Institut de recherche
Robert-Sauvé en santé
et en sécurité du travail

Development of a Confined Space Risk Analysis and Work Categorization Tool

Yuvin Chinniah
Ali Bahloul
Damien Burlet-Vienney
Brigitte Roberge

STUDIES AND RESEARCH PROJECTS

R-955

MECHANICAL AND PHYSICAL RISK PREVENTION

OUR RESEARCH
is working for you !

The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), established in Québec since 1980, is a scientific research organization well-known for the quality of its work and the expertise of its personnel.

Mission
To contribute, through research, to the prevention of industrial accidents and occupational diseases and to the rehabilitation of affected workers;

To disseminate knowledge and serve as a scientific reference centre and expert;

To provide the laboratory services and expertise required to support the public occupational health and safety network.

Funded by the Commission des normes, de l'équité, de la santé et de la sécurité du travail, the IRSST has a board of directors made up of an equal number of employer and worker representatives.

To find out more
Visit our Web site for complete up-to-date information about the IRSST. All our publications can be downloaded at no charge.
www.irsst.qc.ca

To obtain the latest information on the research carried out or funded by the IRSST, subscribe to our publications:

- *Prévention au travail* the free magazine published jointly by the IRSST and the CNESST (preventionautravail.com)
- InfoIRSST, the Institute's electronic newsletter

Legal Deposit
Bibliothèque et Archives nationales du Québec
2017
ISBN : 978-2-89631-916-9
ISSN : 0820-8395

IRSST – Communications and Knowledge Transfer Division
505 De Maisonneuve Blvd. West
Montréal, Québec
H3A 3C2
Phone: 514 288-1551
publications@irsst.qc.ca
www.irsst.qc.ca

Development of a Confined Space Risk Analysis and Work Categorization Tool

Yuvin Chinniah[1], Ali Bahloul[2], Damien Burlet-Vienney[2], Brigitte Roberge[2]

[1]Polytechnique Montréal
[2]IRSST

STUDIES AND RESEARCH PROJECTS

R-955

This study was funded by the IRSST. The conclusions and recommendations are solely those of the authors.
This publication is a translation of the French original; only the original version (R-928) is authoritative.

PEER REVIEW
In compliance with IRSST policy, the research results published in this document have been peer-reviewed.

ACKNOWLEDGEMENTS

We would first like to express our thanks to all the organizations and companies that took part in the research project and all the people who were involved. Without their co-operation, availability and openness, the project could not have been completed.

We also wish to underscore the contribution of the joint follow-up committee headed by Marie-France d'Amours, of the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), which played a significant role in defining the research goals and validating the results. The members of the follow-up committee were Caroline Godin (MultiPrévention), François Granger (Commission des normes, de l'équité, de la santé et de la sécurité du travail), Élaine Guénette (Association paritaire pour la santé et la sécurité du travail, Secteur affaires municipales), Charbel Mouawad (Association sectorielle – Fabrication d'équipement de transport et de machines), Mireille Pelletier (Confédération des syndicats nationaux), Pascal Rousseau (Associations de la santé et de la sécurité des pâtes et papier et des industries de la forêt du Québec), Geneviève Royer (Hydro-Québec), Jean-François Spence, Elsa Dagenais (Via Prévention) and Bernard Teasdale (Association paritaire pour la santé et la sécurité du travail, Secteur construction). We would also like to note the contribution, at certain stages in the project, of Marc-Antoine Busque and Laurent Giraud (IRSST), as well as that of consultant Nicole Goyer, CIH.

The research team also wishes to thank the IRSST for the project funding and the support of its staff, especially Chantal Tellier.

ABSTRACT

The Quebec Regulation respecting Occupational Health and Safety (ROHS) defines an enclosed area [confined space] in section 1. A confined space is any area that is completely or partially enclosed and is not designed for human occupation, nor intended to be, but may occasionally be occupied for the performance of work. A worker may therefore enter such a space that (i) is not a workstation, (ii) has restricted access and (iii) represents a risk to health and safety. The issue of confined space work cuts across a wide range of sectors: municipal, manufacturing, chemical, military, agricultural, construction and transportation. The most common confined spaces in industry are tanks, reservoirs, silos, vats, manholes, pits, sewers, pipes and tank cars or trucks that have certain characteristics defined in the regulations. Workers enter confined spaces to perform maintenance, manufacturing or other tasks (e.g., construction industry). The occupational health and safety hazards are primarily atmospheric, biological, physical and ergonomic. The risks run by workers who enter these confined spaces are potentially high because of the confinement, inadequate natural ventilation, need to work in isolation, and access, rescue and communication problems. Moreover, accidents are common in confined spaces. In Quebec, for instance, between 1998 and 2011, 40 fatalities occurred in 32 confined space accidents, accounting for 4% of the investigation reports of the Commission des normes, de l'équité, de la santé et de la sécurité du travail (CNESST).[1]

Confined space work is regulated in Quebec with respect to worker qualifications, hazard identification, atmospheric control, entry monitoring and rescue procedures. Canada has a standard for confined space work: CSA Z1006 – Management of Work in Confined Spaces. In practice, before starting work in a confined space, a qualified person must conduct a risk assessment in order to take appropriate risk elimination and reduction measures.

The purpose of this research project was to contribute to confined space accident prevention by helping companies apply existing regulations. Two specific objectives were to (i) gain a better understanding of confined space risk management and identify issues based on the literature and field observations, and (ii) develop a confined space risk analysis and work categorization tool that meets the needs defined in the first stage of the project.

The research method included (i) a critical review of the literature on confined space risk management, (ii) an analysis of fatal confined space accident investigations in Quebec in order to identify failings that led to the accidents and (iii) visits to 15 or so companies and organizations that manage confined space entries for their workers and subcontractors. The findings showed that, first, the number of fatal accidents caused by an equipment energy control problem highlights the importance of mechanical hazards in confined spaces. A more multidisciplinary approach would therefore seem desirable. Second, the risk estimation and assessment stages are seldom dealt with formally in the literature, with the exception of atmospheric risks. The literature focuses primarily on identifying hazards related to different kinds of confined space work. The main confined space risk analysis tools suggested in the literature (e.g., checklists, risk matrices) are often incomplete and do not take into account certain specific factors such as the physical characteristics of the confined space, rescue conditions, the variety of hazards, or the

[1] The Commission de la santé et de la sécurité du travail (CSST) became the Commission des normes, de l'équité, de la santé et de la sécurité du travail (CNESST) on January 1, 2016.

physical and psychological condition of the person entering the space. Furthermore, none of the organizations the research team visited estimated risks, relying instead solely on the experience of the permit issuer. In some cases, this approach can lead to inaccurate assessments of risk (e.g., omission or underestimation) and possibly to inadequate risk reduction measures. Third, in the literature, the concept of similar confined space, which is intended to lighten the burden of risk analysis, is not supported with practical assessment criteria. The idea of categorizing confined spaces to facilitate risk management and communication is described in the literature, but is not used much in the field. Fourth, field visits revealed that most rescue procedures had neither been tested nor made available to the local fire department. Last, it should be noted that the literature stresses the importance of rescue procedures, worker training and the conditions to be met before entering confined spaces, but pays little attention to the safe design of such spaces, although that is the risk control measure that deserves the greatest emphasis.

On the basis of these findings and standard ISO 12100 – Safety of Machinery – General Principles for Design – Risk Assessment and Risk Reduction, a five-step risk assessment tool was developed for confined spaces, in order to meet the project's second objective. Step 1 of the tool consists of a list of 26 closed-ended questions intended to characterize the confined space, its environment and working conditions. The purpose of step 2 is to describe the accident process related to the risks identified by the tool user. Step 3 facilitates risk estimation using a risk matrix and criteria tailored to the context of confined spaces. For this purpose, risk estimation tool design criteria recently proposed for machine safety were applied. Step 4 provides a graphic classification by risk categories and levels. Last, step 5 consists of a feedback loop that estimates residual risks once the risk reduction measures have been selected. The tool can be used to determine, on the basis of explicit criteria, whether any two confined space job assignments are actually identical, with a view to simplifying risk reduction work if possible. The tool can also help decide, on the basis of predetermined criteria, whether rescue without entry is possible a priori and whether the residual risks are acceptable. Twenty-two confined space experts were asked to test the tool's practicality and suitability. The tool was also compared with other types of tools recommended in the literature or by businesses for analysing risks associated with confined space work. The distinguishing characteristics of the tool are (i) the exhaustive, multidisciplinary scope of its risk identification, (ii) the detailed selection criteria used to estimate risks, (iii) the use of the risk analysis results and (iv) the impact of the confined space risk reduction measures on risk parameters. This study provides support for designers, safety officers and rescuers in their respective efforts to improve the health and safe working conditions of people who must enter confined spaces. The tool can be used to design a confined space or to assess an existing one.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

ACGIH®	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute
API	American Petroleum Institute
ASSE	American Society of Safety Engineers
BCGA	British Compressed Gases Association
CNAMTS	Caisse nationale de l'assurance maladie des travailleurs salariés [French national health insurance fund for salaried employees]
CNESST	Commission des normes, de l'équité, de la santé et de la sécurité du travail [Quebec occupational standards, equity, health and safety commission] (formerly the CSST)
CSA	Canadian Standards Association
FACE	Fatality Assessment and Control Evaluation
FARSHA	Farm and Ranch Safety and Health Association
HSE	Health and Safety Executive
IDLH	Immediately Dangerous to Life or Health
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INRS	Institut national de recherche et de sécurité [French national research and safety institute]
IRSST	Institut de recherche Robert-Sauvé en santé et en sécurité du travail [Quebec occupational health and safety research institute]
ISO	International Organization for Standardization
LEL	Lower Explosive Limit
MIG	Metal Inert Gas
NEMA	National Electrical Manufacturers Association
NIOSH	National Institute for Occupational Safety and Health
OHS	Occupational Health and Safety
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PEV	Permissible Exposure Value
PPE	Personal Protective Equipment
PRCS	Permit-Required Confined Space

ROHS	Regulation respecting Occupational Health and Safety [Quebec]
TLV	Threshold Limit Value

1 INTRODUCTION

1.1 Confined Space Work

Section 1 of the Quebec Regulation respecting Occupational Health and Safety (ROHS) provides a legal definition of "enclosed area" (confined space):

> Confined Space: "Enclosed area" means any area that is completely or partially enclosed, especially a reservoir, a silo, a vat, a hopper, a chamber, a vault, a tank, a sewer including a ditch and a temporary manure storage ditch, a pipe, a chimney, an access shaft, a truck or freight car tank, which has the following inherent conditions:
>
> 1° is not designed for human occupation, nor intended to be, but may occasionally be occupied for the performance of work;
>
> 2° access to which can only be had by a restricted entrance/exit;
>
> 3° can represent a risk for the health and safety of anyone who enters, owing to any one of the following factors:
>
> *a)* its design, construction or location, except for the entrance/exit provided for in paragraph 2;
>
> *b)* its atmosphere or insufficiency of natural or mechanical ventilation;
>
> *c)* the materials or substances that it contains;
>
> *d)* or other related hazards. (Government of Québec, 2016)

The general conditions that determine whether a place should be considered a confined space in Quebec are that (i) a worker may enter the space, (ii) the space is not a workstation, (iii) access to the space is restricted and (iv) the space presents health and safety risks for workers. These same criteria are used in various forms in most countries, including the United States (U.S. Department of Labor, OSHA, 1993), Canada (Government of Canada, 2015), the United Kingdom (Government of United Kingdom, 1997), France (Guilleux and Werlé, 2014) and Australia (Standards Australia, 2001). Regulations in these various countries differ significantly with respect to the presence or absence of hazards in the space. In the United States, the presence of hazards is not included in the criteria defining a confined space, as this concept is taken into account when entry permits are issued (i.e., for permit-required confined spaces). In the other definitions, either atmospheric risks exclusively are mentioned, or specific risks (e.g., atmospheric, engulfment, drowning or temperature), or the concept of risk in general (e.g., ROHS). Some definitions are more restrictive than others, which can have an impact on the inventory of confined spaces.

The most common confined spaces in industry are reservoirs, silos, vats, manholes (figure 1), pits, sewers, pipes and tanks. The issue of confined space work cuts across a wide range of sectors: municipal, manufacturing, chemical, military, agricultural, construction and transportation (Rekus, 1994). In the United States, a study conducted by the National Institute for Occupational Safety and Health (NIOSH) showed that between 1984 and 1988, 40.9% of confined space accidents occurred in the municipal sector, 20.4% in the processing industry, 15.9% in construction, 11.4% in the storage of chemicals, 6.8% in transportation and 4.6% in agriculture (Rekus, 1994).

Confined spaces are entered for various reasons, including maintenance (e.g., repair, inspection, cleaning, unjamming), manufacturing (e.g., transportation equipment manufacturing) or to perform other work (e.g., construction industry). Examples of occupational health and safety hazards are atmospheric (e.g., poisoning, asphyxiation, explosion), biological (e.g., allergenic animals, insects and plants, moulds and other microorganisms), physical (e.g., mechanical, electrical, engulfment, falling) or failure to respect the principles of ergonomics (e.g., awkward posture, limited workspace). Occupational risks in confined spaces are often high because of the confinement, inadequate natural ventilation, need to work in isolation, and access, rescue and communication problems (CSA, 2010).

Figure 1 – Manhole

In Quebec, employers have a legal obligation to comply with division XXVI (sections 297 to 312) of the ROHS for confined space work. The topics covered, as in most such regulations, are

- Worker qualifications, training and information
- Information on hazards and preventive measures must be gathered and made available to workers in writing before work is undertaken
- Ventilation must be used to maintain acceptable atmospheric conditions
- Management of dust from hot work
- Measurements and readings of gas concentrations
- Mandatory supervision
- Rescue procedures
- Workers are prohibited from entering a confined space if material is flowing
- Workers must wear and attach a safety harness if there is a potential free flow of materials

In addition, Canadian standard CSA Z1006-10 and U.S. standard ANSI/ASSE Z117.1-2009 respecting confined spaces provide guidelines on the management program to be set up, workers' roles and responsibilities, associated planning (e.g., training, emergency response plan) and implementation and review of the program (e.g., work permits) (CSA, 2010; ANSI/ASSE, 2009).

1.2 Statistics on Fatal Confined Space Accidents

Fatal accidents frequently occur in the course of confined space work, as the statistics in the literature show (table 1). In 1993, the Occupational Safety and Health Administration (OSHA) estimated, when it was drafting its regulations on confined space work, that each year in the United States, 1.6 million workers were involved in 4.8 million confined space entries, and 63 deaths occurred (U.S. Department of Labor, OSHA, 1993; ANSI/ASSE, 2009).

Table 1 – Statistics on fatal confined space accidents

Country	Sector	Period	Statistics
U.S.A.	Non-specific	1992–2005	On average per year, close to 38 deaths occurred in the United States as a result of poisoning or asphyxiation in a confined space; 20% of those accidents resulted in multiple fatalities (Wilson et al., 2012).
		1993–2004	According to the databases consulted, 65% of the confined space fatalities in the United States were associated with atmospheric hazards, 10% with engulfments (ANSI/ASSE, 2009).
		1993–2010	On average per year, there were 2.5 fatalities related to a flammable atmosphere in a confined space in the United States. Most of these accidents occurred after 2003 (U.S. Chemical Safety and Hazard Investigation Board, 2010).
		1984–1994	86.3% of cases of hydrogen sulphide poisoning in the United States occurred in a confined space, for a total of 80 fatalities (Fuller and Suruda, 2000).
	Construction	1990–1999	In the construction industry in the United States, 62% of cases of carbon monoxide or hydrogen sulphide poisoning and nitrogen aphasia occurred in a confined space (Dorevitch et al., 2002).
	Agriculture	1964–2010	On average per year, 27 people died in confined space accidents in the agricultural sector in the United States (the actual number is no doubt higher) including: – 71% in connection with grain storage (e.g., engulfment); – 10.5% with liquid manure pits (e.g., asphyxiation, poisoning), including 77 deaths in 56 accidents between 1975 and 2004 (Beaver and Field, 2007). – 9.2% with grain transportation (e.g., engulfment) – 5.7% with feed storage (e.g., asphyxiation). Workers under the age of 16 accounted for 20% of the victims (Riedel and Field, 2011).
Canada	Agriculture	1984–1994	On average per year, three fatalities are recorded in confined space accidents in the agricultural sector in Canada (FARSHA, 2012).

What most fatal accidents had in common was improvised work organization and a lack of work procedures. As a result, means of risk reduction were unsuitable or simply non-existent. Workers sometimes do not realize that they are working in a hazardous area and they proceed without taking appropriate risk reduction measures (NIOSH, 1994). Moreover, according to the NIOSH (1994), over 30% of fatalities are due to improvised rescues.

1.3 Risk Assessment and Reduction

In practice, there is an admission that risk assessment is necessary before suitable risk elimination or reduction measures can be taken (ISO, 2009; ISO, 2010; ANSI/ASSE, 2011b). Under the risk management standards used in occupational health and safety (OHS), risk assessment consists in (i) identifying the hazards, (ii) estimating the risks (i.e., quantifying) and (iii) evaluating them (figure 2). Risk evaluation consists in making a judgment about whether a risk is acceptable or whether it must be reduced, based on a comprehensive analysis of the risk.

Standards CSA Z1006-10 and ANSI/ASSE Z117.1-2009 on confined space management follow the same principles, with a few minor terminological differences. In the standards, risk assessment includes the risk estimation stage. Risk assessment is defined as “a comprehensive evaluation of the probability and degree of possible injury or damage to health in a hazardous situation, undertaken to select appropriate controls” (CSA, 2010). The standards do not propose any tools to use for risk estimation.

The risk estimation stage involves taking into consideration the possible severity of the harm and its likelihood of occurrence in order to determine the associated risk index. There are many different risk estimation techniques, both quantitative and qualitative (IEC/ISO, 2009; Chinniah et al., 2011). In OHS, the information available is often qualitative (e.g., pain felt, exposure time, likelihood of occurrence of a hazardous event, body posture at work). That has led to the use of estimating tools such as ordinal scales (e.g., minor/serious/major) and risk matrices (table 2). Moreover, the simpler a tool is, the more people will tend to use it. A complex tool that demands a lot of time and effort from the user will tend to be shunned. A balance needs to be sought between effectiveness and simplicity. It should be noted that a risk estimation tool does not assign an absolute value to a risk, but instead allows comparison with other levels of risk. The aim of risk estimation is to prioritize prevention measures. Whatever the technique, there will always be uncertainty in connection with, for example, (i) the parameters used, (ii) the model chosen and (iii) the completeness of the factors taken into account (Abrahamsson, 2002). Duijm (2015) sums up the main shortcomings associated with risk matrices (e.g., subjective classification, limited resolution). Chinniah et al. (2011) provide a list of recommendations for developing such tools (e.g., number of levels per parameter, definitions of parameter levels, relative influence of each parameter, uniform distribution of levels).

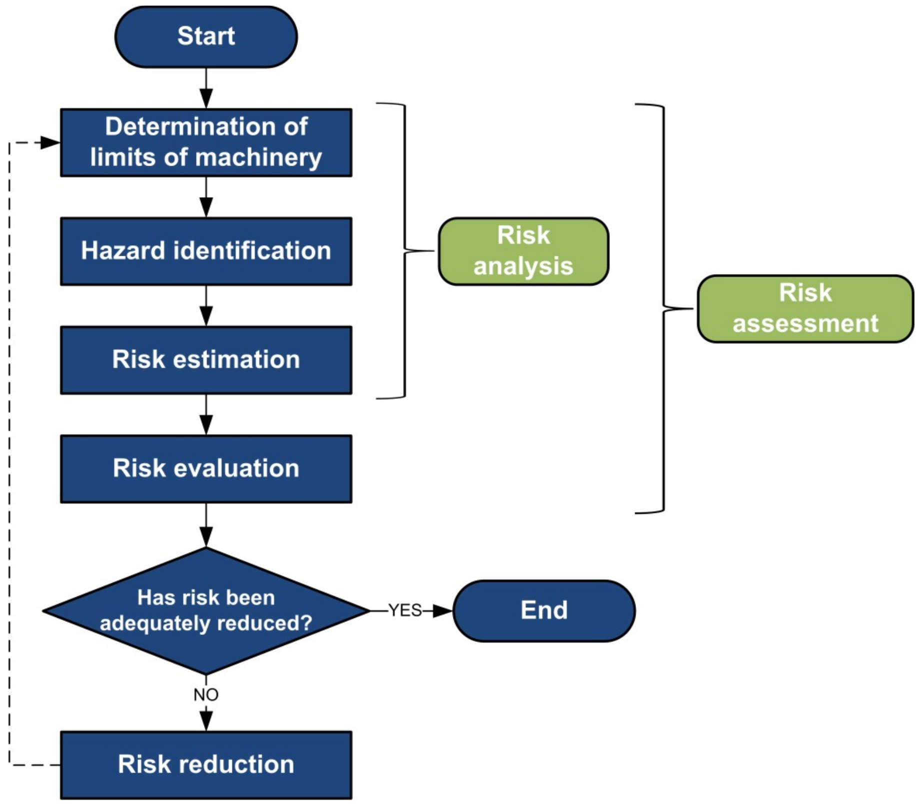

Figure 2 – Risk assessment and reduction process (ISO, 2010)

Table 2 – Two-parameter, six-index risk matrix (MMMPIC, 2002)

Likelihood that hazardous event will cause injury	**Possible severity of injury**		
	Minor	Major	Catastrophic
Very unlikely	6	5	4
Unlikely	5	4	3
Likely	4	3	2
Very likely	3	2	1

Despite its limitations, a structured approach to risk assessment makes it possible to (i) be proactive in identifying and controlling potential losses (Eaton and Little, 2011), (ii) dispose of useful information for decision making and improve communication about risks (IEC/ISO, 2009), (iii) promote safe design (Main, 2004) or (iv) reduce risks to an acceptable level (Manuele, 2010).

Following risk evaluation, risks that have not been deemed acceptable according to the criteria set by the organization must be reduced. The main control measures, by order of effectiveness, are (i) eliminate hazards at source at the design stage, (ii) reduce the frequency of exposure to risks or the potential harm by using less hazardous methods, (iii) incorporate engineering control mechanisms (e.g., guards, alarms), (iv) apply administrative controls (e.g., procedures) and (v) supply personal protective equipment (PPE) (ISO, 2009; ANSI/ASSE, 2011b). The confined space management standards take this approach to risk reduction (CSA, 2010; ANSI/ASSE, 2009).

It is worth noting that the literature places significant emphasis on rescue procedures, worker training and the conditions to be met before entering a confined space. Little attention is given to the safe design of confined spaces. Yet when it comes to risk reduction, efforts should always focus first on eliminating hazards at source. The conditions of use of a confined space, and the work to be performed there, should be considered right from the design stage, with a view to eliminating or limiting risks (ANSI/ASSE, 2011a). To ensure maximum safety for confined space work (AIHA, 2014; CSA, 2010), it is essential to:

1. Avoid creating confined spaces, whether at the initial design stage or when making changes to an existing space.
2. Eliminate the need to enter the space. This often means a change in work methods, such as:
   - Placing components on which work will be needed outside of the confined space (e.g., valves, breakers, flowmeters, dials that require manual operation or human intervention).
   - Staying outside the space and using special tools (e.g., hooks, valve keys, booms, magnetic tools or tools with clips), new technologies (e.g., cameras, robots) or making minor changes to the structure (e.g., transparent openings that allow readings to be taken from outside) so as to be able to reach, see or remove objects located inside the confined space.
   - Making components in the confined space accessible and operable from the outside so that they can easily be removed for maintenance or cleaning operations.
3. Limit the need to enter the space by taking preventive measures such as (i) an automatic cleaning mechanism (e.g., robotization of cleaning), (ii) materials suited to withstand the confined space conditions (e.g., humidity, chemical stressors, temperature) or (iii) appropriate design of the facilities to ensure materials will not become jammed in the confined space (e.g., space sweeping or vibratory mechanisms to prevent so-called “grain bridges” from forming in silos).
4. If it is absolutely essential to enter the space, then eliminate or reduce the risks by providing, among other things:
   - Safe access by means of a suitable fixed ladder, platform or walkway
   - Appropriate entrances/exits large enough to allow rescue and the wearing of personal protective equipment (e.g., minimum diameter of 575 mm)
   - Davit arm bases and fall protection anchor points built into the structure
   - Ventilation incorporated into the structure of the space
   - Fixed gas detectors that measure concentration levels
   - Means of communication within the confined space

- Reduced penetration distances and sources of obstruction
- Built-in disposal outlet for waste materials
- Isolation of piping and integrated lockout
- Grounding
- Protection of mechanical components and live parts
- Replacement of hazardous products in the process with other materials
- Adequate lighting
- Encapsulation of noise sources
- Sufficient clearance to allow workers to maintain good working posture

1.4 Industry Needs

Under the regulations and standards on confined space work management cited earlier, the hazard identification and risk assessment process is a crucial preliminary step to taking appropriate risk elimination or reduction measures, whether at the design stage or when using the confined space. However, the statistics and accident reports referred to reveal that one of the sources of problems in confined space work is a lack of awareness of the risks or an assessment of the risks unsuited to the situation, especially at the design stage. As a result, some companies have trouble applying the regulations governing confined space work. There is a need to raise awareness of risk assessment for confined space work. The purpose of the research findings presented in this report is to help companies apply existing regulations by focusing specifically on the risk assessment stage, which is the foundation of the risk reduction process.

The first objective of the study, presented in the following section, was to provide a better understanding of the issues involved in risk assessment for confined space work. The second was to propose a suitable risk assessment tool that addressed the shortcomings identified in the first part of the study.

2 RESEARCH OBJECTIVES

A significant number of accidents and fatalities still occur in confined spaces in Quebec and elsewhere in the world. The purpose of this research project was therefore to help prevent this type of accident. The findings had to (i) provide knowledge relevant to the requirements set out in the regulations, standards and guidelines on confined spaces and (ii) support designers, safety officers and rescuers in their respective efforts to improve occupational health and safety.

The two specific objectives were to

1. Gain a better understanding of confined space risk management and identify issues based on the literature and field observations.
2. Develop a confined space risk analysis and work categorization tool that addresses the needs identified in the first part of the study.

