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CONCEPTION ET ÉVALUATION D'UN OUTIL POUR ANALYSER ET CATÉGORISER LES RISQUES MULTIFACTORIELS ENCOURUS PAR LES TRAVAILLEURS LORS DES INTERVENTIONS EN ESPACE CLOS AU QUÉBEC

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Cette thèse intitulée :

CONCEPTION ET ÉVALUATION D'UN OUTIL POUR ANALYSER ET CATÉGORISER LES RISQUES MULTIFACTORIELS ENCOURUS PAR LES TRAVAILLEURS LORS DES INTERVENTIONS EN ESPACE CLOS AU QUÉBEC

présentée par : BURLET-VIENNEY Damien

en vue de l'obtention du diplôme de : Philosophiae Doctor

a été dûment acceptée par le jury d'examen constitué de :

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DÉDICACE

À Geneviève, Édouard et Daphnée

À mes parents

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RÉSUMÉ

Au Québec, selon l'article 1 du Règlement sur la santé et la sécurité du travail, un espace clos est un espace qui possède les caractéristiques suivantes : (i) il n'est pas conçu pour être occupé par des personnes, ni destiné à l'être, mais qui à l'occasion peut être occupé pour l'exécution d'un travail, (ii) on ne peut y accéder ou on ne peut en ressortir que par une voie restreinte et (iii) il peut présenter des risques pour la santé, la sécurité ou l'intégrité physique pour quiconque y pénètre. Ces critères sont repris sous différentes formes dans de nombreux pays (ex. États-Unis, France, Australie, Royaume-Uni). Le travail en espace clos est une problématique transversale qui concerne à la fois les secteurs municipal, manufacturier, chimique, militaire, agricole et du transport. Les espaces clos parmi les plus courants en industrie sont les réservoirs, les silos, les cuves, les puits d'accès, les fosses, les égouts, les tuyaux et les citernes. Les entrées en espace clos sont généralement effectuées pour des raisons de maintenance : réparation, inspection, nettoyage, déblocage. Les principaux phénomènes dangereux pour la santé et la sécurité des travailleurs sont atmosphériques (ex. intoxication, asphyxie, explosion), biologiques, physiques (ex. mécanique, électrique, ensevelissement, chute) et ergonomiques. Ces risques sont potentiellement élevés à cause du confinement, de la ventilation naturelle déficiente et des difficultés d'accès, de sauvetage et de communication.

Les interventions en espace clos sont réglementées au Québec et dans la plupart des pays industrialisés que ce soit au niveau de l'habilitation du personnel, de l'identification des dangers, de la maîtrise de l'atmosphère, de la surveillance des entrées ou encore des procédures de sauvetage. Toutefois, malgré tous les efforts réglementaires et normatifs entrepris, les accidents en espace clos restent nombreux. Par exemple, au Québec, entre 1998 et 2011, 40 décès lors de 32 événements ont été dénombrés dans des espaces clos, ce qui représente 4% des rapports d'enquête de la Commission de la santé et de la sécurité du travail suite à un accident du travail grave ou mortel. De même aux États-Unis, entre 1992 et 2005, 38 décès par intoxication ou asphyxie ont eu dans des espaces clos en moyenne chaque année.

Ce travail de recherche vise donc à réduire le nombre d'accidents en espace clos en améliorant la prévention des risques pour la santé et la sécurité des travailleurs. Les objectifs spécifiques sont (i) de déterminer dans la littérature et en entreprise les lacunes concernant la gestion des risques lors des interventions en espace clos, puis (ii) de développer un outil d’appréciation du risque qui répond aux besoins identifiés préalablement.

Pour atteindre ces objectifs, la méthode de recherche inclut une revue critique de la littérature sur la gestion des risques en espace clos, une analyse des enquêtes d’accidents mortels en espace clos au Québec puis l’étude de 15 organisations qui gèrent des entrées en espace clos. Ces travaux ont mis en évidence le besoin pour une approche globale et multidisciplinaire lors de l’identification des phénomènes dangereux afin d’obtenir une meilleure représentation de la réalité lors des interventions en espace clos. Également, il a été identifié un manque de formalisme dans la littérature pour les étapes d’estimation et d’évaluation du risque ainsi que pour les notions d’espace clos similaire et de catégorisation des espaces clos. Enfin, des lacunes ont été observées en entreprise concernant (i) l’estimation des risques, (ii) la gestion des sous-traitants, (iii) les audits dédiés à l’utilisation des moyens de réduction du risque, et (iv) l’intégration de la conception sécuritaire.

Basé sur ce bilan et inspiré par les normes en gestion du risque utilisées en sécurité des machines (c.-à-d. ISO 12100:2010 et ANSI/ASSE Z690.3-2011), un outil d’appréciation du risque en 5 étapes a été développé en collaboration avec des entreprises au Québec. L’étape 1 est une liste de 26 questions fermées pour caractériser l’espace clos, son environnement et les conditions d’intervention. L’étape 2 permet de décrire le processus accidentel lié aux phénomènes dangereux retenus par l’utilisateur. L’étape 3 guide l’estimation des risques à l’aide d’une matrice de risque et de critères adaptés au contexte des espaces clos. L’étape 4 propose une catégorisation graphique par familles et niveaux de risque. Enfin, l’étape 5 est une boucle de rétroaction pour estimer les risques résiduels une fois les mesures de réduction du risque choisies. L’utilisation de cet outil permet en outre de déterminer à l’aide de critères explicites si deux espaces clos sont réellement identiques afin de simplifier, le cas échéant, le travail de réduction du risque. L’outil développé permet également de déterminer à l’aide de critères prédéterminés si le sauvetage sans entrée est possible et si les risques résiduels sont acceptables. L’utilité et la pertinence de l’outil ont été testées auprès de 22 experts en espace clos. L’outil développé a également été comparé à d’autres types d’outils préconisés dans la littérature ou en entreprise pour l’analyse du risque dédiée aux interventions en espace clos. L’outil développé se distingue notamment par (i) l’exhaustivité et la multidisciplinarité de l’identification des phénomènes dangereux, (ii) les critères de choix détaillés pour l’estimation du risque, (iii) l’exploitation des résultats de l’analyse des risques et (iv) l'impact des mesures de réduction du risque dédiées aux espaces clos sur les paramètres du risque. Cette recherche permet de soutenir à la fois les concepteurs, les préventionnistes et les sauveteurs dans leurs démarches respectives pour améliorer la santé et la sécurité des travailleurs en espace clos.

ABSTRACT

In section 1 of the provincial occupational health and safety regulation of Quebec, a confined space refers to a space which has the following inherent conditions: (i) is not designed for human occupation, nor intended to be, but may occasionally be occupied when carrying out work, (ii) access to which can only be made by a restricted entrance/exit and (iii) can represent a risk for the health and safety of anyone who enters. These criteria are reiterated in various forms in most countries (e.g. United States, France, Australia and United Kingdom). Work-related interventions in confined spaces are a cross-field issue that concern for example the municipal, manufacturing, chemical, military, agricultural and transportation sectors. Confined spaces among the most common in industry are reservoirs, silos, vats, access shafts, ditches, sewers, pipes and truck or freight car tanks. Confined spaces are primarily entered for the purpose of maintenance: repair, inspection, cleaning, unclogging. The main occupational hazards are atmospheric (i.e. poisoning, asphyxiation, explosion), biological, physical (e.g. mechanical, electrical, engulfment, falls) and ergonomics. These risks are potentially high because of the confinement, inadequate natural ventilation, and access, rescue and communication problems.

Confined space entries are regulated in Quebec and in most industrialized countries whether on employee qualifications, risk identification, atmospheric monitoring, mandatory supervision and rescue procedures. However, despite all the regulatory and standard-setting efforts that have been made many accidents related to work in confined spaces still occur. For example, 40 fatalities in 32 events associated with confined spaces were counted in the province of Quebec between 1998 and 2011, representing 4% of investigation reports published by the provincial workers' compensation board following a serious or fatal accident at work. In the same way, between 1992 and 2005, there was an average of close to 38 deaths per year by poisoning or asphyxiation in confined spaces in the United States.

This research aims to reduce the number of accidents in confined spaces by improving occupational risk prevention. The specific objectives are (i) to determine deficiencies in literature and organisations regarding risk management for entries in confined spaces, and (ii) to develop a risk assessment tool that addresses the deficiencies observed. To achieve these objectives, the research method includes (i) a literature review on risk assessment specific to confined spaces, (ii) analysis of fatal work accident reports occurring in confined spaces in Quebec and (iii) the study of 15 organizations that manage entries in confined spaces. This work has highlighted the need for a comprehensive and multidisciplinary hazard identification approach to take into account the real complexity of confined spaces. Also, it was identified a lack of guidelines in the literature concerning risk estimation and evaluation steps as well as for categorization and similar confined spaces. Finally, deficiencies were observed in organisations regarding (i) risk estimation, (ii) management of subcontractors, (iii) auditing how risk reduction means are used, and (iv) integration of prevention through design.

Based on this appraisal and inspired by the approach used in the standards on machine safety (i.e. ISO 12100:2010 and ANSI/ASSE Z690.3-2011), a 5 step risk assessment tool has been developed in collaboration with companies in Quebec. Step 1 is a list of 26 closed-ended questions to describe the configuration of the selected confined space, its environment and the work situation. Step 2 describes the accidental process associated with the hazards. Step 3 estimates risks using adapted criteria and matrix. Step 4 uses a graph for categorizing the intervention by class and level of risk. Step 5 is a feedback loop for estimating residual risks after risk reduction measures have been taken. By using objective criteria, this tool allows determining if two situations are indeed identical in terms of risks in order to simplify risk reduction when appropriate. The tool also determines using predetermined criteria if external rescue is feasible and residual risks acceptable. Usefulness and relevance of our tool was tested by 22 experts managing entries in confined spaces. The tool developed was also compared to other types of risk analysis tools recommended in the literature or in organisations for confined space entries. Our risk assessment tool has the following distinguishing features: (i) a multidisciplinary and comprehensive hazard identification approach, (ii) detailed criteria for risk estimation, (iii) utilization and communication of the risk analysis results and (iv) impact of the different strategies used to reduce risks for interventions in confined spaces on the component of the risk. This research provides support to designers, OHS personnel and rescuers in their effort to improve safety during confined space entries.

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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
CSA	Canadian Standard Association
CSST	Commission de la Santé et de la Sécurité du Travail
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
IRSST	Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail
ISO	International Organization for Standardization
LEL	Low Explosive Limit
MIG	Metal Inert Gas
NEMA	National Electrical Manufacturers Association
NIOSH	National Institute for Occupational Safety and Health
OHS	Occupationnal Health and Safety

OSHA	Occupational Safety and Health Administration
PPE	Personal Protective Equipment
PRCS	Permit-Required Confined Space
ROHS	Regulation respecting Occupational Health and Safety
RSST	Règlement sur la Santé et la Sécurité du Travail
SST	Santé et Sécurité du Travail

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CHAPITRE 1 INTRODUCTION

1.1 Éléments de la problématique

1.1.1 Travail en espace clos

Les espaces clos sont légalement définis au Québec dans le Règlement sur la santé et la sécurité du travail (RSST) à l'article 1 :

> Espace clos : Tout espace totalement ou partiellement fermé, notamment un réservoir, un silo, une cuve, une trémie, une chambre, une voûte, une fosse, y compris une fosse ou une préfosse à lisier, un égout, un tuyau, une cheminée, un puits d'accès, une citerne de wagon ou de camion, qui possède les caractéristiques inhérentes suivantes :
>
> 1° il n'est pas conçu pour être occupé par des personnes, ni destiné à l'être, mais qui à l'occasion peut être occupé pour l'exécution d'un travail;
> 2° on ne peut y accéder ou on ne peut en ressortir que par une voie restreinte;
> 3° il peut présenter des risques pour la santé, la sécurité ou l'intégrité physique pour quiconque y pénètre, en raison de l'un ou l'autre des facteurs suivants :
>   *a)* l'emplacement, la conception ou la construction de l'espace, exception faite de la voie prévue au paragraphe 2°;
>   *b)* l'atmosphère ou l'insuffisance de ventilation naturelle ou mécanique qui y règne;
>   *c)* les matières ou les substances qu'il contient;
>   *d)* les autres dangers qui y sont afférents. » (Gouvernement du Québec, 2014)

Les critères énoncés dans le RSST sont repris sous différentes formes dans la plupart des pays comme au gouvernement fédéral des États-Unis (U.S. Department of Labor, OSHA, 1993), au Canada (Government of Canada, 2014), au Royaume-Uni (Government of United Kingdom, 1997), en France (Guilleux & Werlé, 2014) ou encore en Australie (Standards Australia, 2001). Les espaces clos parmi les plus courants en industrie sont les réservoirs, les silos, les cuves, les puits d'accès (Figure 1-1), les fosses, les égouts, les tuyaux, et les citernes. Le travail en espace clos est une problématique de santé de sécurité transversale qui concerne à la fois le secteur municipal, manufacturier, chimique, militaire, agricole ou du transport (Rekus, 1994).

