and the material. The objective of this coding was to standardize the different terms used in the data sources to describe a similar situation in Québec.

The occupation titles were coded from the list of occupations in the *Regulation respecting the vocational training of the workforce in the construction industry* [35] and the occupations described in the most recent collective agreements for the Québec construction industry (Civil

Engineering and Roadwork Sector, Institutional and Commercial Sector, Residential Sector and Industrial Sector) [36-39].

The authors coded the tasks, tools and materials when the parameters of each data source were entered. Standardization of the terms retained to describe each of the values of these three parameters was finalized after review of all of the terms retained during data entry.

3.4 Data compilation

The quantitative data and descriptive exposure parameters were entered and compiled in the OEMD using a spreadsheet that allows input of the exposure measurements as well as all their descriptive parameters. Each line of the spreadsheet corresponded either to a single exposure measurement or to a set of “n” measurements whose distribution is represented by one or more statistical parameters, such as an arithmetic mean and an arithmetic standard deviation or a range.

If the descriptive parameter data was not specified or not applicable, “NS” or “NA” was entered in the field. If the numerical parameter information indicating the exposure level was unavailable, the field was either left empty or filled with an estimate of the information by the person responsible for inputting the information.

When the same exposure evaluation measurements were present in more than one data source, if one of them was an article from a peer-reviewed journal, the latter was retained as a source of information and the other data source was eliminated or used to complete certain aspects of the article.

3.5 Data processing

The data were processed in five distinct and sequential steps.

Digital processing

1. First, all exposure values (whether represented or not by statistical parameters such as the arithmetic or geometric mean) that were “below the limit of detection” were replaced by the value LD/2, where LD represents the concentration at the limit of detection of the analytical method [40].
2. The method of Lavoué *et al*. [31] was used to estimate a geometric mean (GM) when the lines representing “n” measurements were described by statistical parameters other than the GM. According to the authors, when there is no geometric mean, it can be estimated by mathematical treatment of other parameters such as the arithmetic mean and the arithmetic standard deviation, or the maximum and minimum values of this distribution.

Restrictions based on the type of document and the type of statistical parameter

1. Any line where the available information did not allow a GM to be calculated was eliminated.

2. Any line from an article that was considered non-transformable for calculating descriptive statistics was eliminated, as for example, a line that produces an average exposure value for all construction workers.

Restriction based on the type of sampling

Only lines where the information indicated that the sample was collected in the worker's breathing zone were retained.

Restriction based on the nature of the contaminant

Only lines where the nature of the contaminant indicated that the contaminant was respirable dust or respirable crystalline silica were retained.

Creation of individual measurements

Each line representing "n" measurements was transformed into "n" lines by copying it integrally "n-1" times. In this way, a series of "individual" measurements was simulated for calculating the descriptive statistics in order to evaluate the exposure levels of construction workers.

3.6 Descriptive statistics

Our first objective was to identify those workers at high risk of being exposed to high concentrations of crystalline silica based on their occupation title, workstation, or task. To achieve this objective, we used a subset of the database created using the method presented in Section 3.4 to calculate the descriptive statistics on exposure levels. Data selection was based on the following criteria:

1. The quality score for the parameter description had to be acceptable to excellent (see Appendix 3).
2. Sample collection and analysis had to be done according to recognized methods (NIOSH, Health and Safety Executive of the United Kingdom (HSE), INRS, IRSST) or similar methods.
3. Only the site classes representing real construction situations were retained.
4. Only respirable crystalline silica exposure was retained.
5. Only the analytical results obtained by X-ray diffraction and infrared spectroscopy methods were considered.
6. Finally, only the parameter values with a measurement number $n \geq 5$ were retained for the descriptive statistics.

The geometric mean and geometric standard deviation rather than the arithmetic mean and the arithmetic standard deviation were chosen to represent the exposure measurement distributions. In fact, the majority of the data sources used these parameters to represent their distribution because they are generally log-normal. Use of the geometric mean reduces the impact of extreme values, which are likely to occur, considering the disparity of data sources. The geometric standard deviation (GSD) values were calculated for each parameter, by using the individual values available in the original data sources. When an individual value was not available, “NS” was entered instead of the GSD value.

The descriptive statistics were calculated using S-Plus software [41].

3.7 Identification and evaluation of the control methods

The second objective was to identify the exposure control methods and to document their effectiveness. Identification was done using information gathered from the different publications. A summary of the general information applying to all of the control methods was developed, followed by a synthesis of the methods used for the tools producing the most dust. The efficiency is reported as a percentage in relation to the concentration of dust observed in the absence of control methods and in terms of the capacity of these methods to reduce the exposure below the threshold limit values (TLV) applicable in the jurisdictions involved.

3.8 Development of a relational database

Consultation of spreadsheets containing large numbers of columns and rows is painstaking. Also, inputting thousands of rows produces nearly half a million information cells. Another method must be developed for a preventionist to facilitate access to these data.

Construction of this relational database must fulfill the following objectives:

1. Facilitate access to the information by the creation of menus leading directly to this information when the database is opened.
2. Allow on-screen consultation or the printing of the complete bibliographical reference for each of the data sources.
3. Allow on-screen consultation or the printing of all the exposure data presented in a specific data source. The exposure data should be accompanied by the description of the occupation title, task, tool and material as presented by the authors, as well as the coded values corresponding to the Québec context.
4. Allow on-screen consultation or the printing of the lists of all the exposure data available in the data sources for:
    a. a given occupation title;
    b. a given task;
    c. a given tool;
    d. a given material.

4. RESULTS

4.1 Sources of exposure data and exposure control data

Table 1 presents the distribution of the data sources. The first line in the table presents the number of sources identified, in order to evaluate whether they contained data on construction workers' exposure to crystalline silica or information relating to the effectiveness of the control methods. Only sources containing the desired information are presented on lines 2 and 3 of the table. Following the verification process described in Section 3.4, 13 documents of the 539 in our bibliography were eliminated due to duplication of data from other documents. Appendix 1 contains the list of the 116 sources used to create the database.

Table 1 – Data source distribution

Type of document	Journal article	Report from public organization	Report from private organization	Database	All types of documents
1- Number of documents resulting from searches of data sources	263	267	7	2	539
2- Number of documents with exposure data	45	69	0	2	116
3- Number of documents with information on control methods	18	40	7	2	67

Three documents were not retained in creating the database. The German report "*BGIA - Report 8/2006e: Exposure to quartz at the workplace*" [42] was not used because the average exposure levels presented are a synthesis of the breathing zone measurements and stationary sampling measurements, where each type was weighted by committees of experts. The synthesis reports "*Draft Final Report: Technological Feasibility Study and Cost and Impact Analysis of The Draft Crystalline Silica Standard for Construction*" [43] and "*Silica Exposure on Construction Sites: Results of an Exposure Monitoring Data Compilation Project*" [11] contained data from already compiled documents, which were impossible to separate from all of the presented results.

The ACGIH construction committee did a compilation of occupational exposure data in the United States construction industry. This study was the subject of a recent publication by Flanagan *et al*. [11]. We obtained a file [44] containing the individual data that were used to produce the various descriptive statistics in this publication.

The InVS assembled a database of crystalline silica exposure measurements [33] collected in various industrial environments in France, including a measurement search of the literature. The aim of this compilation was to develop an occupation-exposure matrix of workers exposed to crystalline silica in France [45] in the context of the Matgéné program. A significant proportion of this search involved BPW. The InVS agreed to share all of their raw data as well as their methodology for exposure assessment classification.

BGBAU is a group insurance company with one of its mandates being to compensate German construction workers following industrial accidents or occupational diseases. This organization inputs information into a database on construction workers' exposure to several contaminants, including approximately 1250 individual crystalline silica measurements [42]. We were unable to obtain the relevant data from the BGBAU on these individual measurements.

While the data sources come from all over the world, more than 80% come from North America and 17% from European countries.

4.2 Database parameters

The input template containing 76 parameters is presented in Appendix 2. The parameters making up the template are grouped according to whether they involve coding of the data source, the occupation, construction sites, the description of quantitative exposure parameters, the exposure characteristics, the control methods, the respirators, and general comments.

All of the occupation titles, coded according to the Québec context, were verified by three representatives of the *Association de la construction du Québec* to ensure that they were representative of the Québec context.

In some cases the tasks, tools and materials coded to represent the Québec context were assigned names such as "Multiple tasks…", "Various materials containing…" ,"Multiple tools…" because the available information did not allow a more precise value to be assigned. For example, in the case of the "Task" parameter, there are four values with the name "Multiple tasks" namely "Multiple tasks (Sawing masonry and other tasks)," "Multiple tasks (Grinding masonry and other tasks)," "Multiple tasks (Breaking masonry and other tasks)," and "Multiple tasks (other masonry-related tasks)." The information provided in the data source was assigned to one of the available values based on a preliminary evaluation of the level of exposure associated with some tool or some task. If sawing was among the tasks described in the original data source, all of these tasks were assigned to "Multiple tasks (Sawing masonry and other tasks)." If no sawing was involved, but there was grinding, all the tasks were assigned to "Multiple tasks (grinding masonry and other tasks)" and so on.

The values of all the coded parameters are presented in Appendix 3.

4.3 Distribution of exposure data

Table 2 presents the distribution of the data by type of document.

Table 2 – Data distribution

Type of document	Journal article	Report from a public organization	Report from a private organization	Database	All types of documents
Number of documents with exposure data	45	69	0	2	116
Number of lines of information in the DB	1055	2709	246	2115	6125

Of the 6125 lines of information, 5628 contained individual exposure measurements, while 497 lines had from exposure measurements represented by statistical parameters.

Table 3 presents the result of the sequential transformation process used to create the individual data as described in Section 3.5. In total, 8388 individual data were created by this process. The majority of these data came from the United States (68%), while 30% came from European countries, and 2% from Québec and Ontario.

Table 3 – Result of the transformation of exposure data

Number of lines after compilation	Restriction steps			Transformation into individual measurements	
	Number of lines after the first restriction step*	Number of lines with breathing zone samples	Number of lines with dust or respirable silica	Number of individual respirable dust measurements	Number of individual respirable crystalline silica measurements
6125	6099	5105	4739	4137	4251

*: Elimination of lines of information according to the method “Restrictions based on the nature of the document and the type of statistical parameter.”

More than 75% of the lines of information (4739/6125) presented measurements of construction workers’ breathing zone exposure to dust and crystalline silica.

The 8388 individual exposure measurements are almost equally distributed between respirable crystalline silica (4251) and respirable dust (4137).

Few sources of data were sufficiently detailed to allow us to document the value of each of the parameters in our database. Table 4 presents the distribution of a few parameters, based on whether the value could be specified or not.

Table 4 – Distribution of certain parameters identified in the DB

Parameter	Number of values identified in the DB	Number of individual measurements* where the value is specified	Number of individual measurements* where the parameter value is not specified (NS)
Occupation titles (QC)	24	7706	682
Tasks (QC)	40	6984	1404
Tools (QC)	29	4930	3458
Materials (QC)	23	5735	2653
Classes of construction sites	9	4722	3666
Control methods	7	4321	4067
Respirator	12	2780	5608

*: The total number of individual exposure measurements is 8388.

The occupation title coded for Québec (Qc) was the parameter that could be specified most often (92% of the time) from the information documented in the data sources, followed by the task (83%). The lowest percentage was found for respirators (33%). For the other determinants presented in Table 4, this percentage varied from 52 to 68%. Also, 57 occupation titles coded for Québec were not documented in the data sources with respect to crystalline silica exposure.

4.4 Exposure to respirable crystalline silica

This section presents the analysis of the workers' respirable crystalline silica exposure measurements in order to establish the list of occupations and tasks with the highest risk as well as to attempt to evaluate the impact of different parameters on these exposures.

The results are presented in graphical form (Figures 1 to 5). Each graph presents the geometric mean of the exposure measurements represented by the horizontal bar as well as the number of individual measurements (n) used to calculate this mean and the number of studies (nS) from which these measurements are taken. By relating these two numbers to the geometric mean, the representativeness of these data could be evaluated and the exposure levels could be more easily compared.

All of the statistical parameters retained to describe the distribution of the measurements are presented in tables in Appendices 4 to 9. This completes the information presented in the graphs and shows the data dispersion including the extreme values in the distribution.