There are five chapters to the report. Chapter 1 presents the issue of risk management for confined space work, while chapter 2 defines the objectives of the research project. Chapter 3 discusses the method used to meet the objectives. Additional methodological information is provided in the appendixes. Chapter 4 summarizes the needs identified in the critical review of the literature and the assessment of company practices related to risk management for confined space work. The confined space risk analysis and work categorization tool is also presented in chapter 4. Last, chapter 5 presents the conclusion, which covers the original findings from the research, as well as a discussion of the study limitations and future directions for research into the issues examined.

Note that this research report seeks only to present the specifications of the risk assessment tool developed. It will be made available to stakeholders and be publicized as part of a later knowledge transfer activity in conjunction with our partners.

3 METHOD

The research was a five-step process, as shown in figure 3. To determine the difficulties involved in managing risks for confined space work, the research method included (i) a critical review of the reference documents on confined space risk management, including the risk assessment tools available, (ii) an analysis of the investigations of confined space fatal accidents in Quebec to shed light on the failings that led to the accidents and (iii) visits to some 15 organizations and companies in Quebec that manage the confined space entries of their own workers and/or their subcontractors. A multidisciplinary approach was taken so that the variety of different risks found in confined spaces could be taken into consideration. Based on the needs identified, a confined space risk analysis and work categorization tool was developed and tested in conjunction with experts.

Figure 3 – Overall research approach

3.1 Critical Review of the Literature

A keyword-based search strategy was conducted in English and French for the period 2000–2012. The two concepts used were (i) *confined space*, which is a standardized term in both languages (*espace clos* or *espace confiné* in French; *confined space* in English), and (ii) *hazard/risk*, which made it possible to focus the search on confined space risks and hazards using the following keywords: *risk, hazard, toxic, asphyxiation, explosion, electricity, fall, flammable, fire, biological, engulfment, mechanical*. It should be noted that the field related exclusively to the modelling of confined space ventilation was not selected when it dealt chiefly with risk reduction rather than risk analysis or evaluation. The COMPENDEX, PASCAL and PUBMED databases were searched, as well as those of institutions such as NIOSH in the United States, CNESST in Quebec, HSE in the United Kingdom and INRS in France. Using these criteria, the search identified 77 peer-evaluated publications, i.e., (i) 4 standards, (ii) 15 scientific papers, (iii) 7 regulations, (iv) 9 scientific reports, (v) 5 books and (vi) 37 technical guides or codes of practice. The vast majority of the publications (50/77) came from North America. This high number can be explained by the fact that the United States and Canada have already adopted standards and regulations on confined spaces (e.g., OSHA, ANSI and CSA). Table 3 presents the document references by type, origin and main topic. For greater clarity, the references in the table, as well as in tables 7 and 8, have been numbered. The correspondence is provided in Appendix A.

Table 3 – Documents selected in review of the literature, classified by type, origin and main topic

References (Numbers correspond to references listed in Appendix A)		**General/cross-disciplinary**	**Toxic atmosphere**	**Accident investigation**	**Work management**	**Work to be performed**	**Statistical analysis**	**Rescue**	**Risk identification**	**Gas testing**	**Ventilation**	**Flammable atmosphere**	Total
Scientific paper	U.S.A.	23	19–21	1			12–15	3	17				11
	Sweden		2, 24										2
	Canada		28										1
	France		22										1
												Subtotal	**15**
Code of practice	U.K.	28, 29											2
	U.S.A.	27											1
	Australia	31											1
	Canada	30											1
												Subtotal	**5**
Technical guide	Canada	16, 48, 70, 73, 74, 76			54, 66, 67, 71			72	56, 77				13
	France	50, 51, 57, 61	55			69				62	63	65	9
	U.K.	59, 64	49			4							4
	Australia	75			58								2
	U.S.A.	53, 68											2
	Other	52, 60											2
												Subtotal	**32**
Book	U.S.A.	35, 38						36					3
	Canada	37											1
	U.K.				39								1
													5
Standard	U.S.A.	6, 25											2
	Australia	26											1
	Canada	9											1
												Subtotal	**4**
Scientific report	U.S.A.			11, 43–47									6
	Canada		40			42							2
	France					41							1
												Subtotal	**9**
Regulation	Canada	7, 8, 10, 33											4
	U.S.A.	5, 32											2
	U.K.	34											1
												Subtotal	**7**
	Total	**37**	**10**	**7**	**6**	**4**	**4**	**3**	**3**	**1**	**1**	**1**	**77**

The reading checklist used is provided in Appendix B. It was designed for the purposes of more detailed study of (i) risk identification, (ii) work activities related to confined space entries, (iii) factors influencing risks, (iv) risk estimation stage (e.g., suggested method, parameters taken into consideration, risk index) and (v) confined space categorization.

3.2 Analysis of Workplace Accidents

The CNESST is a public insurer that covers close to 95%[2] of Quebec's labour force. Its database was consulted to compile a list of the confined space workplace fatalities that occurred in Quebec between 1998 and 2011 (CSST, 2015). The CNESST investigates most fatal workplace accidents that occur in companies under its jurisdiction. The originality of this study lies in the fact that all the investigation reports for serious and fatal accidents (819) that occurred during the target period were examined. No extraction by keyword was done, which traditionally excludes certain confined space accidents not related to atmospheric risks. The reports related to confined space work were selected using the definition of a confined space given in section 1 of the ROHS (see section 1.1 of this report). Selection of the more contentious cases was decided by two researchers. The reading checklist for the accidents is provided in Appendix C. The accident report analysis focused on the (i) date of the accident, (ii) economic sector, (iii) type of confined space, (iv) main cause, (v) availability of risk analysis, work procedure and rescue documentation and (vi) design aspects.

Thirty-two investigation reports were selected for the target period, i.e., approximately 4% of the cases considered (32/819). These events led to 40 fatalities, i.e., three per year on average. Close to 20% (6/32) of the accidents involved multiple fatalities. Three of the multiple-fatality accidents were related to rescue attempts, and three to the fact that the work was performed by several different confined space entrants. Among the 40 people who lost their lives in the accidents, there were two owners, six managers, 31 operators/technicians and one third party. No confined space work risk analysis documents were available at the companies were the accidents occurred.

As figure 4 shows, the trend in the number of fatalities per year seems to be declining, as 28 deaths occurred between 1998 and 2004, followed by 12 over the same period of time between 2005 and 2011. The coming into force in 2001 in Quebec of the ROHS provisions on confined space work may have been a significant factor in this decline.

An analysis of all confined space occupational injuries in Quebec, and not just fatal accidents, was contemplated to gather more background information. However, the coding used by the CNESST to describe occupational injuries made it impossible to extract accidents that had occurred in a confined space, thus depriving safety officers and researchers of a major source of data on this topic.

[2] According to the Association of Workers' Compensation Boards of Canada, the CNESST covered 93.17% of the Quebec labour force in 2014. *Detailed Key Statistical Measures Report (KSM) – 2014*, http://awcbc.org/?page_id=9759.

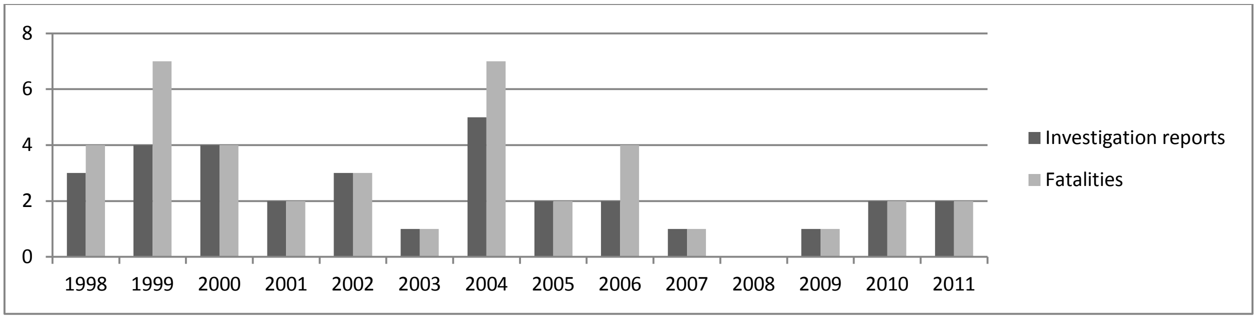

Figure 4 – Distribution of the number of confined space investigation reports and fatalities in Quebec between 1998 and 2011

3.3 Confined Space Risk Management by Companies

Visits were made to 15 organizations and companies between April 2013 and January 2014. To take part in the study, establishments had to have implemented a confined space work management program more than a year previously. In addition, an effort was made to recruit establishments that varied by sector, location, type of confined space, number of employees and number of confined spaces. The number of 15 visits was arrived at as a compromise between recruiting constraints and the exploration of different work situations. It was also based on the principle of saturation (Gillham, 2000). This means that data collection ceases when the information collected in the various situations becomes repetitive.

To ask organizations whether they wanted to take part, an invitation was published in a specialized OHS electronic newsletter, and it was also passed on through the Quebec OHS joint representation network. An information and consent form was provided to those contacted in the recruitment process, in compliance with the ethics certificate delivered by Polytechnique Montréal. The form, duly signed by the parties concerned, ensured that all data collected would be kept confidential.

Table 4 presents the sample of organizations recruited and confined spaces observed. The sample covered the public (8) and private (7) sectors almost equally. It also covered seven economic sectors among those most concerned by confined space work. It was impossible to include the agricultural sector in the sample, even though it does have an issue with confined space work. The exclusion was due to the selection criteria (i.e., confined space management program in effect for at least one year) and the problem of recruiting agricultural establishments. However, a member of the follow-up committee responsible for agriculture provided information about the problems experienced in the sector. The urban areas of Montreal and Quebec City accounted for half of the visits. The fact that the organizations selected had to manage confined space work risks themselves led, in most cases, to the recruitment of organizations with over 100 employees and well-established OHS structures (e.g., OHS committee [14/15]; program implemented for over five years [11/15]). Four organizations with fewer than 50 employees were included in the study, however. The collection of confined spaces managed ranged from as few as 30 to over a thousand, notably in the municipal sector with its manholes providing access to sewer and water supply systems. In these organizations, preventive maintenance (i.e., inspection and cleaning), with or without work, was the main reason for confined space work, followed by breakage and unblocking.

Table 4 – Sample of 15 organizations visited to examine confined space work management

	Sector	Number of employees	Number of confined spaces	Entries/ year	Program start date	Confined space observed	Depth (m)	Penetration (m)
A	Education	500–1000	10–50	10–50	2012	Crawl space	N/A	15
B	Public administration	100–500	>500	>500	2008	Valve chamber	2.5	3
C	Public administration	100–500	>500	>500	2005	Manhole	4.5	2
D	Oil processing	100–500	>500	>500	<2000	Tank	N/A	15
E	Equipment manufacturing	500–1000	100–500	>500	2003	Tank	N/A	3
F	Public administration	50–100	>500	100–500	<2000	Manhole	3	N/A
G	Public administration	<20	10–50	10–50	2011	Manhole	3.5	N/A
H	Equipment manufacturing	>1000	>500	100–500	2004	Mechanical room	2.5	6
I	Energy generation	20–50	10–50	100–500	2002	Pipe	9	30
J	Energy generation	<20	10–50	100–500	2002	Manhole	9	6
K	Energy generation	20–50	10–50	<10	<2000	Manhole	3	3
L	Transportation and warehousing	50–100	100–500	>500	2007	Tanker truck tank	2	15
M	Transportation and warehousing	50–100	10–50	100–500	2004	Tanker truck tank	2	3.5
N	Construction	>1000	N/A	>500	2002	Manhole	3	N/A
O	Equipment manufacturing	100–500	50–100	10–50	2010	Electroplating basin	3.5	N/A

N/A: Not applicable

On the site visits, which lasted from three to five hours, the research team was accompanied by the organization's OHS advisor and key confined space management employees (e.g., manager, supervisor, operator). There were two stages to each visit. A semistructured interview on the risk management process was conducted before a confined space work crew was observed in action as part of the assessment of real working conditions. The visits were spread out over several seasons so as to cover different weather conditions and different types of confined space work. Two researchers took care of gathering the data, using an interview guide for the semistructured interviews, an observation checklist and a verification checklist for the content of the confined space work management program (Flick, 2006; Gillham, 2000; Robson et al., 2001; Silvermann, 2011). These instruments were tested during the first visit (Appendix D).

The interview guide was designed with closed-ended or short-development questions so that the interviews would be conducted in the same way each time. In the first part of the interview, data were gathered on the organization's structure, its confined spaces and the individuals concerned.

Literature on confined space management was collected at this stage. Then, based on the regulations and standards in force in Quebec, the following issues were covered in the interview guide (Gouvernement du Québec, 2016; CSA, 2010):

- Identification of all confined spaces managed
- Content of confined space work management program
- Audits
- Training for confined space workers, including subcontractors
- Preparatory work related to confined space entry permits and related documentation: identification of hazards, risk estimation and evaluation
- Planned risk reduction measures and their application to work assignments
- Rescue measures and their organization

The observations provided an opportunity to compare the theoretical answers from the interviews with the reality of confined space work. Using checklists, the following information was gathered: characteristics of the confined space, work environment, workers and their perception of the risks, type of work, work permits and documentation used, preparation and entry stages with risk control and rescue measures. Videos were shot and photos taken to document the observations. The data from the 15 interviews, observations and documents collected were compiled into a dozen or so tables to summarize the topics mentioned above for analysis and comparison purposes. Standard CSA Z1006 on confined space entry management was used as a reference for the analyses (see tables in section 4.1.3).

3.4 Design and Application of a Risk Assessment Tool for Confined Space Work

3.4.1 Tool Design

In light of the problems found in the literature and the needs of companies identified in the initial stages of the research project, a risk assessment tool tailored to confined space work was developed. In the specifications, the main working hypothesis was to model the structure of the approach on the stages prescribed in standard ISO 12100:2010. As a reminder, the five main stages prescribed in risk management are characterization of the situation, identification of the hazards, risk estimation, risk evaluation and risk reduction. A machine safety design standard was transposed to confined spaces, because a confined space is a physical structure that is often part of the equipment (e.g., reservoir, tank, hold of a ship) or that contains equipment (e.g., piping, motor, pump, electrical panel). Standard ISO 12100 dissects the components of risk, which helps to identify them properly and find appropriate, effective risk reduction methods.

To meet the expressed needs, it was decided that the sequence of the approach had to involve development of the following modules: a list of questions to characterize the confined space work, an exhaustive list of hazards and accident processes, an appropriate method for estimating risks, a visual summary of the results of the risk estimation. When the tool was designed, consultations were held with the follow-up committee, consisting of 10 or so advisors responsible for confined space issues in their respective organizations (i.e., joint occupational health and safety associations, parapublic agencies).

3.4.2 Workplace Testing

Once the tool design was completed, its applicability was tested with 10 organizations that formally manage their confined space entries. The workplace tests, which took two hours, consisted in using the tool for a routine job at the organization. When the tool was used, the organization's safety officer was accompanied by two members of the research team. To facilitate exchanges, a utility based on the tool was programmed using Excel™ (2010, Microsoft, WA). In addition, a questionnaire (see Appendix E) was used to gather feedback and improve the tool. The questions mainly concerned the structure, logic and complexity of the approach, the parameters used at the different stages, the results obtained and possibilities for improvement.

Most of the establishments that agreed to take part in the study were large (>100 employees), private-sector (8/10) organizations. The economic sectors, types of confined space and types of work examined were diversified in order to test the approach on a variety of industrial processes (table 5). A consent form duly signed by the parties concerned ensured that all data collected were kept confidential.

Table 5 – Sample of 10 organizations visited for the purpose of trying out the confined space risk analysis and work categorization tool

	Number of employees	Sector		Type of confined space	Work to be done
A	>1000	Private	Construction	Ditch	Equipment installation
B	50–100	Private	Transportation and warehousing	Tanker truck tank	Cleaning
C	>1000	Private	Transportation and warehousing	Sewer system manhole	Pump replacement
D	>1000	Private	Equipment manufacturing	Tank	Welding
E	>1000	Private	Pulp and paper	Pulp mixer	Change bearings
L	>1000	Private	Oil processing	Fractionating column	Welding
G	>1000	Private	Transportation and warehousing	Tank	Cleaning
H	>1000	Public	Public administration	Tank	Cleaning
I	100–500	Private	Construction	Electrical manhole	Demolition
J	>1000	Public	Public administration	Incinerator smokestack	Inspection

3.4.3 Comparison Tests

The research team also compared the developed tool with existing risk analysis tools found in the literature and in organizations. Three tools that take distinct approaches, in addition to the tool developed by the research team, were tested on three risk scenarios.

A tool was selected for each of the different structures described in the literature and in organizations with respect to confined space risk analysis: checklist (Enterprise X, 2014), risk scale (Government of South Australia, 2011) and risk calculations (UK Ministry of Defence, 2014). When the tools were selected, those designed solely for atmospheric risks, and those included on the same reference document as another tool were excluded. For each of three types of structure, the tools selected were those that were clearly the most comprehensive with regard to the list of risks and the selection criteria. The tools also had to be as distinct as possible. Only the "risk analysis" part (i.e., risk identification, risk estimation) was tested on the risk scenarios. However, all the information gathered by the tools was analysed. There is no obligation to use the tools in countries where information about them has been published.

The three scenarios developed for testing the different tools were based on work observed in workplaces or on accident reports. The scenarios, along with the application of each tool to one of the scenarios, are described in detail in Appendix F. The selected scenarios illustrate common situations in the workplace and cover various types of risks. In addition, each scenario had to be associated with a distinct overall risk level (i.e., low, medium, high). No risk-reduction measures were considered in the testing of the three scenarios. Scenarios 1 and 2 concerned the same confined space (i.e., an access shaft), but involved two different types of work. This choice highlights the importance of considering not only the confined space, but also the work to be performed when analysing risks. Scenario 1, which involved a visual inspection at level 1 of an access shaft, was a priori considered to be low risk. Scenario 2, i.e., installing measuring instruments at level 4 of the shaft, was considered to be medium risk, chiefly because of the potential harm that could result from falling from one level to another. Scenario 3, in which welding is done at the bottom of a diesel truck tank, was a priori considered to be high risk because of the possibility of a fatal accident resulting from the welding (e.g., poisoning).

Before a tool was applied, the structure was evaluated on the basis of the following points:

- Comparison with risk management steps recommended in standards (IEC/ISO, 2009)
- Means to ensure completeness and systematization of risk analysis
- Summary and measurements to communicate identified risks (e.g., risk categorization)
- Structure of risk estimation and criticism in terms of chosen architecture (ISO, 2010; Duijm, 2015; Chinniah et al., 2011; Gauthier et al., 2012; Cox, 2008)

Furthermore, the time required for each analysis, learning to use the tool (i.e., easy, difficult), the list of risks, as well as the subjectivity and precision of the possible answers were noted to assess the usability of the tools (table 6).

Table 6 – Structure and usability of four types of tools tested

	Checklist	Risk scale	Risk calculations	Questionnaire + Matrix
Definition of context	Space to identify the confined space and describe the work for the four tools			
Risk identification	List of possible answers	Set list of risks	N/A	Questionnaire and validation
Risk estimation	N/A	Choice of 4 risk levels	2 parameters and 3 risk levels	Matrix with 2 parameters and 4 risk levels
Risk evaluation	N/A	N/A	Actions required according to 3 risk levels	Acceptable risk level adjustable by user
Risk reduction	List of means of risk reduction available for the 4 tools			
Other steps	N/A	N/A	Estimation of residual risks	– Estimation of residual risks – Work categorization – A priori characterization of rescue
Time per scenario	<5 min	5 min	10 min	20 min
Ease of use and understanding of tool	Easy: checkboxes	Easy: tick off risk levels	Demanding: no help for identifying risks	Demanding: very detailed

N/A: Not applicable

4 RESULTS AND DISCUSSION

The results and discussion section is divided into two parts. The first part, titled “Theoretical and Practical Assessment,” presents the results and discussion of (i) the critical review of the literature on confined space risk management (Burlet-Vienney et al., 2014), (ii) the analysis of reports on fatal confined space accidents in Quebec and (iii) the visits conducted at 15 organizations and companies (Burlet-Vienney et al., 2015a). The second part, titled “Confined Space Risk Analysis and Work Categorization Tool,” presents the risk estimation tool (Burlet-Vienney et al., 2015b), as well as its validation in workplaces, including the comparative analyses with existing tools (Burlet-Vienney et al., 2016).

4.1 Theoretical and Practical Assessment

4.1.1 Critical Review of Risk Assessment for Confined Space Work

In analysing the 77 documents found in the review of the literature on risk assessment specific to confined spaces, special attention was given to shortcomings with respect to (i) hazard identification, (ii) risk estimation and (iii) risk evaluation.

4.1.1.1 Identification of Confined Space Hazards

Based on the analysis of the literature, an extensive list of confined space work hazards was drawn up (table 7). The list revealed that atmospheric hazards are cited in over two thirds of the documents. The other hazards, in order of importance, are heat, electricity, engulfment and falling. Conversely, hazards related to the confined space environment, worker physiology and psychology, clothing worn or entry accessibility are given less attention. In the literature, atmospheric risks are cited first, in most cases. So-called physical risks come next, but fewer details are provided.

Interactions among hazards, largely neglected in regular risk analysis, are a factor that takes on greater importance in confined space work because of the restricted nature of the space. These interactions tend to increase the likelihood that a hazardous event might occur and may in some cases amplify the effects (Lyon and Hollcroft, 2012). A risk initially estimated to be non-fatal could lead to a fatal accident as a result of hazard interaction. For example, in Quebec, in 2004, a worker went down into a liquid manure storage pit to unblock a pump. At the end of the job, he fell off the ladder into the pit. His fall released hydrogen sulphide that up to that point had been confined under a thin organic layer at the surface of the liquid. The worker died from poisoning (CSST, 2015).

Table 7 – Inventory of confined space hazards, by type of document

Hazard	Scientific paper (15)	Standard (4)	Regulation (7)	Code of practice (5)	Book (5)	Scientific report (9)	Technical guide (32)	Total
References*	1–3, 12–15, 17–24	6, 9, 25, 26	5, 7, 8, 10, 32–34	27–31	35–39	11, 40–47	4, 16, 48–77	
Poisoning	13	4	7	5	5	6	29	69
Asphyxiation (atmospheric)	8	4	7	5	4	3	28	59
Explosion, fire	2	4	7	5	5	3	29	55
Heat	5	4	4	2	5	6	24	50
Electrical	2	3	4	3	4	3	23	42
Engulfment	3	3	6	4	5	2	18	41
Fall from height	1	2	3	2	2	4	23	37
Drowning/Flowing material	3	2	3	3	1	1	20	33
Moving parts	3	3	4	3	3	3	13	32
Noise and vibration	1	3	1	4	4	2	17	32
Introduction of substance	1	2	2	5	5	1	14	30
Activity, equipment used	3	2	3	4	2	1	13	28
Biological, animals	1	2	1	2	3	1	18	28
Fall on same level	1	4	1	4	1	1	14	26
Spatial structure	2	4	4	3	3	0	8	24
Lighting/Visibility	0	2	0	2	2	1	14	21
Falling object	1	1	0	1	4	1	12	20
Radiation	1	4	0	4	3	0	8	20
Entrance/egress small	1	2	1	2	2	1	8	17
Waste-related	1	0	2	1	1	1	10	16
Outside traffic	0	3	0	2	1	0	10	16
Environmental	0	2	1	2	2	0	9	16
Overexertion/Posture	0	1	1	1	2	1	3	9
Psychology/Stress	1	1	0	0	1	0	5	8
Entrance accessibility	1	0	0	1	0	0	5	7
Clothing/PPE-related	0	1	0	2	1	0	2	6

*Numbers correspond to references listed in Appendix A.

Hazard interaction has not specifically been studied in the literature, but here are the interactions reported in the course of confined space work:

- Poisoning, asphyxiation or electric shock may cause a fall or lead to drowning. This is the most commonly mentioned interaction (Beaver and Field, 2007; Veasey et al., 2006; Workplace Health and Safety Queensland, 2010).
- A fall can lead to poisoning (e.g., heavy gas at bottom of space) (CSST, 2015) or to engulfment (e.g., grain silo) (Cal/OSHA, 2012).
- High temperature in the confined space may increase (i) the risk of explosion and fire, (ii) microbacterial activity and (iii) exposure to chemicals and toxic substances, since a higher temperature can make a substance more volatile, increase vasodilation in workers and thereby heighten absorption of the product, especially through the skin (Carlton et al., 2000; Svedberg et al., 2009; Standards Australia, 2001; Veasey et al., 2006).
- Animals, temperature, noise, the small size of the space, etc., may cause high levels of stress in workers (Abelmann et al., 2011; Workplace Health and Safety Queensland, 2010).
- Restricted entry and exit and difficult access influence risks, with exposure and rescue time being a major issue in the event of poisoning, asphyxiation, engulfment, drowning or entrapment.

4.1.1.2 Confined Space Risk Estimation

Table 8 summarizes the risk management stages described in the 77 publications selected. Three types of combinations were identified. It is interesting to note that all the documents address the topics of risk identification and risk reduction, even though the degree of detail varies from one document to the next. With regard to risk estimation: (i) 26 documents do not deal with this stage, (ii) 29 take only atmospheric risks into account, using permissible exposure limits and (iii) 22 tackle the estimation of all types of risks. Of these last 22 documents, only nine suggest using a tool for the job (NIOSH, 1994; Standards Australia, 2001; Maritime and Coastguard Agency, 2010; Standards Australia, 2003; UK Ministry of Defence, 2014; Rekus, 1994; BCGA, 2009; Government of South Australia, 2011; Workplace Health and Safety Queensland, 2010).

Table 8 – Risk management stages covered in selected documents – Types of combinations inventoried

Risk management stages	Combination No. 1	Combination No. 2	Combination No. 3
Risk identification	Yes	Yes	Yes
Risk estimation	No	Atmospheric risk only	All risks
Risk reduction	Yes	Yes	Yes
Total/ references*	26/ 1, 3, 4, 12–15, 18, 23, 39, 42, 44, 50–52, 54, 56, 61, 62, 66, 68, 69, 72, 74, 77	29/ 2, 5, 10, 16, 19–22, 24, 25, 27, 32, 33, 37, 38, 40, 41, 43, 47, 48, 53, 57, 63–65, 67, 70, 71, 76	22/ 6–9, 11, 17, 26, 28–31, 34–36, 45, 46, 49, 55, 58–60, 75

*Numbers correspond to references listed in Appendix A.