Figure 1-1. Puits d'accès

Aux États-Unis, une étude menée par le National Institute for Occupational Safety and Health (NIOSH) a démontré qu'entre 1984 et 1988 : 40,9 % des accidents en espace clos sont associés au domaine municipal, 20,4 % à l'industrie de la transformation, 15,9 % à la construction, 11,4 % au stockage de produits chimiques, 6,8 % au transport, et enfin 4,6 % à l'agriculture. Les entrées en espace clos sont principalement effectuées pour des raisons de maintenance : réparation, inspection, nettoyage, déblocage, etc. (Rekus, 1994). Les dangers en espace clos pour les travailleurs sont de nature multiple. Les principaux phénomènes dangereux sont atmosphériques (c.-à-d. intoxication, asphyxie, explosion), biologiques et physiques (ex. mécanique, électrique, ensevelissement, chute, éclairage, circulation extérieure) (NIOSH, 1994). Les risques encourus par les travailleurs qui œuvrent en espace clos sont potentiellement élevés à cause du confinement, de la ventilation naturelle déficiente et des difficultés d'accès, de sauvetage et de communication (CSA, 2010).

Au Québec, les employeurs ont l'obligation légale pour le travail en espace clos de respecter la section XXVI (articles 297 à 312) du RSST. Les thèmes mentionnés sont :

- l'habilitation, la qualification et l'information des travailleurs impliqués;
- la cueillette de renseignements par écrit préalable à l'exécution d'un travail sur les dangers et les mesures de prévention;
- l'utilisation de la ventilation pour conserver des conditions atmosphériques acceptables;
- la gestion des poussières du travail à chaud;
- les mesures et les relevés des gaz;
- la surveillance obligatoire;

- les procédures de sauvetage;
- l'interdiction d'entrée dans un espace clos si un écoulement est en cours;
- le port et l'attache du harnais obligatoire s'il y a un écoulement libre potentiel.

En complément, la norme canadienne CSA Z1006-10 et la norme américaine ANSI/ASSE: Z117.1-2009 relatives aux espaces clos donnent des balises sur le programme de gestion à mettre en place, les rôles et responsabilités des intervenants, la planification associée (ex. formation, plan d'urgence) et la mise en application du programme (ex. permis de travail) (CSA, 2010; ANSI/ASSE, 2009).

1.1.2 Statistiques d'accidents mortels en espace clos

Les accidents mortels liés au travail en espace clos sont fréquents comme en témoignent les statistiques disponibles dans la littérature (Tableau 1.1).

Tableau 1.1 : Statistiques sur les accidents mortels en espace clos en Amérique du Nord

Pays	Secteur	Période	Statistiques
États-Unis	Non spécifique	1992-2005	En moyenne par année, près de 38 morts reliés à une intoxication ou une asphyxie en espace clos ont eu lieu sur cette période aux États-Unis. 20 % de ces accidents ont impliqué des décès multiples (Wilson et coll., 2012).
		1993-2010	En moyenne par année, 2,5 décès reliés à une atmosphère inflammable en espace clos ont eu lieu sur cette période aux États-Unis. Une majorité de ces accidents s'est déroulée depuis 2003 (U.S. Chemical safety and hazard investigation board, 2010).
		1993-2004	Selon les bases de données consultées, 65 % des morts en espace clos aux États-Unis impliquent des risques atmosphériques, 10 % des ensevelissements (ANSI/ASSE, 2009).
		1984-1994	86,3 % des intoxications au sulfure d'hydrogène sur cette période aux États-Unis ont eu lieu dans un espace clos pour un total de 80 décès (Fuller et coll., 2000).
	Agricole	1964-2010	1255 décès ont été recensés sur cette période en espace clos dans le secteur agricole aux États-Unis (moyenne de 26,7 décès par an): - 71 % liés à l'entreposage grains (ex. ensevelissement) - 10,5 % dans les fosses à lisier (ex. asphyxie, intoxication), dont 77 décès de 56 accidents entre 1975-2004 (Beaver, 2007) - 9,2 % dans le transport du grain (ex. ensevelissement) - 5,7 % dans l'entreposage de fourrage (ex. asphyxie). Les moins de seize ans comptent pour 20 % des cas (Riedel & Field, 2011).
	Construction	1990-1999	Dans le secteur de la construction aux États-Unis, 62 % des intoxications au monoxyde de carbone, au sulfure d'hydrogène et à l'azote sur cette période ont eu lieu dans un espace clos (Dorevitch et coll., 2002).
Canada	Agricole	1984-1994	37 décès ont été recensés sur cette période en espace clos dans le secteur agricole au Canada (FARSHA, 2012).

En 1993, the Occupational Safety and Health Administration (OSHA) a estimé lors de la préparation de son règlement pour le travail en espace clos qu'il y avait annuellement aux États-Unis 4,8 millions d'entrées en espaces clos impliquant 1,6 million de travailleurs et 63 décès (U.S. Department of Labor, OSHA, 1993; ANSI/ASSE, 2009). Plus récemment, selon Wilson *et coll.* (2012), il y a eu en moyenne par année entre 1992 et 2005 près de 38 décès par intoxication ou asphyxie dans des espaces clos aux États-Unis. 20% de ces événements ont engendré plusieurs décès. Le point commun entre la plupart des accidents mortels recensés est que l'activité de travail était improvisée et qu'aucune procédure de travail n'avait été appliquée. Les moyens de réduction du risque étaient par le même fait inadaptés, voire inexistants. Ainsi, les intervenants n'ont pas toujours conscience de travailler dans une zone à risque, et ils interviennent sans réduire les risques de manière appropriée (NIOSH, 1994). D'ailleurs, selon le NIOSH (1994), plus de 30% des décès seraient dus à des sauvetages improvisés.

1.1.3 Appréciation et réduction du risque

Dans le domaine de la santé et de la sécurité du travail, un phénomène dangereux (ou danger) est défini comme une source potentielle de dommage. Cette notion ne doit pas être confondue avec un risque qui est défini ici comme la combinaison de la probabilité d'un dommage et de la gravité de ce dommage (ISO, 2010).

En pratique, il est admis qu'il faut effectuer un travail d'appréciation du risque afin de prendre des mesures d'élimination ou de réduction du risque adaptées (ISO, 2009; ISO, 2010; ANSI/ASSE, 2011b). Selon les normes en gestion du risque utilisées en SST, l'appréciation du risque consiste à (i) identifier les phénomènes dangereux, (ii) estimer les risques (c.-à-d. les quantifier) et (iii) les évaluer (ISO, 2009; ISO, 2010) (Figure 1-2). L'évaluation du risque est un jugement destiné à établir si un risque est acceptable ou s'il doit être réduit, et ce jugement se base sur une analyse complète de ce risque.

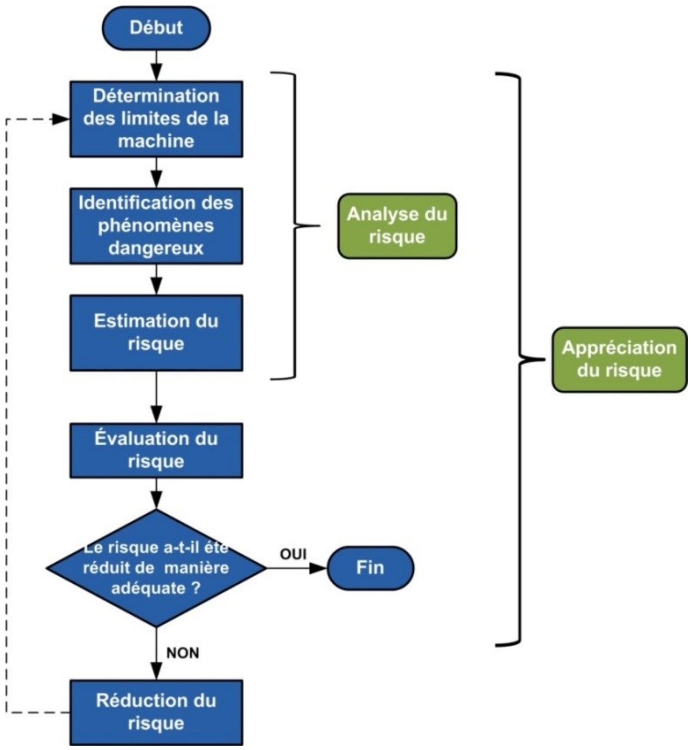

Figure 1-2. Processus d'appréciation et de réduction du risque selon la norme ISO 12100 (2010)

L'étape d'estimation du risque revient à prendre en considération la gravité possible d'un dommage et la probabilité d'occurrence de ce dommage pour déterminer l'indice de risque associé. De nombreuses techniques d'estimation du risque quantitatives, semi-quantitatives et qualitatives existent (IEC/ISO, 2009; Chinniah *et coll.*, 2011). En SST, les informations disponibles sont souvent de nature qualitative (ex. douleur ressentie, temps d'exposition, probabilité d'occurrence d'un événement dangereux, posture de travail, etc.). Cela a mené à l'utilisation d'outils tels que des échelles ordinales (ex. mineur/sérieux/majeur) ou des matrices pour estimer les risques (Tableau 1.2). Il convient de mentionner qu'un outil d'estimation du risque ne donne pas une valeur absolue d'un risque. Quelle que soit la technique, il y aura toujours des incertitudes liées par exemple (i) aux paramètres utilisés, (ii) à la modélisation choisie, et (iii) à l'exhaustivité des facteurs pris en compte (Abrahamsson, 2002). Duijm (2015) résume d'ailleurs les principales critiques associées aux matrices de risque (ex. classification subjective, résolution limitée). Chinniah *et coll.* (2011) énumèrent également une liste de recommandations pour la construction de tels outils (ex. nombre de niveaux par paramètres, définitions des niveaux des paramètres, influence relative de chaque paramètre, distribution uniforme des niveaux).

Tableau 1.2 : Exemple de matrice à deux paramètres et six indices de risque (The MMMPIC, 2002)

Probabilité que l'événement dangereux cause une blessure	**Gravité possible de la blessure**		
	Mineure	Majeure	Catastrophique
Très improbable	6	5	4
Improbable	5	4	3
Probable	4	3	2
Très probable	3	2	1

Malgré les limitations, il convient qu'apprécier les risques selon une démarche structurée permet (i) d'être proactif dans l'identification et le contrôle de pertes potentielles (Eaton & Little, 2011), (ii) d'apporter des informations pour les prises de décision et d'améliorer la communication sur les risques (IEC/ISO, 2009), (iii) d'aller dans le sens de la conception sécuritaire (Main, 2004), ou encore (iv) de réduire les risques à un niveau acceptable (Manuele, 2008).

Suite à l'évaluation des risques, il faut réduire les risques qui n'ont pas été jugés acceptables selon les critères fixés par l'organisation. Les principales mesures de contrôle par ordre d'efficacité sont : (i) éliminer les dangers par la conception, (ii) réduire la fréquence d'exposition aux phénomènes dangereux ou les dommages potentiels en utilisant des méthodes moins dangereuses, (iii) intégrer des dispositifs de contrôle d'ingénierie (protecteurs, alarmes, etc.), (iv) appliquer des contrôles administratifs (ex. procédures, formation), et (v) fournir des équipements de protection individuelle (ISO, 2009; ANSI/ASSE, 2011a). Ainsi, les conditions d'utilisation et les travaux effectués dans les espaces clos devraient être envisagés dès la conception afin de supprimer ou de limiter les risques (ANSI/ASSE, 2011a).

1.2 Objectifs et hypothèses de recherche

Malgré les règlements et les normes mis en place pour encadrer les interventions en espace clos et gérer les risques pour la santé et la sécurité des travailleurs, de nombreux accidents et décès ont encore lieu au Québec comme dans le reste du monde. Ainsi, les questions à l'origine de ce travail de thèse sont : Pourquoi y a-t-il encore autant d'accidents et de décès en espace clos?

Quels sont les lacunes et les facteurs qui entrent en jeu? Comment améliorer la prévention du travail en espace clos?

L'objectif général de cette thèse est de donc réduire le nombre d'accidents en espace clos en améliorant la prévention des risques pour la santé et la sécurité des travailleurs. Les résultats de cette thèse doivent (i) générer des connaissances complémentaires aux exigences mentionnées dans les règlements, normes et guides sur les espaces clos, et (ii) soutenir les concepteurs, les préventionnistes et les sauveteurs dans leurs démarches respectives pour améliorer la santé et la sécurité des travailleurs en espace clos.