4.4.1 Exposure by occupation title

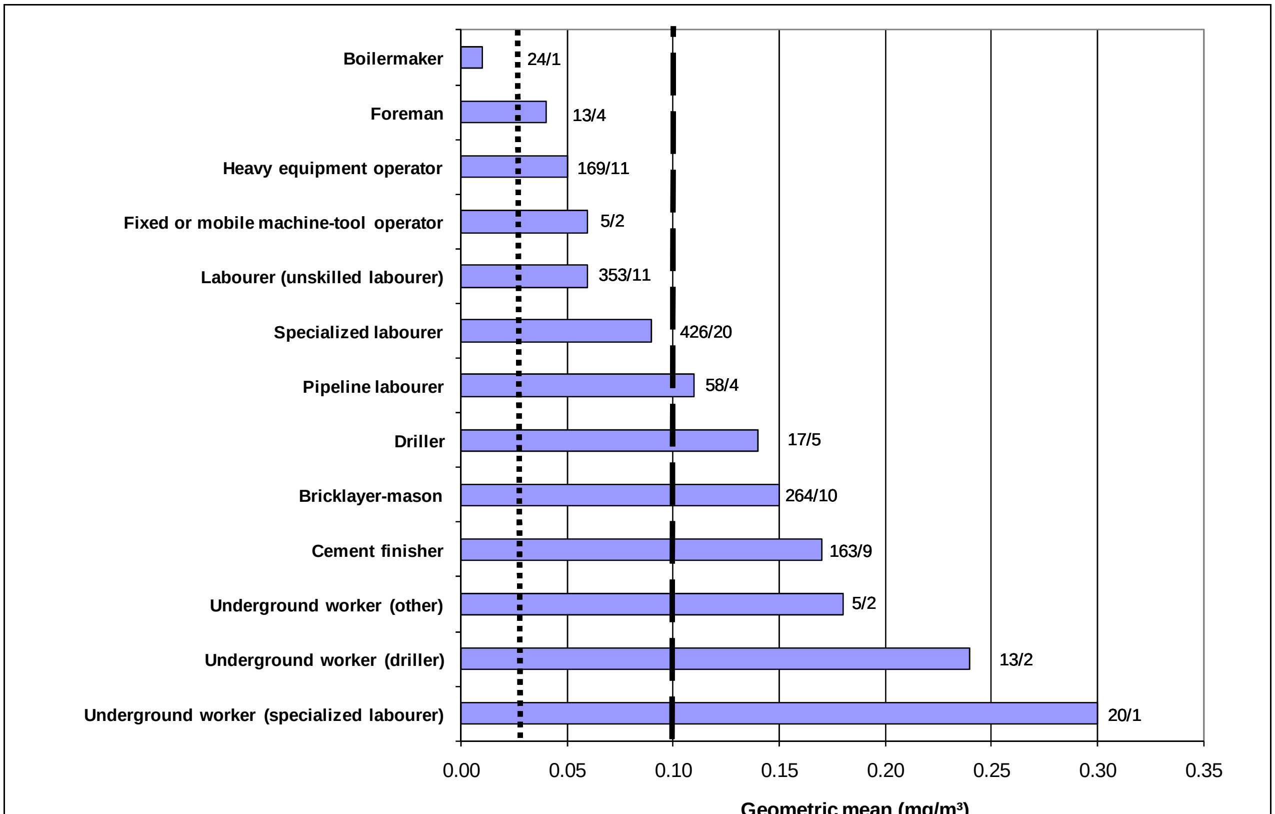
Appendix 4 presents all of the measurements grouped by occupation title coded for Québec.

Only those measurements whose objective was to evaluate an average 8-hour exposure in order to compare them to an exposure limit value (OEL) were retained. There were 1,745 measurements, or 41% of the available individual respirable crystalline silica measurements.

Note that the OEL for Québec, namely the permissible exposure value – time-weighted average exposure value (PEV-TWAEV) for quartz is 0.1 mg/m³ [21] while the ACGIH *Threshold Limit Value* (TLV) is 0.025 mg/m³ [20]. These TLV are used in these graphs only to indicate the order of magnitude of the documented measurements and not to show compliance with or exceedence of Québec's regulatory values.

Figure 1 presents the exposure levels for the 13 occupation titles documented in the database that meet the selection criteria mentioned above.

Figure 1 - Respirable crystalline silica exposure by occupation title



•••••••••	ACGIH TLV	- - - - - -	Québec OEL
n/nS	n: number of measurements		nS: number of studies

Underground workers, with an average 8-hour exposure close to 2 to 3 times the Québec TLV, stand out from the other occupation titles. The tasks associated with these measurements are essentially work near a tunneling machine for the first two occupation titles, and breaking masonry in the case of the underground worker (specialized labourer).

Drillers, bricklayer-masons and cement finishers make up a second group in which the average exposure levels are between 1.4 and 1.7 times the Québec TLV. In the case of drillers, all the measurements are associated with the use of a drilling machine. For bricklayer-masons, the measurements are associated with a range of tasks, including grinding brick/stone joint grinding with an exposure level of 0.49 mg/m³ (40% of the measurements) and joint filling with 0.022 mg/m³. For cement finishers, when the measurements are associated with surface grinding (38% of the measurements), the exposure level is 0.24 mg/m³, while it is 0.052 mg/m³ for “other tasks” (21% of the measurements). However, for this last occupation title, tasks “not specified” (25% of the measurements) produce an exposure level of 0.48 mg/m³.

Pipeline, specialized and unskilled labourers, as well as fixed or mobile machine-tool operators make up a third group, with average exposure levels of 0.6 to 1.1 times the Québec TLV. In the case of pipeline labourers, the average exposure level includes the levels associated with abrasive blasting; without these levels, the pipeline labourer’s exposure level would be 0.03 mg/m³. Unskilled labourers’ exposure is essentially related to the use of shovels, brooms, squeegees and blowers. The activity of the specialized labourer involves a wide range of tasks and tools, definitely the most varied in the construction industry. For example, this worker may be exposed on average in 8 hours to 0.053 mg/m³ when he mixes mortar or cement (5% of the measurements), 0.11 mg/m³ in drilling masonry (11% of the measurements), 0.13 mg/m³ when providing support to bricklayer-masons (4% of the measurements), and 0.26 mg/m³ when breaking masonry using a jackhammer or percussion drill (25% of the measurements). The measurements relating to fixed or mobile machine-tool operators all correspond to rock crushing.

The fourth group, where the average exposure levels are below half the TLV, consists of heavy equipment operators, foremen and boilermakers. For heavy equipment operators, their exposure is 0.062 mg/m³ (63% of the measurements) with the use of a road-milling machine, and is 0.019 mg/m³ (22% of the measurements) when machines such as backhoes, excavators, bulldozers, bucket loaders or mechanical diggers are involved. The only results for boilermakers come from measurements of exposure to coal dust containing a small percentage of respirable crystalline silica in the renovation of coal boilers.

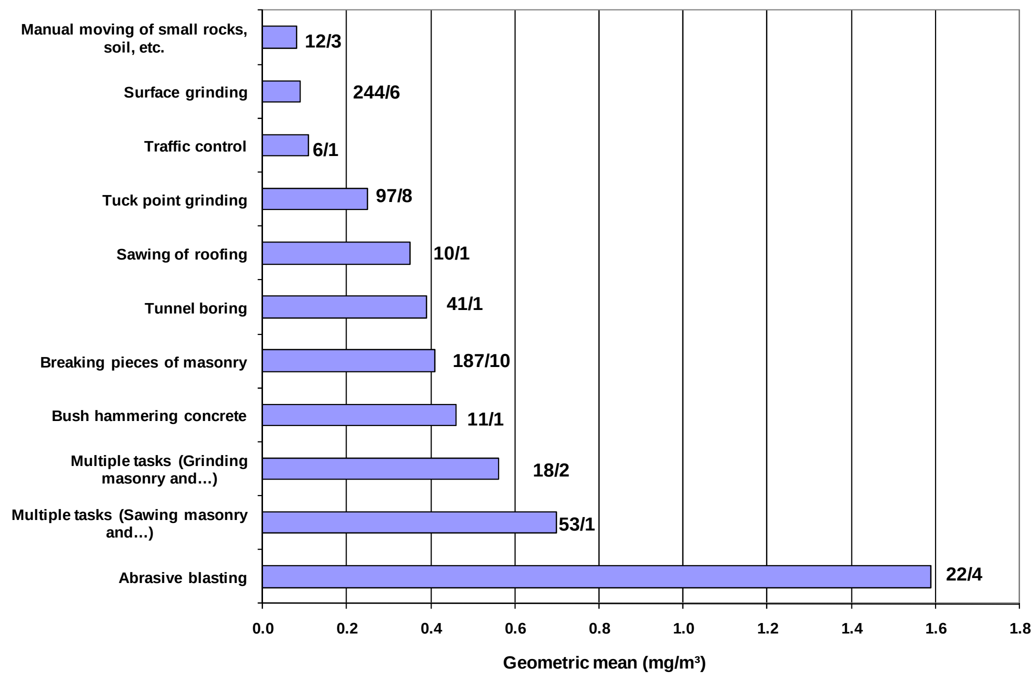
The occupation titles of carpenter-joiner, truck driver, electrician, specialized labourer (tile setter), plasterer, interior systems installer and pipe fitter are in the database, but were excluded from these descriptive statistics based on the selection criteria (see Section 3.6).

4.4.2 Exposure by task performed, materials and tools

Appendix 5 presents all of the measurements grouped by task coded for Québec. Figure 2 shows the exposure levels for all tasks with exposure levels above the Québec TLV of 0.1 mg/m³, as well as the two tasks whose exposure level is slightly below the TLV. Appendix 6 presents all of the measurements grouped by material, while Appendix 7 presents those measurements grouped by tool. Figures 3 and 4 present all the values for these two parameters, whose exposure levels are above the Québec TLV, as well as the first value whose exposure level is slightly below the TLV.

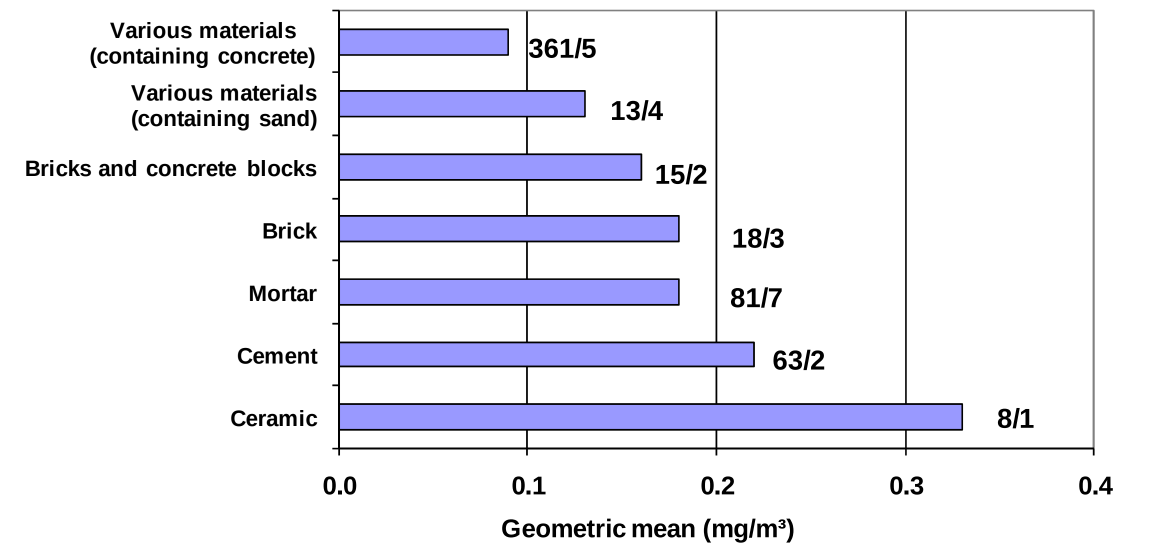
Only those measurements whose objective was to evaluate the exposure during the task performance period were retained. The duration of these tasks varied from a few minutes to several hours.

Figure 2 –Respirable crystalline silica exposure by task



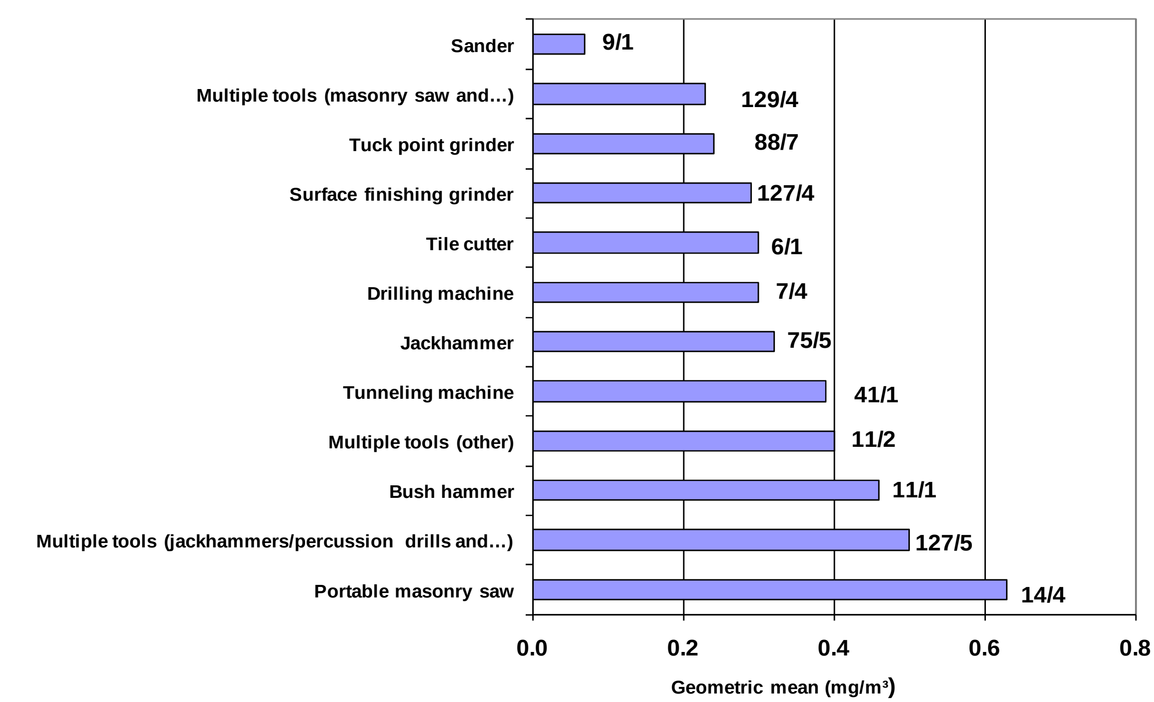
n/nS n: number of measurements nS: number of studies

Figure 3 – Respirable crystalline silica exposure by material



n/nS n: number of measurements nS: number of studies

Figure 4 – Respirable crystalline silica exposure by tool



n/nS n: number of measurements nS: number of studies

The crystalline silica exposure level associated with the “Abrasive blasting” task in Figure 2 is indicated only to show the specific nature of this activity. There was no search for sources of data associated with this task because it was not included in this study’s mandate. However, values in sources of data relating to other tasks were entered in our database.