4.1.1.3 Overall Risk Estimation

First, two different risk scales were found: “High, Medium, Low” and “Extreme, High, Moderate, Low” (Maritime and Coastguard Agency, 2010; Government of South Australia, 2011). However, no definitions or indications are associated with these terms. Given the lack of a sound basis for estimation, the use of such scales is limited to a ranking and handling of risks.

Furthermore, three different risk matrices using two parameters, severity and likelihood of occurrence of harm, were found in the confined space documents (Standards Australia, 2001; UK Ministry of Defence, 2014; Rekus, 1994). In the matrices, the scales of each of the two parameters are defined in terms of four or five levels. Risk is defined in terms of three to four levels, and each level is associated with an action. The matrices remain generic, with parameters that are not tailored to the characteristics of confined spaces (e.g., influence of physical characteristics of confined space, restricted access and exit, multiple risks). An example is provided at the end of Appendix F (UK Ministry of Defence, 2014).

4.1.1.4 Estimation of Atmospheric Risks

The regulatory criteria used to determine whether the atmosphere in a confined space can be considered not hazardous vary with the regulations. Table 9 provides an overview of the conditions under which the atmosphere within the space is considered to be not hazardous and entry is permitted without supplementary measures being necessary. Only the main regulations and standards were considered.

If the minima and maxima specified in table 9 for the percentage of oxygen are considered, the maximum range where entry is regarded as not hazardous extends from 18% to 23.5%. The most common values are 19.5% for the minimum and 23% to 23.5% for the maximum. Regarding explosives, the most common value is less than 10% of its Lower Explosive Limit (LEL). However, some countries like Canada adjust this percentage according to the work to be done (e.g., hot work, cold work, inspection). For exposure to toxic substances or asphyxiants, all the documents specify compliance with the permissible exposure values in force. However, the regulatory references and limit values vary from one country to the next (e.g., permissible exposure value (PEV) in Quebec; Permissible Exposure Limit (PEL) stipulated by the OSHA or Threshold Limit Value (TLV) established by the ACGIH, in the United States) (Gouvernement du Québec, 2016; U.S. Department of Labor, OSHA, 1989; ACGIH, 2016).

Last, some general information is available about dust concentrations. The risk of explosion seems low if visibility is more than five feet or if the concentration is under 10 mg/m^3.

The differences in the regulatory values specified in table 9 indicate that there are no precise limits between a hazardous situation and a non-hazardous one. The regulatory exposure limits are instead established to ensure a relative degree of protection for the majority of exposed workers (Rekus, 1994). In practice, the lowest possible exposure should be targeted, even when the measured exposure values are below the permissible levels (Workplace Health and Safety Queensland, 2010).

Table 9 – Atmospheric conditions that must be met in order for entry into a confined space to be considered not hazardous in various countries

Country	Regulation/Standard	% O_2	% LEL*	Toxicity
Australia/NZ	Standards Australia (2001)	19.5–23.5	<5 or <10 if continuous monitoring	<Permissible exposure value in force
France	CNAMTS (2010)	19–21	<10 if entry	
Canada	Gouvernement du Québec (2015)	19.5–23	<10	
	Ontario Ministry of Labour (2011)	19.5–23	<5 if hot work <10 if cold work <25 if inspection	
	CSA (2010)	19.5–23	<5 if hot work <10 if cold work	
	Government of Canada (2015)	18–23	<10 if hot work <50 if not	
United States	OSHA (1989) ANSI (2009)	19.5–23.5	<10	
	NIOSH (1994)	19.5–21.4	<10	

*LEL: Lower explosive limit

4.1.1.5 Confined Space Categories

Risk analysis results are used to assess risks and determine appropriate risk reduction measures. Grouping similar confined spaces together or categorizing them are two approaches found in the literature as a way of simplifying risk analysis when there is a large number of confined spaces to manage.

4.1.1.6 Similar Confined Spaces

The idea behind the concept of similar confined spaces is to try to group identical confined spaces together. The goal is to simplify management of confined space entries by facilitating permit procedures and the planning of the required resources, by type of confined space. Here is an example of the explanations provided: "A single work procedure may apply to a group of confined spaces that have substantially similar characteristics with respect to the health and safety of workers" (CSA, 2010). The factors specified for determining whether the spaces are similar are its construction, the risks, the outside environment and the work done. However, the criteria for determining whether two confined spaces are similar are often not precise enough (e.g., "similar characteristics," "same risks," "because of their similarities"). Furthermore, it would be more accurate to talk about similar confined space work, as the type of work performed influences the risks encountered. Last, for some regulations, the goal behind confined space similarity is to be able to do a single risk evaluation for a group of spaces together. There are limits to this approach, however, since to determine whether two confined space jobs really are similar, it would theoretically be necessary to conduct an analysis of the confined space work to be performed in each case.

4.1.1.7 Types of Categorization in the Literature

Three approaches to establishing confined space categories were found in the literature. Used primarily in the United States, the first approach is based on the need to obtain an entry permit (ANSI/ASSE, 2009). If there is a serious risk in a confined space, then an employer in the U.S. must comply with the Permit-Required Confined Space (PRCS) regulations.

The second approach involves categorizing confined spaces by risk level. The following three categories summarize the concepts mentioned in the different definitions (NIOSH, 1994; Rekus, 1994; WorkSafe BC, 2008):

- Category A: Confined spaces that present situations which are immediately dangerous to life or health (IDLH). More specifically, these are spaces that are deficient in oxygen, or where the atmosphere is explosive, flammable or toxic (e.g., oxygen concentration of less than 16%, or greater than 25%; concentration of a flammable gas that is more than 20% of its LEL; concentrated toxic substance IDLH). Workers cannot exit the space without help in the case of a ventilation system or respirator failure.
- Category B: Confined spaces that do not present an immediate threat to life or health; however, they have the potential for causing injury or illness if protective measures are not used (e.g., oxygen concentration between 16.1% and 19.4% or between 21.5% and 25%; concentration of a flammable gas between 10% and 19%; concentration of a toxic substance above the permissible values). Conditions are not likely to reduce a worker's ability to exit the space without help in the case of a ventilation system or respirator failure. There may be additional physical hazards (e.g., noise, heat, handling).
- Category C: Confined spaces where any hazards posed are insignificant. They contain a breathable atmosphere with no buildup of contaminants and a normal oxygen level (e.g., oxygen concentration of between 19.5% and 21.4%; concentration of a flammable gas

of less than 10%; concentration of a toxic substance below the permissible values). Conditions are not likely to change over the course of the work.

The Canadian standard takes another approach based on the nature of the risks with (i) confined spaces with hazards associated with limited entrance and egress only, (ii) confined spaces with hazards that require controls other than for atmospheric hazards and (iii) confined spaces with the potential for atmospheric hazards alone or in combination with other hazards (CSA, 2010, Annex A, clause A.17).

4.1.2 Confined Space Occupational Accidents in Quebec

An analysis of the 40 confined space fatalities (32 accident reports) that occurred in Quebec between 1998 and 2011 highlighted a number of factors that can play an important role in accident prevention, i.e., time of year, type of confined space, sector, type of accident, entry preparation and design problems.

4.1.2.1 Time of Year

Forty percent (40%) of the confined space fatalities inventoried in Quebec from 1998 to 2011 occurred in the months of July and August, even though the two months represent less than 20% of the study period.

A first hypothesis that can be stated in connection with this finding (i.e., higher number of fatal accidents during the summer) would be that summer is a more suitable time for performing certain types of confined space work, whether owing to milder weather conditions, greater agricultural activity or planned production shutdowns. This phenomenon was also noted on the field visits, when close to half the organizations surveyed said they preferred doing most of their confined space work during the summer. A second related hypothesis would be that higher outdoor temperatures in summer could be the cause of hazards less likely to occur outside of summer, such as (i) increased production of hydrogen sulphide (H_2S) in sewer systems, (ii) less effective natural ventilation and (iii) a high-humidity work environment, which can increase worker fatigue.

4.1.2.2 Sector and Type of Confined Space

The economic sectors where confined space accidents occurred in Quebec between 1998 and 2011 are listed in table 10. Note that the CNESST uses its own in-house coding system. The types of confined spaces where the surveyed accidents occurred are listed in table 11.

Table 10 – Number of confined space workplace accidents investigated, fatalities and injuries in Quebec between 1998 and 2011, by sector

Sector	Number of accidents investigated	Number of fatalities	Number of related injuries
Agriculture	12	12	1
Communications, energy transmission, other utilities	4	6	3
Mining, quarrying and oil and gas extraction	4	5	1
Other commercial and personal services	3	5	4
Buildings and public works	2	2	-
Chemical industry	1	3	-
Metal fabricating	1	2	-
Public administration	1	1	-
Lumber (excluding sawmills)	1	1	-
Commerce	1	1	-
Non-metallic mineral products industry	1	1	-
Paper and allied industry	1	1	-
Total	32	40	9

Table 11 – Number of confined space workplace accidents investigated, fatalities and injuries in Quebec between 1998 and 2011, by type of confined space

Type of confined space	Number of accidents investigated	Number of fatalities	Number of related injuries
Grain silo	9	9	1
Shaft/Vent stacks	5	6	1
Mixer	4	4	-
Vat	3	5	-
Water tank/Inspection chamber/Pumping station	3	5	7
Turbine	3	4	-
Storage and transfer pits	1	1	-
Truck tank	1	2	-
Other	3	4	-
Total	32	40	9

Confined space work and accidents concern a wide range of sectors. This study focused on 12 of them. Agriculture is the one that sees the greatest number of accidents, accounting for around 40% (12/32) of the accidents investigated. There is no lack of confined spaces in the agricultural sector, such as (i) grain silos, (ii) storage and transfer pits on farms and (iii) feed mixers. Grain silos that hold corn are the type of confined space where the greatest number of accidents occurred in Quebec over the period studied.

The sectors most affected after agriculture are

- Mining, with its shafts and vent stacks
- The "Communications, energy transmission and other utilities" sector, which involves the generation of electrical power, and also includes wastewater treatment facilities that feature turbines, inspection chambers and vacuum trucks
- The "Other commercial and personal services" sector, which includes running recreational activities (e.g., camping, winter sports) and subcontracted maintenance services. In these sectors, there is a variety of different confined spaces (e.g., vats, ventilation plenums, pumping stations)

There are also sectors related to industry (e.g., chemical industry, pulp and paper industry, wood, metal and other product manufacturing), to public administration with water treatment, and to buildings and public works. The confined spaces found in industry are primarily vats and mixers.

4.1.2.3 Type of Accident

The types of confined space accidents that led to fatalities in Quebec between 1998 and 2011 are illustrated in figure 5.

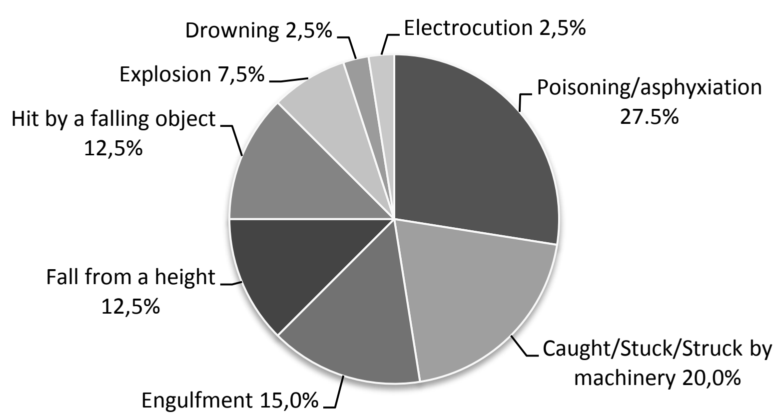

Figure 5 – Distribution of confined space fatalities in Quebec between 1998 and 2011, by hazard

Poisoning and asphyxiation are the leading causes of fatalities (11) in confined spaces. Seven deaths resulted from exposure to hydrogen sulphide (H_2S), which is found in particular in wastewater treatment facilities and liquid manure storage pits. Accidents attributable to moving machinery were just as frequent as cases of poisoning/asphyxiation, but fewer fatalities (8) resulted from them. Hazards such as engulfment, falls from heights and falling objects are also significant. Accidents due to atmospheric hazards, with over 1.75 fatalities per accident (14 deaths in 8 events) caused more multiple deaths than did accidents of a physical origin (26 deaths in 24 events). Atmosphere-related accidents accounted for a third of the fatalities, whereas accidents resulting from physical hazards were associated with the remaining two thirds. This ratio is the reverse of the statistics cited in the literature (ANSI/ASSE, 2009). The reason for this is that all accidents with a physical cause were included in this study.

4.1.2.4 Confined Space Work

The initial confined space work assignments that resulted in fatalities in Quebec between 1998 and 2011 involved, in two thirds of the cases, unplanned repair, troubleshooting or unblocking jobs. In most of the accidents, problems with identifying hazards and underestimating risks were clearly set out in the investigation reports. Confined space operations were improvised, not planned. No risk analysis documents were available in the companies in question, and no work procedure was followed. As a result, risk reduction measures were inappropriate or simply non-existent. Furthermore, no rescue plan was available in the workplace. These findings confirm what was seen in the case of other fatal accidents (see table 1) and thus constitute a major risk factor.

4.1.2.5 Confined Space Design

A design problem may sometimes explain the underlying cause of an accident. The points raised in the accident reports are concrete examples that confined space designers should take into account:

- Access to a confined space is hazardous because the means for entering the space (rungs, ladder) are inadequate or because of a lack of fall protection when the space is open (e.g., railings).
- Work such as greasing or unblocking must be performed from inside the confined space, even when there is no technical constraint preventing such work from being done from outside.
- Control systems (e.g., emergency stops, sensors, programmable logic controllers) and mechanisms for controlling hazardous energy sources (e.g., valves, breakers) are not integrated into equipment in accordance with standard practices in order to maximize their use.
- The real operating conditions of the confined space are not taken into account: outdoor temperatures that can cause frostbite, growth of mould on stored equipment or under-sizing leading to blockages.

4.1.3 Risk Management by Companies

Analysis of the risk management practices of 15 organizations and companies for confined space work focused, first, on written documentation (i.e., program and permits) and, second, on the practical implementation of the prescribed measures. The Quebec ROHS and Canadian standard CSA Z1006-10 were used as references (Gouvernement du Québec, 2016; CSA, 2010).

4.1.3.1 Confined Space Management Program

The content of a confined space management program is addressed in clause 4 of standard CSA Z1006-10. A list of topics that should be covered was drawn up (see Appendix D), and the programs surveyed were examined to see whether those topics were included. The programs consisted of anywhere from 5 to 50 pages. The topics most commonly dealt with in the programs are (i) presence of an attendant, (ii) identification of hazards, (iii) ventilation, (iv) personal protective equipment, (v) gas detectors, (vi) lockout, (vii) work procedures and entry permits, (viii) emergency measures, (ix) training, (x) roles and responsibilities and (xi) program review. The topics the least covered in the programs (<10/15) were (i) auditing of program implementation, (ii) risk evaluation process, (iii) actions to do with safe design of confined spaces, (iv) confined space inventory and access reporting, (v) risk reduction equipment purchase and management and (vi) management of contracting out. The shortcomings noted in programs were confirmed in the interviews and by observation (sections 4.1.3.2 to 4.1.3.8). These topics are therefore the main points organizations should focus their development and monitoring efforts on.

4.1.3.2 Confined Space Identification Issues

All the organizations visited used the definition in the Quebec regulation to characterize their confined spaces, even though the definition was not formally cited in a third of the programs surveyed. Identification of a space as a confined space is a source of disagreement in practice. Trenches are a common example. For disputed cases and the delisting of confined spaces, two approaches were observed (table 12). However, a space that is not “confined” within the meaning of the regulations does not exempt an organization from having to manage its associated risks appropriately.

Identifying confined spaces by means of a sign or pictogram is an essential means of warning people and restricting access to authorized personnel (Gouvernement du Québec, 2015, sec. 299). This point was an issue during the visits. At two thirds of the organizations visited, confined space signage was either only partial or did not exist not at all. The most serious examples were access shafts and ventilation systems, in terms of number and location. Possible improvements in this area are indicated in table 12.

Table 12 – Problems observed and possible improvements in confined space identification

Problem [organizations]	**Possible improvement** [clauses of CSA Z1006-10; organizations where observed]
– Identification of space as confined space or not [in most organizations]	Two approaches in case of disagreement: – Systematically consider location as being a confined space [H, J and O]. – Secure a written consensus based on the three criteria for the definition of a confined space, involving at least two qualified people [cl. A.17; C, D, I and O].
– Signage only partial or non-existent at entrance to confined space [A, B, D, F–K, M and O]	– Write on sign the information recommended in the standard. When signage is not possible, other formal measures can be taken to compensate (e.g., restrict control) [cl. 7.2.2.1]. – Provide information specific to the configuration of the confined space or the risks identified in the risk assessment. It is not compulsory to provide such information, but doing so could help improve communication with workers when it is realistic to make it available [O]. This approach is commonly taken for industrial machinery (ANSI/NEMA, 2011).

4.1.3.3 Problems with Worker Training

The Quebec regulation stipulates that only workers having the knowledge, training and experience required to perform confined space work are qualified to do so. This obligation applies to the person in charge of risk assessment and reduction (e.g., permit issuer), to the person entering the space and to the attendant. Clause 7.1 of standard CSA Z1006-10 sets out the detailed training requirements according to the worker's role.

Theoretical and practical training for confined space entry workers was planned by all managers in the organizations visited. However, the content and details of the training programs differed according to the person in charge. For instance, organization D provided a training session of 2 h, 30 min for workers qualified to enter confined spaces, whereas organization J released its workers for three days, including one day devoted entirely to a practical session on the organization's installations. Supplementary training sessions for permit issuers, attendants (e.g., gas readings, ventilation, fall protection) and rescuers were not always planned, even though these roles were always involved in confined space entries. Very few management programs set out in detail the (i) skills required by role, (ii) means of testing acquired knowledge and (iii) frequency and means of refresher training sessions. During our field visits, the main shortcomings were identified at organizations where training sessions were not specific to the role of the workers involved, especially persons responsible for the supervision.

4.1.3.4 Problems Related to Risk Analysis, Entry Permits and Work Documentation

To prepare an entry permit, the issuer requires information about the confined space, the work to be done and the work environment (e.g., changeable conditions, access). Many different parameters must be taken into consideration to choose appropriate work methods and means of risk reduction. More than half of the organizations based their decisions to perform the work solely on the permit issuer's experience. No organization had a written procedure for estimating risks or categorizing confined spaces. In half of the organizations, risk identification was the only stage that was a document-based procedure.

In the sample of permits and documents the research team collected, the most neglected points were (i) a detailed description of the hazards, which were often glossed over in moving on directly to equipment needs, (ii) checking the level of training of the people involved, (iii) monitoring of confined space entries/egresses, (iv) details about ventilation (e.g., time), (v) atmospheric testing management and (vi) closing and cancellation of permits. The main issues raised in the interviews regarding permit management were the availability of a qualified person at all times to issue permits, and planning with other departments in case of joint operations, production stoppage or lockout of associated equipment. On the basis of this observation, analysis of the permits obtained and the entry permit information requirements, as listed in standard CSA Z1006-10 (clauses 7.2.5.1 and 7.2.5.2; clause B.1 of Annex B), table 13 sets out in detail all the information required for an entry permit. Section 1 of the proposed permit must be completed ahead of time, well before the start of the confined space work. Such a permit should serve as a checklist to ensure that nothing is forgotten before or during the work.

Table 13 – Content of an entry permit that consolidates all the information required for entry – Section 1 *Preparation*

Section/Topic		Information to be included
Section 1: Preparation	General	Work to be done. Work order. Date of work. Name and contact information of permit issuer.
	Identification and location of confined space	Reference number. Type of confined space. Function. Address, room number. Information on problems accessing confined space and means required to reach it (e.g., confined space located in confined space).
	Characteristics of confined space	Dimensions of space (sketch). Height. Depth. Type of access inside. Openings: number, location, dimensions. Content: chemicals, waste materials, equipment, piping inlet/outlet, etc.
	Description of work	Goal of work to be done. Expected time required. Number of workers needed. Nature of work: what part of confined space, tools required and energy supply.
	Hazards	Identification using hazard checklist: 1. Inherent to confined space, immediate environment and possible changeable conditions. 2. Specific to work, checking possible interactions with other hazards. List of main hazards: – Atmospheric: poisoning, asphyxiation, explosion/fire, dust build-up. – Mechanical and physical: electrical, moving parts, engulfment, falling (heights, object, on same level), heat (surface, ambient), drowning, noise, vibration, light, radiation, pressure, sharp edges. – Biological: animals, excrement, insects and allergenic plants, bacteria, mould, viruses, other micro-organisms. – Chemical: corrosive/irritant residues, toxic substances, carcinogens. – Spatial structure: restricted entry/egress, robustness, obstacles, pinch/entrapment points, spatial mobility. – Outside conditions: outside traffic, weather, adjacent work, accessibility, introduction of substances. – Entrant-related: psychology/stress, physical exertion/posture, clothing/PPE-related constraints.
	Work and risk reduction equipment	Checklists (with technical specifications): 1. Work equipment required for access and work to be done. 2. Specific protective equipment/clothing. 3. Risk reduction equipment: air quality (respiratory protection, ventilation, gas detection), fire protection, lockout, fall protection, heating/fresh air, hearing protection, lighting, safety perimeter, administrative restrictions (e.g., weather, physical and psychological condition of entrant). 4. Monitoring and rescue equipment. 5. Confined space preparation stages: cleaning, flushing, lockout, ventilation.
	Monitoring and emergency measures	Instructions to be followed by attendant. Means of communication to use. Emergency procedure, with telephone number to call and general steps to follow. Criteria to enable a rescue without entry (e.g., victim's condition, wearing of a class AE harness), or wait for arrival of first-aid and rescue workers. Instructions to maintain adequate conditions and prepare for arrival of rescuers.
	Rescue	Tried and tested rescue plan (by whom and when) with appendix detailing rescue procedure with entry.

Table 13 (cont'd) – Section 2 *Work* and Section 3 *Follow-up*

Section/Topic		Information to be included
Section 2: Work	Issuing of permit	Date and time permit issued. Length of time permit valid.
	Workers and training	Name and role of workers involved in entry (attendant, gas readings, entrants, etc.). Specify whether contractor (contracting out).
	Checks before entry	Checklist: – Training of workers identified above according to their role. – Physical condition of entrants. – Oral transmission to workers of information in section 1 *Preparation*. – Absence of additional risks on basis of actual working conditions. – Use and inspection of work, monitoring and risk reduction equipment (use checklist from subsection 1 *Work and risk reduction equipment*). – Check that harness being worn properly, as well as respiratory protection if needed. – Preparation in accordance with operating method: emptying, cleaning, lockout, etc. – Model of ventilator and installation configuration. Ventilation time required before entry (Garrison, 1991). – Rescuers notified of imminent entry (give telephone number).
	Management of atmospheric readings	Number of device. Use of a sensor of appropriate length and of a pump. Dates of most recent calibration and functional testing. Required wait times for each measurement. Frequency of measurements during work.
	Table for gas detection results	Each line corresponds to a measurement: before entry (before opening; after preparation; entry after an egress) then periodic measurements according to specified frequency. The last line can be used to note an alarm. Each line can be split up if measurements must be taken at different spots in the confined space. The columns include the time of the measurement, the initials of the officer in charge, and the different gases measured, specifying the limit values permitted by the organization.
Section 3: Follow-up	Signatures	Name, date and signature of people involved to certify they have understood the instructions.
	Workers' entries/egresses	Table that allows attendant to track confined space entries and egresses. One line per worker. Alternating columns: Time of entry/Time of egress.
	Closing/Cancellation/ Extension of permit	Closing permit: points to check (e.g., notify rescue personnel when work has been completed, egress of equipment and workers, removal of lockout), date, time, comments for improvement/audit, name and signature of permit issuer. Allow for possibility of extending permit, including reasons (e.g., permit issuer has to leave workplace and be replaced), precautionary measures and necessary signatures. Ditto for a cancellation.

4.1.3.5 Audit-related Issues

In the literature, periodic audits of the confined space work management program and its implementation are recommended to ensure continued improvement in practices (CSA, 2010; Lindsay, 1992). Such audits help with employee and subcontractor follow-up, and the correction of bad practices. However, formal audits of compliance with the rules for confined space entry are performed in only a third of the organizations visited. Ways to improve performance in this regard are discussed in table 14.

Table 14 – Problems noted and possible improvements respecting audits

Problem [organizations]	**Possible improvement** [clauses of CSA Z1006-10; organizations where observed]
No formal audit of compliance with confined space entry rules in two thirds of organizations visited [A-G, J, K and O].	– Comply with recommendations in standards [cl. 8]. – Incorporate audits into manager's goals. Draw up a relevant checklist [L, M and N]. – Introduce a culture of safety through field presence of experienced managers (Huang et al., 2014). – Record and check gas detector readings by means of a docking station [D, G, N and L].

4.1.3.6 Subcontractor-related Issues

Occupational health and safety management of subcontractors is a legal obligation in Quebec, and contract client must demonstrate appropriate due diligence (Gouvernement du Québec, 1979). Confined space work is commonly subcontracted, especially for major or specialized projects that require specific skills. Thirteen of the 15 organizations visited subcontracted, or were subcontractors, for confined space work. According to the management programs and semistructured interviews, in virtually all cases, subcontractors were supposed to follow the same rules as the host organization, received specific information about the confined spaces, and were submitted to a basic check of their training ahead of time. However, according to foremen in the field, subcontractors do not always follow the rules if their work is not being monitored. It would also seem insufficient to check a subcontractor's training certificate to assess competency. Ways to improve safety performance in this area are indicated in table 15.

Table 15 – Problems noted and possible improvements regarding subcontracting

Problem [organizations]	**Possible improvement** [clauses of CSA Z1006-10; organizations where observed]
– Non-compliance by subcontractors respecting real use of entry permits, gas readings prior to entry, ventilation times and use of recommended protective equipment [D, F, H and N].	– Audit subcontractors [cl. 5.4.2].
– Training certificates of subcontractors not sufficient to assess their competency (Hardison et al., 2014). For instance, in some cases, in a bid to save time, the theoretical training was taken online by the subcontractor's administrative staff, on behalf of its field staff [D].	– Verify real acquisition of knowledge conveyed in training when observing subcontractor at work, at least during the first contract [cl. 7.1.13]. One effective way is for the contracting organization to issue the permit in the presence of the subcontractor, take the first gas reading, check that all necessary preparations have been made before the entry, then remain at the subcontractor's disposal during the work, as needed [H and O].