Le premier objectif spécifique de cette thèse est de déterminer dans la littérature et en entreprise les lacunes concernant la gestion des risques lors des interventions en espace clos. Les hypothèses de recherche liées sont :

Hypothèse de recherche 1 : Les accidents en espace clos sont causés par des risques multifactoriels et interdépendants, pas seulement atmosphériques.

Hypothèse de recherche 2 : Les outils d'aide et d'appréciation du risque présentés dans la littérature pour les interventions en espace clos possèdent des lacunes.

Hypothèse de recherche 3 : Les pratiques de gestion des interventions en espace clos par les entreprises sont insuffisantes notamment concernant la présence de procédure de travail, la préparation des permis d'entrée, et les mesures de réduction du risque et de sauvetage.

Hypothèse de recherche 4 : Les étapes préconisées dans les normes pour l'appréciation du risque en SST (ex. ISO (2010) et ANSI/ASSE (2011b)) ne sont pas toutes utilisées en entreprise. Ces étapes sont l'identification, l'estimation et l'évaluation du risque.

En s'appuyant sur les résultats obtenus lors de la validation de ces quatre hypothèses de recherche, le deuxième objectif spécifique de cette thèse est de développer un outil d'appréciation du risque adapté aux particularités du travail en espace clos. Cet outil doit répondre aux besoins identifiés dans la littérature et en entreprises. L'hypothèse de recherche liée est :

Hypothèse de recherche 5 : Les démarches normatives sur l'appréciation du risque en sécurité des machines (ex. ISO 12100:2010) peuvent être adaptées afin d'analyser et d'évaluer les risques en lien avec les interventions en espace clos de manière plus systématique.

1.3 Plan de la thèse

Ce travail de thèse est organisé en sept chapitres. Le chapitre 1 a permis de présenter la problématique liée à la gestion des risques lors du travail en espace clos et de définir les objectifs et les hypothèses de la recherche. Le chapitre 2 aborde la méthodologie utilisée pour répondre aux objectifs de recherche. Les annexes A à D fournissent des éléments méthodologiques complémentaires. Le chapitre 3 est une revue critique de la littérature sur la gestion des risques lors des interventions en espace clos. Ce chapitre reprend l'article *The Need for a Comprehensive Approach to Managing Confined Space Entry: Summary of the Literature and Recommendations for Next Steps*. Le chapitre 4 présente l'article *Occupational Safety during Interventions in Confined Spaces.* Il s'agit d'un bilan des pratiques de 15 organisations sur la gestion des risques lors des interventions en espace clos. Les chapitres 5 et 6 présentent les articles *Design and application of a 5 step risk assessment tool for confined space entries* et *Risk analysis for confined space entries: critical analysis of 4 tools applied to 3 risk scenarios.* L'outil développé pour améliorer l'appréciation du risque lors des interventions en espace clos y est détaillé puis comparé avec des outils déjà existants. Enfin, le chapitre 7 inclut les contributions originales issues des travaux de recherche, ainsi qu'une analyse des limites et des perspectives de recherche en lien avec la problématique étudiée.

CHAPITRE 2 DÉMARCHE DE L'ENSEMBLE DU TRAVAIL DE RECHERCHE

Afin de déterminer les lacunes concernant la gestion des risques lors des interventions en espace clos, la méthode de recherche comprend (i) une revue critique des documents de référence sur la gestion des risques en espace clos incluant les outils d'appréciation du risque disponibles, (ii) une analyse des enquêtes d'accidents mortels en espace clos au Québec et (iii) l'étude des pratiques de 15 organisations au Québec qui gèrent des entrées en espace clos. Une approche multidisciplinaire a été adoptée afin de prendre en considération les différents phénomènes dangereux présents dans les espaces clos.

À partir des besoins identifiés et en s'inspirant des normes en gestion des risques utilisées en sécurité des machines, un outil d'appréciation des risques dédié aux interventions en espace clos a par la suite été développé, comparé aux outils existants et testé auprès d'experts.

2.1 Revue de la littérature

Étant donné les conséquences pour la santé et la sécurité des travailleurs lors des interventions en espace clos et que le processus d'appréciation du risque est une étape primordiale afin de prendre des mesures d'élimination ou de réduction du risque adaptées, une revue de la littérature sur l'appréciation du risque spécifique aux espaces clos a été menée. Les bases de données qui ont été ciblées pour effectuer cette revue de la littérature sur l'appréciation du risque en espace clos sont COMPENDEX, PASCAL, PUBMED ainsi que les bases documentaires d'institutions comme le NIOSH, la Commission de la Santé et de la Sécurité du Travail au Québec (CSST), le Health and Safety Executive en Grande-Bretagne (HSE), l'Institut National de Recherche et de Sécurité en France (INRS). Une stratégie de recherche par mots-clés en anglais et en français a été élaborée. Les deux concepts qui ont été utilisés sont (i) *confined space* qui un terme normalisé dans les deux langues (espace clos ou espace confiné en français), et (ii) danger/risque qui a permis de centrer la recherche sur les risques et les dangers en espace clos avec les mots-clés suivants : risque, danger, toxique, asphyxie, explosion, électricité, chute, inflammable, incendie, biologique, ensevelissement et mécanique. Cette revue de la littérature a permis d'identifier (i) les recommandations réglementaires et normatives, (ii) les spécificités, et (iii) les outils disponibles dans la littérature concernant la gestion des risques pour les interventions en espace clos. Les résultats obtenus sont présentés dans l'article 1 *The need for a comprehensive approach to managing confined space entry: summary of the literature and recommendations for next steps* au chapitre 3. La grille de lecture est disponible à l'annexe A.

Au total, 77 documents revus par des pairs sur la gestion des risques en espace clos ont été étudiés dont 15 articles scientifiques, 4 normes, 7 règlements, 9 rapports scientifiques 5 livres, et 37 guides techniques. Par ailleurs, des recherches complémentaires ont été menées sur les outils d'estimation du risque couramment utilisés dans d'autres domaines comme celui de la sécurité des machines afin d'alimenter le développement de l'outil d'appréciation du risque (ISO, 2010; ISO, 2009; Duijm, 2015).

2.2 Analyse des accidents du travail

Afin de compléter les connaissances issues de la littérature, les enquêtes d'accidents du travail mortels ayant eu lieu en espace clos au Québec entre 1998 et 2011 ont été étudiées à partir de la base de données de la CSST. La CSST, qui assure 85 % des travailleurs actifs au Québec, enquête tous les accidents du travail mortels au Québec sous sa compétence à l'exclusion des accidents de la route et des agressions (CSST, 2015). Les résultats sont présentés dans l'article 2 *Occupational safety during interventions in confined spaces* au chapitre 4.

L'originalité de cette étude a consisté dans le fait que tous les rapports d'enquête pour des accidents graves et mortels (819) ayant eu lieu sur la période ciblée ont été consultés. Il n'y a pas eu d'extraction par mots-clés qui exclut traditionnellement certains accidents en espace clos non reliés aux phénomènes dangereux atmosphériques. Les rapports liés aux interventions en espace clos ont été sélectionnés en se basant sur la définition d'un espace clos disponible dans le RSST.

Au total, 32 rapports d'enquête ont été retenus sur la période ciblée, soit environ 4 % des dossiers consultés. Ces événements ont causé le décès de 40 personnes soit une moyenne de près de trois décès par année. La grille de lecture de ces accidents est disponible à l'annexe B. La période de l'année, le genre d'accident et les problèmes de gestion et de conception sont les facteurs de risque qui ont été retenus.

2.3 Gestion par les entreprises des risques en espace clos

Quinze organismes ayant implanté un programme de gestion du travail en espace clos depuis plus d'un an ont par la suite été visités. Les résultats sont présentés dans l'article 2 *Occupational safety during interventions in confined spaces* au chapitre 4.

Les visites ont été étalées sur plusieurs saisons afin de couvrir différentes conditions météorologiques. Le nombre de quinze visites a été un compromis entre les contraintes de recrutement d'organismes admissibles au Québec et l'exploration de diverses situations de travail. Les quinze organismes ont été choisis pour leur profil varié : secteur d'activité; localisation; type d'espace clos; taille en nombre d'employés et en nombre d'espaces clos (Table 4.1).

Les visites sur site, d'une durée de trois à cinq heures, ont eu lieu en présence du conseiller en SST et d'employés clés dans la gestion des espaces clos (ex. directeur, superviseur, opérateur). Ces visites se sont déroulées en deux temps. Un entretien semi-dirigé sur le processus de gestion du risque mis en place précédait l'observation d'une équipe d'intervention en espace clos afin d'analyser les conditions réelles de travail. Les observations ont permis de confronter les réponses théoriques des entrevues à la réalité d'une intervention en espace clos. Les outils de collecte de données avec les points abordés lors des visites sont disponibles à l'annexe C. La confidentialité des données recueillies a été garantie à l'aide d'un formulaire de consentement dûment signé par les parties impliquées.

2.4 Conception et application d'un outil d'appréciation du risque pour les interventions en espace clos

En considérant les lacunes identifiées dans la littérature et les besoins en entreprises, un outil d'appréciation du risque adapté aux interventions en espace clos a été développé. Son développement et son application sont présentés à l'article 3 *Design and application of a 5 step risk assessment tool for confined space entries* au chapitre 5.

L'outil proposé est inspiré des normes en sécurité des machines pour l'aspect multidisciplinaire (ISO, 2010). L'outil a été testé auprès de 22 experts incluant dix organisations qui gèrent formellement leurs entrées en espace clos (Table 5.1). Les tests consistaient à faire appliquer l’outil sur une intervention existante dans l’organisation. Afin de faciliter les échanges, l’outil a été programmé à l’aide du logiciel Excel (2010, Microsoft, WA). Un questionnaire disponible à l’annexe D a été utilisé afin de recueillir les commentaires puis améliorer l’outil. La confidentialité des données recueillies a été garantie à l’aide d’un formulaire de consentement dûment signé par les parties impliquées.

2.5 Comparaison de l’outil d’appréciation du risque développé

La pertinence de l’outil développé a été testée à l’article 3. La plus-value de l’outil par rapport aux outils d’analyse du risque disponibles dans la littérature et en entreprise a été étudiée à l’article 4 *Risk analysis for confined space entries: critical analysis of 4 tools applied to 3 risk scenarios* au chapitre 6.

Lors de la revue de la littérature sur la gestion des risques pour les interventions en espace clos, peu d’outils d’analyse du risque ont été répertoriés. Ces outils ont été classés en trois groupes selon leur structure: check-list, échelle de risque et calcul du risque (matrice de risque). L’outil le plus complet pour chacune de ces trois structures ainsi que l’outil développé lors de cette thèse ont été testés sur 3 scénarios à risque. La structure des outils, leur utilisation et les résultats obtenus ont été étudiés.

CHAPITRE 3 ARTICLE 1: THE NEED FOR A COMPREHENSIVE APPROACH TO MANAGING CONFINED SPACE ENTRY: SUMMARY OF THE LITERATURE AND RECOMMENDATIONS FOR NEXT STEPS

Cet article a été publié dans le *Journal of occupational and environmental hygiene* 11(7), 485-498, 2014. DOI:10.1080/15459624.2013.877589. Pour plus de clarté, les références dans certains tableaux ont été numérotées. La correspondance est disponible à la suite de l'article.

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Abstract : Despite all the regulatory and standard-setting efforts that have been made in North America, judging from the most recent statistics, many fatal incidents related to work in confined spaces still occur. In Canada, fatal incidents in the province of Quebec reveal failures in and absence of the identification and preparation of work situations in confined spaces and in risk management. In this study, we performed a literature review consisting of 77 documents on existing hazards and risk assessment for confined spaces. Moreover, we formulate proposals regarding the design of specific and improved tools for assessing such risks. We found that atmospheric hazards monopolized attention in the literature on confined spaces, while risk estimation specific to confined space interventions received little practical coverage overall, apart from atmospheric hazards. The parameters used to establish classes or groupings of confined spaces in existing tools were imprecise. The development of a risk analysis process that is (i) more systematic and based on the concepts recognized in risk management standards, (ii) multidisciplinary and (iii) adapted to the specific characteristics of confined spaces is therefore needed. Such a process will better support managers and OHS personnel in their efforts to prioritize and reduce risks. Suggestions on such a risk analysis tool and categorization of interventions in confined spaces are proposed in this paper. Lastly, risk analysis tools adapted to confined space interventions are needed to ensure the inherently safe design of these spaces.

Keywords: Confined space; Risk assessment; Accident prevention; Fatal incident

3.1 Introduction

3.1.1 Occupational health and safety problem

A poignant example of the fact that confined space work is a longstanding problem is that children as young as seven used to work as London chimneysweeps during the 1800s (Kletz, 2007). Yet the emergence in recent years of new problems, such as (i) the transportation of wood pellets in ship holds (Svedberg *et al.*, 2008), (ii) the inadequate real availability of emergency intervention services for rescue operations (Wilson *et al.*, 2012), or (iii) asbestos abatement work (Asbestos Removal Contractors Association, 2007), clearly indicates that confined space work is still a subject that warrants our full attention.