The average exposure level during the “Multiple tasks (Sawing masonry and other)” task is associated only with the work of the specialized labourer with several tools on various materials containing concrete for an average period exceeding three hours.

The average exposure level associated with the “Multiple tasks (Grinding masonry and other)” task is strongly influenced by one of the two documented studies. This task was performed during the sanding and smoothing of a stone surface of an historical building, in Europe, by a stonecutter (1.0 mg/m³) with various tools, over an average period exceeding 8 hours.

Bush hammering concrete is a task performed by specialized labourers. The bush hammer, in the only study presented here, was used with and without spraying built into the equipment. The worker’s average exposure level over a period of 6.5 minutes reached 0.97 mg/m³ without spraying, while it was 0.19 mg/m³ with spraying. Note that measurable exposure levels were able to be obtained for such short task durations by using cyclones, whose volume flow rate is 4.2 litres per minute [46]. These instruments are not commonly commercially available in Québec.

Breaking masonry is associated with the use of jackhammers/percussion drills on concrete or various materials containing concrete by a specialized labourer (0.46 mg/m³) on average for approximately three hours, or on ceramic by a specialized labourer (tile setter) (0.34 mg/m³) for an average of approximately one hour. The same task performed by heavy equipment operators or fixed or mobile machine-tool operators produces exposure levels of approximately 0.05 mg/m³.

Tunnel boring is done solely by a tunneling machine operator drilling into stone for an average period of 390 minutes, while brick/stone joint grinding is done by bricklayer-masons grinding mortar for an average period of four hours.

The average exposure level associated with traffic control depends on the dust levels on a road maintenance site caused by passing passenger vehicles as well as those associated with the site work.

Surface grinding, lasting approximately four hours on average, is the activity of a single occupation, the cement finisher, using a surface finishing grinder on concrete or cement.

The “manual moving of small rocks, soil, etc.” is done by unskilled labourers with shovels, brooms and occasionally motorized tools, depending on the scope of the task to be performed and the materials involved.

Figure 2 does not show the masonry sawing task due to its low average exposure value of 0.07 mg/m³. However, it should be noted that while the use of a masonry saw bench or a walk-behind concrete saw produces only an average exposure level of 0.05 to 0.06 mg/m³ over 4 to 5 hours on average, the use of a portable masonry saw may expose workers to concentrations of 0.74 mg/m³ for more than one hour. Another example shows important potential disparities in the respirable crystalline silica exposure levels for a given task, but this time, between two occupation titles for “Drilling masonry”: Electrician (0.004 mg/m³ for 380 minutes on average) and Specialized labourer (0.048 mg/m³ for 380 minutes on average).

4.4.3 Other parameters that can affect exposure

Use of respirators

A synthesis of the information in the database yields the following respirator portrait. When the data sources contained information on the wearing of respirators, 70% of the workers wore a respirator when the measurements were taken. When the level of respirator use was mentioned (841 measurements), only 63% of the workers wore it continually during the work period. When the type of respirator was specified (1140 measurements), 59% of the workers wore a filtering facepiece respirator. No data were available about the quality of the fit of the respirator’s facepiece. Only 33% of the 6,125 lines in the database contain information about respirators.

Nature of the sampling site

Comparison of the geometric means of the exposure levels associated with each of the values of the “Nature of the sampling site” parameter does not confirm the intuitive assumption that these levels should progressively decrease when going from an enclosed space to a completely open outdoor environment.

Class and type of construction site

The measurements used for the following results were collected to evaluate the task alone or evaluate an average over 8 hours.

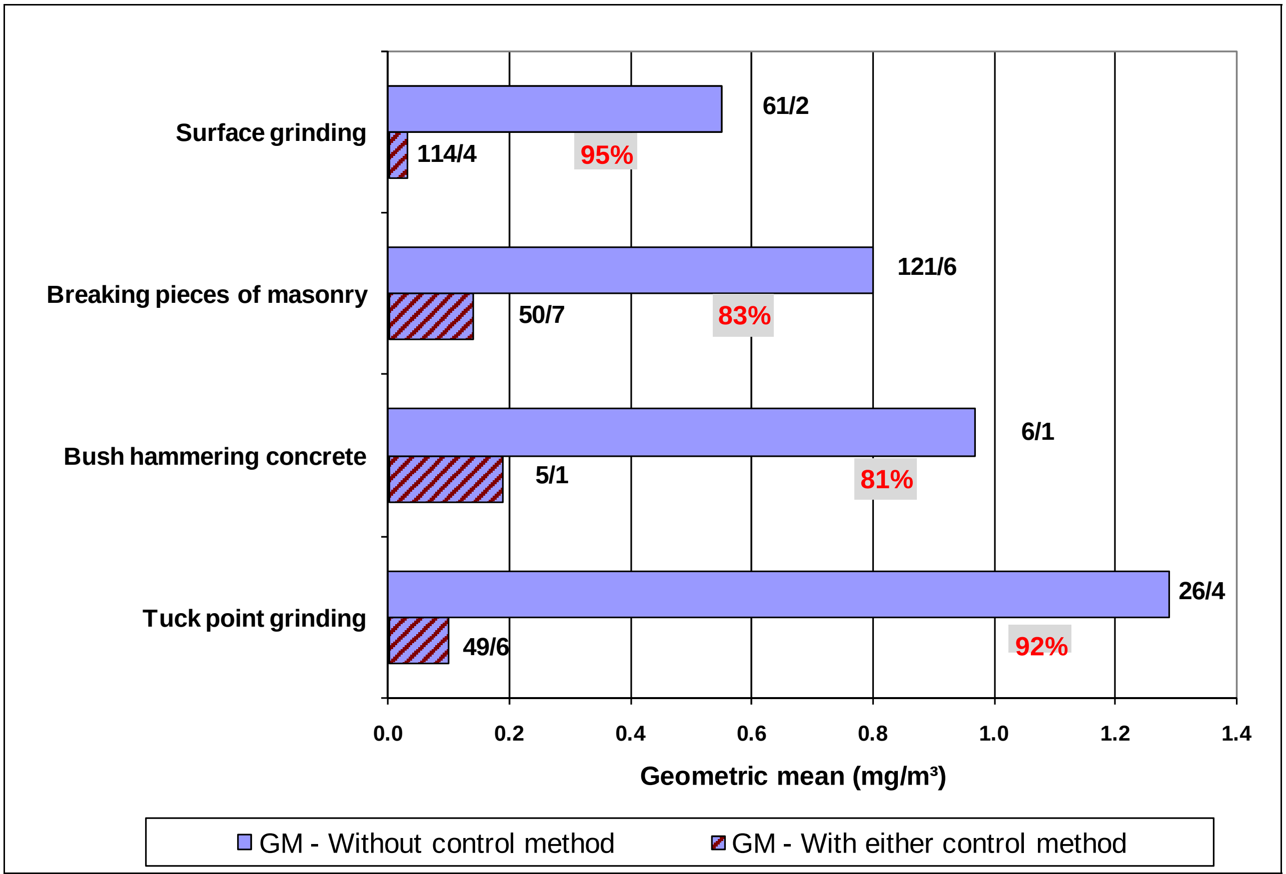
While the “Industrial” and “Civil engineering/Roadwork” site classes generated average exposure levels of 0.028 and 0.030 mg/m³ of respirable crystalline silica in the workers’ breathing zone, “Residential” and “Institutional and Commercial” sites produced levels of 0.087 and 0.097 mg/m³ respectively.

“New construction” sites are associated with an average exposure level of 0.027 mg/m³, “Renovation” sites with 0.048 mg/m³, and “Demolition” sites with 0.098 mg/m³.

Use of a control method during certain tasks

Figure 5 presents four tasks whose exposure level exceeds 0.4 mg/m³ without any means of control. The results in this figure were taken from workers’ breathing zone exposure measurements where it was possible to identify whether or not a control method was used during the task, and if so, which was used. The measurements used for the following calculations were taken for evaluation of the task alone or evaluation of an average over 8 hours.

Figure 5 – Impact of the use of a control method on exposure during a task



n/nS n: number of measurements nS: number of studies

With either of the control methods, one or a combination of the following was used: general ventilation, local exhaust ventilation near the tool, local exhaust ventilation on the tool, spraying of the material, built-in spraying, isolation of the emission source, or any other control method.

This graph clearly shows that, for the tasks presented, the use of a control method had a major impact on the exposure level.

4.5 Exposure control methods

4.5.1 Identification of control methods

General means of prevention

Numerous organizations (NIOSH [47], HSE [48], WorkSafeBC, [49, 50], Occupational Safety and Health Administration (OSHA) [23, 24, 51], Arbouw [52], COSH - Commission for Occupational Safety and Health Australia [53], Industrial Accident Prevention Association (IAPA) [54], CSST [55], Ontario Ministry of Labour [56], ASTM [57]) have published general methods for preventing crystalline silica dust on construction sites. Below is a summary of these recommendations adapted to Québec laws and regulations:

- Identify situations where there is a possibility of emission of respirable dusts containing crystalline silica
- Plan for the elimination of crystalline silica at source by substitution or by the use of materials containing only a small amount, where possible
- Control dust emissions by technical means such as confinement, spraying and local exhaust ventilation
- Ensure that the equipment used for exposure control is properly maintained
- Confirm the performance of technical controls by environmental monitoring campaigns whose strategy is presented in detail in the IRSST's Sampling Guide [58]
- Know and use "good work practices"[2]
- Use respirators according to the requirements described in the *Guide pratique de protection respiratoire*, with the most important requirement being the existence and application of a respiratory protection program [59]. The choice of respiratory protective equipment must be based on the workplace sampling results
- Train and inform workers likely to be exposed to crystalline silica dust
- Verify the effectiveness of general site housekeeping
- Use fans only for cooling the environment when there is excessive heat. They are not effective for reducing dust concentrations in the air
- Avoid the use of compressed air for cleaning clothing or other objects[3]
- Consider using a worker booth

Technical controls

Spraying and local exhaust ventilation apply to most situations where technical means are used to control the dust emissions from tools. First, a summary of aspects of spraying, local exhaust

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[2] The term "**good practices**" designates, in a given occupational environment, a set of agreed-upon necessary practices, generally presented in the form of Good Practices Guides (GPG).

[3] In Québec, it is prohibited to use compressed air to clean a person (ROHS, section 325). To clean a machine or equipment, the compressed air pressure must be less than 200 kilopascals, unless it is done in an enclosure specially designed for abrasive air blasting cleaning and equipped with a vacuum system (ROHS, section 326).

ventilation, and a few other general control techniques is presented, with specific methods that apply to each of the tools.

Spraying

The challenge in optimizing the effectiveness of spraying is that water droplets the same size as the dust particles be sprayed at the dust emission point. With this approach, the least amount of water possible can be used while remaining effective, and allow proper management of the water supplied and eliminated.

The following components must be part of a spraying system at the dust emission point:

- A water source (municipal hydrant, tank with pump, etc.)
- A strong flexible hose
- A tap for adjusting the water flow
- A sprayer that adjusts the size the water particles
- A connection to the tool

Water use requires that possible freezing be taken into consideration and that a ground fault circuit interrupter and waterproof electrical connectors be used for electrical tools and other equipment on the construction site.

Maintenance of the spraying system must include:

- Frequent checking for clogging of the sprayer
- Checking that the water is directed towards the emission source
- Checking for a uniform water flow
- Air circulation in enclosed areas, to avoid any sudden increase in dust levels in the air due to a reduction in the effectiveness of the exposure control systems
- Piping and treatment of wastewater according to applicable regulations

Local exhaust ventilation

The following components must be part of a local exhaust ventilation system:

- A dust collector adapted to the tool
- An industrial vacuum
- A suction hose and a filtration system for collecting the dust

Other considerations:

- Systematic cleaning of the vacuum system
- Verification of the effectiveness of particle exhaust and filtration

The adoption of "good work practices" increases the efficiency of the exhaust ventilation. Details about local exhaust ventilation systems are given in the OSHA [24] and NIOSH [60, 61] documents. The points to be considered in choosing a dust collector are weight, ease of use, ability to see the work surface, and durability [62]. The advantages of using local exhaust ventilation built into the tool are: reduced risk, the possibility of using a lower level of respiratory protection, protection of other workers on the same site during the work, protection of the worker during exposures to high concentrations during short-duration work episodes, and reduced clean-up [63]. Particular attention must be paid to the outlet of the local exhaust ventilation system so that harmful substances (crystalline silica, etc.) are not released back into the ambient air.