4.1.3.7 Rescue-related Issues

Management of confined space residual risks is based on rescue (with or without entry). The time required to perform a rescue is critical in a confined space. Yet implementing rescue measures brings its own challenges. Problems and possible improvements are presented in table 16.

For rescues with confined space entry, two thirds of the organizations visited were counting on assistance from the local fire department. However, most rescue procedures had not been tested, contrary to what is specified under Quebec regulations. In addition, a minimum of 60 to 90 minutes was estimated by several organizations for the time it would take local firefighters to rescue a victim, taking into account the various time frames specified by Wilson et al. (2012). These time frames are often incompatible with emergencies, especially given that only a small minority of Quebec fire departments (65 out of 800) have firefighters trained in confined space rescue procedures. As a result, private companies now offer rescue services.

Table 16 – Problems noted and possible improvements regarding rescues

Problem [organizations]	**Possible improvement** [clauses of CSA Z1006-10; organizations where observed]
Rescue with entry	
– Time required by firefighters to rescue a victim often incompatible with emergencies [A–C, F, G, and J–O].	– Ensure better communication between organization and fire department concerned. Test rescue procedures together [cl. 6.6.3 and 6.6.4]. – Have on site, or share, a professional emergency response team, properly trained and equipped [D, E, H and I]. However, that requires investments that are difficult for smaller organizations to make.
Rescue without entry	
– A rescue without entry cannot be performed if moving the victim will worsen the person's medical condition. – Sometimes workers cannot attach their harnesses to the lifeline because of obstacles, the work to be done, the configuration of the confined space or the distance they penetrate the space. – Horizontal entries involve different rescue constraints from vertical entries and are sometimes not given sufficient attention.	– Define, in the management program, the criteria for allowing a rescue without entry, or else wait for first responders and rescuers [I]. – Train attendants to manage and perform outside rescues [cl. 7.1.9 and 7.1.10]. – Define more precisely, in the emergency procedure, the measures to take to prepare for the arrival of rescuers and stabilize the medical condition of the victim, whether inside or outside the confined space.
– Cheaper Class A harnesses are often used (dorsal rings; victim not in an upright position when removed from space) [in most organizations].	– Use Class E harnesses (rings at shoulders) which help to keep victims upright during a vertical rescue and to bring them out through a restricted access (CSA, 2012).

To reduce emergency response times, all the organizations visited have recently made investments so that rescues without entry can be performed by attendants. This investment includes the incorporation of a davit arm or tripod equipped with a rescue winch for vertical entries, combined with the requirement to wear a harness (figure 6). However, rescues without entry are not always possible.

Figure 6 – Tripod and winches for fall protection and rescue without entry; wearing of a Class A harness

4.1.3.8 Problems Related to Risk Reduction Measures

Problems or mistakes were noted in the use of gas detectors, ventilation, respiratory protection and fall protection equipment, compared with generally accepted good practices. These problems, along with possible improvements, are presented in table 17. All this information confirms the need for regular audits and suggests certain possible control points. Alternatives to worker entry (e.g., cameras, magnetic tools, readout, lubrication or isolation devices outside a confined space) were not yet in use when we visited. Last, only a few organizations had begun involving an OHS coordinator in the design of facilities having confined spaces.

Table 17 – Problems noted and possible improvements regarding use of risk reduction measures

Problem [organizations]	**Possible improvement** [clauses of CSA Z1006-10; organizations where observed]
Gas detection	
– No readings taken (i) before fully opening the confined space, especially for flammable gases, and (ii) when entering after lunch break [B, C, F and I]. – Calibration not up to date (e.g., expiration of calibration gas) [C, G and N]. – Required gas testing time not respected [I and L]. – Enter detector directly in confined space rather than use a probe [most organizations]. – Workers don't always realize that the detectors test for only four gases and that a deviation of just a few tenths of a percent from an oxygen concentration of 20.9% can be a source of contamination by a non-targeted gas [F, K, M and N]. – Workers relied primarily on alarms rather than on variations in gas concentrations (e.g., left gas detector in confined space all day without taking readings or checking battery) [K, J and N]. – Additional photoionisation detectors, such as for volatile organic compounds (e.g., solvents), are rarely used [D, E, G and M].	For effective management of all these approximations, detector maintenance and use should be centralized in the hands of a trained and experienced core team [cl. 7.2.8 and A.14; H].
Ventilation	
– No information on required configuration, required ventilation time before entry and ventilation needed during entry [in most organizations].	– Analyse the ventilation required (e.g., equipment, ventilation outlet in confined space) in order to flush out the space fully and eliminate pockets of contaminants [cl. 7.2.9.3 and A.15]. – If changes to a confined space are planned, we recommend incorporating permanent ventilation ducts into the structure of the space, taking into account the configuration of the space and the anticipated work [cl. 6.2.1.3, 6.4.2.3, A.3 and A.7].
Fall protection	
– Problems installing davit arm and railings owing to size and weight of equipment [B, D, F, G, K, L and N].	– Incorporate bases and anchor points into structure on ground (figure 7) [cl. 6.2.1.3, 6.4.2.3, A.3 and A.7). Use a truck specially designed for handling equipment [G and H].
– Harness not worn or not fastened during work [B, C, E, F, H and I].	– Conduct periodic audits [cl. 4.5 and 8.2].
– Possible falling object [C and K].	– Keep the area around the entry clear, protect entries and have a planned method for lowering tools into the confined space [cl. 7.2.3].

Table 17 (cont'd)

Problem [organizations]	**Possible improvement** [clauses of CSA Z1006-10; organizations where observed]
Respiratory protection	
– Uncertainty about the need to wear half-masks with cartridges and for fit testing (e.g., wearing glasses, clean shaven) [A, D and E]. – No special precautions taken when storing used cartridges [A and D].	– Perform a risk evaluation [cl. 6.3, 6.4 and 7.2.10]. – Conduct periodic audits [cl. 4.5 and 8.2]. – Follow manufacturer's instructions [cl. 7.2.10]. Use a bag that can be resealed hermetically [A and D].
Special configuration	
Ensure communication, rescue and gas testing in spaces that penetrate over a long distance (e.g., crawl space) and for confined spaces within confined spaces (e.g., tank in an underground mechanical room) [A, C, D, H, I and J].	Use an underground rescue attendant or a camera as an intermediary between the confined space entrants and the above-ground attendant [I and J].

Figure 7 – Permanently installed davit arm base, ladder and railing

4.1.4 Summary of Needs

The combined results of the literature review, the accident analysis and the field visits highlight a number of needs regarding risk assessment for confined space work and the development of a specialized tool for that purpose. As a reminder, the reason for developing the tool is to help companies apply the principles of risk assessment for confined space work. During the development of the tool, certain shortcomings noted in the literature and in companies that actively manage confined space risks were taken into account.

4.1.4.1 Multidisciplinary Approach

The literature review and the research conducted on field visits to workplaces revealed the need for a comprehensive, multidisciplinary approach to identifying confined space risks in order to capture a more accurate picture of the situation under which the work must be done. The number of fatal accidents due to machinery-related energy control problems shows that mechanical hazards must not be overlooked. So far, atmospheric hazards (i.e., asphyxiation, poisoning, explosion) have garnered all the attention. When hazards are identified, they are the ones cited most often and dealt with at greatest length. The checklists proposed for identifying hazards are incomplete with respect to physical hazards (e.g., falling, engulfment, mechanical, ergonomic). In addition, the statistics available concern atmospheric hazards almost exclusively (e.g., Wilson et al., 2012; Dorevitch et al., 2002). This approach is due to the fact that these hazards are specific to the nature of confined spaces. Nevertheless, physical hazards can also be serious, make hazardous situations more complex and require appropriate rescue measures. Furthermore, hazards may be present permanently in a confined space, but they may also develop as the work progresses (e.g., use of welding or grinding equipment). A third of all accidents related to atmospheric hazards are caused by the work activity itself (WorkSafeBC, 2008). Risk management should therefore be conducted by taking a comprehensive, multidisciplinary approach that considers the real complexity of confined space work situations.

4.1.4.2 Systematic Entry Preparation

In most of the fatal accidents studied, it appears that the confined space work was performed in an improvised fashion, no thorough risk analysis was conducted, and no work procedures were followed. As a result, risk reduction measures were inappropriate or simply non-existent. Faced with logistical constraints and limited resources, companies often encounter problems implementing risk assessment and work procedures (Chinniah, 2015). In addition, over half of the organizations visited did not conduct any preparatory analysis (e.g., risk fact sheets) before issuing an entry permit, and based their decision solely on the experience of the permit issuer. No risk estimation was observed. Considering the complexity and diversity of the work involved, this approach can lead to poor risk assessment in certain circumstances (e.g., omission or underestimation) and possibly to inadequate or inappropriate risk reduction measures. As was observed in a number of organizations, prior development of a databank of fact sheets on the hazards inherent to each confined space and related activities seems to limit individual subjectivity by systematizing the information available to the permit issuer. These fact sheets and the rescue plan should be centralized in the entry permit in order to limit the number of documents (table 13). More systematic preparation for confined space work would therefore appear to be necessary.

4.1.4.3 Risk Estimation

The risk estimation and evaluation stages prescribed in the risk management standards are not dealt with formally in the literature, nor implemented systematically in the organizations visited, with the exception of atmospheric risks. The literature on confined spaces chiefly focuses on identifying hazards related to different types of work. The risk estimation and risk evaluation stages are pretty well overlooked. Only nine tools that include a comprehensive risk estimation stage for confined spaces were found, among the 77 reference documents selected. The main confined space risk analysis tools suggested in the literature (e.g., checklists, risk scales and matrices) are often incomplete and do not take into account certain specific factors such as the physical characteristics of the confined space, rescue conditions, the variety of hazards, or the physical and psychological condition of the person entering the space. Last, the architecture of these risk estimation tools is flawed, containing defects such as vague parameter level definitions or a non-uniform distribution of the risk levels in the matrix (Chinniah et al., 2011; Duijm, 2015).

4.1.4.4 Criteria for Categorizing Confined Space Work

In the literature, the concept of similar confined space as a way of facilitating risk analysis has no practical assessment criteria. In practice, this decision (i.e., regarding similar confined spaces) should be made following risk identification and contextualization. That is what was proposed in the tool developed for this study.

The idea of categorizing confined spaces to facilitate risk management and communication is described in the literature, but is not used much in the field. These concepts can be improved using the results of multidisciplinary risk analysis adapted to confined spaces. Thus, categorization could combine concepts such as risk type, origin and level. This is the option that was chosen for the tool developed for this study.

4.1.4.5 Adequate Risk Reduction

The organizations visited seemed to pay little attention, with regard to both prescribed formalities and actual work, to (i) the management of subcontractors, (ii) audits focusing on the use of means of risk reduction and (iii) the integration of safe design. In addition, the lack of guidelines in the organizations' management programs limited the real effectiveness of measures related to training, rescue and the use of certain means of control (e.g., gas detection, ventilation, respiratory protection, fall protection). The conditions of use and the work performed in the confined spaces were not considered at the design stage, although they are the most effective ways to reduce risks.

4.1.4.6 Anticipation of Rescue Conditions

During confined space work, residual risk management was based on rescue, with or without entry, depending on the conditions. The analysis of fatal accidents in Quebec showed that 15% of the people who died (6) were involved in an improvised rescue attempt. No rescue plan was available in the workplace. Field visits revealed that most rescue procedures had neither been tested nor made available to the local fire department. Rescue measures took up most of the discussion time, as preparing for them entails overcoming a number of challenges (e.g., response time of external departments, equipment, training). Anticipating what the rescue conditions would be like and what measures would have to be taken (e.g., choose between rescue without entry or with entry) when beginning a confined space assignment is an important aspect of an organization's OHS.

4.2 Confined Space Risk Analysis and Work Categorization Tool

Based on the findings set out in section 4.1.4 and the risk management standards for machine safety, a five-step risk assessment tool was developed. The tool is presented below by applying it to an example. The work assignment was a welding repair job to be performed at the bottom of a tanker truck compartment. The example involves a variety of different hazards (e.g., falling, physical, atmospheric). It was inspired by an investigation conducted as part of the Fatality Assessment and Control Evaluation (FACE) program run by the NIOSH (NIOSH, 2014).

4.2.1 Tool Design

4.2.1.1 Step 1. Characterization of Confined Space Work

To identify the root causes of confined space work hazards, cause-and-effect diagrams were used (Ishikawa, 1979). This method involves reviewing the causes of an event on the basis of five aspects: machine, material, environment, method and manpower. When this technique was adapted to the context of confined space work, the aspects considered in the approach were (i) the configuration of the confined space (machine), (ii) its environment, (iii) the work to be done (method, material) and (iv) the workers (manpower). For each of these aspects, closed-ended questions with a choice of possible answers were drawn up for characterizing all hazardous situations and not only those related to the structure of the confined space. These questions, applied to our example, are presented in table 18. A copy of the blank questionnaire can be found in Appendix G.

The concepts and vocabulary are those used in the ROHS. Questions about confined space configuration primarily concern entry/egress, its internal shape, past content of the space (e.g., tank contents), mobility, natural ventilation, equipment in the space and piping. Questions about the environment refer to the conditions of access to the space, the configuration of the area around the entrance, adjacent work and changeable conditions. Lastly, questions about the work to be done and the people doing it focus on the material and human resources required. The answers to these exhaustive questions provide a comprehensive profile of the situation.

Table 18 – Questionnaire used to characterize confined space work risks applied to an example

A. General information (section to be filled in once)
Name/Type of confined space: Tanker truck tank The space must satisfy the three following criteria in order to be considered an “enclosed area” (confined space) under the ROHS: ☒ It is not designed for human occupation, nor intended to be, but may occasionally be occupied for the performance of work; ☒ Access to which can only be had by a restricted entrance/exit; ☒ It can represent a risk for the health and safety of anyone who enters.
Reference No.: /
Purpose: Transportation of diesel fuel
Shape: Cylindrical, horizontal Dimensions: 1.4 m in diameter, 8 m long Interior volume (useful for ventilation): 50 m^3
Location (address, building): Washing station outside buildings
B. Configuration of confined space (without work) (section to be filled in once)
1. Is the confined space stationary or mobile? ☐ Stationary ☒ Mobile
2. Is the confined space open (e.g., basin, pit, trench) or partially/totally closed?** ☐ Open ☐ Partially closed ☒ Totally closed – Walls are made of: ☐ Concrete ☐ Steel ☒ Stainless steel ☐ Other: – Accessibility of walls of confined space from outside: ☒ Accessible ☐ Not accessible – Thickness of walls: 12.7 mm (½ inch)
3. How many entrances does confined space have? What are the dimensions of each entrance?** ☒ 1 ☐ 2 ☐ 3 ☐ >3 Shape: ☒ Round ☐ Rectangular; Dimensions: ☒<610 mm (24’’) in diameter or equivalent
4. Is access to the confined space vertical or horizontal?* ☒ Vertical ☐ Horizontal then vertical – Height: 1.4 m – Means of access: ☐ Fixed ladder ☐ Ladder brought by team ☐ Rungs – Condition of means of access: ☐ Good ☐ Poor ☐ Very poor ☒ Does not apply ☐ Horizontal – Means of access: – Condition of means of access: ☐ Good ☐ Poor ☐ Very poor ☐ Does not apply
5. Does the design of the confined space involve one or more of the following hazardous situations? ☒ Inadequate natural or mechanical ventilation** ☒ Restricted interior volume, limiting possible movements in space** (e.g., low ceiling, narrow section) ☒ Moving around is difficult because of obstacles (on ground or at height), curved floor, compartments, different levels or a noticeable slope* ☐ Presence of traps because of converging walls or funnel shape** ☐ Presence of structural weaknesses such as cracks, collapse, corrosion, offset entrance** ☐ Presence of sharp, pointed structural features**. ☒ Insufficient light** ☐ Extreme temperature/humidity (see Schedule V of the ROHS) ☐ High noise level (without work)** ☐ Other: ☐ None of the above

Table 18 (cont'd)

6.	Does the general use of the confined space involve one or more of the following hazardous situations?** ☒ Presence of toxic agents or asphyxiants ☒ Presence of flammable products or explosives, of combustible dust ☒ Presence of corrosive products, irritants, reagents or carcinogens ☐ Presence of decomposition products, sediments, residues, slow oxidation (e.g., rust) ☐ Presence of mould/fungus or various biological pathogens (e.g., dirty objects) ☐ Presence of animals, insects, allergens ☐ Unknown substances Specify the agents in question, their physical state and their density in the case of gases: Diesel, liquid ☐ Other: ☐ None of the above
7.	Is the confined space connected to pipes or drains that must be locked out or blocked off (risk of uncontrolled introduction or return of products, risk of drowning, equipment upstream/downstream)?** ☒Yes ☐No If so, specify: Openings for locked-out open drainage
8.	Is any equipment permanently installed in the confined space (or does any run through it) that is energized and needs to be locked out?** ☐ Yes ☒ No If so, specify:
9.	Does the confined space contain any free-flowing materials (e.g., grain, sand) that expose workers to a risk of being engulfed?** ☐ Yes ☒ No. If so, specify:
C.	**Environment** (section to be filled in once)
10.	Is the access to the confined space ... ?** (several possible answers) ☐ Isolated (e.g., far from another structure, few passers-by and/or hard to reach by vehicle) ☒ Technically difficult (e.g., at height, at end of narrow stairwell, on unstable ground) ☐ In another confined space or in a hazardous restricted access room ☐ None of the above
11.	Is the work area around the entrance ... ? (several possible answers) ☐ Exposed to road traffic or to a roadway within a facility ☐ Exposed to other workers ☐ Exposed to the public ☐ Exposed to weather (e.g., bad weather, outdoor temperatures) ☐ In another work area (e.g., workstation with operating stationary or mobile machinery) ☒ Poorly laid out (e.g., very little room, slope, ragweed, mud) ☐ Other: ☐ None of the above
12.	Is there a possibility of work being done nearby that would affect the conditions in the confined space? ☒ Yes ☐ No If yes, specify: Vehicle repairs
13.	Are hazardous materials being stored in an adjacent tank/space? ☐ Yes ☒ No If yes, specify:
14.	Are the conditions in the confined space subject to change (e.g., gas migration through walls, introduction of hazardous substances or gases [exhaust gases])?** ☐ Yes ☒No If yes, specify:
D.	**Work to be done / Entrants** (section to be filled in when appropriate for each job to be done) Work to be done: ☐ Cleaning ☐ Inspection ☒ Maintenance ☐ Other: Description of work: Repairing a crack in the tank. MIG welding For this work, is it really necessary for the worker to enter the confined space? ☒ Yes ☐ No
15.	How many entrants are required at the same time to perform the work? ☒ 1 ☐ 2 ☐ >2
16.	How many attendants outside are required for the work? ☒ 1 ☐ 2 ☐ >2

Table 18 (cont'd)

17.	Does the work (entry into space and job) require any particular experience/expertise? ☒Yes ☐No If yes, specify: Welding
18.	Does the work (entry into space and job) require being in any particular physical shape or mental health? <u>Examples</u>: Entry into the confined space is long and demanding, workspace very restricted (claustrophobia), need to go up and down ladder repeatedly, etc. ☒ Yes ☐ No If yes, specify:
19.	How frequently must such work be done? ☒ Daily ☐ Weekly ☐ Several times per year ☐ Each year ☐ Less than once a year ☐On an emergency, priority basis ☐ Unknown
20.	At what time of year usually? ☐Winter ☐Spring ☐Fall ☐Summer ☐Variable ☒All year
21.	How long does the work take and when is it done? ☐ Short length, <30 minutes ☒ Less than one shift ☐ Longer than one shift ☒Day ☐Night
22.	Are there time constraints related to the work (e.g., very short time frame, other department waiting, essential service) that put pressure on the workers? ☐ Yes ☒ No If yes, specify:
23.	What type of progression is required to get from the entry of the confined space to the place where the job is to be done?* ☒ Vertical progression only ☐ Horizontal progression only ☐ Vertical and horizontal
24.	During the work, will the attendant be able to see, hear or otherwise communicate with the worker in case a rescue procedure needs to be initiated?* ☒ Yes ☐ No
25.	Does the work to be performed involve any additional hazards? (several possible answers) ☐ High-pressure cleaning** ☒ Hot work (e.g., welding)** ☐ Working at heights** ☒ Using specific tools (e.g., mechanical, electric, hydraulic, compressed-air)** ☒ Temporary lighting in the confined space (fixed or portable utility light)** ☐ Use of a generator ☒ Use of chemicals (e.g., paint, resin, solvent, welding electrodes)** ☒ Release of particles, dust, aerosols** ☐ Work under load, load at height, falling tools** ☐ Handling of heavy objects ☐ Fall on same level, slip due to working conditions** ☒ Ergonomic constraints of wearing clothing or personal protective equipment (e.g., visibility, sweating) ☐ Other: ☐ No additional risk
26.	During the work, will it be possible for the worker to have his/her harness fastened at all times to a lifeline solidly secured to an anchoring point outside the confined space?* ☒ Yes ☐ No

*Questions designed to determine whether a potential rescue could a priori be done without entering the confined space

**Questions designed to determine whether a rescue with entry could become more complex because of the working conditions

An examination of the answers to the questions suggests a characterization of rescue conditions that focuses a priori on two concepts: (1) rescue without entry is (is not) potentially possible, and (2) the prevailing conditions make (or do not make) rescue with entry more complex. Based on the work of Wilson et al. (2012), for a rescue without entry to be possible a priori, the penetration into the confined space must be primarily vertical, with no obstacles, with contact ensured between worker and attendant, and with the workers fastened at all times by their harnesses to a lifeline. Questions related to these points (Q. 4, 5, 23, 24, 26) are marked with an asterisk in table 18. Note that even if these conditions are met, it does not guarantee that rescue without entry is possible. Other factors, such as the nature of the injury and the number of simultaneous entrants, may force the rescuers to enter the confined space. The existence of complex conditions affecting a rescue operation requiring entry is dealt with through accessibility to the confined space (Q. 10), accessibility to the victim (e.g., narrow opening, obstacles/need to move, free-flowing material) (Q. 2, 3, 5 and 23) and the potential hazards in the confined space (Q. 5–9, 14, 25). These points are marked with a double asterisk in table 18. In the example given, a rescue without entry is possible a priori.

This first step serves to generate a list of potential situation-related hazards using a conversion table that associates each answer with potential hazards (table 19, indicated in italics are the hazards related to the selected accident example). The conversion table was created on the basis of a consensus among the members of the research team. The hazards were grouped into seven categories: atmospheric, chemical, biological, falling, mechanical, physical and ergonomic. The breakdown is based on the accident process related to hazardous phenomena and the relative importance of certain types of hazardous phenomena in the accidents studied (e.g., machinery, falling).

Last, this step helps to determine whether two work situations really are identical in terms of hazards, based on the replies received (considering the parameters confined space, environment and work to be done). As some answers are open-ended (e.g., “other”; “specify”) or cover several hazards, the tool cannot automatically determine similarity, and in these cases the user must decide.

Table 19 – Correspondence table between answers given at work characterization step and suggested potential risks

Q.	Answers	Risk category	Type of risk
1	*Mobile confined space*	*Mechanical*	*Mobility of space*
3	*Entrance dimensions <24''*	*Ergonomic*	*Entry/egress*
4	*Entrance totally or partially vertical*	*Falling*	*Fall from height, falling object*
5	*Restricted interior volume*	*Ergonomic*	*Work posture, psychology/stress*
	Hard to move around	*Falling*	*Fall on same level*
		Ergonomic	*Internal layout*
	Presence of entrapment areas	Ergonomic	Internal layout
	Presence of structural weaknesses	Mechanical	Structural failure
	Presence of sharp, structural features	Mechanical	Sharp objects
	Inadequate light	*Ergonomic*	*Inadequate lighting/Reduced visibility*
	Extreme temperature/humidity	Ergonomic	Heat constraints
	High noise level	Physical	Noise
6	*Presence of toxic agents, asphyxiants*	*Atmospheric*	*Poisoning, asphyxiation*
	Presence of flammable products, etc.	*Atmospheric*	*Explosion/fire, asphyxiation, poisoning*
	Presence of corrosive products, irritants, etc.	*Chemical*	*Irritant/corrosive products, reagents, toxic or carcinogenic products*
	Presence of decomposition products, sediments, etc.	Atmospheric	Poisoning, asphyxiation
		Biological	Viruses, bacteria, protozoa, toxins, parasitic and other worms, moulds, fungi
	Presence of moulds, fungi or various pathogenic biological agents	Biological	Viruses, bacteria, protozoa, toxins, parasitic and other worms, moulds, fungi
	Presence of animals, insects, etc.	Biological	Viruses, toxins, bites
		Ergonomic	Psychology/stress
	Unknown or other substances	Atmospheric	Explosion/fire
			Asphyxiation
			Poisoning
		Chemical	Irritant/corrosive products
			Reagents
			Toxic chemicals or carcinogens
		Biological	Viruses, bacteria, protozoa, toxins, parasitic and other worms, moulds, fungi
7	*Yes (piping, drains)*	*Chemical*	*Irritant/corrosive products, reagents, toxic or carcinogenic products*
		Physical	*Drowning, heat (temp. of material)*
8	Yes (lockout)	Mechanical	Moving parts, flying pieces, objects with potential energy
		Physical	Electricity, heat, optical and ionizing radiation, noise, vibration
9	Yes (free flowing)	Physical	Engulfment, drowning
10	*Technically difficult access to entrance*	*Ergonomic*	*Physical exertion, access, environmental pressure*
		Falling	*Fall from height*
	Entrance in another confined space	Ergonomic	Access, inadequate lighting/Reduced visibility

Table 19 (cont'd)

Q.	Answers	Risk category	Type of risk
11	Entrance exposed to road traffic	Mechanical	Outside traffic
	Entrance exposed to other workers	Falling	Falling object
	Entrance exposed to public	Falling	Falling object
	Entrance exposed to bad weather	Physical	Electricity (lightning)
		Ergonomic	Heat constraints
	Entrance in a work area	Ergonomic	Access
	Entrance area poorly laid out	*Falling*	*Fall on same level*
12	*Yes (work nearby)*	*Atmospheric*	*Poisoning, asphyxiation, explosion/fire*
		Chemical	*Irritant/corrosive products*
		Mechanical	*Flying parts, outside traffic, structural failure*
		Physical	*Heat, noise*
13	Yes (hazardous materials stored)	Atmospheric	Poisoning, asphyxiation, explosion/fire
		Chemical	Irritant/corrosive products, reagents, toxic or carcinogenic products
14	Yes (changeable conditions)	Atmospheric	Poisoning, asphyxiation, explosion/fire
21	Nighttime work	Ergonomic	Inadequate lighting/Reduced visibility
	Work not short in duration	*Ergonomic*	*Physical exertion*
22	Yes (time constraints)	Ergonomic	Psychology/stress
25	High-pressure cleaning	Mechanical	Flying parts
	Hot work (e.g., welding)	*Atmospheric*	*Poisoning, explosion/fire*
		Physical	*Heat, optical and ionizing radiation*
	Working at heights	Falling	Fall from height
	Use of specific tools	*Mechanical*	*Moving parts, sharp objects, parts with potential energy, flying parts*
		Physical	*Electricity, optical and ionizing radiation, heat, noise*
	Setting up temporary lighting	*Physical*	*Electricity*
		Atmospheric	*Explosion/fire*
	Use of a generator	Atmospheric	Poisoning
		Physical	Noise
	Use of chemicals	*Chemical*	*Irritant/corrosive products, reagents, toxic or carcinogenic products*
	Release of particles, dust, etc.	*Atmospheric*	*Poisoning, explosion/fire*
	Work under load, load at height	Falling	Falling object
	Handling of heavy objects	Ergonomic	Physical exertion
	Fall on same level, slip	Falling	Fall on same level
	Wearing clothing or PPE	*Ergonomic*	*Physical exertion, work posture, heat constraints*

4.2.1.2 Step 2. Identification of Hazards and Accident Process

From the list of hazards generated in the previous step (table 19), the qualified person chooses those that actually apply to the situation in question.