A confined space is defined in the United States Occupational Safety and Health Administration (OSHA) regulation as "a space that: (1) is large enough and so configured that an employee can bodily enter and perform work; (2) has limited means of entry or egress; and (3) is not designed for continuous employee occupancy" (U.S Department of Labor, OSHA, 1993). Confined spaces are primarily entered for purposes such as maintenance, repair, inspection, cleaning, and unclogging.

Confined space work is widely regulated and standardized in North America (ANSI/ASSE, 2009; Government of Canada, 2014; Ontario Ministry of Labour, 2014; CSA, 2010; Quebec Government, 2014). Unfortunately, despite the substantial efforts made, the most recent statistics taken from various scientific or regulatory publications (Table 3.1) indicate that too many fatal incidents related to work in confined spaces still occur. Major risks involved when working in confined spaces are summarized by the definition of a Permit-Required Confined Space (PRCS) that is a confined space that has one or more of the following characteristics: (1) contains or has a potential to contain a hazardous atmosphere; (2) contains a material that has the potential for engulfing an entrant; (3) has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor which slopes downward and tapers to a smaller cross-section; or (4) contains any other recognized serious safety or health hazard" (U.S Department of Labor, OSHA, 1993).

Table 3.1 : Statistics on fatal incidents in confined spaces

Country/ Province	**Sector**	**Period**	**Statistics**
US	Non-specific	1980-1989	On average per year, 67 deaths related to poisoning, drowning or asphyxiation in a confined space occurred during this time period in the United States. 12% of these fatal incidents involved multiple deaths (NIOSH, 1994).
		1992-2005	On average per year, nearly 38 deaths related to poisoning or asphyxiation in a confined space occurred during this time period in the United States. 20% of these fatal incidents involved multiple deaths (Wilson *et al.*, 2012)
		1993-2004	According to the databases studied, 65% of the deaths in confined spaces in the United States involved atmospheric hazards and 10% involved engulfment (ANSI/ASSE, 2009).
		1993-2010	On average per year, 2.5 deaths related to a flammable atmosphere in a confined space took place during this period in the United States. The majority of these incidents have occurred since 2003 (U.S. Chemical safety and hazard investigation board, 2010).
		1984-1994	86.3% of the hydrogen sulfide poisonings during this period in the United States took place in a confined space, for a total of 80 deaths (Fuller & Suruda., 2000).
	Construction	1990-1999	In the construction sector in the United States, 62% of the poisonings involving carbon monoxide, hydrogen sulfide, and nitrogen during this period occurred in an confined space (Dorevitch *et al.*, 2002).
	Agriculture	1964-2010	On average per year, nearly 27 deaths in confined spaces were reported during this period in the agricultural sector in the United States (the real figure is undoubtedly higher), with: - 71% related to grain storage (e.g. engulfment). - 10.5% in manure pits (e.g. asphyxiation, poisoning), including 77 deaths in 56 incidents between 1975-2004 (Beaver & Field, 2007). - 9.2% in grain transportation (e.g. asphyxiation) - 5.7% in forage storage (e.g. asphyxiation). Workers under age 16 accounted for 20% of the cases (Riedel & Field., 2011).
Canada	Agriculture	1984-1994	On average per year, three deaths in confined spaces were reported over this period in the agricultural sector in Canada (FARSHA, 2012).
Quebec	Non-specific	1998-2011	On average per year, 3 deaths in confined spaces occurred during this period in Quebec in all sectors. Fatal incidents due to atmospheric hazards accounted for one-third of these deaths, while incidents involving physical hazards accounted for the remaining two-thirds (Burlet-Vienney *et al.*, 2013).

3.1.2 Lack of knowledge of the risks

Analysis of all the investigation reports of fatal incidents related to confined space entries in the province of Quebec over the period 1998-2011 (33 cases, 41 deaths) reveals that no predetermined safe working procedure had been applied before the incidents irrespective of the work activity. Moreover, one third of the workers involved in those incidents were conducting an improvised rescue attempt. In only two of the thirty-three organizations involved, risk management for confined spaces was carried out. Finally, in 45% of cases the worker had intervened alone. Employers failed to identify hazards linked to confined spaces and did not plan safe work conditions in confined spaces and omitted risk management (Burlet-Vienney *et al.*, 2013). Thus, persons performing interventions in these spaces do not always know or tend to underestimate the risks involved. For example, farm workers interrogated in an accident investigation reported knowing that the manure pit was dangerous, but that they were unable to assess the degree of danger compared to other risky work situations (Beaver & Field, 2000).

In theory, according to the regulations and standards, all confined spaces must be considered dangerous and entry forbidden until a qualified person has determined the requisite intervention conditions (ANSI/ASSE, 2009; CSA, 2010).

3.1.3 Standardized risk management process

The standardized risk management process is usually based on the following main steps: (i) establishing the context, (ii) identifying the work situations and hazards, (iii) estimating the risks, i.e. determining their level, (iv) evaluating the risks, i.e. judging, on the basis of the prior steps, whether the risk is acceptable or not, and (v) adopting, implementing, and maintaining risk reduction measures (ISO, 2009; ANSI/ASSE, 2011a; ANSI/ASSE, 2011b). The standards on risk management stipulate that risk reduction measures shall be based on the following hierarchy of controls: (i) eliminate the hazard by using process conditions that are non-hazardous (inherent risk reduction), (ii) reduce the frequency or consequence of the hazard by substituting less hazardous methods or materials (passive risk reduction), (iii) incorporate engineering controls devices, provide warning system (active risk reduction), (iv) apply administrative controls and provide personal protective equipment (procedural risk reduction) (ISO, 2009; ANSI/ASSE, 2011a; ANSI/ASSE, 2011b).

3.1.4 Questions and objectives

In light of the above, several questions arise about the risk management process specific to confined space interventions:

- What hazards and specific factors must be taken into account when analyzing the risks associated with a confined space intervention?
- Does the literature document any risk estimation tools that are adapted to confined spaces?
- How do the results of risk analysis and evaluation impact on risk reduction in the context of confined space interventions?

In an attempt to answer these questions, we performed a literature review on risk assessment specific to confined spaces. A multidisciplinary approach was adopted in order to factor in all the risks present in confined spaces.

3.2 Methods

3.2.1 Research criteria

The databases targeted for this review of the literature on risk assessment specific to confined spaces were COMPENDEX, PASCAL, and PUBMED, as well as the documentary holdings of institutions such as the National Institute for Occupational Safety and Health in the United States (NIOSH), and the Health and Safety Executive in Great Britain (HSE). These databases were consulted in February 2012 and covered literature from the year 2000 on. Complementary searches were also performed using Internet search engines, and some reference works before the year 2000 were added. A search strategy using English and French key words was developed. The two concepts used were (i) confined space, a standardized term in both languages (espace clos or espace confiné in French), and (ii) hazard/risk, which allowed the search to target research on the risks and hazards using the following key words: risk, hazard, toxic, asphyxiation, explosion, electricity, fall, flammable, fire, biological, engulfment, and mechanical. The field related exclusively to the modeling of ventilation for confined spaces was not retained when it focused primarily on risk reduction. Lastly, articles for the general public were consulted but not retained for this study.

3.2.2 Publications retained

3.2.2.1 Types, origin and primary focus

The previously defined research criteria led to the retention of 77 documents on confined spaces that are listed in the references. Type, origin and primary focus of these documents are given in Table 3.2.

The vast majority of the documents (50/77) come from North America. This large number is attributable to the fact that standards and regulations on confined spaces have been adopted (e.g. OSHA, ANSI, and CSA). It would also have been possible to include the state-specific regulations in the United States that are based on the OSHA regulation, but for little added value. Europe (22/77) and Australia (4/77) are also proactive on this subject.

The majority of the fifteen scientific articles identified consist primarily of studies on toxic atmosphere, and refer either to a particular work situation (e.g. transportation of wood pellets, welding) or statistical analysis (e.g. hydrogen sulfide poisoning).

3.2.2.2 Industry sectors

It is well known that work in confined spaces is a cross-field issue. The industry sectors specifically identified in the documentation were (i) agriculture, (ii) construction, (iii) maritime operations, (iv) aviation, (v) education, (vi) municipal services, and (vii) oil and gas extraction. The main subjects pertaining to each sector are detailed in Table 3.3.

3.2.3 An analytic spreadsheet

A spreadsheet was developed for the purpose of conducting a more in-depth investigation. The following topics were retained: (i) hazard identification, (ii) work activities requiring entry into a confined space, (iii) factors influencing the risks, (iv) the risk estimation step, and (v) the classification of confined spaces. The factors related to the safe design of confined spaces and control strategies were also analyzed. The results for each topic are described in the following section.

Table 3.2 : Type of documents retained, by origin and primary focus

		Primary focus											
		Cross-disciplinary	Toxic atmosphere	Accident investigation	Management of work	Work activity related	Statistical analysis	Rescue	Risk identification	Atmospheric testing	Ventilation	Flammable atmosphere	Total
Scientific article	US	1(23)	3(19-21)	1(1)			4(12-15)	1(3)	1(17)				11
	Sweden		2(2,24)										2
	Canada		1(28)										1
	France		1(22)										1
		1	7	1			4	1	1				15
Code of practice	UK	2(28,29)											2
	US	1(27)											1
	Australia	1(31)											1
	Canada	1(30)											1
		5											5
Technical guide	Canada	6(16,48,70,73,74,76)			4(54,66,67,71)			1(72)	2(56,77)				13
	France	4(50,51, 57,61)	1(55)			1(69)				1(62)	1(63)	1(65)	9
	UK	2(59,64)	1(49)			1(4)							4
	Australia	1(75)			1(58)								2
	US	2(53,68)											2
	Other	2(52,60)											2
		17	2		5	2		1	2	1	1	1	32
Book	US	2(35,38)						1(36)					3
	Canada	1(37)											1
	UK				1(39)								1
		3			1			1					5
Standard	US	2(6,25)											2
	Australia	1(26)											1
	Canada	1(9)											1
		4											4
Scientific report	US			6(11,43-47)									6
	Canada		1(40)			1(42)							2
	France					1(41)							1
			1	6		2							9
Legal regulation	Canada	4(7,8,10,33)											4
	US	2(5,32)											2
	UK	1(34)											1
		7											7
Total		37	10	7	6	4	4	3	3	1	1	1	77

Table 3.3 : Industry sectors involving confined spaces, identified in the documents retained

Industry sector	Total	Main subjects covered
Non-specific	41(3,5-12,20,21,23,26,28,30-32,35,36,38,39,42,48,50-55,57,59,60,62,63,65,68,72,73,75-77)	/
Agriculture	8(14-16,18,40,44,56,67)	Grain elevators, forage silos, manure pits
Construction	6(4,13,33,41,66,69)	Surface treatment, painting, asbestos removal
Maritime operations	6(2,22,24,29,47,64)	Ship holds, risks of asphyxiation and poisoning
Aviation	4(1,19,45,46)	Fuel tanks
Education	3(37,58,71)	Management programs at universities
Municipal services	3(61,70,74)	Drinking water and wastewater infrastructures
Oil and gas extraction	2(25,27)	Storage and disposal tanks
Other	4(17,34,43,49)	Agrifood operations, performing arts, leisure activities, military operations

3.3 Results

3.3.1 Identification of hazards present in confined spaces

Before entering a confined space, an inspection must be carried out to identify all hazards that could potentially be encountered during the intervention. The hazards present during confined space interventions were examined for purposes of this article by studying the definitions of a confined space and identifying all relevant hazards and their interactions.

3.3.1.1 Definitions

Based on the definitions given in the main regulations and standards examined, the notion of confined space generally refers to a space (i) in which a person can physically enter, (ii) that is partially or fully enclosed, (iii) that is not designed for continuous human occupancy, (iv) that has restricted means of access and egress, and (v) that contains hazards. However, none of the definitions found covers all five of these points explicitly.

One major difference in the definitions concerns the presence or not of hazards in the space. In the United States, the presence of hazards is not a mandatory criterion for defining a space as a confined space (U.S Department of Labor, OSHA, 1993). In other country, definitions of a confined space mention either exclusively atmospheric hazards, specific hazards (e.g. atmospheric, engulfment, drowning, or temperature), or the notion of hazard in general (Government of Canada, 2014; Ontario Ministry of Labour, 2014; Quebec Government, 2014;

Standards Australia, 2001; UK Ministry of Defense, 2014). Some definitions are therefore more restrictive than others on this point which may mean that some spaces potentially at risk are not identified.

3.3.1.2 Relevant hazards

All documents retained address many hazards during interventions in confined spaces. Thus, according to the type of document, an extensive list of the relevant hazards present during confined space interventions was drawn up (Table 3.4).

