AKADÉMIAI KIADÓ

UNIVERSITY of DEBRECEN

International Review of Applied Sciences and Engineering

13 (2022) 3, 357–373

DOI:
10.1556/1848.2022.00486

ORIGINAL RESEARCH PAPER

Towards better control of chemical risks associated with mining operations in Quebec (Canada) Part 1: Repertory of chemicals used in mining

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Received: February 28, 2022 • Accepted: August 2, 2022
Published online: August 30, 2022

ABSTRACT

As of 2020, the mining industry in the province of Quebec (Canada) has been providing 16,000 jobs, the majority of these in the north part of the province and in the Abitibi-Témiscamingue region. From the exploration phase to the mining site rehabilitation phase, numerous chemical processes are used, often involving some of the most dangerous substances used on industrial scales.

The hazards associated with many of these substances are in some cases not obvious, and symptoms of exposure may take years to appear. The risks associated with the industrial use of chemicals in Canada and abroad has long preoccupied health authorities, given the severity of the diseases that can occur. In Quebec, occupational diseases associated with exposure to industrial chemicals are reaching 1,500 cases per year.

The principal focus of this study, presented in two articles, is to set a preliminary theoretical framework for categorizing chemicals in terms of their effects on the health of workers throughout the various phases of mining projects. The objective is to decrease (over the long term) the number of occupational diseases due to the use of chemicals by raising awareness among employers and exposed workers in the mining sector.

This research was conducted in four phases. The present article contains the results of the first two stages, that is, a review of the literature to catalog the industrial chemicals used in mines and to list the potential effects of exposure to them, based on Safety Data Sheets. Eighty-five (85) chemicals used in at least one mining project phase and dozens of potential effects on worker health were identified. The rest of the study is presented in a second article [1]

KEYWORDS

occupational health and safety, mining projects, chemicals, safety records, globally harmonized system of classification and labeling of chemicals, safety data sheets, Quebec, Canada

1. INTRODUCTION

The mining industry, currently undergoing profound changes, is destined to play an increasingly important economic role in the province of Quebec in Canada. Activity in this sector looms large in public discourse, its real net impact on government tax revenue, the economy, and the creation of wealth in the province being the subject of lively debate [2]. In a study by Ecotec (2018), an expert firm in the analysis of economic value, data compiled by the Quebec Mining Association (AMQ) for 2016 compared to 2014 reveal the cyclic nature of this industry and its effect on overall economic output. Total expenditures by mining companies reached $8.5 billion in 2016 [3]. The industry accounted for 40,500 new jobs that year throughout the province. Of this number, 12,351 were associated with mining company operations, which contributed directly to the quality of life of the surrounding population and to revenues at all levels of government [4].

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Besides the number of jobs that it creates, the mining industry also asserts that its working conditions are excellent, and that its inclusion of minorities is enviable. Mining is among the few industries that survive economic downturns largely unscathed [5]. In recent years, the sector has weathered large fluctuations in metal prices, closures of mines here and abroad, political instability in competing producer countries, tightening of environmental legislation, and shifts in social perception and acceptability, to name a few. About 25 mines are currently operating in Quebec, including non-metallic productions, such as peat, stone, silica, mica, and others [6]. According to data compiled by the provincial bureau of statistics, mining companies invested $3.57 billion in 2018 in various sites and projects, up from $3 billion in 2017 [7].

The Quebec Mining Association (AMQ) supports its members through its accident prevention and health committee, which allows participants to exchange views on the best occupational health and safety practices [8]. Statistics for this sector in relation to chemicals for the period of 2010–2012 reveal an average of 1,827 lesions accepted for compensation by the CNESST (*Commission des normes, de l'équité, de la santé et de la sécurité du travail: the organization responsible for applying the occupational health and safety laws and regulations in the province*), of which 355 were deemed causes of associated occupational disease [9].

Airborne long mineral particles in gold and iron mining contribute to increased risk of cancers and lung disease and increased numbers of mesotheliomas (cancers generally associated with exposure to asbestos), certain cancers of blood-cell-generating bone marrow, of lymph nodes, and so on [10]. Among the non-cancerous respiratory diseases, most studies show an increased risk of silicosis and pneumoconiosis, due to the presence of crystalline silica in most mines [11]. Quebec mineralogy is conducive to the formation of amphibolic long particles, since geological pressure and temperature shifts that favor rock metamorphism are more widespread in this region of the globe than elsewhere, for example, in the USA. The health effects of exposure to long mineral particles in mines remain difficult to evaluate because of the simultaneous presence of several fibrous and carcinogenic agents in the same setting. Even where exposure to these particles has not been proven due to a lack of studies, it is nevertheless plausible in Quebec mines [12].

Diseases can occur from exposure to toxic, caustic, or allergenic agents by inhalation, absorption through contact with skin, or ingestion of airborne matter via contact with lips and oronasal mucosa [13]. These risks are attendant to the use of bulk explosives that can produce ammonia, a colorless and irritating gas with a sharp, penetrating odor at low doses and damaging to eyes and lungs at higher concentrations. Exposure to ammonia has caused skin irritation, eczema, eye irritation, rhinitis, and broncho-pulmonary pathologies [14]. According to data gathered in 2019, 4.17% of mining diseases result in inflammations and irritations, and 1.67% cause chemical burns [15].

Mine worker occupational health and safety must remain a high priority throughout all phases of managing a mining project [16]. In view of this imperative, mineworkers receive a wide range of Occupational Health and Safety (OHS) training [16].

The principal goal of this study (presented as two articles in series) is to establish a preliminary framework for categorizing chemicals in terms of their effects on the health of mineworkers throughout all phases of mining projects. The objective is to decrease (over the long term) the number of occupational diseases due to the use of chemicals by raising awareness among employers and exposed workers in the mining sector. The present article contains the results of a review of the literature, from which we catalog the main industrial chemicals used in mines and list the potential effects of exposure to them, based on Safety Data Sheets (SDS) of the Globally Harmonized System of Classification and Labeling of Chemicals (GHS). Following the introduction, the research methodology is described in section 2. The bibliographic search results are summarized in section 3, the limitations of the study are discussed in section 4, and the conclusion is formulated in section 5.

2. METHODOLOGY

The methodological approach to this study leads to a theoretical framework (this article) and a practical framework to be presented in the next article [1]. The theoretical framework comprises two steps: 1) cataloging the main chemicals used in each phase of a mining project, and 2) identifying potential effects of these chemical agents on the health of mine workers. The first step is based primarily on the review of the literature. The second step [1] comprises two additional steps: 3) determining the number of recurrences of health effects potentially due to each chemical, and 4) ranking the potential OHS effects as a function of recurrence (in decreasing order) (Fig. 1).

2.1. Cataloging of the chemicals used in each mining project phase

The bibliographic research methodology is hybrid (not entirely systematic). The reason for this orientation is that the research targets a particular place and sector where technical documentation is dominant. This documentation is of paramount importance for this research. The publications selected in this article are obtained in three stages.