Substitution

Substitution is a primary control method that eliminates the use of a hazardous substance by replacing it with another less hazardous substance or with a different process [64].

Crystalline silica can be replaced in some materials used in the construction industry. The Ontario Ministry of Labour recommends that sandstone grinding wheels be replaced with corundum (aluminum oxide) wheels, and that refractory magnesite (magnesium carbonate) bricks or corundum bricks be installed in furnaces instead of siliceous bricks [56]. Crystalline silica has also been used for a long time as filler material in many products used in the construction industry, for example wood fillers, joint compounds, sealers, and paints [66]. The use of silica-free joint compounds is recommended as the method of choice for preventing silicosis in drywall finishers [24]. In some cases, part of the silica sand could be replaced with limestone in the production of concrete, without compromising its technical qualities [67].

Since construction workers often work with materials that contain crystalline silica, replacement of the silica in the added materials does not eliminate all exposure to this substance. Substitution is therefore a method of prevention that must necessarily be applied at the same time as other exposure control methods in the construction industry. It should be remembered that substitution is also possible in the case of sand blasting [4, 5, 6, 68] but this process was not covered by the mandate of this project.

Other exposure control techniques

VEHICLE CAB

Construction site workers perform some tasks using heavy vehicles whose cab can be designed to protect the operator from dust [24, 69, 70]. For these vehicles to be effective and apply to the requirements for protecting the environment as well as workers not in the cab, local exhaust ventilation (for which sophisticated dust collection systems are commercially available) must be used in conjunction with spraying (which is possible and effective, but more difficult to use in some cases due to problems with clogging and elimination of wastewater). Demolition machinery using a ram [71] is one example. The technology used in mines and agriculture may also apply in construction sectors [69, 72-74]. Clearly, this solution is effective as long as the operator can remain inside the cab with the doors and windows closed. The efficiency of the filtration system for a vehicle cab, which applies to any other heavy equipment, would be 99% for aerosols > 3 µm, but would gradually decrease for the smallest diameters. This is equivalent to a protection factor of 100. To achieve this, the cab should be air-conditioned and the ventilation system should be well maintained. Spraying is possible and effective but more difficult to use in some cases due to problems with clogging and elimination of the wastewater.

DUST SUPPRESSANT

Dust suppressants are used to protect workers doing maintenance on construction sites as well as their coworkers who could be working during the maintenance operations. Dust suppressants involve two main techniques: wetting and encapsulation. Dust suppressants are widely used, but their effectiveness in specific contexts is not well documented [24]. One study compares the laboratory performance, on different concretes, of water (efficiency: 45%), Coherex® (aqueous emulsion of resins of unidentified hydrocarbons or wetting agents) (efficiency: 45%), and a crusting agent (polyacrylate in the aqueous phase) (efficiency: 48%) [70].

SITE HOUSEKEEPING

Site housekeeping is important to avoid the resuspension of deposited dust by cleaning activities and subsequently by regular construction site activities. The following are recommended:

- Replace dry sweeping with wet sweeping, removing water and debris with a squeegee or an industrial water and dust vacuum
- Prohibit the use of an air jet to remove or eliminate dust
- If possible, workers should be located upwind from the dust emission sources
- Use a sufficient amount of water to wet the dust deposits or piles
- As much as possible, thoroughly wet the dusty materials or waste before transporting them or handling them

Clearly, water use requires the prevention of freezing and consideration of the electrical risk. Water is particularly effective for avoiding dust suspension in the air, but the addition of surface-active agents to the water increases its capacity for thorough wetting of the dusts. Other products can be used to reduce the dust coming from the ground. They are:

- Acrylic polymers
- Solid or liquid asphalt
- Chloride salts
- Lignin compounds
- Natural oil resins
- Organic resin emulsions

An OSHA publication [24] provides more details on each of these compounds.

In cases where water cannot be used due to operational considerations when cracked materials or rough surfaces are present, the use of an industrial vacuum with a high efficiency filter is a good method for site maintenance. Workers must therefore be trained in the correct operation of the vacuum, and mainly in the handling of dust bags or collectors.

4.5.2 Control methods specific to certain tools

This section summarizes the control methods described in the scientific and technical literature. A detailed description of each can be consulted in the documents, particularly those of OSHA [24], the HSE [48] and NIOSH [61, 75-77].

The tools are presented in decreasing order of the crystalline silica emissions documented in the section on exposure, namely: the portable masonry saw and masonry saw bench [24] > the jackhammer/percussion drill (rotary hammer, etc.) and the hammerdrill and similar tools > the surface finishing grinder > the brick/stone joint grinder > the drywall sander and other various tools.

For detailed technical information on the tools available in North America, the reader can consult the solutions proposed by the Center for Construction Research and Training [78].

Portable masonry saw and masonry saw bench

Spraying

Built-in water spraying onto the saw blade allows compliance with OSHA's TLV in most cases where a saw bench and a portable saw are used outdoors. For a portable masonry saw used indoors, spraying may not be sufficient to comply with the Québec PEV-TWAEV (0.1 mg/m^3). Respiratory protection then becomes necessary [24].

Local exhaust ventilation

The use of a masonry saw bench with built-in local exhaust ventilation reduces short-term exposure by 80 to 95%. However, this reduction does not result in compliance with the Québec PEV-TWAEV in all cases. Respiratory protection must be used.

Jackhammer/percussion drill, hammerdrill and similar tools

This section covers different tools that are used for breaking, demolishing or drilling small diameter holes in concrete, asphalt and other construction materials. These tools require similar local exhaust ventilation and spraying techniques and good work practices.

Spraying

There are no jackhammers/percussion drills and hammerdrills with built-in spraying systems [76, 79]. However, the addition of a spraying system is simple and inexpensive [76, 80]. Manual spraying by a helper trained in this task is also effective. Spraying seems to result in compliance with the OSHA standard of 0.1 mg/m3, except for use inside a building, but not at the value recommended by the ACGIH, which was 0.05 mg/m3 at the time the consulted report was published [24].

Local exhaust ventilation

All these commercially available tools can be equipped with a flexible cylinder with a suction hose that surrounds the bit or the point of the tool and rests on the surface around the dust emission point. The installation details are described in the OSHA document [24], which also covers occasional users and modifications to an existing tool [24, 76, 80]. Four options are described by Shepherd *et al*. [81] that can reduce by 94% the average concentration of respirable crystalline silica dust. The results are well below 0.1 mg/m^3, but other improvements would be required to ensure compliance with the threshold limit value (TLV) of 0.025 mg/m^3 proposed by the ACGIH. The adaptation of this setup to other tools (surface or joint grinders) is probably not achievable.

Surface finishing grinder

Hand-operated surface finishing grinders are electrical or pneumatic tools that are used for surface finishing or for cutting grooves [24, 61].

Spraying

In general, surface finishing grinders with built-in spraying towards the disk comply with OSHA's exposure limit value even on uneven surfaces or in corners, where local exhaust ventilation is less efficient. Spraying requires that workers receive training because some visual acuity can be lost due to the water mist and the colour change in the moistened surface. In addition, the mud formed by contact between the water and dust requires surface cleaning with an industrial vacuum or by successive rinsing. Despite these limitations, spraying remains a very effective control technique for surface finishing grinders.

Local exhaust ventilation

Commercially available surface finishing grinders with local exhaust can reduce exposure by 80 to 95%, which is not always sufficient to comply with regulations.

Good work practices

Several good work practices reduce the dust emissions from surface finishing grinders:

- Choose the appropriate size and type of disk (small diameter = less dust)
- Use the least coarse disk for the work
- Use poles attached to the tool to distance the worker from the emission point
- Encourage work practices that reduce the grinding time (grinding should only be done on fresh concrete; use a hammer, chisel or pneumatic tool to remove large irregularities; use prefabricated panels, etc.)
- If possible, use an enclosure to keep the dust from being propagated over the rest of the site or building [50]

Tuck point grinder

Hand-operated grinders are used to remove mortar joints between bricks, stones or cement blocks.

Spraying

Generally, spraying cannot be used for two reasons:

- A layer of mortar dust and water form a mud (slurry) on the material
- The water can seep into the building structure

Local exhaust ventilation

Local exhaust ventilation built into the grinder reduces the concentration of crystalline silica and respirable dust in the air. It does not ensure compliance with the exposure limit values, but allows the use of a lower level of respiratory protection. Respiratory protection must therefore be routinely used, in conjunction with local exhaust [24, 77, 82-84].

Good work practices

Good work practices can also reduce the crystalline silica concentration in the air, increase the efficiency of the dust collector, and enable workers to use a lower level of respiratory protection. Good work practices that should be applied during the use of a brick joint grinder are:

- Correctly insert the disk so that the tool comes in contact with the surface, and the dust collector can exhaust the dust
- Adjustment of disk depth: the greater the depth, the more mortar dust is produced
- No back-and-forth motion: always move the grinder slowly in the same direction
- Remove the grinder from the surface and wait a short time to allow the system to suction the accumulated dust before replacing the disk
- Apply a normal and constant force
- Prepare and maintain the suction equipment (essential)
- Train the worker (essential)
- Properly position the vacuum under the tool and change the bag regularly before it breaks or plugs
- Use a cyclone vacuum for the initial collection cycle to avoiding plugging of the vacuum's filter (bag) [82]

Several articles emphasize that local exhaust techniques, respiratory protection, and good practices slow the work pace and reduce the efficiency, and that technical improvements are necessary to encourage the use of these techniques [84-87].

Drywall sander

No reference could be found on the crystalline silica exposure of plasterers who use products containing crystalline silica. All the results are expressed as "total" or respirable dust. However, since this operation inevitably creates a great amount of dust, exposure control methods are still recommended.

Local exhaust ventilation

Commercially available drills with built-in ventilation have an efficiency of 80 to 97% for total dust [24]. The use of a pole to distance the worker from the emission source reduces the total dust exposure by 96%, and manual sanding with a pole reduces it by 95%.

Wet sponge

Wetting with a moist sponge can reduce exposure by 60% during sanding [88]; this is an improvement but remains below the effectiveness of local exhaust ventilation.

4.5.3 Evaluation of the effectiveness of control methods

The data on the effectiveness of technical exposure-control methods are presented in Table 5, as reported in the documents, and include the breathing zone and stationary sampling results, and observations with direct-reading instruments (DRI). Note that the interpretations of the capacity of different control methods to comply with the exposure values originated from the authors of the cited articles. When the authors mentioned efficiencies at different equipment adjustment levels, such as the water flow or ventilation rates, the configuration with the best performance was reported in the table.

Table 5 – Exposure reduction using a control method as reported in various documents

Tool	Material	Control method	AMpr[1]	N[2]	AMq[3]	C[4]
			%		%	
Brick/stone tuck point grinder	Mortar[85]	Built-in exhaust ventilation	97	10	92	no
	Mortar[86]	Built-in exhaust ventilation	98	NS[5]	-	NA[5]
	Mortar[63]	Built-in exhaust ventilation	86	13	85	no
	Mortar[87]	Built-in exhaust ventilation	-	5	91-93	no
	Mortar[89]	Built-in exhaust ventilation	99	5	98	no
		Built-in spraying	81	5	84	no
	Concrete [14]	Built-in spraying	91	5	-	NA
	Calcareous sandstone(stone)[12]	Built-in exhaust ventilation or spraying	>99	-	-	NA
Surface finishing grinder	Concrete[90]	Built-in exhaust ventilation	92		-	NA
	Concrete[63]	Built-in exhaust ventilation	96	2	94	no
	Concrete [62]	Built-in exhaust ventilation	>90	40	-	NA
	Concrete block[87]	Built-in exhaust ventilation	94	5	-	NA
	Brick[87]	Built-in exhaust ventilation	91	5	-	NA
	Calcareous sandstone(stone)[12]	Built-in exhaust ventilation	>99	3		NA
	Concrete[91]	Manual surface spraying by a water mist	97	7	98	no
Jackhammer	Concrete[92]	Built-in spraying	72-90	4	-	NA
		Built-in exhaust ventilation	58	4	-	NA
	Concrete[93]	Built-in spraying	71[6]	4	77[6]	no
	Concrete [81]	Built-in exhaust ventilation	85	14	94	no
	Concrete [94]	Built-in spraying (atomization)	73	4	86	no
			85	4	64	no
	Concrete [95]	General ventilation	17	4	25	no
		Local exhaust ventilation	54	4	69	no
		General and local exhaust ventilation	69	4	78	no
Portable masonry saw	Concrete block[63]	Built-in spraying	91	5	-	NA
Saw bench	Concrete block[87]	Built-in spraying	91	5	-	NA
	Brick[87]	Built-in spraying	91	5	-	NA
Broom	Calcareous sandstone (stone)[12]	Local exhaust ventilation	84-99	-	-	NA
		Spraying	12-99	-	-	NA
Hand sander	Joint compound [96]	Built-in exhaust ventilation	80-97	-	-	NA
		Use of a pole without local exhaust ventilation	45	-	-	NA
Compacting machine (light, 81 kg)	Soil [94]	Built-in spraying	87	8	88	no

Tool	Material	Control method	AMpr[1]	N[2]	AMq[3]	C[4]
			%		%	
Compacting machine (heavy, 449 kg)	Soil [94]	Built-in spraying	56	8	0	no
Cold road-milling machine	Asphalt [97]	Spraying (17 gpm[6])	-	-	74	-
		Spraying (conveyor, 7 gpm[6])	-	-	60	-
	Asphalt [98]	Spraying	-	-	0	-
	Asphalt [99]	Spraying	50-75	-	65	No[7]
Drill	Concrete [100]	Local exhaust ventilation	89	21	-	NA

1: arithmetic mean for exposure reduction using respirable dust measurements.
2: number of results.
3: arithmetic mean for exposure reduction using respirable quartz measurements.
4: capacity of the control method to ensure compliance with national regulations or the reference value for crystalline silica by assuming an 8-hour exposure.
5: NS = Not specified and NA = Not applicable, due to lack of results for crystalline silica.
6: gpm: gallons (US) per minute.
7: compared to the Dutch limit value of 0.075 mg/m^3. The results refer to large milling machines (width: 2100 mm). Smaller machines are below the standard.