Table 3.4 : Confined space hazards identified, by type of document

Hazards	**Scientific article (15)** (1-3,12-15,17-24)	**Best-practice standard (4)** (6,9,25,26)	**Legal regulation (7)** (5,7,8,10,32-34)	**Code of practice (5)** (27-31)	**Book (5)** (35-39)	**Scientific report (9)** (11,40-47)	**Technical guide (32)** (4,16,48-77)	**Total**
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
Thermal	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
Falls from heights	1	2	3	2	2	4	23	37
Drowning	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
Release of substances	1	2	2	5	5	1	14	30
Activity, equipment used	3	2	3	4	2	1	13	28
Biological, animal	1	2	1	2	3	1	18	28
Falls 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 objects	1	1	0	1	4	1	12	20
Radiation	1	4	0	4	3	0	8	20
Limited means of access/egress	1	2	1	2	2	1	8	17
Residues	1	0	2	1	1	1	10	16
Traffic	0	3	0	2	1	0	10	16
Environmental	0	2	1	2	2	0	9	16
Excessive exertion/posture	0	1	1	1	2	1	3	9
Psychological, stress	1	1	0	0	1	0	5	8
Accessibility of the entrance	1			1			5	7
Related to clothing/PPE		1		2	1		2	6

This summary indicates that atmospheric hazards are cited in more than two-thirds of the documents. Thermal, electrical, engulfment, fall, and other hazards come next. Conversely, hazards related to the confined space environment, worker physiology or psychology, clothing worn, or entry accessibility receive less coverage. For the most part, atmospheric hazards are cited first in the documents. So-called physical hazards come next and include fewer details.

In addition, it should be added that rescue attempts are also hazardous situations to consider. In fact, emergency response is required in all regulations and standards consulted. Requirements mainly address planning, retrieval equipment, training and communication. Some regulations require that procedures be tested (e.g. OSHA, Quebec). Response time is also a major issue in most regulations (e.g. immediately, timely manner). However, explicit regulatory requirements on this point vary. For example, the Canadian federal regulation requires the use of a retrieving system with a qualified person for each entry while other regulations provide less guidance on means to implement emergency response (Wilson *et al.*, 2012).

3.3.1.3 Interaction among hazards

Interactions among hazards, which are largely ignored during risk analysis, are a particularly important factor during confined space interventions due precisely to the confined and limited size of these spaces. These interactions tend to increase the probability of occurrence of a hazardous event and can sometimes amplify the consequences (Lyon & Hollcroft, 2012). A risk initially estimated to be non-fatal could in fact lead to a fatal incident due to hazard interaction. For example, in Quebec in 2004, a worker descended into a manure pit to unclog a pump. When he had finished the job, he fell off the ladder into the pit, releasing hydrogen sulfide that had been trapped under a thin organic layer sitting on the liquid’s surface. He died from poisoning (CSST, 2014).

While no specific studies focusing on hazard interactions were found in the literature, the following interactions were identified in connection with confined spaces:

- Poisoning, asphyxiation, or electrocution can lead to falls or drowning. This was the most frequently cited interaction (Beaver & Field, 2007; Veasey *et al.*, 2006; Workplace health and safety Queensland, 2010).
- Falls can lead to poisoning (e.g. heavy gas at the bottom of a space) or engulfment (Cal/OSHA, 2012).

- A high temperature in a confined space can increase (i) the risks of explosion and fire, (ii) micro-organism activity, and (iii) exposure to chemical and toxic products, as higher temperatures can make products more volatile, increase a worker's vasodilation, and thereby increase cutaneous absorption of the product (Carlton *et al.*, 2000; Svedberg *et al.*, 2009; Standards Australia, 2001; Veasey *et al.*, 2006).
- Animals, temperature, noise, small space size, and other factors can induce high stress in the entrant (Abelmann *et al.*, 2011; Workplace health and safety Queensland, 2010)
- When means of access and egress are limited and difficult to access, risks in which exposure and rescue time is a major issue (e.g. intoxication, asphyxiation, engulfment, drowning, or entrapment) are increased.

3.3.2 Estimation of risks present in confined spaces

Table 3.5 summarizes the extent of risk assessment strategies included in the seventy-seven documents retained. It is interesting to note that all the documents address the risk identification and risk reduction steps even if the level of detail varies (e.g. check-list, technical explanations, etc.). Regarding risk estimation as referred in standards (i) twenty-six documents don't really address it, (ii) twenty-nine deal with atmospheric hazards only using the permissible exposure values, and (iii) finally twenty-two tackle overall risk estimation. Of these twenty-two papers, only nine suggest practical tools for estimating risk (NIOSH, 1994; Standards Australia, 2001; Maritime and Coastguard Agency, 2010; Standards Australia, 2003; UK Ministry of Defense, 2014; Rekus, 1994; BCGA, 2009; Government of South Australia, 2011; Workplace health and safety Queensland, 2010).

3.3.2.1 Overall risk estimation tools

First, two basic risk scales of the "High, Medium, Low" or "Extreme, High, Moderate, Low" type were found (Maritime and Coastguard Agency, 2010; Government of South Australia, 2011). However, no definitions or details were provided for these terms. Given the absence of a solid basis for estimating the risk, such scales are of limited use for the purpose of prioritizing and addressing risks.

Table 3.5 : Extent of risk assessment strategies included in the documents retained

Risk identification	**Risk estimation/evaluation**		**Risk reduction**	**Total**
	Atmospheric hazards only	Overall hazards		
X			X	26(1,3,4,12-15,18,23,39,42,44,50-52,54,56,61,62,66,68,69,72,74,77)
X	X		X	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)
X		X	X	22(6-9,11,17,26,28-31,34-36,45,46,49,55,58-60,75)

Moreover, three different risk matrices using the two parameters of severity and probability of occurrence of harm were found in the documents on confined spaces (Standards Australia, 2001; Standards Australia, 2003; UK Ministry of Defense, 2014; Rekus, 1994; Workplace health and safety Queensland, 2010). In these matrices, the rating scales for each of the two parameters were broken down into four or five levels. The risk itself was defined at three or four levels, and each level associated with an action. The matrices remain generic; definitions used are vague and parameters are not adapted to the particular characteristics of confined spaces (e.g. the influence of the physical characteristics of the confined space, limited means of access and egress, and multiple types of risks, real rescue conditions, and interactions among hazards). This type of configuration may lead to a rough analysis with a limited added value (Ball & Watt, 2013). An example of matrix is provided in Table 3.6.

3.3.2.2 Estimation of atmospheric hazards

Regulatory criteria for determining whether the atmosphere in a confined space is hazardous or not vary from one regulation to another.

Table 3.7 summarizes the conditions for which the atmosphere inside a confined space is considered non-hazardous and where entry is permitted without further measures. Only the principal regulations and standards of a given country were taken into consideration.

Table 3.6 : Risk matrix proposed in the australian standard on the management of risks in confined spaces (Standards Australia, 2001)

	Consequences				
Likelihood	**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 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.

Table 3.7 : Atmospheric conditions required in various countries for entry into a confined space to be considered non-hazardous

Country	**Regulation/Standard**	**%O_2**	**% LEL**	**Toxicity**
Australia/ New Zealand	AS/NZS standard(26)	19.5%-23.5%	<5% or <10% if continuous monitoring	< Permissible exposure limits in force
France	CNAMTS(51)	19%-21%	<10% if entry	
Canada	Quebec regulation(10)	19.5%-23%	<10%	
	Ontario regulation(8)	19.5%-23%	<5% if hot work <10% if cold work <25% if inspection	
	CSA standard(9)	19.5 %-23%	<5% if hot work <10% if cold work	
	Federal regulation(7)	18%-23%	<10% if hot work <50% otherwise	
United States	Federal regulation(5), ANSI standard(6)	19.5%-23.5%	<10%	
	NIOSH(11)	19.5 %-21.4%	<10%	

Taking the minimum and maximum percentages of oxygen listed in Table 3.7, the maximum range for which entry is considered non-hazardous runs from 18% to 23.5%. The most common minimum value is 19.5% and the most common maximum values are 23% to 23.5%. The most common value for concentrations of explosive products is less than 10% of the low explosive limit (LEL). However, some countries such as Canada adjust this percentage in light of the type of work to be performed (e.g. hot work, cold work, or inspection). Regarding exposure to toxic products or asphyxiants, all the documents require compliance with the permissible exposure limits in force. However, the regulatory references and exposure limits (e.g. for time-weighted average, short-term, and immediately dangerous to life and health exposure limits) can vary from one country to the other (Quebec Government, 2014; ACGIH, 2011; U.S Department of Labor, OSHA, 1989)

Judging from the differences between the regulatory values presented in Table 3.7, there is no specific dividing line between hazardous and non-hazardous situations. In fact, regulatory exposure limits are established to ensure relative protection for the majority of exposed workers (Rekus, 1994). In practice, even if the measured exposure values are below the permissible exposure limits, the exposure to toxic contaminants during an intervention must be reduced as much as possible (Workplace health and safety Queensland, 2010)

3.3.3 Classes of confined space

The risk analysis results are used to evaluate the risks and determine appropriate mitigation measures. The grouping together of similar confined spaces or the classification of confined spaces are two approaches documented in the literature that are used to simplify this task when a large number of confined spaces have to be managed.

3.3.3.1 Similar confined spaces

The concept of similar confined spaces attempts to group identical types of confined spaces together. The following is an example of the explanations given: “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 cited for determining similarity among confined spaces are their construction, hazards present, outside environment, and work performed. However, the criteria for determining whether two spaces are similar often lack details (e.g. "similar characteristics", "same hazards," "due to their similarities"). Moreover, it would be more appropriate to talk about similar interventions in confined spaces since the nature of the work performed influences the risks encountered. Lastly, in some regulations, the reason for defining similarity in confined spaces is to allow for a single risk assessment for this type of space. However, this logic has its limitations because, in theory, establishing whether two interventions are truly similar requires analyzing the risks related to the interventions.

3.3.3.2 Classifications found in the literature

Three approaches to classifying confined spaces were found in the literature. The first approach, used mainly in the United States, is based on the need for an entry permit, with non-permit confined spaces and permit-required confined spaces (ANSI/ASSE, 2009).

The second approach classifies confined spaces according to risk level. The following three classes summarize the concepts documented in the various definitions (NIOSH, 1994; Rekus, 1994; WorkSafe BC, 2008):

- Class A: Confined spaces that pose immediately dangerous and life- or health-threatening situations (e.g. oxygen level of less than 16% or greater than 25%; flammable gas level greater than 20% of its LEL; an immediately dangerous to life or health (IDLH) concentration of toxic products). Workers cannot exit these spaces without assistance in the event of failure of the ventilation system or respiratory equipment.
- Class B: Confined spaces that are not immediately life- or health-threatening, but that have the potential of causing injury and illness if preventive measures are not taken (e.g. oxygen levels between 16.1% and 19.4% or 21.5% and 25%; flammable gas levels between 10% and 19% of its LEL; a toxic product higher than permissible limits). Additional physical hazards may be present (e.g. noise, temperature, materials handling).
- Class C: Confined spaces where minor hazards are present (e.g. oxygen level between 19.5% and 21.4%; flammable gas level lower than 10% of its LEL; a toxic product concentration lower than permissible limits). The risk analysis revealed that the conditions are not likely to change during the course of the work activity.

Annex A.17 of the Canadian standard proposes another approach based on the nature of the hazards, with (i) confined spaces with hazards associated with limited access and egress only, (ii) confined spaces with hazards that present a risk (other than atmospheric) that require controls, and (iii) confined spaces potentially containing atmospheric hazards alone or in combination with other hazards (CSA, 2010).

3.4 Discussion and recommendations

The results of our review of the literature on risk assessment specific to confined spaces revealed many gaps regarding (i) the implementation of a multidisciplinary approach to confined space management, (ii) the adaptation of the risk estimation process to the confined space context, and (iii) the purpose of the proposed classes of confined spaces.

3.4.1 Multidisciplinary problem

Regardless of which risk management step is involved, atmospheric hazards monopolize attention in the literature on confined spaces. These are the most frequently identified and extensively detailed hazards. In addition, the risk estimation tools specific to confined spaces found in the literature are mainly designed to handle these hazards. Lastly, the proposed hazard classes are for the most part based on atmospheric hazard estimation. This approach can be explained by the fact that these risks are specific to the enclosed nature of confined spaces and that these spaces are regarded very much as an industrial hygiene problem. As evidence, the available statistics concern atmospheric hazards almost exclusively because physical hazards were not taken into consideration for methodological reasons (ANSI/ASSE, 2009; NIOSH, 1994). It is therefore difficult to obtain data on confined space incidents of physical origin without consulting all fatal accident reports. This work was done for the province of Quebec over the period 1998-2011 and the results obtained shed new light compared to other studies since fatal incidents involving physical hazards accounted for two-thirds of the deaths. Fatal incidents due to atmospheric hazards accounted only for the remaining one-third (Burlet-Vienney *et al.*, 2013).