First, a reading list was identified following a systematic search by keywords. This study began with a literature search and a selection of relevant publications. Keywords were used to consult the Scopus scientific database as well as specialized databases on websites such as the *Institut de recherche Robert-Sauvé en santé et en sécurité du travail* (IRSST, Quebec), the *Institut national de la recherche scientifique* (INRS, France), the *Association minière du Québec* (AMQ) and the CNESST. The same keywords were used more freely with Google's search engine and Google Scholar. Searches were conducted in French and English, with keywords grouped together using the operators "and" or "or".

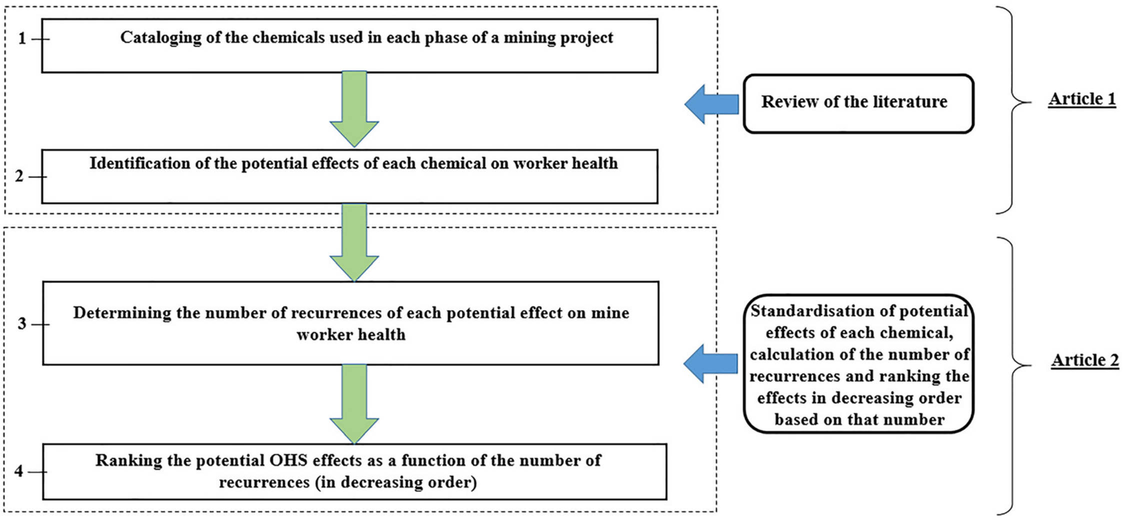

Fig. 1. Methodological approach of the OHS study presented in a series of two articles

Keywords included "occupational health and safety", "mines", "mining", "SST", "OHS", "agents chimiques", "chemical agent", "activités minières", "mining activities", "maladie professionnelle", "occupational disease (illness)".

In order to enrich the review, we have included all the documents deemed relevant to our study: articles from scientific journals or conferences, theses, reports, standards, regulations and technical documents. The choice of publications was made according to the quality and credibility of the sources, in accordance with a unanimous opinion of the experts involved in the research project. Documents published mainly from 2001 to 2021 were analyzed and evaluated on the basis of relevance and clarity of content.

Second, several publications from the first selected list referred to other more in-depth readings (quotes and bibliographic lists). Some of them were added to the literature review because of their relevance.

Third, other relevant publications have been added to the bibliography, to help readers better understand the different concepts and definitions related to this study such as occupational diseases, hazard groups, effects and consequences, etc. In addition, the SDS were added since they are necessary for the extraction of the relevant data in order to achieve the objectives of the research.

2.2. Identification of the potential effects of the chemicals on mine worker health

Figure 2 illustrates the potential causal relationship between the industrial chemical and its effects on health (occupational

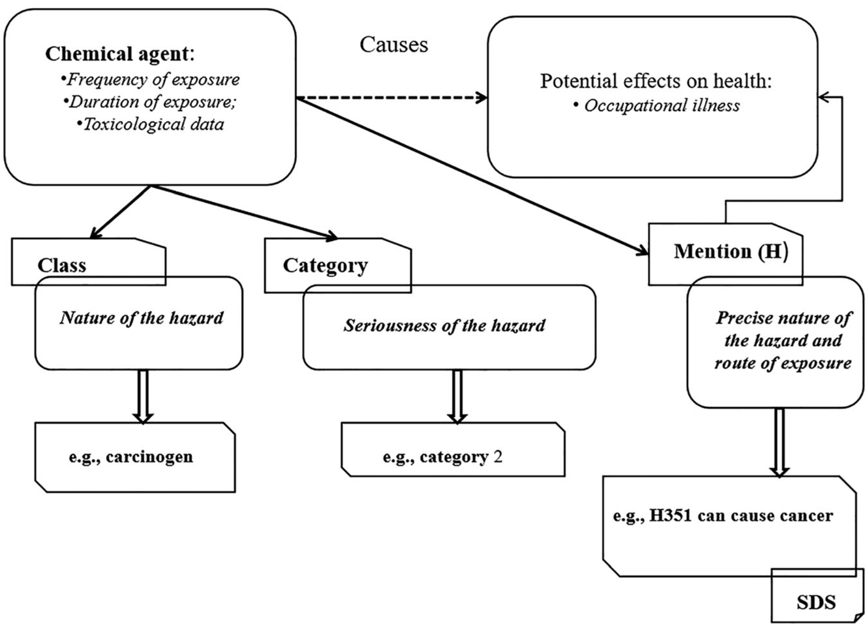

Fig. 2. Process of identifying potential effects based on GHS SDS

disease or illness) in terms of the nature of the hazard, its degree of seriousness and route of exposure to the chemical.

Each hazard group includes hazard classes that have specific hazardous properties (Physical hazards or Health hazards group) [17]. Hazard classes are a way of grouping together products that have similar properties. Most of the hazard classes are common to GHS and will be used worldwide by all countries that have adopted GHS. Each hazard class contains at least one category. The hazard categories are assigned a number (e.g., 1, 2, etc.). Categories may also be called “types”. Types are assigned an alphabetical letter (e.g., A, B, etc.). In a few cases, subcategories are also specified. Subcategories are identified with a number and a letter (e.g., 1A and 1B) [17].

All hazardous products must be labeled according to the regulations, and must have a corresponding SDS. The hazard class and category will be provided in Section 2 (Hazard Identification) of the SDS [17]. Each hazard class or category must use specific pictograms and other label elements to indicate the hazard that is present, and what precautionary measures must be taken. The hazard statement (or mention) on the label and SDS will describe the nature of the hazard [17].

For the purposes of this non-exhaustive repertory of chemicals that may be present during any of the different phases of the lifecycle of a mining project, the SDS provides information on the detection of potential effects related to OHS [18]. At least two types of chemicals are present during each phase: the first type is metallic and the second includes oils and lubricants (used in mechanical maintenance, cleaning products and specialty paints used in laboratory activities), flotation and wastewater treatment reagents (used in conjunction with ore production) [19]. The hazards associated with each of these chemical agents are grouped according to the thresholds derived from the short-term and weighted average exposure indexes and the potential effects on health according to the GHS [20].