For comparison to the Québec context, the reader must take into account the different exposure limit values proposed by the various organizations or imposed by government regulations. OSHA uses a reference value of 0.1 mg/m^3 (8 hours)[4] identical to the current PEV-TWAEV in Québec for respirable crystalline silica (quartz), while NIOSH proposes 0.05 mg/m^3 (10 hours) and the ACGIH recommends 0.025 mg/m^3 (8 hours). The ACGIH proposes an average Threshold Limit Value (TLV) of 3 mg/m^3 (8 hours) for insoluble or poorly soluble respirable particles not otherwise classified (PNOS), while Québec has no exposure limit value for respirable dust not otherwise classified.

In summary, Table 5 indicates that built-in local exhaust on brick/stone joint grinders as well as local exhaust or spraying built into surface finishing grinders, portable masonry saws and saw benches have efficiencies between 90 and 99%. Joint compound sanding with built-in ventilation provides efficiencies of 80 to 97% for respirable dust. No publications were found on the crystalline silica exposure level for sanding. The efficiencies varied from “nonsignificant” to 88%. The very fragmentary results (0%) for soil compacting and cold road-milling machines are outdoor measurements, where the few exposure determinants do not explain the results.

4.6 Relational database

A Microsoft Access® database was prepared in order to meet the objectives presented in Section 3.7. The information that it contains comes from the compilation of all the exposure data before their transformation, as described in Section 3.4.

[4] The legal value in the United States (OSHA) for construction sites is 250 mppcf / (% crystalline silica + 5). However, this value is considered as obsolete by OSHA scientists in the context of evaluating the performance of technical exposure control methods, and a benchmark value of 0.1 mg/m^3 is recommended [19].

5. DISCUSSION

5.1 Analysis of exposure levels

The results presented in Section 4.4 come from a synthesis of studies from different countries, motivated by various objectives (epidemiology, exposure control or verification of regulatory compliance) and whose exposure conditions are unequally documented. However, since the great majority of exposure data are from North America, and considering the effort to adapt data to the Québec context, the exposure levels presented in this work can accurately represent the Québec situation, particularly when establishing an intervention priority in the construction sector.

The InVS occupation-exposure matrix [45], BGIA report [42], ERG report [43] and ACGIH project [11] were chosen for comparison with the results of our study. Appendix 8 presents the comparison of the exposure levels associated with the occupation titles in the database with the other sources of information, while Appendix 9 presents the comparison involving the tasks performed. Several task values in the BGIA report [42] have been included for information purposes in Appendix 9, even though they have no equivalent in our database.

Occupation titles

Figure 1 (Section 4.4.1) shows that several occupation titles are potentially associated with average 8-hour crystalline silica exposure levels exceeding the Québec PEV-TWAEV.

Underground workers seem to be at particular risk of overexposure, possibly due to the "confined" nature of their work environment. For these workers, a clarification is necessary. In the Québec construction collective agreements [36-39], only the "Underground worker" occupation title exists. A distinction according to the type of work performed was added, creating four occupation subtitles: surveyor, pipeline labourer, driller and specialized labourer. However, the first two occupation subtitles were combined into "Underground worker (Other)" to comply with the rule of "n" $\geq$ 5 (see Section 3.6). The "Underground worker (Surveyor)" obtained the highest average exposure of the underground workers, namely 0.37 mg/m³ of respirable crystalline silica for 3 measurements. While the surveyor's work does not generate crystalline silica, his frequent presence near the tunneling machine would explain this exposure level. Furthermore, the value of 0.39 mg/m³ measured over a 390-minute period for the tunneling machine operator, as described in Section 4.4.2, is consistent with this hypothesis.

Frequent grinder use by bricklayer-masons and cement finishers as well as the continual use of drilling machines by drillers are certainly the reasons for the high exposure levels for these 3 occupation titles. A more detailed analysis of the results in Figure 1 (Section 4.4.1) shows that occupation titles, such as the bricklayer-mason and cement finisher, involve a variety of tasks with very different exposure levels. Also, these tasks can be sufficiently long during a work day that they become the only source responsible for the average 8-hour respirable crystalline silica exposure level. The exposure of roofers, whose average exposure is 0.14 mg/m³, was excluded from Figure 1 because it applies only to workers installing or renovating concrete slab roofing, an unusual situation in Québec. These results cannot be applied to roofers who use other materials, such as those materials for tar roofs.

When sand blasting is excluded from the tasks of pipeline labourers, the specialized labourer has the highest respirable crystalline silica exposure among the three labourers (specialized, pipeline and unskilled labourers), during a large number of different tasks. Since this worker regularly uses tools generating the highest exposure levels, such as a portable masonry saw and jackhammer, it is clear that particular attention must be paid to this occupation title.

The occupation titles presented in the InVS occupation-exposure matrix are not directly comparable due to the coding used in our database. Also, the exposure levels are expressed in a relative way in this matrix, which makes a comparison with levels presented in mg/m³ impossible. However, the workers associated with the various demolition and cleaning activities (specialized labourer, pipeline and unskilled labourer), bricklayer-masons, and cement finishers are associated with the most exposed groups in this matrix, just as they are in our list (Figure 1 and Appendix 4).

A low level of exposure is observed for heavy equipment operators, at the controls of closed-cab machines. An operator in his cab is in fact isolated from the emission source, while an operator in an open cab on the same machine, or a worker performing the same task with a portable tool, are not. While no exposure measurement in the database shows this phenomenon, the difference between these two ways of performing the same task is visible in a compilation of similar occupations in surface mines in the United States. All the manual occupations evaluated between 1988 and 1992 (3192 measurements) had exposure levels above 0.05 mg/m³, while all operators of machinery (closed or open cab) had levels below 0.05 mg/m³ (5672 measurements) [101]. Among heavy equipment operators, the operators of road-milling machines and tunneling machines must be considered separately.

Contrary to several machines that can be equipped with closed ventilated cabs, the road-milling machines described in our data sources do not have them. Only spraying and local exhaust on the movable parts of this machine reduce the operators' exposure levels. The measurements describing this exposure come from three data sources and involved the field testing of several effective control methods for reducing the emission of respirable dusts from this equipment. These recent machines were designed to reduce the operators' exposure to a minimum. However, the database contains no exposure levels associated with the use of road-milling machines operating without control methods. While the average exposure level at the controls of road-milling machines is three times that of operators of heavy equipment with closed cabs, it is likely the lowest that can be found with this type of equipment. Furthermore, Appendix 9 shows a large disparity for "Diamond cutting of concrete or asphalt," which corresponds to the task of a "Heavy equipment operator" at the controls of a road-milling machine. The German measurements, collected during the task, indicate an exposure level of 0.42 mg/m³ (146/23), while our database proposes 0.02 mg/m³ (40/3), a value twenty times lower. Since the measurements in the database reflect the "ideal" operating conditions for a road-milling machine, the exposure level proposed by the BGIA would be more representative of the conditions encountered in Québec. Evaluation of the exposure of a heavy equipment operator at the controls of a tunneling machine for tunnel boring, carried out for more than six hours, indicates that the TWAEV is at least 0.32 mg/m³. This daily exposure level is the same as that of the most highly exposed underground workers.

Comparison of the exposure levels associated with the occupation titles in Appendix 8 shows no major disparity, except for the “Fixed or mobile machine-tool operator” where the exposure level recorded by the ERG is 5 times the level in our database. The small number of measurements (n=5, in the two cases) could be the reason for this difference, as well as the type of “fixed and mobile machine tool.”

The task description for each of these occupation titles in the *Regulation respecting the vocational training of the workforce in the construction industry* [35] and in the collective agreements in the Québec construction sector [36-39] shows that a few tasks can be assigned to more than one occupation title in Québec. One constraint of our input template made it impossible to input more than one occupation title on the same information line. In cases where tasks could be performed by more than one occupation title, one of these occupation titles had to be chosen. For example, sawing masonry can be assigned to a bricklayer-mason or to a specialized labourer, breaking masonry to a specialized labourer or to a pipeline labourer, and the manual moving of small rocks, soil, etc., to a labourer (unskilled labourer) or to a specialized labourer. A more detailed analysis of this data should take this constraint into account.

Tasks and other parameters

Sawing masonry using a portable masonry saw is the task that generates the highest exposure levels, except for sand blasting. Precarious conditions, which often justify the use of this tool rather than a masonry saw bench, probably make control methods such as local exhaust ventilation or spraying harder to use; these are more easily installed on a saw bench or on a walk-behind concrete saw.

Breaking concrete or ceramic masonry with jackhammers/percussion drills is the task with the second highest crystalline silica exposure levels. Also, as with sawing, these tasks can represent nearly a half day of work for a specialized labourer.

The average exposure level of 0.1 mg/m³ for traffic applies to anyone working on a large construction site with heavy traffic on dry friable ground. Considering the level observed, regular spraying of the traffic lanes on large sites is strongly recommended.

The use of control methods that are or can be built into the tool seems to have the greatest impact on the exposure levels observed during manual tasks, such as grinding and breaking masonry. The majority of the tools used for manual work, whose brand name was identified, included accessories from the manufacturer, designed to reduce dust emissions. The brand name versions of the documented tools are available on the global market. Figure 5 clearly shows the effectiveness of these accessories in reducing the exposure level in the worker’s breathing zone under actual condition of use.

Several tasks have the potential of exposing construction workers to very high levels of respirable crystalline silica over periods of less than one hour, such that their TWAEV has been reached or exceeded at the end of these tasks. Due to the low volume flow rate of the sampling instruments currently used in Québec, identification of these exposure levels is impossible. Commercially available instruments with a higher volume flow rate exist [46] and could be used to study these high-risk short-duration tasks.

5.2 Analysis of the control methods and their effectiveness

Technical exposure control methods and “good work practices” exist that significantly reduce the crystalline silica concentrations in the air of construction sites. In general, spraying is considered as the most effective technique, but local exhaust has fewer operational disadvantages for applicability. However, publications on the effectiveness of spraying and local exhaust ventilation (Table 5) do not seem to support this. In addition, though few and often incomplete, these studies indicate the inability of these methods to ensure compliance with the TLVs. Therefore, priority must be given to studies on improving exposure control techniques in order to reduce the number of silica-related occupational diseases.

Two observations can be added to the results on the effectiveness of the control methods. First, the evaluation of respirable dusts generally gives efficiency percentages close to those found for the evaluation of respirable quartz. As a result, either of the contaminants could be measured to evaluate the effectiveness of control methods. However, while compliance with the TLV for respirable dust (3 mg/m^3) is almost always achieved with engineering controls, Table 5 shows that with these same means, compliance with the TLV for quartz (0.1 to 0.025 mg/m^3) can be less often achieved. Respirable dust results, while useful in other situations such as evaluating the effectiveness of control methods, should not be used for risk assessment.

No studies were found on the effectiveness of “good practices” and the simultaneous use of spraying and local exhaust ventilation, when possible. Based on current knowledge, respiratory protection [83] or administrative measures must be used in conjunction with engineering controls.

From the information collected on respirators (see Section 4.4.3), it seems that the workers do not systematically wear their respirators while doing their work, which significantly reduces their effectiveness. When respiratory protection becomes necessary to reduce exposure levels below regulatory values, respiratory protection programs complying with the requirements of the ROHS [21] must be implemented on construction sites. The collection of additional data could determine the task with the highest use of respiratory protection and justify the choice of the type of respirator.

The use of administrative measures was mentioned in a few publications. Echt *et al*. [93] established a maximum time of 4 to 6 hours per day for the use of a jackhammer, based on their knowledge of the exposure levels for certain tasks. The same authors [89], in another industry, evaluated a maximum exposure duration of 22 minutes for the use of a hand-held cut-off saw with built-in exhaust ventilation during an 8-hour shift. This great variation clearly shows the need for knowing the exposure level associated with each task, in each sector, before implementing administrative measures.

Respiratory protection and administrative measures should not be considered as definitive solutions, but rather as temporary measures until the exposure levels and the effectiveness of the control methods are better understood. Also, even if the Québec *Safety code for the construction industry* [102] does not require environmental monitoring, more information about exposure levels should be collected to ensure the proper use of respiratory protection and the proper control of the effectiveness of means of protection.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Occupations and tasks with the highest exposure

The construction occupations with the highest risk have been classified into three groups based on their respirable crystalline silica exposure level.

1. Underground workers (specialized labourer, pipeline labourer, surveyor and driller) as well as heavy equipment operators at the controls of tunneling machines make up the first group, with exposure levels clearly exceeding the regulatory value in Québec (by two to four times).