While physical hazards are not specific to confined spaces, they do form part of the equation to be resolved. These hazards interact with atmospheric hazards, can be severe, render risky situations more complex, and necessitate appropriate rescue measures. In our opinion, to take into account the real complexity of confined spaces, risk management should therefore be multidisciplinary.

3.4.2 Adapted risk estimation

Confusion exists in the vocabulary used in the confined space literature, with risk evaluation being used indiscriminately for hazard identification or risk estimation. In reality, the knowledge available on confined spaces allows above all for hazard identification and risk reduction during various interventions, as illustrated by the many checklist-type tools identified. Thus, little emphasis is put on the overall risk estimation step while it is an essential consultation period that allows designers and the various parties involved (i) to identify the main factors contributing to the risks, (ii) to evaluate the risks consistently using the same criteria, and (iii) to prioritize risks reduction measures to implement (IEC/ISO, 2009). Moreover, the handful of risk estimation tools documented do not propose a process adapted to the particular characteristics of confined space interventions and possess perceived flaws (Gauthier *et al.*, 2012). For example, it would be possible to adapt and improve qualitative risk matrices proposed in the literature for interventions in confined spaces, while leaving them easy to use, by:

- Taking into account the nature of hazards in criteria defining the thresholds of the severity of harm parameter. This should include use of permissible exposure values for atmospheric hazards while physical hazards require other criteria (e.g. height, force, pressure).
- Calibrating the thresholds of the severity of harm parameter with respect to the fact that there may be several workers entering confined spaces at the same time.
- Taking into account frequency and duration of interventions in the criteria defining the thresholds of the probability of harm parameter. For example, the duration of intervention should take into account the real task, the number and size of entries and egress, the type of access (vertical or horizontal), the presence of obstacles, the distance of penetration inside, etc.
- Taking into account the following factors in the criteria defining the thresholds of the probability of harm parameter: (i) some interactions among hazards, (ii) possibility of changing conditions in the confined space and its immediate environment, and (iii) physical and psychological condition of the person who enters.
- Integrating rescue conditions in the risk analysis as they can increase the final severity of harm especially in lengthening the total duration of exposure. This should influence the overall evaluation of the confined space.

- Calibrating matrices for high risks so that risk level obtained were not always the same. Indeed, the goal is to prioritize risks and, because of the configuration, risks in confined spaces are generally considered higher than in “classic” work situation.

Thus, a risk estimation that is more specific to the confined space problem and that takes the problem’s complexity into account would help OHS personnel and rescue personnel plan their respective processes to reduce, control, and communicate information on the risks.

3.4.3 Aids to risk reduction

In the literature, confined space classes and the concept of similar confined spaces are suggested for systematizing the assessment of some risky work situations in confined spaces. However, several limitations were identified. For example, there are currently no practical criteria for defining the similar confined space concept, and it is used (perhaps wrongly) for the purpose of simplifying risk analyses. The classes, in order to support decision makers and designers in the process of risk reduction, should clearly be improved by taking into account (i) the type and nature of work being carried out, (ii) the configuration of the confined space, (iii) the combination of hazards/risks involved, (iv) the level of each of the major classes of risk, and (v) the rescue conditions. It is believed that information to categorize interventions in confined spaces should originate from risk analysis process adapted to confined spaces. A mix of the categorization suggested in the literature (e.g. by risk level and nature of risk) should also be considered. However, these categories should not force the decision maker in risk reduction measures to be implemented (from the hierarchy of control), but rather help to make a decision by characterizing and categorizing the risky work situation. Indeed, decision makers must make their choices based on other parameters such as the time available, monetary resources, etc.

Lastly, the prevention-through-design concept, which involves the elimination of hazards at the source, applied to confined spaces should always be the favored risk reduction method. The safe design of confined spaces is a topic rarely covered in depth, except in standards. Starting with the safest principle, it is essential to (ANSI/ASSE, 2009; CSA, 2010; Standards Australia, 2001) :

1. Avoid creating confined spaces, whether during a design process or during the modification of an existing space.

2. Eliminate the need for entry. This often necessitates a change in working methods, such as:
    - placing the elements that will require intervention outside the confined space (e.g. valves, flow meter).
    - adapting the design such that the task can be performed from outside, either by using a tool (e.g. hook, valve wrench, or pole) or new technologies (e.g. video or robot).
    - making the elements in the confined space accessible and maneuverable from outside the space to allow for easy removal.
3. Reduce the need to enter the space through preventive measures such as (i) a self-cleaning device, (ii) durable materials, structure, and surface treatments, or (iii) a space-sweeping or vibratory device to prevent the formation of grain bridges in grain elevators.
4. Reduce risks during the design phase where entry is absolutely necessary (e.g. reducing penetration distances and sources of obstruction, incorporating the disconnection of pipes and lockout/tagout procedures, incorporating or promoting ventilation, proper grounding, shielding mechanical components and live parts).

Prevention through design would appear to be particularly worthwhile for confined spaces because the risks involved are often very high and the consequences serious and the related maintenance activities are reasonably foreseeable right from the design phase. However, ensuring the effective and safe design of confined spaces will require the use of risk analysis tools adapted to the context and complexity of these spaces (ANSI/ASSE, 2011b; Manuele, 2010).

3.5 Conclusion

Based on the literature review on confined space, it can be concluded that existing risk assessment is limited to hazard identification or atmospheric hazard estimation, without taking into account the overall context of confined space interventions and the rescue issues. Furthermore, the existing groupings and classes of confined spaces are generic and do not provide information specific to eliminating and reducing risks.

It therefore appears that the development of a systematic risk analysis process that is (i) based on recognized concepts in risk management standards, (ii) multidisciplinary, to address the multi-risk problem posed by confined spaces, and (iii) adapted to the specific characteristics of confined spaces, such as rescue conditions, is needed to generate practical knowledge that will complement the requirements cited in the regulations, standards, and guides on confined spaces. These development initiatives could help decision makers when using the hierarchy of control strategies, support rescue personnel, promote communication and provide basic guidelines for the safe design of confined spaces. Suggestions on such a risk analysis tool and categorization of interventions in confined spaces have been proposed in this paper.

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CHAPITRE 4 ARTICLE 2: OCCUPATIONAL SAFETY DURING INTERVENTIONS IN CONFINED SPACES

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Abstract: The aim of this study was to examine how organizations in Quebec manage risks associated with confined space interventions. Fatal work accidents that occurred in confined spaces in Quebec between 1998 and 2011 were therefore studied using the database of the provincial workers' compensation board. Thirty-two accident investigation reports involving 40 fatalities were obtained for the target period. The risk factors studied were the time of year, type of accident, and management and design problems. The risk management practices of 15 Quebec organizations were also analyzed through semi-structured interviews and observation of confined space interventions. Organizations with different profiles were chosen to cover a wide range of confined spaces and work situations. With respect to the regulatory in force in Quebec and based on the Canadian standard on the management of work in confined spaces, the organizations visited neglected the following points, in terms of both prescribed directives and actual practices: (i) management of subcontractors, (ii) auditing how risk reduction means are used, and (iii) integration of prevention through design. The lack of guidelines limited the real effectiveness of measures pertaining to training, rescue, use of certain control measures, and the preparation of entry permits. Given the complexity and diversity of the work involved in the issuance of permits, uncertainties during their preparation can lead to poor risk assessment and eventually to inadequate risk reduction measures. This article therefore proposes an entry permit consolidating all the information needed to prepare for entry, as well as recommendations regarding the aforementioned challenges.

Keywords: Confined space, Risk management, Entry permit, Fatal accident

4.1 Introduction

In the federal and provincial occupational health and safety (OHS) regulations of Canada and Quebec respectively, a confined space refers to a space in which a worker can physically enter, but that (i) is not a regular workspace, (ii) has restricted means of access and egress, and (iii) poses risks to the worker's health and safety (Quebec Government, 2014; Government of Canada, 2014). These criteria are reiterated in various forms in most countries including the United States (U.S Department of Labor, OSHA, 1993), the United Kingdom (Government of United Kingdom, 1997), France (Institut National de Recherche et de Sécurité, 2010a) and Australia (Standards Australia, 2001). For example, reservoirs, silos, vats, access shafts, ditches, sewers, pipes, crawl spaces, and truck or freight car tanks are all potentially confined spaces from a regulatory standpoint. Work-related interventions in confined spaces concern the municipal, manufacturing, chemical, military, agricultural, and transportation sectors in particular (Rekus, 1994). In 1993, when drafting its regulation on work in confined spaces, the US Occupational Safety and Health Administration (OSHA) estimated that 4.8 million confined space entries were made annually in the United States and involved an average of 1.6 million workers and 63 deaths (U.S Department of Labor, OSHA, 1993; ANSI/ASSE, 2009). Many potential hazards exist in confined spaces. The main ones are atmospheric (i.e. poisoning, asphyxiation, explosion), biological, and physical (e.g. mechanical, electrical, engulfment, falls, lighting, outside traffic) (NIOSH, 1994). Between 1992 and 2005, an average of nearly 38 deaths occurred per year in the United States due to poisoning or asphyxiation in confined spaces. Twenty percent of these events resulted in several deaths (Wilson *et al.*, 2012). Other revealing statistics about the risks involved in confined space interventions were inventoried by Burlet-Vienney *et al.* (2014) in a literature review (e.g. Fuller & Suruda, 2000; Dorevitch *et al.*, 2002; Beaver & Field, 2007; Riedel & Field, 2013).

In Quebec, employers are legally bound to respect Division XXVI (sections 297 to 312) of the *Regulation respecting occupational health and safety* (ROHS) (Quebec Government, 2014) when it comes to work in confined spaces. This regulation is equivalent to OSHA 29 CFR 1910.146 in the United States. The following topics are discussed:

- the training of the workers involved and the information made available to them;

- the gathering of information, in writing, about hazards and preventive measures to be taken prior to work in a confined space;
- the use of ventilation to maintain acceptable atmospheric conditions (i.e. oxygen, contaminants, lower explosive limit);
- the management of combustible dusts presenting a fire or explosion hazard, and hot work;
- gas monitoring and measurement;
- mandatory supervision;
- tested rescue procedures that make rapid rescue possible;
- prohibition of entry into a confined space if a filling or emptying operation involving free-flow materials is under way;
- mandatory wearing of a safety harness and its attachment to a lifeline if free-flow materials are stored in the confined space.

In addition, Canadian standard CSA Z1006-10 and American standard ANSI/ASSE: Z117.1-2009 on confined spaces provide guidelines regarding the management program to be put in place, roles and responsibilities of those involved, related planning (e.g. training, emergency response plan), and program implementation (e.g. entry permits). Risk management consists of identifying hazards, assessing risks, and introducing adequate control measures. The Canadian standard defines risk assessment 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). Control measures must be chosen in accordance with the following priority: (i) elimination of the hazards by design, (ii) reduction of the frequency of exposure to risks or potential harm by the use of less hazardous methods, (iii) integration of engineering controls (guards, alarms, etc.), (iv) application of administrative controls (e.g. procedures), and (v) provision of personal protective equipment (International Organization for Standardization, 2009; ANSI/ASSE, 2011a). Safety design is the most effective risk reduction method and should always be favored despite the challenges involved (Fadier & De la Garza, 2006; Hale *et al.*, 2007).

However, when confronted with the actual constraints and limited resources in the field, all these regulatory and normative measures can prove difficult to implement. For example, when assessing the risks associated with confined spaces, theoretically the following points must be taken into account: (i) the physical characteristics, configuration, and location of the confined space, (ii) the past use and contents of the confined space, (iii) the work to be carried out and duration of the intervention, (iv) the number of entrants and their physical and psychological condition, (v) interactions among the various hazards, (vi) variations in conditions over time, and (vii) rescue conditions (ANSI/ASSE, 2009; Burlet-Vienney *et al.*, 2014). In addition, the problem of delays in firefighters' interventions during rescue operations in confined spaces was raised by Wilson *et al.* (2012), as were problems with the identification of risks in certain situations: ocean transportation of wood pallets (Svedberg *et al.*, 2008), aircraft fuel tank repair (Carlton *et al.*, 2000), shielded metal arc welding in an enclosed area (Harris *et al.*, 2005) or work in a vessel of a gas carrier (Lucas *et al.*, 2010).

The primary aim of this study was therefore to examine how organizations in Quebec manage risks associated with confined space interventions. Another aim was to propose a generic entry permit that incorporates an exhaustive list of risk factors to be considered prior to a confined space intervention. To achieve these aims, fatal work accidents occurring in confined spaces in Quebec between 1998 and 2011 and the risk-management practices of 15 Quebec organizations were investigated. This work provides a better understanding of the risk factors and risk management practices associated with confined spaces.