3. RESULTS

3.1. OHS legislative framework in Quebec

Legislation clarifying guidelines intended to ensure at least minimal workplace hygiene and safety in Quebec date back to May 9, 1885: the factory workers’ lives and health protection act [21]. In 1979, Quebec witnessed major reform of the workplace accident prevention regime, thanks to adoption of the occupational health and safety act (LSST) followed by the workplace accident and occupational disease bill (LATMP) in 1985 [22]. This legislation constitutes the foundation of the current OHS regime. The aim of the LSST is to eliminate hazards at the source by obliging registered employers and workers to comply with applicable OHS regulations [22]. In 2016, the commission (CSST) created in 1979 to administer OHS in Quebec was merged with other governmental services to form the current commission for OHS equity standards (CNESST).

The Quebec mining industry subscribes to the so-called “free-mining” principle, that is, a law that upholds free access to mineral resources. The first legislative framework for mining activity in this province appeared in 1880 in the form of the Quebec general mining act [5], which made the state the sole owner of below-ground property and consequently of all mines in its territory, and set forth rules and regulations [23]. On December 9, 2013, the legislature adopted bill 70 to modernize the mining act, which became law the next day. The existing legislation was thus modified to include provisions for the environmental and social dimensions of sustainable economic development, with impact primarily on mining exploration and extraction [24].

According to a study by the Fraser Institute, Quebec ranks sixth internationally and third nationally (behind Manitoba and Saskatchewan) in attractiveness for mining [25]. A modification to the OHS regime applicable to mining as of August 3 of 2007 sets forth requirements regarding the training, wearing of high-visibility safety clothing, measures applicable to checking air quality before resuming work, and compliance with the proper use of portable lighting by mineworkers [16].

3.2. Regulations regarding dangerous materials and substances

Regulations regarding protection against dangerous or toxic substances are set forth in chapter 2.1, (art. 22, 23, 24) of the health and safety in mines legislation:

- Article 22 states that wherever dangerous or toxic substances, solutions or gases are used in a mine or workshop, appropriate quantities of antidotes and neutralizing solutions for the treatment of intoxication or lesions caused by these substances, solutions or gases must be kept on hand in an unlocked room located near the site where said substances, solutions or gases are in use. The antidotes and neutralizing solutions must be properly labeled, and the label must bear the instructions for their use. If an antidote must be administered by intravenous injection by a medical doctor or nurse, the phone number and address of this individual must be displayed near the room where the antidote is kept.
- Article 23 states that transporting and storage of acids and cyanides must be carried out in such manner as to avoid any possibility of contact between these substances.
- Article 24 states that when a processing plant ceases activity, all dangerous chemicals such as acids and cyanides must be disposed of in compliance with regulations.

The Workplace Hazardous Materials Information System (WHMIS) has been in effect in Canada since 1988, in support of Hazardous Products Regulations [26]. Health Canada the Canadian Association of Administrators of Labour Legislation have contrasted the WHMIS and the Quebec general harmonized system of chemical classification and labeling with the intention of identifying legislative and regulatory modifications needed at the federal or provincial levels of government [22]. Changes to the federal code have been in effect since February 11, 2015. The Quebec system targets all dangerous substances and mixtures thereof. The two main adjustments concern communication of standardized information using SDS and through recognition (application) of international classification criteria [27].

In 1985, the Canadian government adopted legislation on explosives. However, the only real obligation to emerge from this act specifically for mining activities applies to the use of explosives in the province of Quebec [26]. Article 21 sets forth the monitoring requirements for the category I depots holding 300,000 pounds of explosive or 20,000 detonators authorized in mines accessible by ramps as follows [28]:

- By one visit to the depot per hour at irregular intervals and recorded using a digital monitor
- By closed-circuit television surveillance monitored constantly by a security guard posted at some other part of the mining site.
- By a suitable alarm system in working order and autonomous in the event of electrical power interruption, producing no risk for explosives, capable of functioning under the worst atmospheric conditions and not drawing more than 0.06 amperes of current by induction, radio, electrically or otherwise. Must be connected to a monitoring post located on the premises, remain in continuous operation, and be backed by suitable means of communication and transport for rapid response in the event of theft.
- By an alarm system connected to the nearest police station and in continuous operation.

In-house systems of OHS management in Quebec mining companies are based on preventive measures and programs that the company must develop and implement, beginning with its risk identification registry [29]. Quebec legislation on chemicals follows the example of European legislation on the classification and labeling of dangerous materials and substances [30]. It defines the framework of obligations for users of chemicals, specifying that the employer must obtain from the supplier all information that is necessary for risk evaluation. Most if not all, this information can be gathered from the risk symbols and the SDS [31].

3.3. OHS risk management tools used in mines

In an effervescent economy, the mining industry must meet several OHS challenges that are very complex and fraught with uncertainty [32]. Rigorous management of OHS risks remains indispensable in the quest to avoid falling victim to the hazards. Quebec mining companies are generally compliant with OHS laws and regulations. They are obliged to maintain a health and safety joint committee and a hazard prevention program including specific health-related measures. In exchange, they are free to adopt any validated OHS management system, such as ISO 45000, CSA Z1000-06, OHSAS 18001:2007, ANSI Z10 and so on, as they see fit [33].

Suppliers of chemicals used, handled, or stored during mining operations also have obligations set forth in legislation on dangerous products. Article 17 of the Hazardous Products Information Regulation states that the employer is responsible for producing a SDS on any dangerous chemical that is used in the workplace [34]. The information on the data sheet must include: a description of the general characteristics (product category), the hazard associated with the product, emergency measures, preventive measures, and proper transport and storage [35]. It is the employer who must evaluate hazards to identify the chemicals that can or could have effects on health in the workplace [36].

A mine in Quebec must staff at least one rescue team whose primary function is to save the mineworkers in the event of an emergency or accident. The CNESST mining rescue service currently trains about 400 rescuers distributed in 19 mines throughout the province [37]. The Association paritaire pour la santé et la sécurité du travail du secteur minier (APSM) provides guidance on prevention and validates, as may be required, innovative OHS initiatives of mining companies and sub-contractors [8].

3.4. Concepts of prevention

Defining the concepts of prevention in relation to OHS provides support for the risk management process in any industry setting. In the context of this study, the following definitions shall be used:

Dangerous substance: A chemical substance fitting the criteria of danger as set forth in the controlled substances legislation [38].