The degree of detail that needs to be associated with each hazard was determined by testing several methods, ranging from checklists (e.g., ANSI/ASSE: Z117.1-2009, Annex C) to the breakdown of the accident process used in machine safety (i.e., hazard, hazardous situation, hazardous event, possible harm) (ANSI/ASSE, 2009). The conclusion drawn was that with a tool like a "checklist," it is impossible to target in what context a hazard may have an impact. Conversely, breaking down the accident process may be too complex to do without supervision. A table based on breaking down the accident process into its component parts was therefore developed by simplifying the information required and providing lists of possible choices in order to obtain standardized answers. The multiple-choice lists were drawn up from Annex B of standard ISO 12100:2010 on the safety of machinery (ISO, 2010). Interactions between hazards can be dealt with in the "Hazardous event" column (initiating event). The result is presented in simplified form in table 20 for a few hazards related to the accident example in question and especially for those related to welding and the presence of diesel residue (Carlton and Smith, 2000; Flynn and Susi, 2009). Information regarding the hazards (i.e., origin, category, type, specifics) is automatically extracted from the conversion table (table 19), whereas the accident process must be specified by the user.

Table 20 – Risk and accident process identification applied in part to the example case

Hazards					Hazardous activities			
No.	**Origin**	**Category**	**Type**	**Specifics**	**Hazardous action**	**Who**	**Hazardous event**	**Harm**
1	Confined space	Atmosph.	Poison	Diesel residue	Being in the tank	Entrant	Abnormal concentration	Headache
2	Confined space	Falling	Fall from height	Entry at height	Climbing on tank Being on tank	Entrant Attendant	Slip	Fracture, death
3	Confined space	Ergo.	Entry/egress	Opening <24"	Being in tank	Entrant	Having to strain too much to enter	MSD bruising
4	Confined space	Mechan.	Mobile space	Space fixed to a vehicle	To be on, in or near the tank	All workers	Accidental start-up	Bruising, fracture
5	Work to be done	Atmosph.	Explosion/ fire	Welding-related energy	Entering tank	Entrant	Concentration >10% LEL	Death
6	Work to be done	Physical	Optical rad.	Welding	Being exposed to radiation	Entrant	Abnormal exposure	Visual impair-ment

4.2.1.3 Step 3. Risk Estimation

Development of the risk estimation step was based on the tool proposed in Australian standard AS/NZ 2865:2001. It is the only risk estimation tool suggested in a standard on confined spaces (table 21) (Standards Australia, 2001). Recommendations in the literature for the design of risk estimation tools were taken into account in making changes to the Australian matrix. These recommendations cover, among other things, matrix architecture (ISO, 2010; Duijm, 2015; Chinniah et al., 2011; Gauthier et al., 2012; Cox, 2008), the subjective assessment of parameters, and the development of severity and likelihood scales (Carey and Burgman, 2008; Patt and Schrag, 2003; Hubbard and Evans, 2010).

Table 21 – Risk matrix proposed in standard AS/NZ 2865:2001

Likelihood	**Consequences (i.e., severity)** **1** **Insignificant** No injuries or illness	**2** **Minor** First aid treatment, on-site release immediately contained	**3** **Moderate** Medical treatment required, toxic release on-site contained with outside assistance	**4** **Major** Extensive injuries, toxic release off-site with no detrimental effects	**5** **Catastrophic** Death, toxic release off-site with detrimental effects
A – Almost certain: The event is expected to occur in most circumstances	S	S	H	H	H
B – Likely: The event will occur at some time	M	S	S	H	H
C – Moderate: The event should occur at some time	L	M	S	H	H
D – Unlikely: The event could occur at some time	L	L	M	S	H
E – Rare: The event may occur only in exceptional circumstances	L	L	M	S	S
WITH L – LOW: MANAGE BY ROUTINE PROCEDURES; M – MODERATE: MANAGEMENT RESPONSIBILITY MUST BE SPECIFIED; S – SIGNIFICANT: SENIOR MANAGEMENT ATTENTION NEEDED; H – HIGH: DETAILED RESEARCH AND MANAGEMENT PLANNING REQUIRED AT SENIOR LEVELS.					

The design criteria that were taken into account when modifying the severity and likelihood of harm occurrence scales are (i) keep the estimating process simple; (ii) avoid being too strict when defining levels, leave room for the user to exercise discretion, as risk estimation is done during a preparatory phase; (iii) define clearly what the parameters mean (e.g., time reference for the likelihood of occurrence); (iv) use between three and five levels for the severity and likelihood of harm occurrence; (v) avoid creating too many discontinuities or gaps between the parameter levels; (vi) avoid using vague terms without explanation to define parameter thresholds and (vii) make it possible to select all risks on the same severity and likelihood scale to ensure standardized estimation.

Tables 22 and 23 provide details on the modified severity scale and the modified likelihood of harm occurrence scale, respectively. For the severity of the harm, the definitions of the levels have been fleshed out with a description and some examples. In addition, numbered references based on international or Quebec regulatory values have been added for each type of hazard.

For the likelihood of occurrence, the length of time the work takes was used as the time reference, so that the estimate focused on the work and the parameters to be considered could be reduced. In addition, the level of likelihood labelled *Moderate* in standard AS/NZ 2865:2001 was removed in order to produce a clearer breakdown of the choices (i.e., reduce definition overlap). Last, criteria were added to make it easier to select a likelihood level (table 23). These criteria were assigned according to the three harm occurrence likelihood subparameters used in machine safety (i.e., exposure to hazard, likelihood of occurrence of hazardous event, possibility of avoiding or limiting harm) (ISO, 2010; Aneziris et al., 2013).

The results given by the Australian matrix (i.e., estimated level of risk) were adjusted, taking into account recommendations about the breakdown of risk levels in a matrix (e.g., weak consistency, betweenness) (Cox, 2008; 2009; Gauthier et coll., 2012). However, rather than take a totally theoretical/quantitative approach, the breakdown was done taking into account the actual definitions of the different levels of the two parameters (table 24). For example, severity of level 1 (i.e., insignificant) cannot produce a risk level of "3" on the four levels of likelihood of harm occurrence. Finally, no terms were associated with the four risk levels (unlike the example of the Australian standard with *low*, *moderate*, *significant* and *high*) so as not to influence the user in the subsequent risk evaluation step (i.e., Is the risk acceptable?). Only the digits 1 to 4 are used, 1 being the lowest risk level and 4 the highest.

Note that the rescue conditions and process are not taken into account in this risk estimation; instead, they are dealt with subsequently as an overall aggravating factor if the rescue requires entering the confined space. The rescue process can only occur after the risk has materialized.

Table 22 – Proposed harm severity scale and selection criteria associated with each type of hazard

Level		**Description** – Most severe harm that could result
1	Negligible	Not requiring first aid.
2	Minor	Requiring first aid without loss time. Examples: scratches, bruises, slight irritation.
3	Serious	Requiring medical treatment with loss time. Examples: sprain, simple fracture, vomiting, burn.
4	Major	Major trauma, long-term disability. Examples: multiple fractures, amputation, acute respiratory system damage.
5	Catastrophic	Death of one or more workers.

Atmospheric/chemical/biological:

- Type of product/substance, category of hazardous material, known clinical effects
- Expected concentration and comparison with permissible exposure values
- Expected exposure time, parts of body exposed

Note: Check permissible exposure values in force.

Falling:

- Maximum working height
- Type of surface and lower-level obstacles
- Predictable fall kinetics

Note: Under Quebec regulations, a safety harness must be worn above a height of 3 metres.

Mechanical:

- Mass, shape and speed of parts
- Force/torque/pressure in play in systems

Note: For example, standard ISO14120 (2002) on guards suggests forces of 75–150 N and kinetic energy of 4–10 J to reduce the risk of injury.

Physical:

- Intensity of physical phenomenon (e.g., amperes, volts, decibels, temperature, radioactive dose, wavelength, acceleration) and comparison with reference values, when available
- Exposure time in the case of radiation, noise and vibrations

Note:

Electricity: According to standard CSA Z462 (2015), for an alternating current of 60 Hz, a current intensity of 40 mA can be fatal (heart fibrillation) if the contact lasts one second or more.

Temperature (contact burn): According to standard ISO 13732-1, at 70°C, for a smooth metal surface, one second is sufficient to cause a second-degree burn (Moritz, 1947; ISO, 2006).

Noise: The ROHS sets regulatory values in Quebec (e.g., max. 90 dBA for continuous 8-hour exposure; number of impacts permitted over 8 hours for a noise level of 120–140 dB linear as peak value) (Gouvernement du Québec, 2016).

Ionizing radiation: According to the International Commission on Radiological Protection (ICRP), the effective annual dose limit for workers exposed to radiation, established over a rolling five-year period, is 20 mSv. Above 50 mSv, evacuation is recommended (Wrixon, 2008).

Non-ionizing radiation: For example, according to the American Conference of Governmental Industrial Hygienists (ACGIH), for electric fields of 60 Hz, the exposure limit is set at 25 kV/m. For magnetic fields of 60 Hz, the exposure limit is set at 1 mT (ACGIH, 2016). Other reference values are available (International Commission on Non-Ionizing Radiation Protection, 2010; IEEE, 2002).

Vibration: According to the ACGIH, for hand exposure to vibrations, the maximum value of the weighted acceleration in frequency (m/s^2) in any direction is 12 m/s^2 for exposure of less than 1 h. It is 4 m/s^2 for 4 to 8 hours' exposure (ACGIH, 2016).

Ergonomic (physical):

- Weight and shape of loads to be moved, type and length of moves
- Heat constraints
- Work posture and twisting
- Level of lighting, ambient pressure

Note: Quebec regulations give reference values for physical exertion combined with heat constraints. They also give reference lighting levels for various tasks (Gouvernement du Québec, 2016).

Table 23 – Harm occurrence likelihood scale and criteria to consider

Level		Description – Possibility that harm will occur during work
A	Very likely	Harm is almost inevitable during the work.
B	Likely	Harm may occur during the work.
C	Unlikely	Harm should not occur during the work.
D	Very unlikely	Harm not foreseen during the work.

Factors to take into account:

Exposure to hazards:
- Total duration of work (e.g., atmospheric, biological, chemical, ergonomic risks)
- Length of use of certain devices (e.g., mechanical, physical risks)
- Expected number of times entering and exiting (e.g., risk of falling)
- Number of workers exposed

Likelihood of occurrence of event that could cause harm:
- Incident history for this type of work and confined space
- Time elapsed since the last opening of the confined space can influence conditions in the space
- Past contents
- Possibility of changeable conditions

Possibility of avoiding or limiting harm:
- Knowledge about confined space and work to be done
- Maintenance of confined space
- Physical and psychological conditions required for entrants

Table 24 – Risk matrix proposed for risk estimation

Likelihood of occurrence of harm	Severity of harm				
	Negligible	Minor	Serious	Major	Catastrophic
Very likely	2	3	3	4	4
Likely	1	2	3	4	4
Unlikely	1	2	2	3	4
Very unlikely	1	1	1	2	3

4.2.1.4 Step 4. Summary of Risk Estimation

The summary step serves to present work-related risks by using the data obtained at the risk estimation step. The summary is produced by means of a radar chart, which consolidates on the same diagram all the information related to the risk category, risk levels and risk origin (i.e., layout of the confined space or type of work). The spokes of the radar correspond to the seven risk categories used. The value (i.e., on a scale of 0 to 4) associated with each spoke of the radar corresponds to the highest risk level reached among the risks included in that risk category. The maximum approach is the “strictest,” because it means that all the risks of a risk category associated with the highest level must be reduced in order to bring down the level of risk of that category. Figure 8 presents the summary for the example presented earlier. Without risk reduction measures, the predominant forms of risk in this example are atmospheric (explosion, poisoning), falling from heights, mechanical (space is mobile) and physical (radiation, heat, noise).

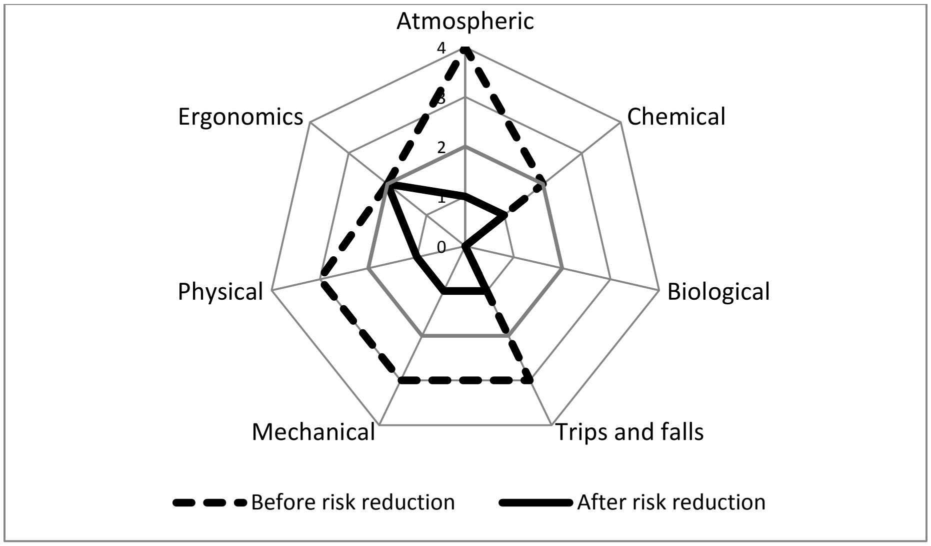

Figure 8 – Summary of risk estimation before and after risk reduction measures applied to the example case

The chart could be split into two so as to break down the risks depending on whether they are (i) inherent to the confined space and its environment (table 18, Q. 1–14), or (ii) related to the work to be done (table 18, Q. 15–26). As additional information, an index keeps track of how many of the seven risk categories exceed an acceptable risk threshold set by the organization (e.g., greater than 2). A (+) is added to this figure if a rescue without entry is a priori not possible. The index value therefore ranges from 0/7 to 7/7+. To refer to the OSHA regulations, as soon as the index is greater than 0/7 without any risk reduction measures, the work must be regarded as requiring a permit (permit-required confined space, or PRCS). The index provides an objective criterion for addressing the concept of serious risk presented in the OSHA regulations (and which can be used to differentiate between a PRCS and a non-PRCS). For the accident example studied, if the acceptable risk threshold is set at “2/4” and if rescue without entry is possible a priori, then the index would be 4/7 (atmospheric, falling, mechanical, physical).

The proposed categorization of confined space work therefore does not consist of a fixed number of categories, but is based instead on a summary associating the type (category), origin and level of the risks involved.

4.2.1.5 Step 5. Risk Reduction and Feedback

The risk reduction strategies commonly used for confined space work are presented in table 25 (ISO, 2010; ANSI/ASSE, 2011a; AIHA, 2014). Their impact on the components of risk (i.e., severity and likelihood of occurrence) is also suggested. Note that risk elimination or reduction at source should be given priority when designing a confined space. In addition, if a risk cannot be eliminated, it should always be reduced as much as possible.

Table 25 – Principles of risk reduction measures and impact on risk components

Risk reduction measure		Impact* on risk components	
		Severity	**Likelihood**
1.	Eliminate risk at design stage	++	++
	e.g., eliminate confined space, a source of energy, hazardous shapes, use of a toxic product, possibility of entry.	Hazards or possibility of exposure are eliminated.	
2.	Reduce hazard intensity at design stage	++	0
	e.g., limit drive force, speeds, amperage, decibels, radiation, vibrations, concentrations of hazardous products; substitute safer products; increase size of space for entrants	The strength/intensity of the hazard is reduced at design stage, intrinsically. Exposure remains the same.	
3.	Reduce need to enter at design stage	0	++
	e.g., move some elements of the confined space; use tools from outside, robots, cameras; preventive maintenance, such as (i) self-cleaning systems, (ii) materials, structures, durable surface treatments.	The hazard itself is not dealt with. However, exposure to the hazard is reduced to a minimum.	
4.	Incorporate collective means of protection	+	+
	e.g., guards, railings, adapted ladders/platforms, anchor points, permanent ventilation.	A collective means of protection can help limit the strength of and exposure to the hazard. However, the source of the hazard is not dealt with.	
5.	Apply technical procedures	+	+
	e.g., lockout, isolation of piping systems, portable ventilation, cleaning/draining of confined space before entry.	If followed properly, a technical procedure can help limit the hazard and exposure to it. However, the hazard itself is not dealt with per se.	
6.	Apply administrative procedures	0	+
	e.g., gas readings, warnings, pictograms, communication, supervision, reduce time spent in confined space, worker rotation.	If followed properly, administrative procedures can help limit risk exposure. The hazard itself is not dealt with.	
7.	Use PPE	0	+
	e.g., harness, respirator, hearing protection, safety footwear, hard hat, gloves, eye protection, coveralls.	If used properly, PPE can help limit risk exposure. Using it does not change the hazard itself.	

* 0: No impact; +: moderate impact; ++: major impact

After risk reduction measures have been taken, feedback is needed to estimate the residual risk. The results of the residual risk estimation are presented in the same way as earlier (radar chart). The risks before and after risk reduction can thus be compared, as in figure 8. For the example studied, in order to attain an index of 0/7 following risk reduction, not only was the tank cleaned, but the following measures were also taken: an attendant was assigned, dilution ventilation in several compartments and extraction ventilation in the compartment where the welding was done, gas detection, personal protective equipment for welding (e.g., gloves, welder's helmet, ear plugs), control over the truck ignition key, placement of wheel chocks and a harness secured to an anchoring point above the truck. The ergonomic risk related to the size of the entrance was not reduced.

4.2.2 Tool Validation

Having safety officers in 10 organizations use the risk analysis and categorization tool and compare it with other tools available highlighted its suitability and originality, but also its limits.

4.2.2.1 Assessment of Tool by Safety Officers

The safety officers who took part in the testing had a high opinion of the tool, giving it generally positive reviews. Their criticisms did not concern the principles of the approach, but rather the completeness and degree of precision of certain proposals. Their suggestions focused on the wording of the questions, the criteria for determining the rescue conditions a priori, the completeness of the lists and possible answers, the clarity of the summary and the automation of the approach. These aspects were corrected as the various versions were tested.

According to the safety officers surveyed, the approach meets their needs for structure and completeness when preparing for confined space entries. The characterization of situations totally specific to confined space work was certainly the aspect most appreciated and most easily transposable to an organizational setting (table 18). The other useful points, according to the safety officers, are (i) the list of potential risks, which makes the user's job easier, (ii) the numbered references that can be used to justify certain requests to decision makers, (iii) the rescue conditions determined a priori to force workers to think about this point, (iv) the visual summary for advising workers of the risks involved and (v) the comparison of the situations before and after risk reduction measures for questions of due diligence or justification of safety-related budgets in connection with calls for tenders.

4.2.2.2 Comparison

The results obtained by the research team over the course of the 12 tests (i.e., four tools with three scenarios) are presented in table 26. The first column in the table lists the risks identified with the four tools for the three scenarios. An empty box means that the risk in question was not identified by the tool used for that scenario. The table thus provides a comparison of the risks identified with each tool and the estimated risk levels for tools B, C and D. The risk levels are specified in the form "estimated risk level/number of risk levels in tool."

Based on the results of table 6 and table 26, table 27 presents the pros and cons of the four tools tested (Burlet-Vienney et al., 2016). Checklist and risk scale tools, favoured by businesses, proved to be quick to use, relying on the user's instincts, and gave acceptable results in relation to the other tools. Their limits have to do with their lack of contextualization for identified risks (e.g., no information about the source or origin of a risk) and their greater reliance on the user's competency in identifying risks, especially in the multirisk context of confined spaces. The likelihood of overlooking risks is high, which limits the scope of these tools. They are therefore more suited for an initial overall analysis of a situation. The tool proposed in this research report and the risk calculation tool represent more systematic approaches that allow users to ask questions about risks, identify risk factors and document the analytic process. They offer support for the risk reduction process by providing criteria for evaluating risk acceptability and residual risks. These tools can produce more homogeneous results from one user to the next, provided the architecture of the risk matrix is free of obvious bias (e.g., inadequate or inconsistent definitions of parameter levels, predominant influence of one parameter). However, they require devoting more time to analysis than the other tools do, which may limit their usefulness in a business setting.

Table 26 – Results of risk identification and estimation from applying four tools tested on three scenarios

	Scenario No. 1				Scenario No. 2				Scenario No. 3			
Risk / **Tool***	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Lack of oxygen	X	1/4	1/3	2/4	X	2/4	2/3	2/4	X	2/4	2/3	3/4
Dirty/rusty parts	X	1/4	1/3	2/4	X	2/4	3/3	2/4				
Traffic	X	2/4	3/3	4/4	X	2/4	3/3	4/4				
Fall from height (empty space)	X	3/4	3/3	4/4	X	3/4	3/3	4/4	X	2/4	3/3	4/4
Fall from height (when entering)			3/3	4/4			3/3	4/4			2/3	2/4
Fall on same level	X	2/4	2/3	2/4	X	2/4	2/3	2/4	X		2/3	3/4
Falling object	X	2/4	3/3	4/4	X	2/4	3/3	3/4			1/3	1/4
Tools (movements, cuts)			2/3	2/4	X	2/4	1/3	2/4				
Animals (bites, stress)				2/4				2/4				
Exposure to weather				2/4				2/4				
Toxic contaminants					X	2/4	3/3	3/4	X	3/4	3/3	4/4
Introduction substances, drowning					X	2/4	1/3	1/4	X	2/4	1/3	1/4
Electricity					X	2/4	2/3	2/4	X	3/4	3/3	3/4
Ambient heat					X	2/4	1/3	2/4	X	1/4	1/3	2/4
Noise					X				X		3/3	3/4
Entry/egress small									X	2/4	1/3	2/4
Explosion, fire									X	3/4	3/3	4/4
Chemicals (residue)									X	2/4	1/3	2/4
Chemicals (other)												2/4
Hot surface									X	3/4	3/3	3/4
Body posture at work											2/3	2/4
Vehicle movement									X	3/4	2/3	3/4
Radiation										4/4	3/3	4/4
Entry/egress small									X	2/4	1/3	2/4
Physical exertion												2/4

*Tool A: Company's risk analysis form Tool B: Government of South Australia
Tool C: UK Ministry of Defence Tool D: Tool developed in this study

Table 27 – Advantages and limitations noted for each type of method of risk identification and estimation

Risk identification	Advantages	Limitations
Checklist	• Quick, effective • Intuitive • Acceptable overview • Easy to use in the field	• Lack of completeness, systematization • Variability among users, depending on their skill • No information on source and origin of risk. Analysis must be completely redone if work changes
Questionnaire-suggestion tool (proposed in this report)	• Dynamic approach, more exhaustive and systemic • Contextualized risks. No need to redo analysis completely if work changes • Useful at design stage	• Fairly long process • Must be used by a qualified person, and part of it must be completed in advance at the office

Risk estimation	Advantages	Limitations
Intuitive or risk scale tool	• Quick, effective • Risk levels determined close to those of analytical tools • Easy to use in the field	• Risk factors not made explicit and documented • Variability among users, depending on their skill
Risk calculation or risk matrix tool (proposed in this report)	• Questioning and documenting of risk factors • Criteria for risk acceptability and evaluation of effectiveness of risk reduction measures taken • Better convergence of scores among users if risk matrix is appropriate • Useful at design stage, but also for evaluation of procedures for existing confined spaces	• Lengthy process • Estimation that is still qualitative and partly subjective, and has to be regarded as such • Must be used by a qualified person. Part must be completed in advance at the office

The tool proposed in this report has a distinctive structure, which formally goes through all the steps suggested in the risk management standards. In addition, it differs from the others because its risk identification stage is very exhaustive, questioning the user about risk factors related to the layout of the confined space, the work environment and the work itself. The risk estimation results are comparable to those obtained with the "risk calculation" tool. Last, the proposed tool makes use of risk identification and estimation by allowing a categorization of risks and an a priori rescue conditions, which the other tools do not do.

4.2.2.3 Limitations of Proposed Tool

The approach taken seeks to address the complexity of confined space work. It is therefore intended only for qualified people who are knowledgeable about such work and risk management. Only they will be able to give appropriate answers to the questions in the first step so as not to bias the results. Similarly, the method is not designed to be used just prior to entry into a confined space because it takes time to complete. Last, the tool does not totally eliminate the subjectivity inherent in this type of analysis (e.g., risk estimation).

The safety officers surveyed were unanimous about the fact that the viability of the approach in an organizational setting, especially organizations that manage a large number of confined spaces, depends on IT development that optimizes its usability and the potential for leveraging the collected data. The Excel™ utility developed for the testing was a first step in this direction to show the tool's real potential. The next stage will involve a subsequent development activity in conjunction with our partners.