2. Cement finishers, bricklayer-masons, drillers, specialized labourers, and heavy equipment operators at the controls of road-milling machines represent a second group, exposed on average to levels greater than or close to the regulatory value (by one to two times).

3. Specialized labourers (tile setters), labourers (unskilled labourers), fixed or mobile machine-tool operators, and heavy equipment operators (other than operators of road-milling machines and tunneling machines) represent a third group exposed to below the regulatory value (between 50% and 100% of the value).

The tasks and tools with the highest exposure (all more than twice the regulatory value during the duration of the task) are, in decreasing order: Sawing masonry with a portable masonry saw, bush hammering, breaking masonry (chipping jackhammers on concrete or ceramic), tunnel boring (tunneling machine), and grinding brick/stone joints.

6.2 The control methods and their effectiveness

The literature search indicates that crystalline silica substitution must be encouraged when possible, but that it remains, most of the time, highly impractical in the construction industry due to the presence of silica in many of the base materials used. Engineering controls, such as spraying and local exhaust ventilation, built into the tools, are well known and significantly reduce the crystalline silica dust concentration in the air, with an effectiveness generally exceeding 90%. However, these means do not allow compliance, in the great majority of cases, with the OELs of the different countries and organizations, while having a negative impact on operations. It is therefore recommended that these technical means be improved as much as possible and that rules of good practice be applied, for example by adopting certain work methods that produce less dust and by adjusting and maintaining tools and equipment. Worker training in these aspects is essential. The use of respiratory protection is also recommended. Studies should focus on improving the control of emissions and on knowing the exposure levels in order to use respiratory protection correctly in situations exceeding the TLVs and to confirm the effectiveness of the implemented control methods.

6.3 Use of the research results

In the document collection and analysis process, much information relating to the control methods associated with several tasks and several specific tools could not be used. Some of this information could be the subject of plain language documents or guides to help employers and workers make informed decisions about the selection and use of various currently available control methods.

6.4 Future research activities

The database created in this project is a unique international resource on crystalline silica exposure levels in the construction industry.

6.4.1 Use of the database by digital simulation and statistical modeling

The analyses performed in the context of this project identified the tasks and occupations with the highest exposures in the Québec construction industry. However, since the analyses were univariate, they did not lend themselves to the study of the simultaneous effects of several variables, since the use of simple stratification leads rapidly to too small sample sizes. Also, the procedure involving the repetition of the same value a certain number of times (to simulate measurements reported as averages) introduces a bias in the estimation of the variability of the exposures, thus making it impossible to quantify correctly the uncertainty associated with the presented results.

The use of an approach initially developed by some authors of this report to study formaldehyde exposure [31] overcame these limitations. It is mainly based on the use of the Monte Carlo simulation to recreate the original sample in the collected data, without introducing bias, and on the use of multivariate statistical models that estimate in an optimal way the simultaneous effects of determinants, while taking into account a “source of information” effect. The use of these methods considerably refined the portrait produced by this study, allowing the exposure results to be applied to decisions about the effectiveness of control methods and about the selection of respirators.

6.4.2 Extension of the time period covered by the literature review

The existing database represents a tool of choice for preventing silica exposure in real conditions. Its extension to past periods (prior to 1990) would represent a major asset in supporting epidemiological studies, but also in establishing time profiles, while demonstrating the prevention actions implemented over time. Also, this work would support the retrospective evaluation of occupational exposure, sometimes required for the compensation of occupational disease victims. As well, the knowledge and expertise acquired in this future research on past exposure to crystalline silica could be used in the retrospective study of occupational exposure to other substances of interest in worker compensation.

The gaps in knowledge about exposure levels in the Québec construction industry will have to be filled through increased environmental monitoring, which will take into account different influential parameters identified in this study. These additional data will ensure that respiratory protection is correctly used and that the effectiveness of the protection methods is properly assessed.

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APPENDICES

APPENDIX 1. LIST OF THE 116 SOURCES IN THE DATABASE

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APPENDIX 2. INFORMATION FIELDS COLLECTED FROM EACH SOURCE

The input template contains 76 information fields with 26 parameters that potentially determine the exposure (d):

- Coding of the data source
    - Reference identification (Number identifying the reference as it appears in the relational database)
    - Type of document
    - Quality score for the determinant description
    - Quality score for sampling and analytical methods
- Description of the occupation titles, tasks, etc., as described in the document
    - Sampling year (d)
    - Coding of the exposure value within the document
    - Occupation/workstation title
    - Task
    - Tool
    - Tool make and model
    - Material
    - Percentage of silica specified in the document
    - % silica (type not specified) in the material
    - % quartz in the material (d)
    - % cristobalite in the material (d)
    - % tridymite in the material (d)
    - % tripoli in the material
    - Analytical method used to identify the bulk material
- Coding of occupation titles, tasks, material and tools
    - Occupation title standardized for Québec (d)
    - Task standardized for Québec (d)
    - Material standardized for Québec (d)
    - Tool standardized for Québec (d)
- Coding of construction sites
    - Class of construction site (d)
    - Type of construction site (d)

- <u>Description of the quantitative exposure parameters</u>
  - Number of samples (n)
  - Arithmetic mean (if n > 1)
  - Arithmetic standard deviation (if n > 1)
  - Geometric mean (if n > 1)
  - Geometric standard deviation (if n > 1)
  - Minimum value (if n > 1)
  - 5th percentile (if n > 1)
  - 10th percentile (if n > 1)
  - Median (if n > 1)
  - 90th percentile (if n > 1)
  - 95th percentile (if n > 1)
  - Maximum value (if n > 1)
  - Other statistical value 1 (if n > 1)
  - Other statistical value 1 - definition (if n > 1)
  - Gross value of the measurement (if n=1)
  - Calculated value based on the measurement objective
  - Sampling duration (minutes) (d)
  - Permissible exposure value (PEV) for quartz in Québec (Québec has only one PEV – TWAEV for quartz, namely a “Time-weighted average exposure value” over a period of 8 hours)
  - Adjusted average exposure value (AAEV) for quartz in Québec (calculation based on the sampling duration)
- <u>Coding of the exposure characteristics</u>
  - Contaminant measured
  - Measurement objective (d)
  - Type of sample (d)
  - Method used for sampling (d)
  - Method used for analyzing the sample (d)
  - Specific method used for analyzing the sample
  - Details of the specific method if it is not referenced
  - Analytical measurement unit
  - Limit of detection of the specific analytical method
  - Origin of the sampling duration value
  - Origin of the exposure value based on the measurement objective from the raw data or the statistical parameters
  - Contribution of a source near the exposure (d)
  - Nature of this exposure source

- Details about the other polluting task
- Nature of the sampling site (d)
- Employee training in the risks associated with silica (d)
- Association of the measurement with another measurement in the database
- Nature of the association
- Details about this association

- <u>Coding of the control methods</u>
    - Use of a means of prevention other than a respirator (d)
    - General ventilation (d)
    - Local exhaust ventilation near the tool (d)
    - Local exhaust ventilation built into the tool (d)
    - Wet process (spraying) (d)
    - Wet process built into the tool (d)
    - Isolation of the source (d)
    - Other control (d)
    - Details about the control methods
- <u>Coding of respirators</u>
    - Use of a respirator
    - Type of respirator used
    - Comments about the respirators
- <u>General information</u>
    - Availability of photographs
    - General comments

APPENDIX 3. CODING IN THE SILICA DATABASE

Coding of the data source

Type of document

Code	Description
1	Not specified
2	Not applicable
3	Other type of document
4	"Peer Reviewed" journal article
5	"Non-Peer Reviewed" journal article
6	Report from public organization
7	Report from a private organization
8	Public database
9	Governmental surveillance agency

Quality score for the determinant description

Code	Description
1	Not specified
2	Not applicable
3	Other
4	Information not provided or insufficient
5	Acceptable information
6	Excellent information

Quality score for sample collection and analysis

Code	Description
1	Not specified
2	Not applicable
3	Other
4	Information not provided
5	Methods similar to the referenced methods
6	Referenced methods

Description of occupation titles, tasks, etc., as described in the document

Analytical method used to identify the bulk material

Code	Description
1	Not specified
2	Not applicable
3	Other method
4	NIOSH7500
5	Other method – X-ray
6	NIOSH7602

Coding of occupation titles, tasks, materials and tools

Occupation titles standardized for Québec

Description
Not specified
Not applicable
Other*
Helper
Lineman helper
Surveyor
Assembler
Blaster
Bricklayer-mason
Insulator
Tile setter
Chainman
Carpenter-joiner
Boilermaker
Steam boiler stoker
Crew leader
Cement finisher
Clerk
Light machine operator
Heavy machine operator
Medium-weight machine operator
Truck driver
Line truck driver
Foreman
Roofer
Electrician
Trimmer
Splicer (fusion splicer) on fibre optic cables
Splicer of underground cables
Tinsmith
Reinforcing iron worker
Driller

Refrigeration specialist
Fibre optic fuser (splicer)
Watchman
Crane operator
Heavy machinery serviceman
Occupational hygienist
Store issue clerk
Labourer (unskilled labourer)
Decontamination labourer
Pipeline labourer
Specialized labourer
Specialized labourer (tile setter)
Elevator mechanic
Millwright (industrial)
Heavy machines mechanic
Fire protection mechanic
“T” lineperson
Reinforcing steel erector
Lineman 1st class
Lineman 2nd class
Lineman 3rd class
Lineman 4th class and lineman helper (groundman)
Erector mechanic (Glazier)
NS
Hoist operator
Fixed or mobile machine-tool operator
Generator operator
Mechanical digger operator
Pump and compressor operator
Puller and/or tensioner operator
Heavy equipment operator
Painter
Plasterer
Pile setter
Resilient flooring installer
Interior systems installer
Tire and body repairman
Diver (professional diver)
Construction locksmith
Welder
Supply welder, pipeline welder and distribution welder
Pipe welder
Gas fitter
Cable puller
Underground worker (miner)
Pipe fitter

Tasks standardized for Québec

Description
NS
Not applicable
Other tasks
Spraying
Bush hammering concrete
Breaking pieces of masonry
Traffic control
Diamond cutting of concrete or asphalt
Scaffold assembly/dismantling/cleaning
Abrasive blasting (Sand blasting)
Other demolition
Demolition with heavy equipment
Manual moving of small rocks, soil, etc.
Mechanized moving of rocks, soil, etc
Tunnel boring
Provides alignments, construction axes, elevations…
Installation of acoustic ceiling tiles
Manual or mechanized mixing of cements and mortars
Handling of dry mortar
Tuck point grinding
Surface grinding
Installation of concrete formwork
Cleaning
Observation/Supervision
Drilling masonry
Ground and stone drilling
Sanding
Installation and attachment of roof parts
Concrete preparation and finishing
Shotcreting
Sawing – Other
Sawing masonry
Sawing roofing
Support to the bricklayer-mason
Multiple tasks (Other masonry-related tasks)
Multiple tasks (Breaking masonry and other tasks)
Multiple tasks (Grinding masonry and other tasks)
Multiple tasks (Sawing masonry and other tasks)
Manual stone cutting
Filling joints of pieces of masonry
Industrial and commercial work - Other
Road work - Heavy equipment operation
Road work - Other
Electrical maintenance work
Mechanical maintenance work

Materials standardized for Québec

Description
NS
Not applicable
Other
Asphalt
Concrete
Concrete blocks
Brick
Refractory brick
Bricks and concrete blocks
Cement roofing tile
Acoustic tiles
Coal ash
Ceramic
Cement
Various materials containing concrete
Various materials containing cement
Various materials containing sand
Granite
Gypsum and jointing material
Marble
Mortar
NS
Stone
Sand
Earth

Tools standardized for Québec

Description
Not specified
Not applicable
None
Other industrial equipment
Other road equipment
Others (inert tools)
Others (mechanical tools)
Broom, shovel, squeegee and blower
Table mounted masonry saw
Bush hammer
Crusher
Tile cutter
Heavy equipment (Backhoe/excavator/bulldozer/bucket loader/mechanical digger)
Road-milling machine
Abrasive blasting machine
Drilling machine
Mortar or cement mixer
Jackhammer
Percussion drill
Surface finishing grinder
Tuck point grinder
Multiple tools (others)
Multiple tools (jackhammers/percussion drills et…)
Multiple tools (masonry saw and …)
Drill
Sander
Walk-behind concrete saw
Portable saw
Portable masonry saw
Tunneling machine

Coding of construction sites

Class of construction site

Code	Description
1	Not specified
2	Not applicable
3	Other class
4	Residential
5	Industrial
6	Institutional and Commercial
7	Civil engineering and roadwork
8	Industrial/Institutional and Commercial
9	Institutional and Commercial / Civil engineering and Roadwork
10	Testing laboratory

Type of construction site

Code	Description
1	Not specified
2	Not applicable
3	Other type
4	New construction
5	Renovation
6	Demolition
7	New construction / Demolition

Coding of exposure characteristics

Measured contaminant

Code	Description
1	Not specified
2	Not applicable
3	Other contaminant
4	Respirable dust
5	Respirable quartz
6	Total dust
7	Inhalable dust
8	Respirable cristobalite
9	Respirable silica
10	Respirable crystalline silica
11	Respirable tridymite
12	Respirable tripoli
13	Thoracic dust
14	Thoracic quartz
15	Inhalable quartz
16	Total quartz
17	Total crystalline silica
18	Total cristobalite