- *Dangerous chemical agent*: The Labour Code defines these as any chemical agent that meets certain classification criteria or carries a known risk to worker health [39].
- *Chemical risk:* Any dangerous situation involving chemicals, under normal conditions of use or exposure capable of leading to an incident, accident, or disease [40].
- *Chemical danger*: Property or intrinsic capacity of a chemical agent of being inclined to cause damage to the health of workers [41].
- *Chemical nomenclature*: System or method of naming chemical products for immediate and universally recognized identification. A given product may be known by several names; only one is official, that being the IUPAC (International Union of Pure and Applied Chemistry, created in 1918) name.
- *CAS number*: A unique registration number established for each chemical, polymer, biological sequence, and alloy by the Chemical Abstracts Service, very practical for any information search and used by all documentaries of chemical information [10].
- *Classification*: Systematic specification of chemicals in terms of their characteristics, properties, toxicity and/or dangers based on criteria recognized nationally or internationally [42].
- *Toxicity*: Harmful effects on living organisms exposed to a substance, appearing during, very soon after or long after exposure [43].

- $^{LD}50$: The lethal dose or quantity of a chemical agent necessary to cause the death of 50% of laboratory animals exposed by the oral route (ingestion) or the cutaneous route [44].
- $^{CL}50$: The concentration of a chemical agent in air necessary to cause the death of 50% of laboratory animals exposed by inhalation, generally for 4 h [44].
- *Respirable fraction*: Percentage of inhalable particles detected or collected that can reach the alveoli of the lungs, defined by a cumulative log-normal distribution with a median aerodynamic diameter of 4.25 μm [45].
- *Thoracic fraction*: Percentage of inhalable particles detected or collected that can reach the bronchial zone, defined by a cumulative log-normal distribution with a median aerodynamic diameter of 11.64 μm [45].
- *Inhalable fraction*: The percentage of total airborne particles of the chemical than can enter the nose and mouth [45].

The chemical agent, whether solid, liquid or gaseous, that comes into contact with the human body, perturbs the function thereof and thereby has apparent health effects of some degree of seriousness according to an accidental or chronic mechanism [46].

3.5. Repertory of chemical agents used in mining projects

Mining activities vary considerably depending on the natural mineral resource being extracted from the Earth's crust. The lifecycle of a mining project (Fig. 3) can be described as comprising four distinct phases: exploration, development, operation and shutdown, the first and last phases being the best defined [47]. The process of upgrading extracted ore to saleable commodities is lengthy. The chemical agents used for this purpose are present in pure form or as mixtures, in the solid, liquid, or gaseous state. They are thus present in reagents, solvents, catalysts, finished products, air, processing water and tailings or residues [48]. In terms of value and volume, the most important minerals extracted in Quebec are gold, iron, nickel, titanium, and zinc [49]. The next sections examine management phases and the chemical agents that expose workers to potential health risks at each phase of a mining project.

3.5.1. Exploration phase. Searching for mineral deposits that are rich enough to be extracted profitably is a lengthy and costly activity requiring several types of specialists, including mining engineers, geologists, metallurgists, and other experts [47]. Quebec mining sites such as Kwyjibo, Queyfus, Mont-de-l'aigle, Schefferville, Lac Jeanine, Aldermac, Normétal are rich in magnetite and hematite [50]. These ores and several other types are analyzed using electronic microprobes that provide information about chemical composition quickly and affordably to classify potential mines at the exploration phase [51].

During mineral exploration, mining companies produce regional prospections and soil stripping excavations (removal of topsoil), drilling and sampling of bedrock [52]. The chemical (additives and lubricants) used during these operations are of the Matex line of drilling additives (DD-2000, DD-955, Utravis, DDX-Pand, SLO, Torqueless, Vibra stop, SAND Drill), drill bit greases and cutting oils (Petro-Canada Vultrex, flaxseed soap, Z-50 Pipe Dote).

Table 1 provides a non-exhaustive list (by CAS number) of chemical agent characteristics, toxicological data, potential health effects and workplace hazards according to the GHS.

3.5.2. Development phase. Development refers to construction of the mining site infrastructure, which requires two to four years and takes place only if the mineral deposit warrants the effort [16]. Paints and the adhesive doping used in asphalting materials during this phase have effects on the health of the exposed workers. Symptoms include irritation of mucous membranes (upper respiratory tract, eyes) as well as headaches, nausea, dizziness, vomiting and rashes [65]. Preventionists have formulated a few hypotheses on a potential relationship between these effects and hard bitumen. Smoke from bitumen is of complex composition and may contain hundreds of compounds of different chemical families [65]. Bitumen itself is a mixture of non-volatile (high molecular mass) mostly straight chain or branched hydrocarbons, but also contains naphthene or cyclic and saturated volatile compounds. It consists of 80–85% carbon, 10–15% hydrogen, 2–3% oxygen, and smaller quantities of sulfur and

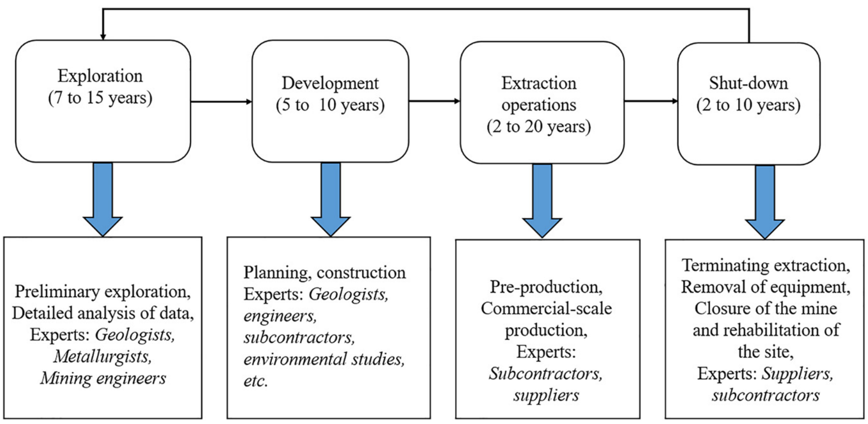

Fig. 3. The four phases of the mining lifecycle Adapted from [47], under Creative Commons CC BY 4.0 licence

Table 1. Chemical agents used in the exploration phase of the deep-mining business