The impact of the changes made to the risk estimation tool of the Australian standard is hard to evaluate. The estimate of the likelihood of harm occurring is especially subject to interpretation. However, efforts were made by defining a reference period and drawing up a list of factors to consider in the case of confined-space entries. Last, it should be noted that a number of studies on qualitative matrices have flagged reliability and interpretation problems with that method (Cox, 2008; Ball and Watt, 2013; Hubbard and Evans, 2010). Nevertheless, risk matrices do provide support in cases where data quantification is impossible (Duijm, 2015), as for confined space work.

5 CONCLUSION

5.1 Summary of Results

Analysis of confined space work statistics and fatal accident reports reveals an ignorance of risks by workers and a lack of risk analysis, work procedures and rescue procedures for this kind of work. As a result, some companies have trouble applying the regulations governing confined space work. Our approach to this research was thus to develop a risk assessment tool tailored to the specific needs of confined space work in order to help companies follow existing regulations. The tool facilitates risk communication and decision making during the risk elimination and reduction process. Certain shortcomings noted in the literature and in companies that actively manage confined space risks were taken into account.

The needs related to developing such a tool were determined on the basis of the results of a review of the literature on confined space risk management, analysis of confined space fatal accidents in Quebec and a study of risk management in 15 organizations and companies. First, the number of fatal accidents caused by an equipment energy control problem highlights the importance of mechanical hazards in confined spaces. A more multidisciplinary approach would therefore seem desirable. Second, the risk estimation and evaluation stages are seldom dealt with formally in the literature, with the exception of atmospheric risks. The literature on confined spaces chiefly focuses on identifying hazards related to confined space work. The main confined space risk analysis tools suggested in the literature are often incomplete and do not take into account certain specific factors such as the physical characteristics of the confined space, rescue conditions, the variety of hazards, or the physical and psychological condition of the person entering the space. Furthermore, none of the organizations visited estimated risks, relying instead solely on the experience of the permit issuer. In some cases, this approach can lead to inaccurate assessments of risk (e.g., omission or underestimation) and possibly to inadequate risk reduction measures. Third, in the literature, leveraging the concept of similar confined spaces to lighten the burden of risk analysis does not rest on any practical evaluation criteria. The idea of categorizing confined spaces to facilitate risk management and communication is described in the literature, but is not used much in the field. Fourth, field visits revealed that most rescue procedures had neither been tested nor made available to the local fire department. Last, the conditions of use of confined spaces and the work done in them should be considered right from the design stage, with a view to eliminating or limiting risks. Conditions of access and appropriateness of equipment are examples taken from accident analysis. Some recommendations, such as the content requirements of an entry permit, audit planning and the management of subcontractors, have been made to promote implementation of other risk reduction measures (e.g., ventilation, respiratory protection).

Based on these findings, a five-step risk analysis and confined space work categorization tool that implements the principles of risk management standards was developed. Step 1 of the tool consists of a list of 26 closed-ended questions intended to characterize the confined space, its environment and working conditions. The answers generate a list of risks divided into seven categories (i.e., atmospheric, chemical, biological, falling, mechanical, physical and ergonomic). This step ensures thorough, multidisciplinary identification of risks. Step 2 serves to describe the risks identified by the user (i.e., related accident process). Step 3 consists in estimating the risk using a risk matrix, parameters and adapted criteria. Step 4 provides a graphic classification by risk categories and levels. The a priori rescue conditions are also assessed on the basis of objective criteria. Last, step 5 consists of a feedback loop that estimates residual risks once risk reduction measures have been selected. On the basis of explicit criteria, the tool serves to determine (i) whether two confined spaces are actually identical, (ii) whether the work space meets the definition of a PRCS, (iii) whether a rescue without entry is a priori possible and (iv) whether the risks are sufficiently reduced. The usefulness and suitability of the tool were confirmed in testing by 22 confined space experts using an automated version running under Excel^{TM}. The tool met their requirements for structure and completeness when preparing for confined space entries.

In addition, the risk assessment tool developed was also compared with three other tools recommended in the literature or in companies for confined space work risk analysis. Three distinct approaches were tested on three risk scenarios: a checklist without risk estimation, a checklist with a risk scale, and a risk matrix without a formal risk identification step. The tool designed as part of this study differs from the other tools with respect to (i) its systematic approach, which allows questions to be raised about hazards, the identification of risk factors and the documentation of the analytical process, (ii) its structure, which formally goes through all the steps suggested in the risk management standards, (iii) the comprehensive, multidisciplinary nature of the risk identification step, (iv) the detailed selection criteria and parameter level definitions for risk estimation and (v) leveraging the risk identification and estimation results by proposing risk categorization and a priori rescue conditions.

The tool developed thus serves to support the risk reduction process by communicating risks and providing criteria for evaluating a priori rescue conditions and residual risks. Moreover, the step 1 questionnaire can also provide support for the safe design process.

5.2 Limitations and Future Research

The company and participant samples provided for in our method have no statistical power. The purpose of the method was to explore the variety of situations rather than their representativity. The criterion set for the number of interviews (between 10 and 15) is based on the principle of saturation (Gillham, 2000). It should also be noted that the agricultural sector could not be included in the sample for methodological and recruitment reasons (i.e., need for a management program).

In addition, the organizations and safety officers met during the research all come from the province of Quebec. The needs expressed and taken into consideration are therefore specific to the province's regulatory requirements and working conditions.

The tool proposed here cannot be used immediately prior to a confined space entry. It must be used by a qualified person as part of the work planning process. In addition, according to our tests, the average time required to examine a risk scenario is around 20 minutes. This is a limitation for using the tool in an organizational setting. This characteristic chiefly concerns small businesses, as they don't always have the necessary OHS resources. The tool will therefore be particularly suited for dealing with complex cases and when there is no urgent time constraint. Lastly, the safety officers surveyed were unanimous about the fact that the viability of the approach in an organizational setting depends on professional IT development that optimizes usability and the potential of the collected data. This type of development goes beyond the goals of this study, however, and will have to be made the subject of a knowledge transfer project in conjunction with our partners.

In addition, the list of potential risks proposed following the completion of the questionnaire could be optimized by cross-tabulating the answers or by using an incremental learning algorithm[3] based on data from a large number of analyses. A learning algorithm of this kind could even eventually reduce the number of questions needed to review all the risk factors and guide the parameter level choices for risk estimation. Last, the IT development of the tool could be incorporated into the overall risk management process for confined space entries. With the support of additional research work, the use of risk analysis results could enable the automated generation of entry permits.

Finally, given that safe design is the most effective way to reduce risks (table 25), another possible line of research would be to use the tool as a starting point for establishing safe confined space design criteria (e.g., silos, sewer systems, water treatment).

[3] Algorithm that learns by receiving input data and the associated results. Ultimately it will learn to predict the optimal result from the input data (Borodin and El-Yaniv, 1998).

BIBLIOGRAPHY

Abelmann, A., Lacey, S.E., Gribovich, A., Murphy, C., Hinkamp D., 2011. Hazard evaluation and preventive recommendations for an unusual confined space issue in an opera set design. Journal of Occupational and Environmental Hygiene 8(9), 81-85.

Abrahamsson, M., 2002. Uncertainty in quantitative risk analysis- characterisation and methods of treatment. Department of Fire Safety Engineering, Lund University, Lund, Sweden.

American Conference of Governmental Industrial Hygienists (ACGIH®), 2016. TLVs and BEIs. Threshold Limit Values for chemical substances and physical agents & Biological Exposure Indices. ACGIH®, Cincinnati, OH.

American Industrial Hygiene Association (AIHA), 2014. Prevention through Design: Eliminating Confined Spaces and Minimizing Hazards. AIHA, Falls church, VA.

American National Standards Institute (ANSI), American Petroleum Institute (API), 2001a. Requirements for safe entry and cleaning of petroleum storage tanks (API, ANSI/API: 2015-2001). API, Washington.

American National Standards Institute (ANSI), American Petroleum Institute (API), 2001b. Guidelines and procedures for entering and cleaning petroleum storage tanks (ANSI/API: RP 2016-2001). API, Washington.

American National Standards Institute (ANSI), American Society of Safety Engineers (ASSE), 2009. Safety requirements for confined spaces (ANSI/ASSE: Z117.1-2009). ANSI, Washington D.C.

American National Standards Institute (ANSI), American Society of Safety Engineers (ASSE), 2011a. Prevention through design: guidelines for addressing occupational hazards and risks in design and redesign processes (ANSI/ASSE: Z590.3-2011). ANSI, Washington D.C.

American National Standards Institute (ANSI), American Society of Safety Engineers (ASSE), 2011b. Risk assessment techniques (ANSI/ASSE Z690.3-2011). ANSI, Washington D.C.

American National Standards Institute (ANSI), National Electrical Manufacturers Association (NEMA), 2011. Criteria for safety symbols (ANSI Z535-3-2011). NEMA, Rosslyn, VA.

Aneziris, O.N, Papazoglou, I.A., Konstandinidou, M., Baksteen, H., Mud, M., Damen, M., Bellamy, L.J., Oh, J., 2013. Quantification of occupational risk owing to contact with moving parts of machines. Safety science, 51, 382-396. DOI:10.1016/j.ssci.2012.08.009

Asbestos Removal Contractors Association, 2007. Guidance note for asbestos removal in confined spaces (N°11). ARCA, Burton upon Trent, UK.

Antonsen, S., Almklov, P., Fenstad, J., 2008. Reducing the gap between procedures and practice lessons from a successful safety intervention. Safety science monitor 12(1), article 2.

Bahloul, A., Chavez, M., Reggio, M., Roberge, B., Goyer, N., 2012. Modeling ventilation time in forage tower silos. Journal of Agricultural Safety and Health 18(4), 259-272.

Bahloul, A., Roberge, B., Goyer, N., Chavez, M., Reggio, M., 2011. La prévention des intoxications dans les silos de fourrage (R-672). IRSST, Montréal.

Ball, D.J., Watt, J., 2013. Further thoughts on the utility of risk matrices. Risk analysis 33(11), 2068-78. DOI:10.1111/risa.12057

Beaver, R.L., Field W.E., 2007. Summary of documented fatalities in livestock manure storage and handling facilities--1975-2004. Journal of Agromedicine 12(2), 3-23.

Bergeron, S., Imbeau, D., Montpetit, Y., 2003. Le travail en espace clos – Nettoyage industriel au jet d'eau sous haute pression et par pompage à vide. CSST, Montréal.

Borodin, A., El-Yaniv, R., 1998. Online Computation and Competitive Analysis. Cambridge University Press, Cambridge, UK.

British Compressed Gases Association (BCGA), 2009. BCGA Guidance note GN9. The Application of the Confined Spaces Regulations to the Drinks Dispense Industry. BCGA, Derby, UK.

Brugnot, C., Beauté, C., Hasni-Pichard, H., Lauzier, F., 2001. Application de résines en espaces confinés dans l'activité BTP. Mise en évidence des expositions et propositions de moyens de prévention (INRS ND 2152-184-01). Cahiers de notes documentaires – Hygiène et sécurité du travail 184, 5-23.

Burlet-Vienney, D., Chinniah, Y., Bahloul, A., 2014. The need for a comprehensive approach to managing confined space entry: summary of the literature and recommendations for next steps. Journal of Occupational and Environmental Hygiene 11(8), 485-498. DOI: 10.1080/15459624.2013.877589.

Burlet-Vienney, D., Chinniah, Y., Bahloul, A., Roberge, B., 2015a. Risk Management Implementation for Confined Space Interventions in Quebec. Safety science 79, 19-28. DOI:10.1016/j.ssci.2015.05.003

Burlet-Vienney, D., Chinniah, Y., Bahloul, A., Roberge, B., 2015b. Design and application of a 5 step risk assessment tool for confined space entries. Safety science 80, 144-155. DOI:10.1016/j.ssci.2015.07.022

Burlet-Vienney, D., Chinniah, Y., Bahloul, A., Roberge, B., 2016. Risk analysis for confined space entries: critical analysis of 4 tools applied to 3 risk scenarios. Journal of occupational and environmental hygiene. DOI:10.1080/15459624.2016.1143949

Burton, N.C., Dowell, C., 2011. Health hazard evaluation report: HETA-2009-0100-3135, evaluation of exposures associated with cleaning and maintaining composting toilets - Arizona. NIOSH, Washington.

Caisse nationale de l'assurance maladie des travailleurs salariés, 2008. Cuves et réservoirs. Interventions à l'extérieur ou à l'intérieur des équipements fixes utilisés pour contenir ou véhiculer des produits gazeux, liquides ou solides R 435. INRS, Paris.

Caisse nationale de l'assurance maladie des travailleurs salariés, 2010. Prévention des accidents lors des travaux en espaces confinés R 447. INRS, Paris.

Caisse nationale suisse d'assurance en cas d'accidents, 2003. La sécurité lors de travaux dans des puits, des fosses ou des canalisations. SUVA, Lucerne, Suisse.

Cal/OSHA, 2012. Is It Safe to Enter a Confined Space? Confined Space Guide. California Department of Education, Sacramento, CA.

Canadian Centre for Occupational Health and Safety, 2012. Confined space – Introduction. Canadian Centre for Occupational Health and Safety, Ottawa.

Canadian Standards Association (CSA), 2010. Management of work in confined spaces (CSA Z1006-10). CSA, Mississauga, ON.

Canadian Standards Association (CSA), 2012. Full body harnesses (CAN/CSA Z259.10-12). CSA, Mississauga, ON.

Canadian Standards Association (CSA), 2015. Workplace electrical safety (CSA Z462-15). CSA, Mississauga, ON.

Carey, J.M., Burgman, M.A., 2008. Linguistic uncertainty in qualitative risk analysis and how to minimize it. Annals of the New York Academy of Sciences 1128(1), 13-17.

Carlton, G.N., Smith, L.B., 2000. Exposures to jet fuel and benzene during aircraft fuel tank repair in the U.S. Air Force. Applied Occupational and Environmental Hygiene 15(6), 485-491.

Castaing, G., Petit, J.M., Triolet, J., Falcy, M., 2007. Le dégazage de capacités ayant contenu des solvants, ED 6024. INRS, Paris.

Ceballos, D.M., Brueck, S.E., 2011. Health hazard evaluation report: HETA-2010-0175-3144, confined space program recommendations for dairy plant inspectors - nationwide. NIOSH, Washington.

Chinniah, Y., 2015. Analysis and prevention of serious and fatal accidents related to moving parts of machinery. Safety science 75, 163-173.

Chinniah, Y., Gauthier, F., Lambert, S., Moulet, F., 2011. Experimental analysis of tools used for estimating risk associated with industrial machines (Report R-684). IRSST, Montréal.

Cloutier, C., Paquet, B., Fontaine, F., Éthier, A., Gingras, B., Legris M., 2000. Faites la lumière sur les espaces clos – Fiche de prévention. CSST, Montréal

Commission de la santé et de la sécurité du travail (CSST), 2015. Le centre de documentation. CSST, Montréal.

Cox, L.A., 2008. What's wrong with Risk Matrices? Risk Analysis 28(2), 497-512. DOI:10.1111/j.1539-6924.2008.01030.x.

Cox, L.A., 2009. What's Wrong with Hazard-Ranking Systems? An Expository Note. Risk Analysis 29(7), 940-948. DOI:10.1111/j.1539-6924.2009.01209.x.

Dorevitch, S., Forst, L., Conroy, L., Levy, P., 2002. Toxic inhalation fatalities of US construction workers, 1990 to 1999. Journal of Occupational and Environmental Medicine 44 (7), 657-662.

Duijm, N.J., 2015. Recommendations on the use and design of risk matrices. Safety Science 76(7), 21-31. DOI:10.1016/j.ssci.2015.02.014

Eaton, G., Little, D.E., 2011. Risk – Assessing & mitigating to deliver sustainable safety performance. Professional safety 56(7), 35-41.

Education Safety Association of Ontario (ESAO), 2007. Confined spaces: Resource book. ESAO, Toronto.

Enterprise X, 2014. Risk analysis sheet. Unpublished/Confidential.

Farm and Ranch Safety and Health Association (FARSHA), 2012. Confined space safety in BC agriculture: A resource guide. FARSHA, Langley, Canada

Flick, U., 2006. An introduction to qualitative research, third ed. SAGE Publications, London.

Flynn, M.R., Susi, P., 2009. Manganese, Iron, and Total Particulate Exposures to Welders. Journal of Occupational and Environment Hygiene 7(2), 115-126. DOI:10.1080/15459620903454600

Fuller, D.C., Suruda, A.J., 2000. Occupationally related hydrogen sulfide deaths in the United States from 1984 to 1994. Journal of Occupational and Environmental Medicine 42(9), 939-942.

Garrison, R.P., Erig, M., 1991. Ventilation to eliminate oxygen deficiency in a confined space. Part III: heavier-than-air characteristics. Applied occupational and environmental hygiene 6(2), 131-140.

Gauthier, F., Lambert, S., Chinniah, Y., 2012. Experimental Analysis of 31 Risk Estimation Tools Applied to Safety of Machinery. Journal of Occupational Safety and Ergonomics 18(2), 245-265. DOI:10.1080/10803548.2012.11076933

Gillham, B., 2000. The research interview. Continuum, London.

Giraud, L., Ait-Kadi, D., Ledoux, E., Paques, J-J., Tanchoux, S., 2008. Maintenance – État de la connaissance et étude exploratoire (R-578). IRSST, Montréal.

Gouvernement du Québec, 1979. Act respecting occupational health and safety (c. S-2.1), s. 196. Québec Official Publisher, Québec.

Gouvernement du Québec, 2008. Safety code for the construction industry (c. S-2.1, r-4). Québec Official Publisher, Québec.

Gouvernement du Québec, 2016. Regulation respecting occupational health and safety (c. S-2.1, s. 223). Québec Official Publisher, Québec.

Government of Canada, 2015. Canada Occupational Health and Safety Regulations (SOR/86-304), Part XI. Government of Canada, Ottawa.

Government of South Australia, 2011. Confined space procedure (n° 0460/05). Government of South Australia, Adelaide.

Government of United Kingdom, 1997. The confined spaces regulations 1997 No. 1713. The Stationery Office Limited, Norwich, UK.

Guilleux, A., Werlé, R., 2014. Les espaces confinés. Assurer la sécurité et la protection de la santé des personnels intervenants (ED 6184). INRS, Paris

Hardison, D., Behm, M., Hallowell, M.R., Fonooni, H., 2014. Identifying construction supervisor competencies for effective site safety. Safety science 65(6), 45-53.

Harris, M.K., Ewing, W.M., Longo, W., DePasquale, C., Mount, M.D., Hatfield, R. et coll., 2005. Manganese exposure during shielded metal arc welding (SMAW) in an enclosed space. Journal of Occupational and Environmental Hygiene 2(8), 375-382.

Health and Safety Authority (HSA), 2010. Code of practice for working in confined spaces. Health and Safety Authority, Dublin.

Health and Safety Executive (HSE), 2013. Safe Work in Confined Spaces. Health and Safety Executive, Bootle, UK.

Hong-Kong Occupational Safety and health council, 2001. Working in confined spaces. Occupational safety and health council, Hong Kong.

Huang, Y.-H., Chen, P.Y., Krauss, A.D., Rogers, D.A., 2014. Quality of the execution of corporate safety policies and employee safety outcomes: assessing the moderating role of supervisor safety support and the mediating role of employee safety control. Journal of Business Psychology 18(4) (2004), 483–506.

Hubbard, D., Evans, D., 2010. Problems with scoring methods and ordinal scales in risk assessment. IBM Journal of Research and Development 54(3), 246-255. DOI:10.1147/JRD.2010.2042914

Institut National de Recherche et de Sécurité (INRS), 2010a. Espaces confinés – Guide pratique de ventilation n°8, ED 703. INRS, Paris.

Institut National de Recherche et de Sécurité (INRS), 2010b. Interventions en espaces confinés dans les ouvrages d'assainissement – Obligations de sécurité, ED 6026. INRS, Paris.

Institut National de Recherche et de Sécurité (INRS), 2011. Détecteurs portables de gaz et de vapeurs – Guide de bonnes pratiques pour le choix, l'utilisation et la vérification, ED 6088. INRS, Paris.

Institute of Electrical and Electronics Engineers (IEEE). 2002. IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 to 3 kHz (C95.6-2002). IEEE, New-York. DOI:10.1109/IEEESTD.2002.94143

International Association of Classification Societies (IACS), 2007. Confined space safe practice. IACS, London, UK.

International Commission on Non-Ionizing Radiation Protection, 2010. Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). Health physics 99(6), 818-836. DOI:10.1097/HP.0b013e3181f06c86

International Electrotechnical Commission (IEC), International Organization for Standardization (ISO), 2009. Risk management – Risk assessment techniques (IEC/ISO31010:2009). ISO, Geneva, Switzerland.

International Organization for Standardization (ISO), 2002. Safety of machinery - Guards - General requirements for the design and construction of fixed and movable guards *(ISO14120:2002).* ISO, Geneva, Switzerland.

International Organization for Standardization (ISO), 2006. Ergonomics of the thermal environment - Methods for the assessment of human responses to contact with surfaces - Part 1: Hot *surfaces* (ISO13732-1:2006). ISO, Geneva, Switzerland.

International Organization for Standardization (ISO), 2009. Risk management – Principles and guidelines *(ISO31000:2009).* ISO, Geneva, Switzerland.

International Organization for Standardization (ISO), 2010. Safety of machinery - General principles for design - Risk assessment and risk reduction (ISO12100:2010). ISO, Geneva, Switzerland.

Ishikawa, K., 1979. Guide to Quality Control. Asian Productivity Organization, Tokyo.

Janes, A., Chaineaux, J., Lesné, P., Mauguen, G., Petit, J.M., Sallé, B., Marc, F., 2011. Mise en œuvre de la réglementation relative aux atmosphères explosives – Guide méthodologique. ED 945. INRS, Paris.

Johnson, K.A., 2008. A consistent approach to the assessment and management of asphyxiation hazards. Institution of Chemical Engineers Symposium Series 154, 630-640.

Kletz, T.A., 1998. What went wrong? Gulf Publishing, Houston, TX.

Kletz, T.A., 2007. Mining the past. J. Hazard. Mater. 142(3), 618–625.

Krake, A.M., King, B., McCullough, J., 2003a. Health hazard evaluation report: HETA-2000-0060-290. NIOSH, Washington.

Krake, A.M., King, B., McCullough, J., 2003b. Health hazard evaluation report: HETA 2000-0065-2899. NIOSH, Washington.

Lindsay, F.D., (1992). Successful health and safety management. The contribution of management audit. Safety science 15(4-6), 387-402.

Lucas, D., Loddé, B., Dewitte, J.-D., Jegaden D., 2010. Occupational risk of exposure to carbon monoxide in a harbour environment: Report of eight cases. Archive des maladies professionnelles et de l’environnement 71, 161-166.

Lyon, B., Hollcroft, B., 2012. Risk Assessments top 10 pitfalls and tips for improvement. Professional Safety 57(12), 28-34.

Main, B.W., 2004. Risk assessment – A review of the fundamental principles. Professional safety 49(12), 37-47.

Manuele, F.A. (2010). Acceptable risk. Professional safety 55(5), 30-38.

Maritime and Coastguard Agency, 2010. Code of safe working practices for merchant seamen. The Stationery Office, Norwich, UK.

Ménard, L., 2009. Guide de prévention pour l’assainissement des systèmes de chauffage, de ventilation et de conditionnement de l’air. CSST, Montréal.

Metal Manufacturing and Minerals Processing Industry Committee (MMMPIC), 2002. A Guide to Practical Machine Guarding. Queensland Government, Brisbane, Australia.

Moritz, A.R., Henriques, F.C., 1947. Studies of thermal Injury II. The Relative Importance of Time and Surface Temperature in the Causation of Cutaneous Burns. Amer J. Path 123, 695-720.

National Institute for Occupational Safety and Health (NIOSH), 1994. Worker deaths in confined spaces. NIOSH, Cincinnati, OH.

National Institute for Occupational Safety and Health (NIOSH), 2014. Welder Dies During Welding Repair Inside of Cargo Tank Compartment. NIOSH, Cincinnati, OH.

Nemhauser, J.B., Ewers, L., 2005. Health hazard evaluation report: HETA-2002-0014-2958. NIOSH, Washington.

Ontario Ministry of Labour, 2011. Ontario regulation 632/05. Confined spaces. Queen's printer for Ontario, Ontario.

Ontario Ministry of Labour, 2014. Confined spaces guideline. Queen's printer for Ontario, Ontario.

Paquet, B., Éthier, A., Fontaine, F., Legris, M., Gingras, B., 2005. La prévention dans les silos. CSST, Montréal.

Patt, G.A., Schrag, D.P., 2003. Using specific language to describe risk and probability. Climatic Change 61, 17-30.

Pettit, T., Linn, H., 1987. A guide to safety in confined spaces. NIOSH, Cincinnati, OH.

Rekus, J.F., 1994. Complete confined spaces handbook. Lewis Publishers, Boca Raton, FL.

Riedel, S.M., Field, W.E., 2011. Estimation of the frequency, severity, and primary causative factors associated with injuries and fatalities involving confined spaces in agriculture. American Society of Agricultural and Biological Engineers Annual International Meeting 2011 2, 943–961.

Riedel, S.M., Field, W.E., 2013. Summation of the frequency, severity, and primary causative factors associated with injuries and fatalities involving confined spaces in agriculture. Journal of Agricultural Safety and Health 19(2), 83-100.

Robson, L.S., Shannon, H.S., Goldenhart, L.M., Hale, A.R., 2001. Guide to evaluating the effectiveness of strategies for preventing work injuries: How to show whether a safety intervention really works. NIOSH, Cincinnati, OH.

Ross, P. (2007). Confined space entry – Mitigating risk in general industry. American Associated Occupational Health Nurses 55(6), 245-251.

Sargent, C., 2000. Confined space rescue. Fire Engineering Books and Videos, Saddle Brook, N.J.

Silvermann, D., 2011. Interpreting qualitative data: a guide to the principles of qualitative research, fourth ed. SAGE Publications, Washington D.C.

Standards Australia, 2001. Safe working in a confined space (AS/NZS 2865:2001). Standards Australia, Sydney.

Standards Australia, 2003. Handbook: Guidelines for safe working in a confined space (HB 213:2003). Standards Australia/Standards New Zealand, Sydney.

Svedberg, U., Petrini, C., Johanson, G., 2009. Oxygen depletion and formation of toxic gases following sea transportation of logs and wood chips. Annals of Occupational Hygiene 53(8), 779-787.

Svedberg, U., Samuelsson, J., Melin, S., 2008. Hazardous off-gassing of carbon monoxide and oxygen depletion during ocean transportation of wood pellets. Annals of Occupational Hygiene 52(4), 259-266.