Objective of the measurement

Code	Description
1	Not specified
2	Not applicable
3	Other objective
4	Specific task
5	8-hr TWA
6	Partial period
7	Worst case
8	Regulatory compliance

Type of sampling

Code	Description
1	Not specified
2	Not applicable
3	Other
4	Source
5	Breathing zone
6	Area
7	Codes #5 and #6

Method used for sampling

Code	Description
1	Not specified
2	Not applicable
3	Other method
4	Closed cassette 37 mm PVC filter + nylon cyclone 10 mm, 1.7 l/min
5	Closed cassette 37 mm PVC filter + aluminum cyclone, 2.5 l/min or 1.9 l/min
6	Closed cassette 25 or 37 mm PVC filter and HD cyclone, 2.2 l/m
7	Direct-reading instrument equipped with a cyclone
8	IOM
9	Closed cassette 37 mm, PVC filter
10	Closed cassette 25 mm, PVC filter
11	Cascade impactor
12	Direct-reading instrument
13	Method #4 and Method #7
14	Closed cassette 37 mm PVC filter + BGI cyclone 2.2 l/min
15	Method #4 and Method #5
16	Method #4 and Method #6
17	(Closed cassette 37 mm PVC filter + BGI 14L cyclone, 4.2 l/min) and (HSE GK2.69 approved cyclone, 4.2 l/min)

Method used for sample analysis

Code	Description
1	Not specified
2	Not applicable
3	Other type
4	Gravimetric analysis
5	X-ray
6	Infrared
7	Direct-reading – photometric particle counter
8	Type #5 and type #6

Specific method used for sample analysis

Code	Description
1	Not specified
2	Not applicable
3	Other method
4	NIOSH 0600
5	NIOSH 7500
6	NIOSH 0500
7	NIOSH 7602
8	NIOSH 7500 and NIOSH 7602
9	MDHS 14/2 or 14/3 (HSE)
10	MDHS 51/2 (HSE)
11	MDHS 76 (HSE)
12	OSHA ID-142
13	MDHS 51/2 and MDHS 76
14	IRSST 206-2
15	IRSST 78-1
16	IRSST 206-2 and 78-1
17	IRSST 48-1
18	IRSST 48-1 (Cycl)
19	INRS Metropol 002
20	INRS Metropol 049
21	INRS Metropol 092

Analytical measurement unit

Code	Description
1	Not specified
2	Not applicable
3	Other unit
4	mg/m^3

Origin of the sampling duration value

Code	Description
1	Not specified
2	Not applicable
3	Other
4	Supplied by the document
5	Not specified but deduced by Beaudry C
6	Not specified but deduced by Senhaji M

Origin of the exposure value based on the measurement objective from the raw data or statistical parameters

Code	Description
1	Not specified
2	Not applicable
3	Other
4	Author
5	Beaudry_C
6	Senhaji_M

Contribution from a source near the exposure

Code	Description
1	Not specified
2	Not applicable
3	Other
4	No
5	Yes

Nature of this source of exposure

Code	Description
1	Not specified
2	Not applicable
3	Other
4	Only source of exposure
5	Secondary source

Nature of the sampling site

Code	Description
1	Not specified
2	Not applicable
3	Other environment
4	Confined space
5	Restricted (staircase, hallway, tunnel)
6	Enclosed (walls, roof and windows)
7	Partially enclosed (floor and ceiling)
8	Open (outdoors)
9	Open (outdoors) and Enclosed (walls, etc.)
10	Confined (…, tunnel) and Open (outdoors)
11	Partially closed and Open

Association of the measurement with another measurement in the database

Code	Description
1	Not specified
2	Not applicable
3	Other
4	No
5	Yes - to calculate the average exposure
6	Yes – to calculate the effectiveness of a control method
7	Yes – to compare two analytical methods

Employee training on the risks associated with silica

Code	Description
1	Not specified
4	No
5	Yes

Identification of measurements whose value is below the limit of detection

For the “Arithmetic mean,” “Arithmetic standard deviation,” “Geometric mean,” “Geometric standard deviation,” “Minimum value,” “5th percentile,” “10th percentile,” “Median,” “90th percentile,” “95th percentile,” “Maximum value,” “Other statistical value,” “Gross value of the measurement” fields:

If the value reported in the document was “below the limit of detection” or “between the limit of detection and the limit of quantification” the value entered in the field was -1.

Coding of control methods

The control methods are represented by a series of 8 columns in the "Silica" database.

Use of a means of prevention other than a respirator

Code	Description
1	Not specified
4	No
5	Yes

- If the choice of this column is "Not specified (1)" on one line, the content of the 7 following columns, "VentGen / ventAspP / ventAspO / procHAr / procHO / isoSrc / MaitrA," is necessarily "Not applicable (2)"
- If the choice of this column is "No (4)" on one line, the content of the 7 following columns, "VentGen / ventAspP / ventAspO / procHAr / procHO / isoSrc / MaitrA," has to be "No (4)"
- If the choice of this column is "Yes (5)" on one line, the content of the 7 following columns, "VentGen / ventAspP / ventAspO / procHAr / procHO / isoSrc / MaitrA," can be either "NS (1)," "No (4)," or "Yes (5)."

General ventilation (VentGen**)**

Code	Description
2	Not applicable
4	No
5	Yes

Local exhaust ventilation near the tool (ventAspP**)**

Code	Description
2	Not applicable
4	No
5	Yes

Local exhaust ventilation on the tool (ventAspO**)**

Code	Description
2	Not applicable
4	No
5	Yes

Wet process (Spraying) (procHAr**)**

Code	Description
2	Not applicable
4	No
5	Yes

Process integrated into the tool (procHO**)**

Code	Description
2	Not applicable
4	No
5	Yes

Insulation of the source (isoSrc**)**

Code	Description
2	Not applicable
4	No
5	Yes

Other control method (MaitrA**)**

Code	Description
2	Not applicable
4	No
5	Yes

Coding of respirators

Use of a respirator

Code	Description
1	Not specified
2	Not applicable
3	Other response
4	No
5	Yes – frequency not specified
6	Yes – very infrequently
7	Yes - infrequently
8	Yes - systematically

- If the choice in this column is “Not specified (1)” on one line, the content of the following column has to be “Not applicable (2)”
- If the choice of this column is “No (4)” on one line, the content of the following column, “APR_T,” has to be “Not applicable (2)”
- If the choice in this column is “Yes (5 to 7)” on one line, the content of the following column, “APR_T,” can be all the choices except “Not applicable (2).”

Type of respirator used (APR_T)

Code	Description
1	Not specified
2	Not applicable
3	Other type of respirator
4	Filtering facepiece
5	Air purifying respirator - Half-mask
6	Air purifying respirator - Full face mask
7	Powered air purifying respirator - helmet and visor
8	Powered air purifying respirator - hood
9	Powered air purifying respirator – Half mask
10	Powered air purifying respirator – Full mask
11	Powered air purifying respirator – Not specified
12	Supplied air respirator
13	Choice #4 and choice #5
14	Choice #5 and choice #6

APPENDIX 4. EXPOSURE LEVELS BY OCCUPATION TITLE

Occupation title	n[1]	nS	GM	GSD	n-GSD[2]	nS-GSD[2]	Min	P25	Med	P75	P90	Max
Underground worker (Specialized labourer)	20	1	0.30	5.3	8	1	0.03	0.27	0.29	0.33	0.77	3.4
Underground worker (Driller)	13	2	0.24	13	13	2	0.01	0.07	0.17	3.0	9.7	16
Underground worker (Other)	5	2	0.18	3.1	5	2	0.05	0.07	0.24	0.24	0.61	0.86
Cement finisher	163	9	0.17	6.8	128	8	0.01	0.05	0.11	0.41	3.0	33
Bricklayer-mason	264	10	0.15	6.9	207	8	0.01	0.05	0.07	0.48	1.9	76
Roofer[3]	68	5	0.14	2.5	68	5	0.01	0.09	0.15	0.28	0.34	0.76
Driller	17	5	0.14	3.1	17	5	0.01	0.12	0.17	0.20	0.34	1.3
Pipeline labourer[4]	58	4	0.11	4.6	58	4	0.01	0.04	0.11	0.27	0.86	5.1
Specialized labourer	426	20	0.09	5.1	337	18	0	0.04	0.09	0.24	0.59	10
Labourer (unskilled labourer)	353	11	0.06	7.1	250	8	0	0.01	0.07	0.14	0.57	24
Fixed or mobile machine-tool operator	5	2	0.06	3.5	5	2	0.01	0.03	0.06	0.18	0.19	0.2
Heavy equipment operator	169	11	0.05	3.5	147	10	0	0.02	0.04	0.11	0.27	1.1
Foreman	13	4	0.04	1.9	5	3	0.01	0.02	0.06	0.06	0.06	0.06
Boilermaker	24	1	0.01	1[5]	24	1	0.01	0.01	0.01	0.01	0.01	0.01
Other	62	1	0.09	3.6	62	1	0.01	0.03	0.08	0.17	0.51	4.0
NS	85	3	0.07	11	11	2	0.02	0.07	0.07	0.07	0.07	18

[1]: The following parameters are used to describe the distribution of the measurements

- n: number of measurements,
- nS: number of studies from which these "n" measurements were taken,
- GM: geometric mean of the "n" measurements,
- GSD: geometric standard deviation assigned to GM (calculated by using only the measurements among the "n" that were individual measurements in the original sources of data),
- Min: lowest measurement among the "n" measurements documented,
- P25: 25th percentile of the distribution of the "n" measurements,

- Med: median of the “n” measurements,
- P75: 75th percentile of the distribution of the “n” measurements,
- P90: 90th percentile of the distribution of the “n” measurements,
- Max: highest measurement among the “n” documented measurements.

[2]: n-GSD (number of measurements) and nS-GSD (number of studies) used to calculate the geometric standard deviation. These measurements were individual measurements in the original data sources.

[3]: This occupation title corresponds to roofers installing only concrete slab roofing. This evaluation is not representative of all roofers in Québec.

[4]: The average exposure of a pipeline labourer is 0.03 mg/m³ when exposure by abrasive blasting is removed.

[5]: All the measurements were below the limit of detection of the analytical method.

APPENDIX 5. EXPOSURE LEVEL BY TASK PERFORMED

Task	n[1]	nS	GM	GSD	n-GSD[2]	nS-GSD[2]	Min	P25	Med	P75	P90	Max
Abrasive blasting	22	4	1.6	4.8	8	3	0.06	1.6	2.6	2.6	2.6	11
Multiple tasks (Sawing masonry and other tasks)	53	1	0.70	*3.3*[2]	0	NA	0.70	0.70	0.70	0.70	0.70	0.7
Multiple tasks (Grinding masonry and other tasks)	18	2	0.56	4.4	13	2	0.03	0.26	0.52	1.3	4.0	5.2
Bush hammering concrete	11	1	0.46	3.1	11	1	0.07	0.24	0.24	1.5	2.1	2.1
Breaking pieces of masonry	187	10	0.41	4.6	89	7	0.00	0.16	1.1	1.1	1.1	4.3
Tunnel boring	41	1	0.39	*2.6*[2]	0	NA	0.39	0.39	0.39	0.39	0.39	0.39
Sawing roofing	10	1	0.35	1.2	10	1	0.29	0.30	0.32	0.41	0.42	0.45
Grinding brick/stone joints (tuck point grinding)	97	8	0.25	9.4	75	6	0.00	0.08	0.21	0.91	3.1	24
Traffic control	6	1	0.11	2.9	6	1	0.04	0.05	0.07	0.28	0.44	0.53
Surface grinding	244	6	0.09	5.9	3	2	0.00	0.06	0.09	0.47	0.70	2.0
Manual moving of small rocks, soil, etc.	12	3	0.08	3.4	12	3	0.00	0.05	0.10	0.20	0.24	0.35
Sawing pieces of masonry	74	8	0.07	7.2	24	7	0.01	0.04	0.04	0.07	0.40	14
Multiple tasks (Breaking masonry and other tasks)	27	2	0.07	NA	0	NA	0.01	0.14	0.14	0.14	0.14	0.14
Drilling masonry	172	9	0.04	15	38	7	0.00	0.03	0.03	0.04	0.42	94
Installation of acoustic ceiling tiles	42	2	0.03	1.4	21	1	0.01	0.02	0.04	0.04	0.04	0.04
Other demolition	32	2	0.03	NA	1	1	0.03	0.03	0.03	0.03	0.03	0.32
Cleaning	30	4	0.03	5.3	6	2	0.00	0.02	0.02	0.03	0.09	0.69

Task	n[1]	nS	GM	GSD	n-GSD[2]	nS-GSD[2]	Min	P25	Med	P75	P90	Max
Industrial and commercial work - Other	7	1	0.03	NA	0	NA	0.03	0.03	0.03	0.03	0.03	0.03
Diamond cutting of concrete or asphalt	40	3	0.02	3.7	40	3	0.00	0.01	0.02	0.05	0.08	0.14
Treatment of masonry joints	16	2	0.02	NA	0	NA	0.00	0.02	0.03	0.03	0.03	0.03
Ground and stone drilling	12	2	0.02	5.1	4	1	0.01	0.02	0.02	0.02	0.11	0.13
Road work - Other	5	2	0.02	1.7	5	2	0.01	0.02	0.02	0.02	0.03	0.04
Installation of concrete formwork	159	3	0.01	1	3	1	0.00	0.01	0.03	0.03	0.03	0.03
Shotcreting	82	1	0.01	*3.1*[3]	0	NA	0.01	0.01	0.01	0.01	0.01	0.01
Electrical maintenance work	41	1	0.01	NA	0	NA	0.01	0.01	0.01	0.01	0.01	0.01
Manual or mechanized mixing of cement and mortar	28	4	0.01	2.3	6	2	0.01	0.01	0.01	0.01	0.02	0.06
Sanding	15	1	0.01	2.8	15	1	0.00	0.00	0.00	0.01	0.03	0.08
Other tasks	125	4	0.01	NA	1	1	0.01	0.01	0.01	0.01	0.03	0.04
NS	138	2	0.15	NA	1	1	0.02	0.07	0.20	0.20	0.20	0.32

[1]: The following parameters are used to describe the distribution of the measurements

- n: number of measurements,
- nS: number of studies from which these "n" measurements are taken,
- GM: geometric mean of the "n" measurements,
- GSD: geometric standard deviation attributed to GM (calculated using only the measurements among the "n" that were individual measurements in the original data sources),
- Min: lowest measurement among the "n" documented measurements,
- P25: 25th percentile of the distribution of the "n" measurements,
- Med: median of the "n" measurements,

- P75: 75th percentile of the distribution of the "n" measurements,
- P90: 90th percentile of the distribution of the "n" measurements,
- Max: highest measurement among the "n" documented measurements.