N°	Chemical agent (N° CAS)	Short-term exposure mg m^{-3}	Weighted average exp. mg m^{-3}	Potential effect on health	GHS hazard category	References
1	Vultrex OGL Synthetic 2200 72623-86-0	10	5	Carcinogenic; eye irritation Skin irritation/dermatitis	1B (H350)	[53]
2	Vultrex EP00 0 72623-85-9	10	5	Skin irritation/dermatitis Eye/eyelid irritation	1B (H317)	[53]
3	Vultrex MPG 64741-95-3	10	5	Skin irritation/dermatitis	Not determined	[54]
4	Vultrex G 8012-95-1	Not determined	Not determined	Eye/eyelid irritation	Not determined	[55]
5	Vultrex-drilling core 68201-19-4	10	5	Harmful to skin/eyelids/eyes/respiratory system	Cat.4 (H302, H312, H332)	[53]
6	Carbon monoxide 630-08-0	230	40	Not determined	Cat.3 (H331) Cat.1A/1B (H360)	[56]
7	Nitrous oxides 10102-43-9	31	25	Eye/eyelid irritation	Cat.1A/1B/1C (H314) Cat.1 (H318)	[57]
8	Sulfur dioxide 7446-09-5	13	5.2	Eye/eyelid irritation	Cat.1A/1B/1C (H314) Cat.1 (H318)	[58]
9	Zerex antifreeze	Not classified	Not classified	Serious damage to organs (kidneys and liver)	Cat.1B (H302) Cat.2 (H360) Cat.4 (H373)	[59]
10	Ammonium thiocyanate 1762-95-4	Not determined	Not determined	Causes serious eye injury Harmful if swallowed, inhaled or in contact with skin	Cat.1 (H318) Cat.4 (H302, H312, H332)	[60]
11	Ethylene glycol 109-86-4	Not determined	16	Harmful if swallowed Risk of damage to internal organs	Cat.2 (H373) Cat.4 (H302)	[61]
12	Methanol 74-93-1	Not determined	0.98	Toxic if ingested, inhaled or absorbed by prolonged skin contact High risk of organ damage, optical nerve, central nervous system	Cat.1 (H370) Cat.3 (H302 H311 H331)	[62]
13	Tributyl phosphate 126-73-8	2,2	Not determined	Harmful if swallowed Causes skin irritation Carcinogenic	Cat.4 (H302) Cat.2 (H315, H351)	[63]
14	Potassium ethyl xanthate 140-89-6	Not determined	Not determined	Skin and eye irritant organ-specific toxicity/respiratory system damage	Cat.2 (H300) Cat.3 (H336) Cat.4 (H312)	[62]
15	Zinc chloride 7646-85-7	Not determined	1	Harmful if swallowed Causes severe burns on skin/eyes Irritation of respiratory system	Cat.1/1B (H318, H314) Cat.3 (H335) Cat.4 (H302)	[62]
16	Citrikleen HD 136-86-3	Not determined	Not determined	Skin and eye irritant Fatal if swallowed Respiratory system damage	Cat.1 (H310) Cat.2 (H300) Cat.3 (H311)	[64]
17	Citrikleen XPC 5989-27-5	Not determined	Not determined	Skin and eye irritant Harmful if swallowed Respiratory system damage	Cat.1 (H372, H304, H334) Cat.2 (H310) Cat.3 (H335)	[64]
18	Elite 149458-07-1	Not determined	Not determined	Causes serious lesions to eyes/skin irritant	Cat.1 (H318) Cat.2 (H315)	[64]

nitrogen as well as trace amounts of various metals bound chemically to the larger molecules [66].

Crystalline silica dust is omnipresent during this phase. During this phase, crystalline silica is mostly generated by the ground-clearing activities. Occupational exposure to this substance should not exceed 0.1 mg per m^3 of air. A recent European directive classifies as carcinogenic processes that release silica [67]. Inhalation of silica dust is regarded as a potential cause of lung cancer, and crystalline silica is now considered as a dangerous chemical substance and underlying cause of silicosis [68]. Silicosis is an occupational chronic lung disease that causes a partial or total loss of lung

Table 2. Chemical agents used during the development phase of a mining site

N°	Chemical name and CAS number	Short-term exposure mg m^{-3}	Weighted average exposure mg m^{-3}	Potential effect on health	GHS category of hazard	References
19	Hexa-methylene diisocyanate (HDI) 822-06-0	Not determined	0.034	Eye irritant/asthma	Cat.3 (H331) Cat.2 (H319, H315) Cat.3 (H335) Cat. 1/1A/1B (H334 H317)	[77]
20	Toluene diisocyanate (TDI) 26471-62-5	0.14	0.036	Skin irritant	Cat.3 (H331) Cat.2 (H319, H315) Cat.3 (H335) Cat. 1/1A/1B	[78]
21	Asbestos 12172-67-7	5 fibers/ cm^3	1 fiber/cm^3	Fibroses/Asbestosis; Mesothelioma	Cat.1A/1B (H350) Cat.1 (H372)	[79]
22	Isophorone diisocyanate (IPDI) 4098-71-9	Not determined	0.045	Skin and eye irritant	Cat.3 (H331) Cat.2 (H319, H315) Cat.3 (H335) Cat. 1/1A/1B	[80]
23	4-4'diphenyl— methyl diisocyanate (DPMDI) 5124-30-1	Not determined	0.054	Skin irritant; eye irritant; carcinogen	Cat.3 (H331) Cat.2 (H319, H315) Cat.3 (H335) Cat. 1/1A/1B	[81]
24	Crystalline silica 148 08-60-7	Not determined	0.05	Silicosis	Cat.1A/1B (H350)	[69]
25	Bitumen PG 8052-42-4	Not determined	Not determined	Dermatitis; cancer	Cat.2 (H351)	[82]
26	Ethylene glycol 107-21-1	127	63	Harmful if swallowed	Cat.2 H302	[20]
27	Quicklime	Not determined	Not determined	Corrosive on skin; skin and lung irritant	Cat.1 (H318) Cat.2 (H315) Cat.1A (H350) Cat.3 (H372)	[83]
28	Hydrogen peroxide 7722-84-1	Not determined	Not determined	Toxic orally, eye irritant, concentrated form causes burns on skin	Cat.1 (H318) Cat.1B (H314) Cat.3 (H335) Cat.4 (H302, H332)	[84]
29	Lead nitrate 10099-74-8	Not determined	Not determined	Toxic orally or if inhaled, damages reproductive organs eye irritant	Cat.1 (H318) Cat.1A (H360Df) Cat.2 (H373) Cat.4 (H302, H332)	[85]
30	Sodium sulfide nonahydrate CAS: not defined	Not determined	Not determined	Toxic, skin irritant, harmful if swallowed, causes burns on skin	Cat.1 (H318) Cat.1B (H314) Cat.3 (H311) Cat.4 (H302)	[86]
31	Sodium hydroxyde 1310-73-2	Not determined	Not determined	Skin and eye irritant	Cat.1 (H318) Cat.1B (H314)	[83]
32	Sodium hypochlorite 7681-52-9	Not determined	Not determined	Skin and eye irritant	Cat.1B (H314) Cat.1 (H318)	[86]
33	Sodium nitrite 7632-00-0	Not determined	Not determined	Oral route toxicity low (approved food additive) Eye irritation and lesions	Cat.2 (H314) Cat.3 (H301)	[87]
34	Sodium meta- silicate pentahydrate 10213-79-3	Not determined	1	Skin, eye, and respiratory system irritant	Cat.1B (H314) Cat.1 (H318) Cat.3 (H335)	[88]
35	Sodium bisulfite 7631-90-5	Not determined	5	Harmful if swallowed	Cat.4 (H302)	[89]
36	Chlorine 7782-50-5	2.9	1.5	Skin and eye irritant, toxic if inhaled	Cat.2 (H315, H319) Cat.3 (H331)	[90]
37	Potassium permanganate CAS: not defined	Not determined	Not determined	Harmful if swallowed, strong oxidizer, causes burns on skin or eyes	Cat.1/1C (H318, H314) Cat.2 (H361d, H373)	[62]
38	Enviro-Trap 7631-99-4	Not determined	Not determined	Causes severe irritation of eyes and skin	Cat.2 (H351)	[91]