Syndicat des entreprises de technologie de production, 2006. Guide de mise en œuvre des technologies du soudage - coupage. Symop, Paris.

Trudel, A., Gilbert, D. 2004. Les espaces clos: Pour en sortir sain et sauf: Guide de prévention. APSAM, Montréal.

U.S. Chemical safety and hazard investigation board, 2010. Investigation report. Xcel energy hydroelectric plant penstock fire (REPORT NO. 2008-01-I-CO). U.S. Chemical safety and hazard investigation board, Washington.

U.S. Department of Labor, OSHA, 1989. 29 C.F.R., 1910.1000. Table Z-1. Toxic and hazardous substances – Limits for air contaminants. U.S. Department of Labor, Washington.

U.S. Department of Labor, OSHA, 1993. 29 C.F.R., 1910.146 - Permit-required confined spaces for general industry. U.S. Department of Labor, Washington.

UK Ministry of Defence, 2014. Management of health and safety in defence: high risk activities on the defence estate (JSP 375 Part 2 Volume 3). Confined spaces (Chapter 6). Defense Safety and Environment Authority, London, UK.

Université du Québec à Montréal, 2005. Procédure de travail en espace clos de l'Université du Québec à Montréal. UQAM, Montréal.

Vaillancourt, C., 2010. Sauvetage sécuritaire en espace clos. CSST, Montréal.

Veasey, D.A., Craft McCormick, L., Hilyer, B.M., Oldfield, K.W., Hansen, S., Hrayer, T.H., 2006. Confined space entry and emergency response. John Wiley & Sons, Hoboken, N.J.

Vida, C., Jones, A.L., 1998. Confined spaces – Law and Practice: Risk assessment management. GEE Publishing Ltd, London.

Washington state department of labor & industries, 2005. Confined spaces WAC 296-809. Washington state department of labor & industries, Washington.

Wilson, M.P., Madison, H.N., Healy, S.B., 2012. Confined space emergency response: Assessing employer and fire department practices. Journal of Occupational and Environmental Hygiene 9(2), 120-128.

Work Safe Alberta, 2009. Guideline for developing a code of practice for confined space entry. Work Safe Alberta, Edmonton.

Work Safe Alberta, 2010. Sewer entry guidelines. Work Safe Alberta, Edmonton.

Workplace health and safety Queensland, 2010. A guide to working safely in confined spaces. The state of Queensland. Department of Justice and Attorney-General, Queensland, Australia.

WorkSafe BC, 2007. Confined space entry program. A reference manual. The Workers' Compensation Board of British Columbia, Vancouver.

WorkSafe BC, 2008. Hazards of confined spaces. The Workers' Compensation Board of British Columbia, Vancouver.

Wrixon, A.D., 2008. New ICRP recommendations. J. Radiol. Prot. 28(2), 161-168. DOI:10.1088/0952-4746/28/2/R02

APPENDIX A – NUMBERED REFERENCES IN TABLES 3, 7 AND 8 TO THE REVIEW OF THE LITERATURE

1. Kletz, T.A., 2007. Mining the past. J. Hazard. Mater. 142(3), 618–625.
2. Svedberg, U., Samuelsson, J., Melin, S., 2008. Hazardous off-gassing of carbon monoxide and oxygen depletion during ocean transportation of wood pellets. Annals of Occupational Hygiene 52(4), 259-266.
3. Wilson, M.P., Madison, H.N., Healy, S.B., 2012. Confined space emergency response: Assessing employer and fire department practices. Journal of Occupational and Environmental Hygiene 9(2), 120-128.
4. Asbestos Removal Contractors Association, 2007. Guidance note for asbestos removal in confined spaces (N°11). ARCA, Burton upon Trent, UK.
5. U.S. Department of Labor, OSHA, 1993. 29 C.F.R., 1910.146 - Permit-required confined spaces for general industry. U.S. Department of Labor, Washington.
6. American National Standards Institute (ANSI), American Society of Safety Engineers (ASSE), 2009. Safety requirements for confined spaces (ANSI/ASSE: Z117.1-2009). ANSI, Washington D.C.
7. Government of Canada, 2015. Canada Occupational Health and Safety Regulations (SOR/86-304), Part XI. Government of Canada, Ottawa.
8. Ontario Ministry of Labour, 2011. Ontario regulation 632/05. Confined spaces. Queen’s printer for Ontario, Ontario.
9. Canadian Standards Association (CSA), 2010. Management of work in confined spaces (CSA Z1006-10). CSA, Mississauga, ON.
10. Gouvernement du Québec, 2016. Regulation respecting occupational health and safety (c. S-2.1, s. 223). Québec Official Publisher, Québec.
11. National Institute for Occupational Safety and Health (NIOSH), 1994. Worker deaths in confined spaces. NIOSH, Cincinnati, OH.
12. Fuller, D.C., Suruda, A.J., 2000. Occupationally related hydrogen sulfide deaths in the United States from 1984 to 1994. Journal of Occupational and Environmental Medicine 42(9), 939-942.
13. Dorevitch, S., Forst, L., Conroy, L., Levy, P., 2002. Toxic inhalation fatalities of US construction workers, 1990 to 1999. Journal of Occupational and Environmental Medicine 44 (7), 657-662.
14. Beaver, R.L., Field W.E., 2007. Summary of documented fatalities in livestock manure storage and handling facilities--1975-2004. Journal of Agromedicine 12(2), 3-23.
15. Riedel, S.M., Field, W.E., 2013. Summation of the frequency, severity, and primary causative factors associated with injuries and fatalities involving confined spaces in agriculture. Journal of Agricultural Safety and Health 19(2), 83-100.
16. Farm and Ranch Safety and Health Association (FARSHA), 2012. Confined space safety in BC agriculture: A resource guide. FARSHA, Langley, Canada

17. Abelmann, A., Lacey, S.E., Gribovich, A., Murphy, C., Hinkamp D., 2011. Hazard evaluation and preventive recommendations for an unusual confined space issue in an opera set design. Journal of Occupational and Environmental Hygiene 8(9), 81-85.

18. Bahloul, A., Chavez, M., Reggio, M., Roberge, B., Goyer, N., 2012. Modeling ventilation time in forage tower silos. Journal of Agricultural Safety and Health 18(4), 259-272.

19. Carlton, G.N., Smith, L.B., 2000. Exposures to jet fuel and benzene during aircraft fuel tank repair in the U.S. Air Force. Applied Occupational and Environmental Hygiene 15(6), 485-491.

20. Harris, M.K., Ewing, W.M., Longo, W., DePasquale, C., Mount, M.D., Hatfield, R. et coll., 2005. Manganese exposure during shielded metal arc welding (SMAW) in an enclosed space. Journal of Occupational and Environmental Hygiene 2(8), 375-382.

21. Johnson, K.A., 2008. A consistent approach to the assessment and management of asphyxiation hazards. Institution of Chemical Engineers Symposium Series 154, 630-640.

22. Lucas, D., Loddé, B., Dewitte, J.-D., Jegaden D., 2010. Occupational risk of exposure to carbon monoxide in a harbour environment: Report of eight cases. Archive des maladies professionnelles et de l'environnement 71, 161-166.

23. Ross, P. (2007). Confined space entry – Mitigating risk in general industry. American Associated Occupational Health Nurses 55(6), 245-251.

24. Svedberg, U., Petrini, C., Johanson, G., 2009. Oxygen depletion and formation of toxic gases following sea transportation of logs and wood chips. Annals of Occupational Hygiene 53(8), 779-787.

25. American National Standards Institute (ANSI), American Petroleum Institute (API), 2001a. Requirements for safe entry and cleaning of petroleum storage tanks (API, ANSI/API: 2015-2001). API, Washington.

26. Standards Australia, 2001. Safe working in a confined space (AS/NZS 2865:2001). Standards Australia, Sydney.

27. American National Standards Institute (ANSI), American Petroleum Institute (API), 2001b. Guidelines and procedures for entering and cleaning petroleum storage tanks (ANSI/API: RP 2016-2001). API, Washington.

28. Health and Safety Authority (HSA), 2010. Code of practice for working in confined spaces. Health and Safety Authority, Dublin.

29. Maritime and Coastguard Agency, 2010. Code of safe working practices for merchant seamen. The Stationery Office, Norwich, UK.

30. Ontario Ministry of Labour, 2014. Confined spaces guideline. Queen's printer for Ontario, Ontario.

31. Standards Australia, 2003. Handbook: Guidelines for safe working in a confined space (HB 213:2003). Standards Australia/Standards New Zealand, Sydney.

32. Washington state department of labor & industries, 2005. Confined spaces WAC 296-809. Washington state department of labor & industries, Washington.

33. Gouvernement du Québec, 2008. Safety code for the construction industry (c. S-2.1, r-4). Québec Official Publisher, Québec.

34. UK Ministry of Defence, 2014. Management of health and safety in defence: high risk activities on the defence estate (JSP 375 Part 2 Volume 3). Confined spaces (Chapter 6). Defense Safety and Environment Authority, London, UK.

35. Rekus, J.F., 1994. Complete confined spaces handbook. Lewis Publishers, Boca Raton, FL.

36. Sargent, C., 2000. Confined space rescue. Fire Engineering Books and Videos, Saddle Brook, N.J.

37. Education Safety Association of Ontario (ESAO), 2007. Confined spaces: Resource book. ESAO, Toronto.

38. Veasey, D.A., Craft McCormick, L., Hilyer, B.M., Oldfield, K.W., Hansen, S., Hrayer, T.H., 2006. Confined space entry and emergency response. John Wiley & Sons, Hoboken, N.J.

39. Vida, C., Jones, A.L., 1998. Confined spaces – Law and Practice: Risk assessment management. GEE Publishing Ltd, London.

40. Bahloul, A., Roberge, B., Goyer, N., Chavez, M., Reggio, M., 2011. La prévention des intoxications dans les silos de fourrage (R-672). IRSST, Montréal.

41. Brugnot, C., Beauté, C., Hasni-Pichard, H., Lauzier, F., 2001. Application de résines en espaces confinés dans l'activité BTP. Mise en évidence des expositions et propositions de moyens de prévention (INRS ND 2152-184-01). Cahiers de notes documentaires – Hygiène et sécurité du travail 184, 5-23.

42. Giraud, L., Ait-Kadi, D., Ledoux, E., Paques, J-J., Tanchoux, S., 2008. Maintenance – État de la connaissance et étude exploratoire (R-578). IRSST, Montréal.

43. Burton, N.C., Dowell, C., 2011. Health hazard evaluation report: HETA-2009-0100-3135, evaluation of exposures associated with cleaning and maintaining composting toilets - Arizona. NIOSH, Washington.

44. Ceballos, D.M., Brueck, S.E., 2011. Health hazard evaluation report: HETA-2010-0175-3144, confined space program recommendations for dairy plant inspectors - nationwide. NIOSH, Washington.

45. Krake, A.M., King, B., McCullough, J., 2003a. Health hazard evaluation report: HETA-2000-0060-290. NIOSH, Washington.

46. Krake, A.M., King, B., McCullough, J., 2003b. Health hazard evaluation report: HETA 2000-0065-2899. NIOSH, Washington.

47. Nemhauser, J.B., Ewers, L., 2005. Health hazard evaluation report: HETA-2002-0014-2958. NIOSH, Washington.

48. Bergeron, S., Imbeau, D., Montpetit, Y., 2003. Le travail en espace clos – Nettoyage industriel au jet d'eau sous haute pression et par pompage à vide. CSST, Montréal.

49. British Compressed Gases Association (BCGA), 2009. BCGA Guidance note GN9. The Application of the Confined Spaces Regulations to the Drinks Dispense Industry. BCGA, Derby, UK.

50. Caisse nationale de l’assurance maladie des travailleurs salariés, 2008. Cuves et réservoirs. Interventions à l’extérieur ou à l’intérieur des équipements fixes utilisés pour contenir ou véhiculer des produits gazeux, liquides ou solides R 435. INRS, Paris.

51. Caisse nationale de l’assurance maladie des travailleurs salariés, 2010. Prévention des accidents lors des travaux en espaces confinés R 447. INRS, Paris.

52. Caisse nationale suisse d’assurance en cas d’accidents, 2003. La sécurité lors de travaux dans des puits, des fosses ou des canalisations. SUVA, Lucerne, Suisse.

53. Cal/OSHA, 2012. Is It Safe to Enter a Confined Space? Confined Space Guide. California Department of Education, Sacramento, CA.

54. Canadian Centre for Occupational Health and Safety, 2012. Confined space – Introduction. Canadian Centre for Occupational Health and Safety, Ottawa.

55. Castaing, G., Petit, J.M., Triolet, J., Falcy, M., 2007. Le dégazage de capacités ayant contenu des solvants, ED 6024. INRS, Paris.

56. Cloutier, C., Paquet, B., Fontaine, F., Éthier, A., Gingras, B., Legris M., 2000. Faites la lumière sur les espaces clos – Fiche de prévention. CSST, Montréal

57. Guilleux, A., Werlé, R., 2014. Les espaces confinés. Assurer la sécurité et la protection de la santé des personnels intervenants (ED 6184). INRS, Paris

58. Government of South Australia, 2011. Confined space procedure (n° 0460/05). Government of South Australia, Adelaide.

59. Health and Safety Executive (HSE), 2013. Safe Work in Confined Spaces. Health and Safety Executive, Bootle, UK.

60. Hong-Kong Occupational Safety and health council, 2001. Working in confined spaces. Occupational safety and health council, Hong Kong.

61. Institut National de Recherche et de Sécurité (INRS), 2010b. Interventions en espaces confinés dans les ouvrages d’assainissement – Obligations de sécurité, ED 6026. INRS, Paris.

62. Institut National de Recherche et de Sécurité (INRS), 2010a. Espaces confinés – Guide pratique de ventilation n°8, ED 703. INRS, Paris.

63. Institut National de Recherche et de Sécurité (INRS), 2011. Détecteurs portables de gaz et de vapeurs – Guide de bonnes pratiques pour le choix, l’utilisation et la vérification, ED 6088. INRS, Paris.

64. International Association of Classification Societies (IACS), 2007. Confined space safe practice. IACS, London, UK.

65. Janes, A., Chaineaux, J., Lesné, P., Mauguen, G., Petit, J.M., Sallé, B., Marc, F., 2011. Mise en œuvre de la réglementation relative aux atmosphères explosives – Guide méthodologique. ED 945. INRS, Paris.

66. Ménard, L., 2009. Guide de prévention pour l’assainissement des systèmes de chauffage, de ventilation et de conditionnement de l’air. CSST, Montréal.

67. Paquet, B., Éthier, A., Fontaine, F., Legris, M., Gingras, B., 2005. La prévention dans les silos. CSST, Montréal.

68. Pettit, T., Linn, H., 1987. A guide to safety in confined spaces. NIOSH, Cincinnati, OH.

69. Syndicat des entreprises de technologie de production, 2006. Guide de mise en œuvre des technologies du soudage - coupage. Symop, Paris.

70. Trudel, A., Gilbert, D. 2004. Les espaces clos: Pour en sortir sain et sauf: Guide de prévention. APSAM, Montréal.

71. Université du Québec à Montréal, 2005. Procédure de travail en espace clos de l'Université du Québec à Montréal. UQAM, Montréal.

72. Vaillancourt, C., 2010. Sauvetage sécuritaire en espace clos. CSST, Montréal.

73. Work Safe Alberta, 2009. Guideline for developing a code of practice for confined space entry. Work Safe Alberta, Edmonton.

74. Work Safe Alberta, 2010. Sewer entry guidelines. Work Safe Alberta, Edmonton.

75. Workplace health and safety Queensland, 2010. A guide to working safely in confined spaces. The state of Queensland. Department of Justice and Attorney-General, Queensland, Australia.

76. WorkSafe BC, 2007. Confined space entry program. A reference manual. The Workers' Compensation Board of British Columbia, Vancouver.

WorkSafe BC, 2008. Hazards of confined spaces. The Workers' Compensation Board of British Columbia, Vancouver.

APPENDIX B – READING CHECKLIST FOR LITERATURE REVIEW

Subject	Document 1	Document 2	…
A. Risks identified			
– Type, nature			
– Description, limit values			
– Related injuries			
– Risk interactions			
B. Activities related to confined space entry			
– Type			
– Description, equipment used			
C. Risk factors (aspects that can influence risks)			
– Design, configuration of confined space			
– Use of confined space			
– Psychology, physiology of worker			
– Other			
D. Risk analysis techniques			
– General method (checklist, matrix, calculations, etc.)			
– Parameters that make up the risk (def., number of levels, etc.)			
– Risk index (def., number of levels, etc.)			
– Use of results, risk evaluation			
E. Confined space categorization			
– Types of categories			
– Categorization criteria			
F. Safe design of confined spaces, alternative methods			
– Suggested techniques			

APPENDIX C – READING CHECKLIST FOR ANALYSIS OF FATAL CONFINED SPACE ACCIDENTS IN QUEBEC

Accident information	**Accident No. 1**	**Accident No. 2**	**…**
Accident date: YY–MM			
Report date: YY			
Company name			
Sector			
Type of confined space			
Activity at time of accident			
Brief description of accident			
Number of fatalities			
Number of injured			
Causes determined by investigation			
Primary cause			
Workers' duties			
Worker alone or in team?			
Appropriate work method followed (procedure)			
Appropriate rescue method (rescue plan)			
Design aspects			
Miscellaneous			

APPENDIX D – QUESTIONNAIRES USED IN ORGANIZATIONAL SETTINGS TO STUDY RISK MANAGEMENT OF CONFINED SPACE WORK

This appendix presents the three data collection tools used on company visits to study their risk management of confined space work:

A. Interview checklist
B. Observation checklist for confined space entry
C. Verification checklist for management program implemented

A. INTERVIEW CHECKLIST

The questions on the interview checklist marked with the (+) symbol refer specifically to Quebec regulatory requirements.

SUMMARY OF VISIT

Compiled by	....
Contact information	Organization: .... Address: ....
Date of visit	............/............/.....................
Contact	Name: .... Position: .... Tel. at work: .... E-mail: .... Experience (confined spaces): ....
Interviewees	Name: .... Position: .... Experience (confined spaces): ....
	Name: .... Position: .... Experience (confined spaces): ....
Summary of documentation received	....

GENERAL INFORMATION ON ORGANIZATION VISITED

Organization visited (10)	Name of company or organization: (100) …………………………………………… Economic sector (according to organization's profile): (101) …………………………………………………………………………… Number of workers in organization: (102) …………………………………… Number and position of workers involved in confined space work: (103) …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… Type of production / Services offered: (104) …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… General organization chart with respect to OHS: (105) – …………………………………………………………………… – …………………………………………………………………… – …………………………………………………………………… – …………………………………………………………………… – …………………………………………………………………… Is there an OHS committee? (106) ☐ Yes ☐ No Is there a subcommittee for the management of confined space work? (107) ☐ Yes ☐ No Is there an OHS manager or safety officer? (108) ☐ Yes ☐ No

TOTAL CONFINED SPACES

Identification **(20)**	What prompted the move to identify confined spaces? (200) .... What definition of a confined space was used to identify them?+ (201) ☐ ROHS ☐ SCCI (Building Code) ☐ Other: .... Who did the identifying?+ (202) ☐ Qualified person ☐ Other: .... When? (203) .... / .... Are the confined spaces physically identified? And is access to them controlled?+ (204) ☐ Yes ☐ No .... If so, how? (205) .... Do you have a process for downgrading a confined space to a restricted space (or hazardous isolated space)? (206) ☐ Yes ☐ No If so, can you specify? (207) ....
Confined spaces **(21)**	Number of confined spaces inventoried: (210) .... Do you have a list of confined spaces, and is it available? (211) ☐ Yes ☐ No If not, what types of spaces do you have (purpose, location)? (212): 1. .... 2. .... 3. .... 4. .... 5. .... 6. .... 7. ....

CONFINED SPACE MANAGEMENT PROGRAM

Program or other (30)	Do you have a confined space management program?+ (300) ☐ Yes ☐ No If not, what management measures have you taken? (301) ………………….………………
Development of confined space management program (31)	What prompted development of the program? (310) ……………………………..……….. Who developed the program? (311) …………………………………………………….......... Date developed: (312) …………/……../……………… What references were used? (313) ☐ ROHS ☐ CSA Z1006-10 ☐ SCCI (Building Code) ☐ Other: ……………………………………….. Was company management involved? (314) ☐ Yes ☐ No Did workers participate? (315) ☐ Yes ☐ No What resources were made available? (316) ……………………………………………............
Program use (32)	How is the program made available to employees? (320) ……………………….…….. How is it integrated into the OHS management system? (321) ……………………… ……………………….………………..…………………..…………………..…………………..……………….........
Audit and review of confined space management program (33)	Has the program already been audited? (330) ☐ Yes ☐ No – If so, why or how frequently? (331) ……………………………………………………... ……………………………………………………………………………………………………….. – By whom? (332) …………………………………………………………………………................ Has the implementation of the program already been audited? (333) ☐ Yes ☐ No – If so, why or how frequently? (334) ……………………………………………..……….. – By whom? (335) ………………………………………………………………………….................
Documentation (summary) (34)	What documents have you drafted? (340)

		Available
Management program:	☐ Yes ☐ No	☐
List of confined spaces:	☐ Yes ☐ No	☐
Fact sheets on confined spaces:	☐ Yes ☐ No	☐
Control forms (entry permits):	☐ Yes ☐ No	☐
Work register:	☐ Yes ☐ No	☐
List of workers (including subcontractors):	☐ Yes ☐ No	☐
Training materials:	☐ Yes ☐ No	☐
Audit and review:	☐ Yes ☐ No	☐

How are the documents updated? (341) ……………………………………….………………

……

CONFINED SPACE WORK

Work performed (40)	How many work assignments do you carry out per year in confined spaces? (400) .... In what kind of confined spaces primarily? (401) – .... – .... – .... – .... At what times of the year? (402) .... For what kinds of work and how frequently (number/year)? (403): ☐ Repair: .... ☐ Unjamming / Adjusting / Troubleshooting: .... ☐ Construction / Dismantling: .... ☐ Inspection: .... ☐ Object retrieval: .... ☐ Cleaning: .... ☐ Other:............
Work planning and problems (41)	What proportion of the work assignments are planned (as opposed to those that are not anticipated)? (410) .... Are there situations where you do not follow any procedure before entering? (411) ☐ Yes ☐ No If so, why not? (412) – .... – .... What are the main problems encountered in confined space work? (413) – .... – .... – .... Have you had any incidents/accidents during confined space entries? (414) ☐ Yes ☐ No If so, what was the cause? (415) – .... – .... – ....

WORKERS

Organization of workers (50)	What is the hierarchy that oversees confined space management? (500) – ……………………………………………………………… – ……………………………………………………………… What is the composition of the work crews? (501) – Entrant – Attendant:+ ☐ Yes ☐ No – Underground attendant: ☐ Yes ☐ No – ……………………………………………………………… How many people are involved in the work, at a minimum? (502) ………………
Training / information for confined space workers (51)	Are the entrants qualified?+ (510) ☐ Yes ☐ No Have the various workers been trained?+ (511) ☐ Yes ☐ No Training: (512) ☐ In-house ☐ External Length: …………………… Is the training tailored to their role? (practice/theory, rescue, supervision, risk analysis, hot work, lockout, etc.) (513) ☐ Yes ☐ No ……………………………………………………………… ……………………………………………………………… Before they start their work assignment, are workers given information specifically about the confined spaces they are going to work in?+ (514) ☐ Yes ☐ No How frequently is refresher training given? (515) ………………………………
Subcontracting (52)	Are some confined space work assignments contracted out? (520) ☐ Yes ☐ No If so, can you specify? (521) ……………………………………………… – ……………………………………………………………… – ……………………………………………………………… How is work by subcontractors managed? How are practices standardized? (522) ……………………………………………… ……………………………………………………………… Before they start their work assignment, are subcontractors given information specifically about the confined spaces they are going to work in?+ (523) ☐ Yes ☐ No When considering estimates, do you make sure that subcontractors have taken training specifically for confined space work? (524) ☐ Yes ☐ No Is subcontractors' work documented? (525) ☐ Yes ☐ No

CONFINED SPACE ENTRY PROCEDURES

Entry permits **Entry fact sheets and preparation checklists (60)**	Do you have a general work procedure for confined space entries? (600) ☐ Yes ☐ No Do you use control forms (entry permits)? (601) ☐ Prepared in advance ☐ Prepared just before entry ☐ No On what bases are your control forms (entry permits) developed and validated?+ (603) ☐ Entry fact sheets and preparation checklists ☐ Risk analysis ☐ Other: .... Who prepares them?+ (604) ☐ Qualified person: .... ☐ Other: .... How are the control form (entry permit) and the entry fact sheet and preparation checklist made available? (605) ☐ Paper file ☐ Computer terminal ☐ Other: .... How is access to the work equipment organized (PPE, ventilation, measuring instruments)? (606) ....
Rescue procedure (61)	Are rescue preparation measures taken for confined space work?+ (610) ☐ In-house ☐ Externally ☐ None Explain (when entering, from the outside, etc.): .... Are these measures tailored to the hazards of a potential rescue operation (e.g., contaminated environment)? (611) ☐ Yes ☐ No Have the measures been tested?+ (612) ☐ Yes ☐ No If rescues are managed internally, how is rescue equipment made available?+ (613) .... Can you provide some more information about the rescue equipment available?+ (614) ....
Lockout procedure (62)	Has a lockout program been developed to support confined space work? (620) ☐ Yes ☐ No If so, can you specify? (621) ....

RISK MANAGEMENT FOR CONFINED SPACE ENTRIES

Hazard identification[+] (70)

Have hazards been identified? (700)

☐ By confined space ☐ By type of work ☐ No

....

Was a form (e.g., checklist) used for this?

☐ Yes ☐ No If so, specify: (701) ....

Who performs the hazard identification? (702)

☐ Qualified person ☐ Other: ....

Was it done in a team? (703) ☐ Yes ☐ No...

Were the following hazards taken into account? (704)

Rate how frequently they are present, from 1: rarely, to 3: very frequently.