4.2 Methods

4.2.1 Fatal work accidents in Quebec – Selection criteria

The database of the provincial workers' compensation board (known as the Commission de la santé et de la sécurité du travail du Québec, or the CSST), which insures 85% of the active workforce, was consulted in September 2013 (CSST, 2014) in order to compile statistics on fatal work accidents occurring in confined spaces between 1998 and 2011 in Quebec. The CSST investigates all fatal accidents that occur within the province and fall under its jurisdiction, with the exception of road accidents and assaults.

The originality of this study lies in the fact that all the investigation reports for serious and fatal accidents (819) occurring during the target period were consulted. No keyword extraction was performed, as it generally excludes certain confined space accidents unrelated to atmospheric hazards. The reports pertaining to confined space interventions were selected on the basis of the definition of confined space provided in section 1 of Quebec's *Regulation respecting* *occupational health and safety* (ROHS). Two researchers performed the selection for the most contentious cases. The analysis of the accident investigation reports concerned primarily the (i) date of the event, (ii) industry sector, (iii) type of confined space, (iv) main causes, (v) presence of work and rescue procedures, and (vi) design-related elements.

Thirty-two investigation reports were retained for the target period, i.e. approximately 4% of the files consulted (32/819). These events caused the deaths of 40 people, or an average of almost three deaths a year. Nearly 20% (6/32) of these events caused multiple deaths, three involving rescue attempts and three others involving several entrants who were carrying out work at the time of the accident. The 40 people involved in these accidents included two employers, six managers, 31 operators/technicians, and one outside observer.

As shown in Figure 4-1, there appears to be a downward trend in the number of deaths per year, with 28 deaths occurring between 1998 and 2004 and only 12 deaths over the same number of years between 2005 and 2011. The introduction in 2001 into Quebec's ROHS of sections on work in confined spaces may have significantly influenced this decline.

An analysis of all occupational injuries in confined spaces in Quebec, not just fatal accidents, was planned for the purpose of obtaining complementary information. However, the coding of the details on the confined space work situations did not allow for such an analysis, thus depriving both OHS personnel and researchers of an important source of data on this topic.

4.2.2 Choice of organizations and visiting procedures

Fifteen organizations with a confined space work management program in place for more than one year were visited between April 2013 and January 2014. The visits were spread over 4 seasons to cover a variety of weather conditions. The number of visits (15) was a compromise to accommodate the constraints of recruiting organizations that met the previously cited criterion in Quebec and the need to explore a range of work situations.

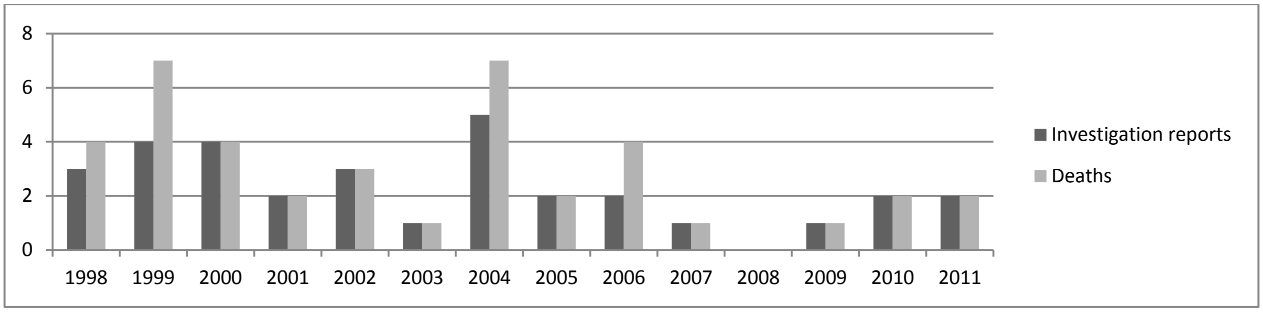

Figure 4-1 : Distribution of the number of investigation reports and confined space deaths in Quebec between 1998 and 2011

The 15 organizations were chosen for their diverse profiles: industry sector; location; type of confined space; and size, in terms of number of employees and number of confined spaces. They were solicited by means of a call for participants published in a specialized OHS electronic newsletter and through stakeholders in Quebec's network of joint sector-based OHS associations.

Table 4.1 presents the study sample of the 15 organizations recruited and the confined spaces observed. The sample included organizations in the public (8) and private (7) sectors in virtually equal proportions. It also included 7 industry sectors from among those most affected by confined space work (Rekus, 1994). The fact that the organizations were responsible for managing the risks related to confined space work for the most part led to the recruitment of organizations with more than 100 employees and well-organized in terms of OHS (e.g. had a health and safety committee [14/15] and a program in place for more than five years [11/15]). Four organizations with fewer than 50 employees were, however, included in the study. The confined space inventories of the organizations retained ranged from around 30 units to over 1,000, notably in the municipal sector, with its access shafts to the sewer/waterworks system. Routine preventive maintenance (i.e. inspection and cleaning), entailing additional work or not, was the main reason for the confined space interventions, followed by breakage repair and unclogging operations.

The on-site visits, which lasted from 3 to 5 hours, took place in the presence of the OHS coordinator and key employees in the management of the confined spaces (e.g. operator, supervisor). The visits had two parts: first, a semi-structured interview on the risk management process in place, and second, observation of a confined space intervention team in action in order to analyze the real working conditions. Two researchers collected this data using an interview guide, an observation checklist, and a verification checklist for the content of the confined space work management programs (Flick, 2006; Gillham, 2000; Robson *et al.*, 2001; Silvermann, 2011). These data collection tools were tested during a first visit. The confidentiality of the data collected was guaranteed by a consent form duly signed by the parties involved. The interview guide included closed-ended or short-answer questions to ensure that the interviews were conducted in a relatively consistent manner. The first part of the interview served to collect data on the organization's structure, confined spaces, and the workers involved. Documents on their confined space management practices were obtained at this stage.

Table 4.1 : Sample of the 15 organizations visited for the purpose of analyzing their management of confined space work

	Industry sector	**No. employees**	**No. confined spaces**	**Entries/ yr.**	**Date of program**	**Confined spaces observed**	**Depth (m)**	**Penetration distance (m)**
A	Educational services	500-1000	10-50	10-50	2012	Crawl space	/	15
B	Public administration	100-500	>500	>500	2008	Valve pits	2.5	3
C	Public administration	100-500	>500	>500	2005	Access shaft	4.5	2
D	Transformation of crude oil	100-500	>500	>500	<2000	Reservoir	/	15
E	Equipment manufacturing	500-1000	100-500	>500	2003	Reservoir	/	3
F	Public administration	50-100	>500	100-500	<2000	Access shaft	3	/
G	Public administration	<20	10-50	10-50	2011	Access shaft	3.5	/
H	Equipment manufacturing	>1000	>500	100-500	2004	Technical room	2.5	6
I	Energy production	20-50	10-50	100-500	2002	Pipe	9	30
J	Energy production	<20	10-50	100-500	2002	Access shaft	9	6
K	Energy production	20-50	10-50	<10	<2000	Access shaft	3	3
L	Transportation and warehousing	50-100	100-500	>500	2007	Tank truck	2	15
M	Transportation and warehousing	50-100	10-50	100-500	2004	Tank truck	2	3.5
N	Construction	>1000	N/A	>500	2002	Access shaft	3	/
O	Equipment manufacturing	100-500	50-100	10-50	2010	Plating bath	3. 5	/

Next, based on the content of the regulations in force in Quebec and on the Canadian Standard, the following safety outcomes were covered in the interview guide (Quebec Government, 2014; CSA, 2010):

- inventory and identification of the confined spaces managed;
- content of the confined space intervention management program;
- audits;
- training of the workers involved, including subcontractors;
- preparation work pertaining to confined space entry permits and to related documentation (e.g. hazard identification and risk assessment);
- the means of risk reduction planned and their use during interventions;
- rescue measures and their organization.

Based on their observations, the researchers compared the theoretical answers obtained in the interviews to the realities of a confined space intervention. The observation checklist provided information on the following: the characteristics of the confined space; the work environment; the workers and their perception of the risks; the type of intervention; the entry permit and the documentation used; the steps in preparation and entry with the implementation of risk-control and rescue measures. Videotapes and photographs were taken to support data collection.

The data derived from the 15 interviews, the observations, and the documents obtained were compiled in twelve tables covering the previously mentioned topics for purposes of analysis and comparison. All recommendations made in the section 4.3.2 are based on regulatory requirements in force in Quebec, the Canadian standard (Quebec Government, 2014; CSA, 2010) and innovations developed in an organisation. The recommendations address the deficiencies or issues encountered in at least two organizations.

4.3 Results and discussion

4.3.1 Characterization of fatal work accidents in confined spaces in Quebec

A number of factors that may play a key role in prevention was identified based on the analysis of the fatal accidents that occurred in confined spaces in Quebec over the 1998-2011 period.

4.3.1.1 Period of the year

Forty percent (40%) of the documented confined space fatalities occurring in Quebec between 1998 and 2011 took place in the months of July and August, yet these two months represent less than 20% of the total study period. One possible explanation is that summer is a more suitable time for carrying out confined space interventions, either due to the weather, agricultural activities, or planned production shutdowns. This was validated during visits, where nearly half of the organizations questioned prioritized their confined space activities during the summer.

4.3.1.2 Type of accident

The types of accidents involved in confined space fatalities in Quebec during the target period are detailed in Figure 4-2.

Poisoning and asphyxiation were the leading cause of death (11). Seven deaths were attributable to hydrogen sulfide, found mainly in water treatment plants and manure pits. There were more events attributable to moving parts of machinery than to poisoning/asphyxiation, but they caused fewer deaths (8). Hazards such as engulfment, falls from heights, and falling objects were also significant in number, but less documented in the literature. Accidents caused by atmospheric hazards, responsible for an average of more than 1.75 deaths per event (14 deaths during 8 events), included more multiple-fatality accidents than events attributable to physical hazards (26 deaths during 24 events). Atmospheric hazard accidents accounted for one-third of the deaths, while physical hazard accidents accounted for the remaining two-thirds.

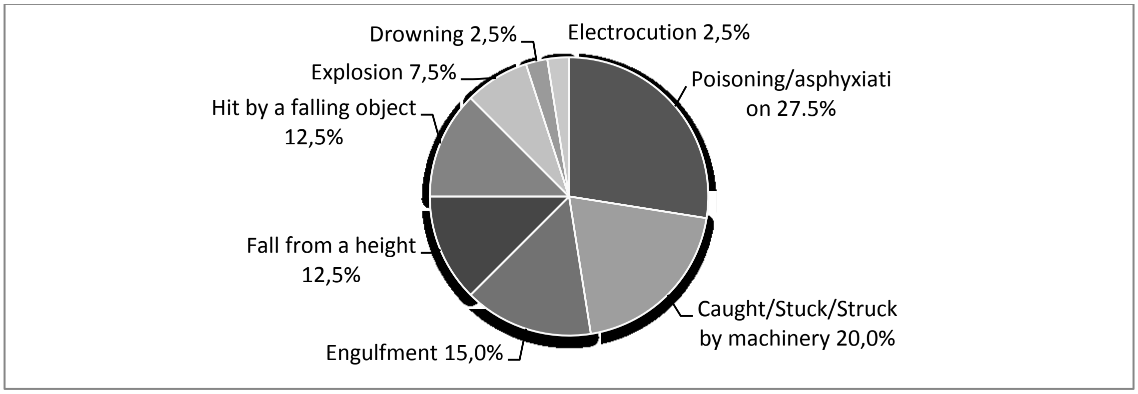

Figure 4-2 : Distribution of deaths in confined spaces in Quebec between 1998 and 2011, by type of hazard

This ratio was the opposite of the figures found in the literature (ANSI/ASSE, 2009), which can be explained by the fact that all physical hazard accidents were included in this study.

The number of deaths and multiple deaths attributable to poisoning or asphyxiation in confined spaces tends to focus OHS coordinators' attention on these hazards. Yet based on all fatal confined space accidents documented over a period of 14 years in Quebec, there is reason to recommend that risk analysis and reduction be a multidisciplinary undertaking in order to more effectively address the complexity of work situations in confined spaces.

4.3.1.3 Improvised interventions

In two-thirds of the accidents studied for the target period, the initial intervention was for unplanned repair, troubleshooting, or unclogging/unjamming operations. In most of the accidents, the investigation report clearly mentioned a problem with identifying the hazards or underestimating the risks. The confined space activities were improvised and no work procedure was applied, both of which in fact constitute a major risk factor. The means used to reduce the risks were therefore poorly adapted or even non-existent. Nor was any rescue plan in place on the work premises, which partly explains why 15% of the individuals who died during the events documented (6) were attempting an improvised rescue (Suruda *et al.*, 1994).

Effective management of confined space interventions is an essential condition for reducing risks. Yet this process is associated with a number of its own challenges, as detailed in section 4.3.2.