(continued)

Table 2. Continued

N°	Chemical name and CAS number	Short-term exposure mg m^{-3}	Weighted average exposure mg m^{-3}	Potential effect on health	GHS category of hazard	References
39	Foam-EZE C-100-1310-73-2	Not determined	Not determined	Causes severe irritation of eyes and skin	Cat.1 (H310)	[92]
40	Teramine NR 68424-85-1	Not determined	Not determined	Causes severe irritation of eyes and skin	Cat.1 (H310)	[93]
41	Westamine 68-424-85-1	Not determined	Not determined	Skin and eye irritant	Cat.1 (H310)	[94]

capacity, appearing after several years of exposure (the first symptoms may take 10–15 years to develop) and in some cases progressing even after exposure has ceased [69]. Silica-based sanding and abrasive products sold under the trade names Ebony Grit and Maxi Blast also contain small amounts of arsenic, lead and cadmium [70].

Radon is considered a carcinogen in humans, a class A-1 substance on the United States Environmental Protection Agency list [71] and a CIRC class 1 substance [72]. Radon concentrations in mines can be considerable. Epidemiological studies of mine workers in Quebec show a causal link between exposure to radon derivatives and lung cancer [73]. Radon 222 is an inert gas. However, it breaks down to short-lived radionuclides, namely polonium 218 and 214, lead 214, and bismuth 214. These form extremely fine solid particles that are adsorbed by suspended aerosols, which are then inhaled [74].

The isocyanate family of paint additives (Table 2) used to slow down rusting of certain mining machines and equipment also represents a health hazard. Eight isocyanates (HNCO, HDI, Me-i to Hex-i) are emitted from the thermal breakdown of these paints [75]. The best illustration of the danger associated with isocyanates occurred in 1984 in a pesticide production plant located in Bhopal, India. The isocyanate dispersed into the air caused 1,048 deaths in the surrounding population, and 20,000 persons remain handicapped today because of this accident [76].

In Quebec, several thousands of mineworkers may be exposed to toxic substances released from thermal decomposition of paints during welding, grinding, or cutting of metal objects [30]. Overexposure to isocyanates can also cause dermatitis, conjunctivitis and acute intoxication that lead to occupational asthma [95]. Processes that involving spraying methylene diphenyl 4,4-diisocyanate (MDI) and hexamethylene diisocyanate (HDI) oligomers increase exposure to isocyanates by accelerating compound evaporation from aerosols with large surface areas of contact with ambient air [96]. The OHS commission is very wary of the risk of exposure to isocyanates in general, starting from the manufacture of the compounds and their distribution and all through their application in the industrial workplace [97].

3.5.3. Extraction operations phase. The principal features of this phase are the commercial production of the mineral being extracted from a deposit by teams of mineworkers, the associated value-adding and maintenance operations [47] and monitoring of these activities [16]. In Quebec, minerals are currently being extracted from about 25 active mines, which include open-pit and subterranean types. Each site has its own unique configuration and environment [98]. The production of metals requires implementation of a series of chemical processes, from ore excavation through transformation of the metal to a saleable form, involving the use of numerous chemical agents [99]. The ore is dissolved to a large degree, and its metal and other constituents are separated from the chemical solution in situ by lixiviation [19]. In the laboratory analysis of drill core samples, hydrofluoric acid is often used [100]. This liquid is highly toxic and corrosive and penetrates rapidly and deeply into skin or eyes on contact [101]. The internal toxic dose depends on the route of absorption, the type and seriousness of the lesion and well as the time required for the lesion to appear [102]. Systemic intoxication is practically inevitable whenever a miner is splashed with concentrated hydrofluoric acid. In 2019, an estimated 2.5–10% of all cases of contact of a body surface with 70% of hydrofluoric acid were reported by the CNESST [77, 97]. Mineworkers also face a chemical hazard associated with the use of explosives [103] that produce carbon monoxide, a highly toxic gas that can cause serious and irreversible neurological damage [104]. An estimated 5,450 mining site workers are also exposed to crystalline silica, notably during sawing rock and breaking rock with jackhammers [105], an activity well recognized as a major source of occupational disease [106]. Prolonged exposure to crystalline silica can cause chronic obstructive diseases, such as poly-arthritic rheumatoid silicosis, lung cancer, and kidney disease [107] as well as pneumoconiosis or black lung disease, caused by carbon particles [108]. Nasal sinus cancer is caused by arsenic extracted during the melting of copper and exposure to nickel compounds in certain refineries [109]. Acute bronchospasm is caused during the use of mercury during extraction of gold in the preparation of the xanthate reagent widely used in hydro-metallurgic mining processes [106]. Mineworkers are also exposed to chemical agents at various concentrations over long periods, leading to accumulation of toxic substances in the body, the clinical manifestations of which may not appear until late in life [109].

Lead is a toxic heavy metal frequently encountered in forms that can be inhaled in mines. At low doses, it concentrates in the intestines. The first clinical manifestations of prolonged exposure are colic symptoms with abdominal