[2]: n-GSD (number of measurements) and nS-GSD (number of studies) used to calculate the geometric standard deviation. These measurements were individual measurements in the original data sources.

[3]: This standard deviation is the one from the original data source.

APPENDIX 6. EXPOSURE LEVELS BY MATERIAL

Material	n[1]	nS	GM	GSD	n-GSD[2]	nS-GSD[2]	Min	P25	Med	P75	P90	Max
Ceramic	8	1	0.33	3.6	8	1	0.04	0.19	0.30	0.88	1.6	1.8
Cement	63	2	0.22	5.7	14	2	0.02	0.06	0.30	0.70	0.70	6.5
Mortar	81	7	0.18	9.3	68	5	0.00	0.04	0.21	0.91	2.8	25
Brick	18	3	0.18	5.2	6	2	0.01	0.20	0.20	0.27	0.33	1.2
Bricks and concrete blocks	15	2	0.16	3.2	15	2	0.01	0.08	0.21	0.34	0.54	0.96
Various materials (containing sand)	13	4	0.13	11	13	4	0.01	0.01	0.19	0.52	1.8	11
Various materials (containing concrete)	361	5	0.09	24	3	2	0.00	0.03	0.04	0.70	1.1	3.8
Sand	18	1	0.08	3.0	18	1	0.01	0.04	0.06	0.19	0.34	0.53
Stone	177	4	0.07	7.4	16	3	0.01	0.03	0.03	0.39	0.39	5.2
Concrete	491	20	0.06	7.4	146	14	0.00	0.01	0.06	0.32	0.90	94
Soil	6	2	0.03	4.1	6	2	0.00	0.02	0.02	0.10	0.15	0.17
Asphalt	40	3	0.02	3.7	40	3	0.00	0.01	0.02	0.05	0.08	0.14
Acoustic tiles	21	1	0.02	1.4	21	1	0.01	0.02	0.02	0.02	0.03	0.04
Gypsum and jointing material	15	1	0.01	2.8	15	1	0.00	0.00	0.00	0.01	0.03	0.08
NS	420	7	0.04	2.7	4	3	0.00	0.01	0.03	0.16	0.20	2.6

[1]: The following parameters are used to describe the distribution of the measurements

- n: number of measurements,
- nS: number of studies from which these “n” measurements were taken,

- GM: geometric mean of the "n" measurements,
- GSD: geometric standard deviation attributed to GM (calculated using only the measurements among the "n" that were individual measurements in the original data sources),
- Min: lowest measurement among the "n" documented measurements,
- P25: 25th percentile of the distribution of the "n" measurements,
- Med: median of the "n" measurements,
- P75: 75th percentile of the distribution of the "n" measurements,
- P90: 90th percentile of the distribution of the "n" measurements,
- Max: highest measurement among the "n" documented measurements.

[2]: n-GSD (number of measurements) and nS-GSD (number of studies) used to calculate the geometric standard deviation. These measurements were individual measurements in the original data sources.

APPENDIX 7. EXPOSURE LEVELS ACCORDING TO THE TOOL USED

Tool	n[1]	nS	GM	GSD	n-GSD[2]	nS-GSD[2]	Min	P25	Med	P75	P90	Max
Portable masonry saw	14	4	0.63	4.7	14	4	0.07	0.40	0.44	1.3	4.6	14
Multiple tools (jackhammers/percussion drills and…)	127	5	0.50	4.1	14	3	0.01	0.14	1.1	1.1	1.1	1.3
Bush hammer	11	1	0.46	3.1	11	1	0.07	0.24	0.24	1.5	2.1	2.1
Multiple tools (others)	11	2	0.40	5.9	6	2	0.03	0.26	0.26	0.72	2.2	4.3
Tunneling machine	41	1	0.39	NA	0	NA	0.39	0.39	0.39	0.39	0.39	0.39
Jackhammer	75	5	0.32	2.8	61	4	0.04	0.15	0.34	0.79	1.5	2.2
Drilling machine	7	4	0.30	2.7	7	4	0.07	0.20	0.41	0.61	0.80	0.81
Tile cutter	6	1	0.30	1.0	6	1	0.29	0.30	0.30	0.31	0.32	0.32
Surface finishing grinder	127	4	0.29	NA	1	1	0.02	0.10	0.47	0.70	1.5	2.0
Tuck point grinder	88	7	0.24	9.3	76	6	0.00	0.06	0.20	1.33	3.3	25
Multiple tools (masonry saw and …)	129	4	0.23	3.3	12	2	0.04	0.04	0.42	0.70	0.70	5.2
Sander	9	1	0.07	NA	1	1	0.06	0.06	0.06	0.06	0.10	0.10
Walk-behind concrete saw	6	3	0.06	5.7	6	3	0.02	0.02	0.03	0.09	0.88	1.6
Drill	32	5	0.05	21.8	25	4	0.00	0.00	0.08	0.33	0.43	94.00
Broom, shovel, squeegee and blower	15	2	0.05	5.3	6	2	0.01	0.03	0.03	0.06	0.47	0.69
Masonry saw bench	5	1	0.05	3.3	5	1	0.01	0.04	0.06	0.07	0.19	0.27
Crusher	5	1	0.05	1.7	5	1	0.03	0.03	0.05	0.08	0.09	0.09
Heavy equipment (Backhoe/excavator/bulldozer/bucket loader/mechanical digger)	9	4	0.04	3.0	9	4	0.00	0.04	0.05	0.08	0.11	0.17

Tool	n[1]	nS	GM	GSD	n-GSD[2]	nS-GSD[2]	Min	P25	Med	P75	P90	Max
Others (inert tools)	42	5	0.02	2.7	29	4	0.00	0.01	0.02	0.03	0.04	0.08
Road-milling machine	40	3	0.02	3.7	40	3	0.00	0.01	0.02	0.05	0.08	0.14
Others (mechanical tools)	18	2	0.02	1.2	10	1	0.01	0.02	0.02	0.02	0.02	0.03
Mortar or cement mixer	9	1	0.01	NA	0	NA	0.01	0.01	0.01	0.02	0.02	0.02
NS	916	15	0.03	4.2	44	9	0.00	0.01	0.03	0.06	0.20	2.6

[1]: The following parameters are used to describe the distribution of the measurements:

- n: number of measurements,
- nS: number of studies from which these “n” measurements were taken,
- GM: geometric mean of the “n” measurements,
- GSD: geometric standard deviation attributed to GM (calculated using only the measurements among the “n” that were individual measurements in the original data sources),
- Min: lowest measurement among the “n” documented measurements,
- P25: 25th percentile of the distribution of the “n” measurements,
- Med: median of the “n” measurements,
- P75: 75th percentile of the distribution of the “n” measurements,
- P90: 90th percentile of the distribution of the “n” measurements,
- Max: highest measurement among the “n” documented measurements.

[2]: n-GSD (number of measurements) and nS-GSD (number of studies) used to calculate the geometric standard deviation. These measurements were individual measurements in the original data sources.

APPENDIX 8. EXPOSURE LEVELS ASSOCIATED WITH THE OCCUPATION – OTHER DATA SOURCES

Occupation title	Database		Québec[1]		ACGIH[2]		ERG[3]	
	GM[4]	n / nS	GM	n / nS	GM	n	Med	n
Underground worker (Specialized labourer)	0.30	20 / 1	0.30	20 / 1	---	---	---	---
Underground worker (Driller)	0.24	13 / 2	0.12	6 / 1	---	---	---	---
Underground worker (Other)	0.18	5 / 2	0.18	5 / 2	---	---	---	---
Cement finisher	0.17	163 / 9	---	---	0.16	229	---	---
Bricklayer	0.15	264 / 10	0.07	8 / 1	0.13	240	---	---
Pipeline labourer	0.11	58 / 4	0.06	5 / 1	---	---	---	---
Specialized labourer	0.09	426 / 20	0.07	61 / 1	---	---	---	---
Labourer (unskilled labourer)	0.06	353 / 11	---	---	0.14	591	---	---
Fixed or mobile machine-tool operator	0.06	5 / 2	---	---	---	---	0.3	5
Underground worker (Pipeline labourer)	0.06	2 / 1	0.06	2 / 1	---	---	---	---
Heavy equipment operator	0.05	169 / 11	0.09	12 / 2	0.05	102	0.01	24

[1]: Exposure levels taken from the database but originating exclusively from measurements taken in Québec.

[2]: Exposure levels taken from the document of Flanagan *et al* [11]

[3]: Exposure levels taken from the document of ERG [43]

[4]: The following parameters are used to describe the distribution of the measurements

- n: number of measurements,
- nS: number of studies from which these "n" measurements were taken,
- GM: geometric mean of the "n" measurements,
- Med: median of the "n" measurements

APPENDIX 9. EXPOSURE LEVELS ASSOCIATED WITH THE TASK – OTHER DATA SOURCES

Task	Database		Québec[1]		ACGIH[2]		ERG[3]		BGIA[4]	
	GM	n / nS	GM	n / nS	GM	n	Med	n	AM[5]	n / nS
Breaking masonry	0.41	187 / 10	0.05	3 / 1	---	---	0.15	100	0.26	56/27
Tunnel boring	0.39	41 / 1	---	---	0.3	8	0.01	30	0.15	407/84
Sawing roofing	0.35	10 / 1	---	---	---	---	---	---	0.81	42/31
Grinding brick/stone joints	0.25	97 / 8	0.17	9 / 1	0.6	101	0.53	107	---	---
Surface grinding	0.09	244 / 6	---	---	0.3	122	0.18	41	0.08	41/19
Manual moving of small rocks, soil, etc.	0.08	12 / 3	---	---	---	---	---	---	0.05	30/13
Sawing masonry	0.07	74 / 8	---	---	0.1	164	0.06	74	0.05 to 0.07	66/30
Drilling masonry	0.04	172 / 9	0.01	14 / 1	0.2	97	0.06	9	0.5	18/9
Cleaning	0.03	30 / 4	---	---	---	---	---	---	0.02 to 0.11	52/31
Diamond cutting of concrete or asphalt	0.02	40 / 3	---	---	---	---	---	---	0.42	146/23
Treatment of masonry joints	0.02	16 / 2	---	---	---	---	---	---	0.03	23/11
Ground and stone drilling	0.02	12 / 2	---	---	---	---	0.05	30	---	---
Installation of concrete formwork	0.01	159 / 3	0.02	3 / 1	---	---	---	---	0.01 to 0.03	66/19
Manual or mechanized mixing of cement and mortar	0.01	28 / 4	---	---	0.1	54	---	---	---	---
Demolition of refractory materials of furnaces or stacks	---	---	---	---	---	---	---	---	1,16	47/22
Mixing of furnace and stack repair materials	---	---	---	---	---	---	---	---	0.66	12/5
Mechanized moving of small rocks, soil, etc.	---	---	---	---	---	---	---	---	0.02	10/8

Task	Database		Québec[1]		ACGIH[2]		ERG[3]		BGIA[4]	
	GM	n / nS	GM	n / nS	GM	n	Med	n	AM[5]	n / nS
Mechanized demolition of masonry	---	---	---	---	---	---	---	---	0.12	25/12
Plaster removal	---	---	---	---	---	---	---	---	0.14	24/10
Plaster spreading	---	---	---	---	---	---	---	---	0.02	35/19
Installation of interior gypsum walls	---	---	---	---	---	---	---	---	0.05	17/7
Grinding gypsum walls	---	---	---	---	---	---	0.01	15	0.05	15/10

[1]: Exposure levels taken from the database but originating exclusively from measurements taken in Québec.
[2]: Exposure levels from the document of Flanagan *et al*. [11]
[3]: Exposure levels from the document of ERG [43]
[4]: Exposure levels from the document of the BGIA – Report 8/2006e [42]
[5]: The following parameters are used to describe the distribution of the measurements:

- n: number of measurements
- nS: number of studies from which these "n" measurements were taken
- GM: geometric mean of the "n" measurements
- Med: median of the "n" measurements
- AM: arithmetic mean of the "n" measurements