Poisoning, asphyxiation	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Explosion, fire, dust	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Hot surface	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Hot ambient temperature	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Electricity	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Engulfment, free flowing material	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Fall from height	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Moving parts	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Drowning, flowing material	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Noise and vibration	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Introduction of substance	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Work to be done (e.g., hot work)	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Biological, animals	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Fall on same level	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Spatial structure (e.g., stability)	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Lighting/visibility	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Falling object	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Radiation	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Entry/egress small	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Waste-related:	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Outside traffic	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Environmental, weather	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Overexertion, posture	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Confined space accessibility	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Psychology, stress	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3
Clothing/PPE-related	☐ Yes ☐ No	☐ 1 ☐ 2 ☐ 3

Other: ....

....

....

Risk estimation* for confined space work (71) *definition of the likely severity of harm and the likelihood of occurrence of this harm (ISO12100:2010)	Are risks estimated ahead of confined space work? (710) ☐ Yes ☐ No How many risk estimations are done? (711) .... Is a risk estimation tool used? (712) ☐ Yes ☐ No Have you incorporated into the risk estimation tool specific information to adapt it to context of confined space work (e.g., rescue conditions)? (713) ☐ Yes ☐ No Can you justify the choices that were made when the tool was developed or selected (e.g., parameters, levels, definitions, etc.)? (714) .... What, in your opinion, are the pros and cons (weaknesses) of your risk estimation tool? (715) .... Who does the risk estimation?+ Was it done in a team? (716) ....
Risk evaluation* for confined space work (72) *judgment, based on risk analysis, about whether the risk reduction objectives have been met (ISO12100:2010)	Are the residual risks evaluated (e.g., unacceptable/acceptable)? (720) ☐ Yes ☐ No If so, on the basis of what criteria? (721) – .... – .... – .... – .... What criteria must be met for a confined space entry to be authorized?+ Can you justify the choice of criteria? (722) – .... – .... What are the main problems involved in risk evaluation? (723) – .... – .... – .... – .... – ....

Risk reduction for confined space work (73)	Have you broken confined spaces down into categories? (730) ☐ Yes ☐ No If so, on the basis of what criteria? (731) – .... – .... Do you work on confined space design with a view to eliminating risks at source? (732) ☐ Yes ☐ No If so, can you give some examples? (733) – .... – .... – .... What other means of risk reduction have been implemented? (734) – Ventilation:+ ☐ Yes ☐ No .... – Protective equipment: – Harness:+ ☐ Yes ☐ No .... – Respirator: ☐ Yes ☐ No .... – Other: .... – Gas detector, tests and readings:+ ☐ Yes ☐ No .... – Means of communication: ☐ Yes ☐ No .... – Purging, degassing or cleaning: ☐ Yes ☐ No .... – .... Do you have an equipment maintenance program for risk reduction? (735) ☐ Yes ☐ No Have you taken steps to facilitate the implementation of risk reduction measures? (736) ☐ Yes ☐ No If so, can you give some examples? (737) – .... – .... What are the main problems involved in risk reduction? (738) – .... – ....

B. OBSERVATION CHECKLIST

Completed by	....
Organization	....
Date of visit	............/.............../............................

WORKERS

Work crew (A)	Name: .... Position: .... Experience (confined spaces): ....
	Name: .... Position: .... Experience (confined spaces): ....
	Name: .... Position: .... Experience (confined spaces): ....
	Other: ....
Risk perception (B)	Risk perception before and during work (e.g., awareness, factors): .... Experiences concerning recovery from incidents or close calls: ....

CONTEXT

<table>
<tr><td rowspan="2">Confined space concerned (C)</td><td>Type of confined space: ....
Purpose: ....
Location: ....
Confined space accessibility: ....
General description of confined space / Diagram:
....
....
....
..........</td></tr>
<tr><td>Number of entrances/egresses: ....
Dimensions of entrances/egresses: .... / .... / ....
Means of access to interior: ....
Depth: ....m Penetration distance: ....m
Contents: ....
Equipment inside: ☐ Yes ☐ No If so: ....
Obstacles: ☐ Yes ☐ No If so: ....
Preparation before opening: ☐ Purge ☐ Cleaning ☐ Ventilation</td></tr>
<tr><td>Outside work environment (D)</td><td>Temp. °C: .... Weather conditions: ....
Sound environment: ☐ Very noisy ☐ Noisy ☐ Normal
Lighting: ☐ Sufficient ☐ Poor ☐ Very poor/Dark
<u>Miscellaneous:</u>
☐ Working at heights
☐ Vehicle traffic nearby
☐ Working alone
☐ Presence of public nearby
☐ Dangerous goods nearby
☐ Other: ....</td></tr>
<tr><td rowspan="2">Reason for work (E)</td><td>☐ Repair
☐ Unjamming
☐ Inspection
☐ Construction / Dismantling
☐ Preventive maintenance
☐ Cleaning
☐ Object retrieval
☐ Rescue</td></tr>
<tr><td>Details: ....
Length: ☐ 15 min ☐ 30 min ☐ 1 h ☐ 2 h ☐ >2 h: ....
Frequency of work: ....</td></tr>
</table>

WORK

Entry permit (F) **Obtained** ☐ Yes ☐ No	Entry permit prepared: ☐ in advance ☐ just prior to work Permit really used: ☐ Yes ☐ No Access to permit: ....
Steps observed in work – Actual operations (G)	1. .... 8. .... 2. .... 9. .... 3. .... 10. .... 4. .... 11. .... 5. .... 12. .... 6. .... 13. .... 7. .... 14. .... Problems and risk factors involved in actual operations: ....
Hazards present (H)	Poisoning ☐ Products, concentrations: .... Asphyxiation ☐ % O_2: .... Explosion, fire ☐ Products, % LEL: .... Ambient heat ☐ Temp. °C: .... Humidity: .... Hot surface ☐ Temp. °C: .... Electricity ☐ Access, volts, amperes: .... Engulfment ☐ Free-flowing substance: .... Fall from height ☐ Height: .... Configuration: .... Moving parts ☐ Moving part: .... Speed: .... Drowning/flowing material ☐ Material: .... Depth: .... Noise and vibration ☐ Source: .... dB: .... Introduction of substance ☐ Substance: .... Source: .... Activity ☐ Technique/Tools: .... Fall on same level ☐ Surface/Obstacle: .... Spatial structure ☐ Stability, internal layout: .... Lighting ☐ Lux: .... Falling object ☐ Mvt of load, protection: .... Radiation ☐ Source: .... Entry/egress small ☐ Number/Dimensions/Access: .... Residue-related ☐ Substances: .... Outside traffic ☐ Road/Pedestrians: .... Environmental ☐ Weather: .... Nearby equip.: .... Overexertion ☐ Handling: .... Posture: .... Entry accessibility ☐ Access/Isolation/Control: .... Psychology, stress ☐ Psychological state: .... Clothing/PPE-related ☐ Comfort/Visibility: .... Static elec.: ......

	Details: ....
	Differences between entry permit and actual work activity: ....
Risk reduction (additional information) (I)	Measures taken to reduce risks: – .... – .... – .... Accessibility of equipment: .... Problems with using equipment for work: ....
Emergency measures (J)	Emergency response procedure in force: .... 1. .... 2. .... 3. .... Equipment that would be used for a rescue: – .... – .... Adapted to types of risks: ☐ Yes ☐ No ....
Comments	....

....
....
....

C. VERIFICATION CHECKLIST FOR CONFINED SPACE ENTRY MANAGEMENT PROGRAMS

CONFINED SPACE MANAGEMENT PROGRAM

Content of confined space management program	Are the following topics covered in the program?		
	General information (date, goals)	☐ Yes	☐ No
	Definition of confined space	☐ Yes	☐ No
	Roles and responsibilities	☐ Yes	☐ No
	Composition of work teams	☐ Yes	☐ No
	Attendant	☐ Yes	☐ No
	Training and communication	☐ Yes	☐ No
	Inventory of confined spaces	☐ Yes	☐ No
	Signs and access	☐ Yes	☐ No
	Confined space design	☐ Yes	☐ No
	Identification of hazards	☐ Yes	☐ No
	Risk estimation	☐ Yes	☐ No
	Risk evaluation	☐ Yes	☐ No
	Risk reduction measures	☐ Yes	☐ No
	Ventilation	☐ Yes	☐ No
	PPE	☐ Yes	☐ No
	Gas detector and readings	☐ Yes	☐ No
	Lockout	☐ Yes	☐ No
	Work procedures	☐ Yes	☐ No
	Entry permit/Control form	☐ Yes	☐ No
	Management of entry permits	☐ Yes	☐ No
	Emergency response, rescue measures	☐ Yes	☐ No
	Equipment purchasing and management	☐ Yes	☐ No
	Management of subcontractors	☐ Yes	☐ No
	Change documentation and management	☐ Yes	☐ No
	Program review	☐ Yes	☐ No
	Audit of program implementation	☐ Yes	☐ No

RISK ESTIMATION TOOLS

Risk estimation* for confined space work *definition of the likely severity of harm and the likelihood of occurrence of that harm (ISO12100:2010)	Tool in matrix form: ☐ Yes ☐ No Parameters used: ☐ Severity of harm ☐ Likelihood of occurrence of harm ☐ Other:		
	Is each parameter associated with a definition?	☐ Yes	☐ No
	Are there 3 to 5 levels per parameter?	☐ Yes	☐ No
	Are parameter levels defined and continuous?	☐ Yes	☐ No
	Was one parameter given priority?	☐ Yes	☐ No
	Are there at least 4 risk levels?	☐ Yes	☐ No
	Is distribution uniform?	☐ Yes	☐ No
	Is the tool calibrated (e.g., multiple fatalities)?	☐ Yes	☐ No

APPENDIX E – QUESTIONNAIRE USED TO TEST RISK ANALYSIS TOOL

This appendix contains the questionnaire that was used to gather respondents' impressions and comments when the risk analysis tool developed for confined space work was tested in an organizational setting.

INFORMATION ABOUT VISIT

Compiled by	………………………………………………………………………………………………
Contact information	Organization: ……………………………………………………………… Address: ………………………………………………………………………………
Date of visit	………../……..……/…………..………
People met	Name: …………………………………………………………………………… Position: ……………………………………………………………………………
	Name: …………………………………………………………………………… Position: ……………………………………………………………………………

GENERAL IMPRESSIONS

Structure of approach (10) 5 steps: 1. Characterization of work situation 2. Identification of accident processes 3. Risk estimation 4. Summary 5. Feedback loop	Suitability/Usefulness of approach: (100) …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… Adaptation to many different realities (including yours): (101) …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… Contribution in comparison with your existing risk analysis methods: (102) …………………………………………………………… …………………………………………………………… …………………………………………………………… Complexity of approach: (103) …………………………………………………………… …………………………………………………………… ……………………………………………………………
Suggestions regarding structure/ approach (11)	Strengths, weaknesses: (110) …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… Aspects that need improving or are missing: (111) …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… ……………………………………………………………

SPECIFIC VALIDATION

Step 1 – Characterization of work situation (20)	Validation of questions (wording, lack, superfluous): (200) …………………………………………………………………… …………………………………………………………………… …………………………………………………………………… …………………………………………………………………… …………………………………………………………………… Validation of approach to a priori rescue conditions: (201) …………………………………………………………………… …………………………………………………………………… …………………………………………………………………… …………………………………………………………………… Validation of concept of similar work: (202) …………………………………………………………………… …………………………………………………………………… …………………………………………………………………… ……………………………………………………………………
Step 2 – Identification of accident processes (21)	Validation of columns of table and lists of possible choices: (210) (type of risk; hazardous situation; hazardous event; harm) …………………………………………………………………… …………………………………………………………………… …………………………………………………………………… ……………………………………………………………………
Step 3 – Risk estimation (22)	Validation of severity scale and selection criteria: (221) …………………………………………………………………… …………………………………………………………………… …………………………………………………………………… Validation of likelihood scale and selection criteria: (222) …………………………………………………………………… …………………………………………………………………… …………………………………………………………………… ……………………………………………………………………

	Validation of risk matrix scale: (223) …………………………………………………………………………………… …………………………………………………………………………………… ……………………………………………………………………………………
Step 4 – Summary (23)	Validation of principle of summary with radar chart (max. risk by category; breakdown by risk origin): (230) …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… Validation of principle of categorization: (231) …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… ……………………………………………………………………………………
Step 5 – Feedback loop (24)	Validation of operating principle of feedback loop: (240) …………………………………………………………………………………… …………………………………………………………………………………… ……………………………………………………………………………………

APPENDIX F – SCENARIOS AND RISK ANALYSIS TOOLS USED FOR COMPARATIVE TESTING OF DEVELOPED TOOL

1. Description of confined space work scenarios used for testing

	No. 1 Shaft/Inspection	No. 2 Shaft/Installation	No. 3 Tank truck/Welding
Use of confined space			
Type	Shaft – Sewer system		Tanker truck tank
Purpose	Access to sewer system pipe		Transportation of diesel fuel
Equipment inside space	Old sewer pipe at 4th level. Low water pressure, can increase during storms		No equipment. Drains and intakes for refuelling
Configuration of confined space			
Location	Sidewalk. Busy road nearby		Shelter adjoining garage
Accessibility	Entrance easily accessible		Entrance on tank (3 m). Access by ladder
Description of interior	4 levels, each 5 m high. Levels with metal grid flooring (10 m x 10 m). No obstacles. No lights.		Cylindrical tank: 1.5 m in diameter, 8 m in length. 4 compartments, no lights
Entrances/egresses	2: regular entrance (circular, 1 m in diameter) and auxiliary (square, 2 m each side)		4: one for each compartment (<1 m in diameter)
Means of access to interior	Ladder rungs set into cement for regular entrance. Appears to be in good condition		Ladder to be placed in tank. Appears to be in good condition
Content	No stored substances. Wet metal grating		Diesel. Tank emptied, steam-cleaned and rinsed with water
Outside conditions			
Temperature	25°C		21°C
Weather conditions	Stormy		Sunny
Sound environment	Noisy		Quiet
Products nearby	No		No
Planned work assignment			
Work	Visual inspection of concrete at 1st level. 1 worker	Installation of measuring instruments at 4th level. 2 workers	Repair bottom of tank compartment by welding. 1 worker
Tools	Conventional tools (e.g., hammer, trowel)	Power (120V) and conventional tools (e.g., pliers). Basket and rope for lowering and raising them	Welding supplies. Product for cleaning surface to be repaired
Length, frequency	30 min., twice a year	1 h 30 min. Once every 3 years. Several exits anticipated	2 h. Once every 2 years
Miscellaneous	Open access to lower level	Open access to lower levels. 8°C at 4th level	N/A

2. Company’s risk analysis form (tool A) applied to scenario no. 1 (Company X, 2014)

Atmospheric/chemical hazards		**Biological hazards**		**Physical hazards**			
Lack of oxygen	☒	Pathogenic microorganisms	☒	Various supply systems	☐	Falling	☒
Excess oxygen	☐	Dirty/rusty parts	☒	Mechanical	☒	Slippery surface	☒
Flammable contaminants	☐	Other	☐	Electricity, electrification	☐	Noise	☐
Toxic contaminants	☐			Thermal (heat)	☐	Pinching, entrapment	☐
Toxic chemicals	☐			Hot surfaces (contact)	☐	Engulfment, drowning	☐
				Chemical burns	☐	Internal layout	☐
				Pressure (stored)	☐	Worker isolated	☐
				Visibility (lack of)	☐	Falling object	☒
				Difficult access or egress	☐	Other	☐

3. Risk scale (tool B) applied to scenario no. 2 (Government of South Australia, 2011)

	Risk			
Potential hazards	Extreme	High	Moderate	Low
Nature of the confined space			X	
Access and Egress				X
Electrical			X	
Lighting				X
Power Failure				X
Contaminated air			X	
Flammable gases				X
Extreme temperatures			X	
Fire				X
Introduced materials			X	
Other contaminants			X	
Activation of plant				X
Method of work selected			X	
Level of oxygen			X	
Possibility of explosion				X
Unauthorised access				X
Floor Access Drop (use ladder)		X		
Lack of PPE				
Other: *traffic, falling object*			X	

4. Risk calculation tool (tool C) applied to scenario no. 3 (UK Ministry of Defence, 2014)

Generic hazards	Caused by/Source?	Likelihood (a)	Severity (b)	Risk rating (a x b)
Oxygen deficiency	Welding	2	2	4
Restricted entrance	Diameter < 1 m	2	1	2
Fall from height	Tank opening > 3 m high	3	3	9
Fall from height	Vertical entrance (1.5 m)	2	2	4
Falling object	Vertical opening	2	1	2
Fall on same level	Curved, slippery tank	2	2	4
Toxic contaminants	Welding fumes	3	4	12
Flammable contaminants	Diesel + welding	2	4	8
Chemicals	Cleaning products	2	1	2
Hot surface	Welding	4	3	12
Noise	Welding	4	2	8
Body posture at work	Cramped + 2 h of labour	2	2	4
Introduction of substances	Drains	1	2	2
Vehicle movement	Moving truck	2	2	4
Radiation	Welding	4	3	12
Electricity	Welding	2	3	6
Heat stress	Welding	2	1	2

With

Likelihood (a)	Criteria	Rating Value
Most Unlikely	Probability close to zero	1
Unlikely	Injury a conceivable occurrence	2
Likely	High possibility of injury	3
Most Likely	Injury probable	4

Severity (b)	Criteria	Rating Value
Trivial	Injuries that could be treated by local First Aiders from a First Aid box	1
Slight	Injuries that may require more expert treatment, administered at a medical centre / hospital department	2
Serious	Injuries involving urgent hospital treatment	3
Major	Injuries involving major trauma or death	4

Risk Rating (a x b)	Action Required
1 or 2	Existing control measures may be considered adequate
3 or 4	Consider introduction of additional controls or supervision
6 or higher	Additional controls are required in the form of a Safety Programme and Permit to Work

APPENDIX G – BLANK COPY OF QUESTIONNAIRE USED TO CHARACTERIZE CONFINED SPACE WORK RISKS

A. General information (section to be filled in once)
Name/Type of confined space: The space must satisfy the three following criteria in order to be considered an "enclosed area" (confined space) under the ROHS: ☐ It is not designed for human occupation, nor intended to be, but may occasionally be occupied for the performance of work; ☐ Access to which can only be had by a restricted entrance/exit; ☐ It can represent a risk for the health and safety of anyone who enters.
Reference No.:
Purpose:
Shape: Dimensions: Interior volume (useful for ventilation):
Location (address, building):
B. Layout of confined space (without work) (section to be filled in once)
1. Is the confined space stationary or mobile? ☐ Stationary ☐ Mobile
2. Is the confined space open (e.g., basin, pit, trench) or partially/totally closed?** ☐ Open ☐ Partially closed ☐ Totally closed – Walls are made of: ☐ Concrete ☐ Steel ☐ Stainless steel ☐ Other: – Accessibility of walls of confined space from outside: ☐ Accessible ☐ Not accessible – Thickness of walls:
3. How many entrances does confined space have? What are the dimensions of each entrance?** ☐ 1 ☐ 2 ☐ 3 ☐ >3 Shape: ☐ Round ☐ Rectangular; Dimensions: ☐ <610 mm (24'') in diameter or equivalent
4. Is access to the confined space vertical or horizontal?* ☐ Vertical ☐ Horizontal then vertical – Height: – Means of access: ☐ Fixed ladder ☐ Ladder brought by team ☐ Rungs – Condition of means of access: ☐ Good ☐ Poor ☐ Very poor ☐ Does not apply ☐ Horizontal – Means of access: – Condition of means of access: ☐ Good ☐ Poor ☐ Very poor ☐ Does not apply

5.	Does the design of the confined space involve one or more of the following hazardous situations? ☐ Inadequate natural or mechanical ventilation** ☐ Restricted interior volume, limiting possible movements in space** (e.g., low ceiling, narrow section) ☐ Moving around is difficult because of obstacles (on ground or at height), curved floor, compartments, different levels or a noticeable slope* ☐ Presence of traps because of converging walls or funnel shape** ☐ Presence of structural weaknesses such as cracks, collapse, corrosion, offset entrance** ☐ Presence of sharp, pointed structural features** ☐ Insufficient light** ☐ Extreme temperature/humidity (see Schedule V of the ROHS) ☐ High noise level (without work)** ☐ Other: ☐ None of the above
6.	Does the general use of the confined space involve one or more of the following hazardous situations?** ☐ Presence of toxic agents or asphyxiants ☐ Presence of flammable products or explosives, of combustible dust ☐ Presence of corrosive products, irritants, reagents or carcinogens ☐ Presence of decomposition products, sediments, residues, slow oxidation (e.g., rust) ☐ Presence of mould/fungus or various biological pathogens (e.g., dirty objects) ☐ Presence of animals, insects, allergens ☐ Unknown substances Specify the agents in question, their physical state and their density in the case of gases: ☐ Other: ☐ None of the above
7.	Is the confined space connected to pipes or drains that must be locked out or blocked off (risk of uncontrolled introduction or return of products, risk of drowning, equipment upstream/downstream)?** ☐ Yes ☐No If so, specify:
8.	Is any equipment permanently installed in the confined space (or does any run through it) that is energized and needs to be locked out?** ☐ Yes ☐ No If so, specify:
9.	Does the confined space contain any free-flowing materials (e.g., grain, sand) that expose workers to a risk of being engulfed?** ☐ Yes ☐ No If so, specify:
C.	**Environment** (section to be filled in once)
10.	Is the access to the confined space ... ?** (several possible answers) ☐ Isolated (e.g., far from another structure, few passers-by and/or hard to reach by vehicle) ☐ Technically difficult (e.g., at height, at end of narrow stairwell, unstable ground) ☐ In another confined space or in a hazardous restricted access room ☐ None of the above
11.	Is the work area around the entrance ... ? (several possible answers) ☐ Exposed to road traffic or to a roadway within a facility ☐ Exposed to other workers ☐ Exposed to the public ☐ Exposed to weather (e.g., bad weather, outdoor temperatures) ☐ In another work area (e.g., workstation with operating stationary or mobile machinery) ☐ Poorly laid out (e.g., very little room, slope, ragweed, mud) ☐ Other: ☐ None of the above

12.	Is there a possibility of work being done nearby that would affect the conditions in the confined space? ☐ Yes ☐No If so, specify:
13.	Are hazardous materials being stored in an adjacent tank/space? ☐ Yes ☐No If so, specify:
14.	Are the conditions in the confined space subject to change (e.g., gas migration through walls, introduction of hazardous substances or gases [exhaust gases])?** ☐ Yes ☐No If so, specify:
D.	**Work to be done / Entrants** (section to be filled in when appropriate for each job to be done) Work to be done: ☐ Cleaning ☐ Inspection ☐ Maintenance ☐Other: Description of work: For this work, is it really necessary for the worker to enter the confined space? ☐ Yes ☐ No
15.	How many entrants are required at the same time to perform the work? ☐ 1 ☐ 2 ☐ >2
16.	How many attendants outside are required for the work? ☐ 1 ☐ 2 ☐ >2
17.	Does the work (entry into space and job) require any particular experience/expertise? ☐ Yes ☐No If so, specify:
18.	Does the work (entry into space and job) require being in any particular physical shape or mental health? <u>Examples</u>: Entry into the confined space is long and demanding, workspace very restricted (claustrophobia), need to go up and down ladder repeatedly, etc. ☐ Yes ☐No If so, specify:
19.	How frequently must such work be done? ☐ Daily ☐ Weekly ☐ Several times per year ☐ Each year ☐ Less than once a year ☐ On an emergency, priority basis ☐ Unknown
20.	At what time of year usually? ☐Winter ☐Spring ☐Fall ☐Summer ☐Variable ☐All year
21.	How long does the work take and when is it done? ☐ Short length, <30 minutes ☐ Less than one shift ☐ Longer than one shift ☐ Day ☐Night
22.	Are there time constraints related to the work (e.g., very short time frame, other department waiting, essential service) that put pressure on the workers? ☐ Yes ☐No If so, specify:
23.	What type of progression is required to get from the entry of the confined space to the place where the job is to be done?* ☐ Vertical progression only ☐ Horizontal progression only ☐ Vertical and horizontal
24.	During the work, will the attendant be able to see, hear or otherwise communicate with the worker in case a rescue procedure needs to be initiated?* ☐ Yes ☐ No

25. Does the work to be performed involve any additional hazards? (several possible answers) ☐ High-pressure cleaning** ☐ Hot work (e.g., welding)** ☐ Working at heights** ☐ Using specific tools (e.g., mechanical, electric, hydraulic, compressed-air)** ☐ Temporary lighting in the confined space (fixed or portable utility light)** ☐ Use of a generator ☐ Use of chemicals (e.g., paint, resin, solvent, welding electrodes)** ☐ Release of particles, dust, aerosols** ☐ Work under load, load at height, falling tools** ☐ Handling of heavy objects ☐ Fall on same level, slip due to working conditions** ☐ Ergonomic constraints of wearing clothing or personal protective equipment (e.g., visibility, sweating) ☐ Other: ☐ No additional risk
26. During the work, will it be possible for the worker to have his/her harness fastened at all times to a lifeline solidly secured to an anchoring point outside the confined space?* ☐ Yes ☐ No

* Questions designed to determine whether a potential rescue could a priori be done without entering the confined space

** Questions designed to determine whether a rescue with entry could become more complex because of the working conditions

APPENDIX H – RISK MATRIX PROPOSED IN THE AUSTRALIAN STANDARD ON THE MANAGEMENT OF RISKS IN CONFINED SPACES (AS/NZ 2865:2001)

Table 28 - Risk Matrix proposed in the Australian Standard on the Management of Risks in Confined Spaces (AS/NZ 2865:2001)

	Consequences				
Likelihood	**1 Insignificant** N° injuries or illness	**2 Minor** First aid treatment, on-site release immediately contained	**3 Moderate** Medical treatment required, toxic release on-site contained with outside assistance	**4 Major** Extensive injuries, toxic release off-site release with no detrimental effects	**5 Catastrophic** Death, toxic release off-site with detrimental effects
A - Almost Certain: The event is expected to occur in most circumstances	S	S	H	H	H
B - Likely: The event will occur at some time	M	S	S	H	H
C - Moderate: The event should occur at some time	L	M	S	H	H
D - Unlikely: The event could occur at some time	L	L	M	S	H
E - Rare: The event may occur only in exceptional circumstances	L	L	M	S	S
WITH: L - LOW: MANAGE BY ROUTINE PROCEDURES; M - MODERATE: MANAGEMENT RESPONSIBILITY MUST BE SPECIFIED; S - SIGNIFICANT: SENIOR MANAGEMENT ATTENTION NEEDED; H - HIGH: DETAILED RESEARCH AND MANAGEMENT PLANNING REQUIRED AT SENIOR LEVELS.					