Table 3. Chemical agents used during the extraction phase of a mining site

N°	Chemical name and CAS number	Short-term exposure mg m^{-3}	Weighted average exposure mg m^{-3}	Potential effect on health	GHS category of hazard	References
42	Hydrofluoric acid 64-18-6	19	9.4	Corrosive skin irritant, vapors can cause dermatitis, eye/eyelid irritation	Cat.2 (H310) Cat.1 (H330, H318) Cat.1A/1B (H314)	[113]
43	Glacial acetic acid 64-19-7	37	25	Carcinogen Eye/eyelid irritation	Cat. 1A/1B/1C H314	[114]
44	Hydrochloric acid 7647-01-0	7.5	Not determined	Corrosive on skin; Organ-specific toxicity	Cat. 3 H314 H335	[115]
45	Sulfamic acid 5329-14-6	Not determined	Not determined	Irritation of skin and eyes	Cat.2 (H315) Cat.2 (H319)	[116]
46	Nitric acid 7697-37-2	10	5.2	Corrosive oxidizer Causes serious burns on skin and eyes Inhaled fumes are toxic	Cat.1 (H318) Cat.1B (H314) Cat.3 (H331)	[62]
47	Oxalic acid 144-62-7	2	1	Harmful if swallowed or in contact with skin Serious lesions on eyes Risk of serious harm to internal organs	Cat.1 (H318) Cat.2 (H373) Cat.4 (H302, H312)	[62]
48	Phosphoric acid 7664-38-2	3	1	Causes burns on skin, lesions on eyes	Cat.1B (H314) Cat.2 (H318)	[62]
49	Mercury 7439-97-6	Not classified	0.1	Bronchospasms	Cat.1 (H372)	[61]
50	Arsine 7784-42-1	Not classified	0.16	Carcinogen	Cat.1 (H314, H318)	[117]
51	Magnesite 546-93-0	10	Not determined	Irritation of skin and eyes	Not determined	[118]
52	Ammonia 7664-41-7	24	17	Irritation of skin and eyes	Cat.1 (H314, H318)	[119]
53	Aluminum sulfate 10043-01-3	Not classified	Not classified	Serious lesions on eyes Eye irritant	Cat.1 H318	[114]
54	Sodium sulfide 27610–45-3	Not classified	Not classified	Skin/eye irritant	Cat.1 (H314, H318)	[120]
55	Ammonium chloride	Not classified	10	Acute toxicity (oral) Serious lesions on eyes Eye irritant	Cat. 2 H302 Cat.4 H319	[114]
56	Ammonium sulfate dodecahydrate 7783-83-7	Not classified	Not classified	Irritation of skin, serious lesions on eyes	Cat.2 H315 H319	[121]
57	Nitrogen 7727-37-9	Not classified	0.25	Not determined	Cat.1 (H318)	[122]
58	Sodium nitrate 7631-99-4	Not classified	Not classified	Eye/eyelid irritant	Cat.1 (H314, H318)	[123]
59	Crystalline silica 14 808-60-7	Not classified	0.1	Eye irritant, causes silicosis and pulmonary fibrosis, carcinogen	Cat. 2 H302 Cat.4	[124]
60	Nickel 13 463-39-3	Not classified	0.007	Carcinogen Exacerbates asthma	Cat.1A/1B (H350)	[125]
61	Plomb 7439-92-1	Not classified	0.05	Kidney afflictions	Cat.2 (H373)	[126]
62	Manganese 7439-96-5	Not classified	0.2	Not determined	Cat.4 (H332, H302)	[127]
63	Ethyl acetate 147-78-6	Not classified	1440	Eye irritant, volatile Causes dizziness	Cat.2 Cat.3 H336 H319	[127]
64	Sodium tetraborate decahydrate 1303-96-4	Not classified	1	Eye irritant, harmful to fertility	Cat.1B (H319) Cat.2 (H360 FD)	[128]

(continued)

Table 3. Continued

N°	Chemical name and CAS number	Short-term exposure mg m^{-3}	Weighted average exposure mg m^{-3}	Potential effect on health	GHS category of hazard	References
65	Caustic soda	Not classified	Not classified	Corrosive, irritant of skin and eyes	Cat.2 H336	[129]
66	Anhydrous chlorine 7705-08-0	Not classified	Not classified	Harmful skin and digestive system irritant Causes lesions on eyes	Cat.1 (H317, H318) Cat.2 (H315) Cat.4 (H302)	[128]
67	Ferrous sulfate heptahydrate 7782-63-0	Not classified	Not classified	Harmful if swallowed Skin and eye irritant	Cat.2 (H319, H315) Cat.4 (H302)	[128]
68	Formic acid 64-18-6	19	9.4	Burns on skin Lesions on eyes	H314	[130]
69	Cobalt 7440-48-4	Not determined	Not determined	Provokes asthma, difficulty breathing Skin irritant	Cat.1/1A/1B (H334, H317)	[131]
70	Copper sulfate pentahydrate 7758-99-8	Not determined	Not determined	Harmful if swallowed Causes serious lesions on eyes	Cat.1 (H318) Cat.4 (H318)	[132]
71	Methyl-2 pentanol 108-11-2	Not determined	Not determined	Can irritate the respiratory system	Cat.3 (H335)	[62]

pain, chronic constipation, loss of appetite, blue line on the gums, insomnia, headaches, confusion, delirium, and erythropoiesis leading to bone marrow hyperplastic erythroid anemia [110]. Anorexia, asthenia, apathy, somnolence, and chronic central nervous symptoms resembling those of Parkinson's disease may follow [111].

Arsenic and its mineral compounds are also absorbed primarily via the digestive tract and the respiratory system. The intensity of the problems caused by arsenic varies as a function of the quantity absorbed and the chemical form. Acute exposure by ingestion can lead to afflictions of the digestive system, central nervous system, and the cardiovascular, hepatic, or renal systems, in some cases with fatal outcome [112]. Table 3 lists chemical hazards associated with the production phase of a mining project.

3.5.4. Shutdown phase. The shutdown phase of a mine includes dismantling and reassigning the equipment and parts of the installation and rehabilitating the mine pits and surrounding land [47]. Numerous chemicals used during general maintenance of the mineral concentrator areas and cleaning of ore extraction equipment and storage facilities have accumulated by this time [64]. These chemicals do not appear to carry much risk as documented within the SDS. However, the volatile organic compounds among them (mostly hydrocarbons varying widely in structure) can affect the health of workers involved in dismantling operations. They can cause damage to kidneys, the digestive system, liver, and heart [133].

Two types of processes are used for the active treatment of acidic water: chemical and physicochemical [134]. Alkalinizing chemicals used to neutralize acids and precipitate soluble metals include quicklime (CaO), slaked lime ($Ca(OH)_2$), magnesium hydroxide ($Mg(OH)_2$), limestone or chalk ($CaCO_3$), ammonium hydroxide (NH_4OH), caustic soda (NaOH) and sodium sulfide (Na_2S). Not even calcium carbonate is totally harmless [135], since massive exposure over short periods of time can be intoxicating, with neurological signs such as difficulty focusing attention, somnolence, impaired vision and so on [136]. Table 4 lists some of the chemicals used during various operations carried out in the process of shutting down a mining site.

4. DISCUSSION AND LIMITATIONS OF THE STUDY

The human body is made up of several vital organs for its specific and general functioning. Unlike the analysis of work accidents, occupational diseases require a more in-depth and elaborate diagnosis. The diagnosis therefore requires more time and effort. It is simplistic to separate the organ from the human body affected by a chemical agent, but this way of analyzing is imposed by the potential effects already worked out by scientists. This is a starting point for implementing a rapid and efficient diagnosis.

The identification of the chemical agents used in the mining sector according to the project phases indicates precisely the organs of the body most at risk, according to their exposure. It is important to note that the presence of the various organs potentially at risk is repeated from one phase to another during the mining project (Tables 1–4). On the other hand, there are also consequences not attributed to specific organs or attributed to unspecified cancers.

Table 5 gives a general overview of the systems and organs most at risk, according to the presence of chemical agents that

Table 4. Chemical agents used during the Shutdown phase of a mining site

N°	Chemical name and CAS number	Short-term exposure mg m^{-3}	Weighted average exposure mg m^{-3}	Potential effect on health	GHS category of hazard	References
Steam-cleaning, foam-washing and vehicle washing areas						
72	Formula FC-1160 (141-43-5)	Not determined	Not determined	Skin and eye irritants	Cat.1 (H318)	[137–140]
73	Formula FC-1161 (1310-73-2)					
74	Metasol 6834-92-0					
75	Penblitz 228M 6834-92-0					
Scrubbing agents and floor cleaners						
76	Penpower 150L 497-19-8	Not determined	Not determined	Skin and eye irritant	Cat. 4 (H30, H312, H332) Cat.3 (H335) Cat.1 (H318)	[141]
Cleaners for parts and electrical and electronic components						
77	Pensolv Pb 2000 106-94-5	Not determined	Not determined	Skin and eye irritant	Cat.1 (H314)	[142]
Degreasers, high-yield degreasers, tar/sludge/grime removers						
78	Citrikleen HD 141-43-5	Not determined	Not determined	Skin and eye irritant	Cat.1 (H314)	[143]
79	Westkleen 4115 7664-38-2	Not determined	Not determined	Causes serious burns on skin, lesions on eyes	Cat.1 (H314)	[144]
80	West Floor Kleen 6834-92-0	Not determined	Not determined	Skin and eye irritant	Cat.2 (H315, H319)	[144]
81	Penpower 500L 1310-73-2	Not determined	Not determined	Causes serious burns on skin and lesions on eyes Irritation of the respiratory system	Cat.4 (H302, H312) Cat.3 (H336) Cat.1 (H318)	[145]
82	Foamchek 7664-38-2	Not determined	Not determined	Causes serious burns on skin and lesions on eyes	Cat.4 (H302) Cat.1 (H318)	[146–148]
83	Ridstone 7664-38-2					
84	Wedac 7664-38-2					
85	Westop 480 CAS not defined	Not determined	Not determined	Skin and eye irritant	Cat.2 (H315, H319)	[149]

could alter them during each phase of the mining project. It excludes unspecified consequences or unspecified cancers.

Table 5 and Fig. 4 show that the skin and eyes are the organs most at risk, followed by the respiratory system in general.

According to statistics for the years 2010–2012, the CNESST accepted on average 130 deaths per year as being attributable to occupational disease caused by exposure to harmful chemicals in the mining sector [150]. Of these, 82% were asbestos-related, 9% were associated with silica

Table 5. General overview of the systems and organs most at risk

Organ/System	Project Phases				Total of citations
	Exploration	Development	Extraction	Shutdown	
Skin	12	19	17	8	**56**
Visual system	11	14	20	8	**53**
Respiratory system	5	5	6	1	**17**
Central nervous system	1		1		**2**
Digestive system			1		**1**
Kidneys	1		1		**2**
Liver	1				**1**

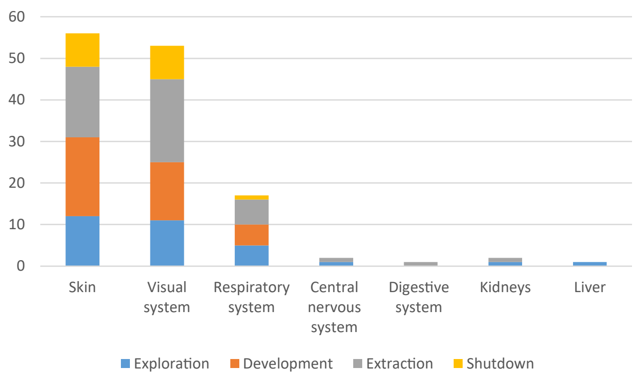

Fig. 4. General overview of the systems and organs most at risk

and the remaining 9% with unspecified chemicals [37]. Most of the chemicals identified are in the inhalation risk category [45]. The respiratory system is the principal route of entry of harmful compounds into the human body in the workplace [151]. This problem is complex because ambient air may be laden with vapors, gases, smoke, and dust. Ingestion of chemicals is rather rare, but can occur accidentally, for example when a worker drinks, eats or smokes in a contaminated work environment [152].

The skin is another route of entry for chemicals used in mines [153]. The resulting problems can be anywhere from minor irritations to serious burns. Some compounds penetrate the skin deeply and thereby enter the body and cause lesions or occupational disease [154].

Dust in mines refers to any solid matter suspended in the ambient air, usually particles produced by mechanical processes such as crushing of ore or use of jackhammers [12]. Particles small enough to reach lung alveoli are a major cause for concern. When air is sampled for analysis, a distinction is made between total dust and breathable dust. Total dust refers to air dustiness, which is usually proportional to what is perceived visually. The sampling device comprises a pump fitted with one or more filters incorporated into holders or cassettes. Respirable dust is the fraction of total dust particles that can reach the alveoli, based on size [154].

Finally, this evaluation of chemical hazards is based essentially on information provided in SDS, mainly the type of danger symbol and the statement of risk on the product, which is a suitable and advantageous approach. However, some chemical agents do not have published short-term exposure or weighted average concentration values, which could make the evaluation less reliable.

Another limitation is the reliance on the SDS for health endpoints. Assessment of chemicals or agents involves lab data and animal studies to assess for cancer alone. Other types of agents acute effects may also require that level of evidence to derive occupational exposure limits.

In addition, because of restrictions imposed by COVID-19 sanitary measures, practically no field analyses of chemical agents have been conducted in recent years on site or in mines, where findings could be influenced by the presence of other contaminants. We were able to consider only the data available at the websites of manufacturers or suppliers of the chemicals.

5. CONCLUSION

The goal of the first part of this project was to compile the repertory of chemicals used during the various phases of mining projects in Quebec and the potential effects of these agents on the health of mine workers, based on a review of the literature. For this analysis, we referred mainly to SDS drawn from the general harmonized system in use throughout the province.

This review yielded a repertory comprising 85 industrial chemicals. Among the OHS risks associated with each of these, 9 potential major effects (occupational diseases) on the health of mine workers were identified: cancers, kidney disease, mesothelioma, lung disease, asbestosis, fibrosis, silicosis, dermatitis (skin and eyes), and asthma.

In view of the considerable number of chemicals handled over the lifecycle of a mining project and the potential effects on the health of its workers, the present study leads us to the recommendation that OHS researchers and experts and businesses in the mining industry examine these effects more closely and with higher priority.

Despite the limitations of our research at this stage, we have established a base on which to build a theoretical framework for describing in detail the risks associated with the use of chemicals in mining activities in Quebec. This description will be presented in a later article [1]. The study overall suggests practical ways of raising greater awareness among exposed workers and thereby decreasing on the long-term the risk of occupational diseases in this industrial sector.

Author Contributions: This paper is entirely based on the results of research conducted by Paul-Patrice Biyick as part of his master's project in industrial safety and hygiene under the direction of Professors Adel Badri and François Gauthier. Adel Badri has written the paper in collaboration with Paul-Patrice Biyick and François Gauthier. All authors have read and agreed to the published version of the manuscript.

Funding: The authors thank the Université du Québec à Trois-Rivières (UQTR), Fonds de recherche du Québec - Société et culture (FRQSC) and Natural Sciences and Engineering Research Council of Canada (NSERC) for their financial support.

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