4.3.1.4 Prevention through design

Sometimes a problem at the design level can explain the underlying cause of an accident (Gambatese *et al.* 2008). The factors identified in the documented accidents provide concrete examples that should be taken into account by the designers of confined spaces:

- Access to the confined space is hazardous because of inadequate means of penetration (rung, ladder), or fall protection is absent (e.g. guardrail) in cases where the confined space is open.
- Interventions such as greasing or unclogging/unjamming are performed inside a confined space even though no technical constraint prevents them from being performed from outside the space.

- The control system (e.g. emergency stop device, sensors, programmable controller), and the mechanisms for controlling hazardous energy (e.g. valves, circuit breaker) are not integrated into the equipment properly to maximize their use.
- The real working conditions associated with the confined space are not taken into account: outside temperatures that can cause freezing; mold in the material stored; or undersizing that causes blockages.

4.3.2 On-site challenges and recommendations regarding confined space risk management

The analysis of the 15 organizations' risk management practices regarding work in confined spaces focused partly on documents (i.e. program and permits) and partly on the on-site application of the prescribed measures. Quebec's ROHS and Canadian standard CSA Z1006-10 served as reference points for the analyses (Quebec Government, 2014; CSA, 2010).

4.3.2.1 Confined space management program

The content to be included in a confined space management program is detailed in section 4 of CSA Z1006-10. A list of topics that should be addressed was made and their presence verified in the collected programs, which ranged from 5 to 50 pages in length. The following topics were the least discussed in the programs (<10/15): (i) the confined space inventory and access signage, (ii) the risk assessment process, (iii) auditing of the application of the program, (iv) management of subcontractors, (v) procurement and management of risk reduction material and (vi) actions regarding prevention through design of confined spaces. The shortcomings observed in the programs were confirmed during the interviews and observations. These topics are therefore the main points that need to be developed and monitored by organizations (sections 4.3.2.2 to 4.3.2.8, Table 4.2 to Table 4.8).

4.3.2.2 Challenges with the identification of confined spaces

All the organizations visited used the definition given in the Quebec regulation to identify their confined spaces even if this definition was not formally mentioned in one-third of the programs collected. The identification of a space as a "confined space" is a source of disagreement in the organizations. Trenches are a common example. Two approaches have been observed in litigious identifications and the decommissioning of confined spaces (Table 4.2). However, a confined space that is not enclosed within the meaning of the regulation does not relieve an organization of its obligation to properly manage the risks associated with this space.

Confined spaces labeled with a sign or pictogram is an essential means of warning personnel and prohibiting entry to workers who are not qualified to work there (Quebec Government, s. 299, 2014). This point was seen to be problematic during the visits, with only partial signage or no signage posted at the entrance to the confined spaces of two-thirds of the organizations. The most problematic examples were access shafts and ventilation systems, in terms of both their number and location. Possible improvements on this point are discussed in Table 4.2.

4.3.2.3 Challenges with the workers' qualifications

The Quebec regulation states that the person responsible for assessing and reducing risks (e.g. the permit issuer), the entrant, and the supervisor must have the requisite knowledge, training, or experience. Section 7.1 of CSA Z1006-10 details the training requirements according to the worker's role.

Theoretical and practical training for the entrant was provided by all the managers in the organizations visited. However, the content and details of the training were not comparable, depending on the training service provider. For example, Organization D offered two and a half hours of training for its workers who were qualified to enter confined spaces, whereas Organization J released its workers for three days, including a full day of actual practice on the organization's installations. Complementary training for the roles of permit issuer, supervisor (e.g. measurement of gas concentrations, ventilation, fall protection measures), and rescuer were not always provided even though someone always filled these roles during entries. The main errors we observed during entries (section 4.3.2.8) occurred in the organizations where the training was not specific to the worker's role, particularly that of the supervisor. Table 4.3 presents some actions to improve training programs.

Table 4.2 : Challenges observed and possible improvements concerning identification of confined spaces

Challenges [organization where it was discussed]	**Possible improvements** [found in which section in CSA Z1006-10; organizations where it was observed]
- Identification of a space as a "confined space" or not [In almost all the organizations].	- Two approaches in case of disagreement: (i) Systematically consider the space as a confined space [H, J and O]. (ii) Obtain a written consensus between at least two qualified workers based on the three criteria set forth in the definition of confined space [s.A.17; C, D, I and O].
- Partial signage or no signage posted at the entrance to the confined spaces [A, B, D, F-K, M and O].	- Put on signage the information recommended by the standard. Where signage is not practical, formal compensatory measures should be implemented (e.g. control of the access) [s.7.2.2.1] - Provide on the signage specific information on the configuration of the confined space or the hazards identified during risk assessment. While not mandatory, when it is realistic to post such signs, it could help improve communication with the workers involved [O]. This is common practice for industrial machines (ANSI/NEMA, 2011).

4.3.2.4 Challenges with the entry permits and intervention documents

To prepare the entry permit, the permit issuer must have information about the confined space, the work to be performed, and the work environment (e.g. changing conditions, means of access). Many parameters have to be taken into consideration in choosing the appropriate means of intervention and risk reduction measures. More than half of the organizations in this study relied solely on the permit issuer's experience in this area. None of the organizations quantified the identified risks or classified the confined spaces in terms of risks. Given the complexity and diverse nature of the task of issuing permits, this practice can lead to poor assessment of the risks (e.g. overlooking or underestimating a risk) and eventually to insufficient or inadequate risk reduction measures.

Table 4.3 : Challenges observed and possible improvements concerning workers' qualifications

Challenges [organization where it was discussed]	**Possible improvements** [found in which section in CSA Z1006-10; organizations where it was observed]
Short and general training. No specific training for the dedicated roles [A, C-F, K, M and N].	Add in the training program: - competencies required for each role and the means to achieve at that competencies [s.7.1.1 and A.11; H], - measures for controlling the knowledge acquired [s.7.1.13.1 to s.7.1.13.4], - frequency and means of providing retraining [s.7.1.13.5].

This was observed repeatedly, it would seem that the prior development of a bank of descriptive fact sheets detailing the hazards inherent in each confined space and the work activities would help limit individual subjectivity by systematizing the information available to the permit issuer. These descriptive fact sheets and the rescue plan should be consolidated in the entry permit so as to limit the number of documents. For example, Organization D divided the information up into six separate documents: descriptive fact sheet, entry permit, rescue plan, reminder for the supervisor, entry register, and task analysis.

In the sample of permits and documents obtained, the most neglected points were as follows: (i) details on the hazards, as the documents often focused directly on the equipment required, (ii) verification of the workers' training, (iii) monitoring of confined space entries/exits, (iv) details on the ventilation (e.g. time to be respected prior to entry), (v) management procedures related to atmospheric testing, and (vi) the "closing" and cancelling of the permit. The main difficulties cited in the interviews in connection with permit management were the availability at all times of a person qualified to issue the permit, and the planning with other departments in cases involving joint activity, production shutdown, or the lockout/tagout of related equipment. Based on our analysis of the permits obtained and the requirements pertaining to the content of an entry permit as enumerated in CSA Z1006-10 (ss. 7.2.5.1, 7.2.5.2, Annex B.1), Table 4.4 details all the points on an entry permit designed to consolidate all necessary information. The other recommendations made in this article have also been incorporated into this form inasmuch as possible. Irrespective of the means (e.g. binder, database), section 1 of each proposed permit must be prepared in advance. Such a permit should serve as a reminder so that nothing is overlooked prior to or during the work.

4.3.2.5 Challenges with the audits

The literature suggests periodic auditing of the confined space intervention management program as well as its enforcement, to ensure continual improvement in practices (CSA, 2010; Lindsay, 1992). Such audits of program enforcement serve as vital reminders to workers and subcontractors of the importance of the rules and to correct bad habits. However, formal audits of the enforcement of the rules regarding confined space entry were observed in only one-third of the organizations visited. Table 4.5 presents recommendations concerning audits based on these organisations.

Table 4.4 : Content of an entry permit consolidating all the information required for entry

Sections/Topics		**Information to be included**
Section 1: Preparation	General	Intervention to be carried out. Work order. Date of the intervention. Name and contact information of the permit issuer.
	Identification and location of the confined space	Reference number. Type of confined space. Function. Address, room number. Information on the challenges related to accessing the confined space and the entry means needed (e.g. a confined space located inside another confined space).
	Characteristics of the confined space	Dimensions of the space (technical plan). Height. Depth. Type of access to the inside. Openings: number, location, dimensions (assessment of the entry/exit challenges). Contents: chemical products, residual materials, equipment, pipes, etc.
	Identification of the work	Purpose of the task to be performed. Anticipated duration. Number of workers needed. Nature of the tasks: which part of the confined space, tools anticipated, and source of energy.
	Hazards	By means of a checklist and by checking for possible interactions with other hazards, identify the hazards: 1. inherent to the confined space, its immediate vicinity, and possible changing conditions, 2. specific to the task. List of main hazards: - Atmospheric: poisoning, asphyxiation, explosion/fire, dust. - Mechanical and physical: electrical, moving parts, engulfment, falls from heights, falling objects, falls from the same level, thermal (surface and ambient), drowning, noise and vibration, lighting, radiation, pressure, sharp parts. - Biological/chemical: animals, bacteria, molds, viruses, fecal matter, corrosive residues/irritants. - Structure of the space: limited or restricted access or egress, solidity, obstacles, entrapment zones, mobility of the space itself. - External conditions: outside traffic, weather, work in the vicinity, accessibility, introduction of substances. - Related to the entrant: psychology/stress, physical effort/posture, constraints related to clothing/PPE. Diagram to summarize the nature and level of the risks (e.g. radar-type diagram).
	Intervention and risk reduction equipment	Checklists (technical characteristics should be specified): 1. Intervention equipment needed to access the space and perform the work. 2. Protective equipment/Specific clothing. 3. Risk reduction equipment: air quality (respiratory protection, ventilation, gas detection), fire protection, lockout/tagout, fall protection, heating/fresh air, hearing protection, lighting, safety perimeter, administrative restrictions (e.g. weather, entrant's physical and psychological conditions). 4. Supervision and rescue equipment. 5. Steps in preparation of the confined space: cleaning, purging, lockout/tagout, ventilation.
	Supervision and emergency measures	Instructions for the supervisor. Communication system to be used. Emergency procedure, including the telephone number to call and general steps to follow. Criteria for deciding whether to allow external rescue (e.g. condition of the victim, wearing of Class E safety harness) or to wait for first aiders and rescuers. Instructions on how to maintain adequate conditions and prepare for the rescuers' arrival.
	Rescue	Tested rescue plan (by whom and when) for entry rescue, provided in annex.

Table 4.4: Content of an entry permit consolidating all the information required for entry (cont. and end)

Section 2: Intervention	Issuance of permits	Date and time when permit issued. Duration of permit validity.
	Workers and training	Names and roles of the different workers involved during entry (supervisor, person taking gas measurements, entrants, etc.). Specify if a subcontractor is involved.
	Verifications prior to entry	Checklist: - Training of aforementioned workers according to role. - Physical condition of the entrants. - Information in Section 1, *Preparation,* orally communicated to the workers. - Absence of additional risks, depending on real intervention conditions. - Use and inspection of the intervention, supervision, and risk reduction equipment (use the checklist in subsection 1*, Intervention and risk reduction equipment*). - Check that the safety harness and respirator (as the case may be) are being worn properly. - Preparation planned: draining/emptying, cleaning, lockout/tagout, etc. - Fan/blower model and installation setup. Ventilation time to be respected prior to entry (Garrison, 1991). - Rescuers informed of an imminent entry (specify the telephone number).
	Management procedures related to atmospheric testing	Number of the device or instrument. Use of a sampling probe of an appropriate length and of a pump. Dates of the last calibration and last function test. Wait time to be respected for each measurement. Frequency of measurements during the intervention.
	Table for gas detection results	Each line is for one measurement: before entry (before opening; after preparation; re-entry after an exit), then periodic measurements at a specified frequency. The last line is for noting any alarms that sound. Each line can be subdivided to enter readings taken at different locations in the confined space. The columns are for entering the time of the measurement; the initials of the person responsible; and the different gas readings, specifying the permissible limits accepted by the organization.
Section 3: Monitoring	Signatures	Dates, names of the persons involved, and their signatures attesting that they have understood the instructions.
	Entries/Exits of workers	Table allowing the supervisor to monitor confined space entries and exits. One line per worker. Alternating "Time of entry/Time of exit" columns.
	Closing/Cancellation/ Prolongation of permit	"Closing" of the permit: points to be verified (e.g. inform rescuers of the end of the intervention, remove equipment and workers, remove lockout/tagout devices), date, time, comments on possible improvements/audit, name and signature of permit issuer. Plan for possible prolongation of the permit, including the reason (e.g. permit issuer has to leave the work premises and must be replaced), precautionary measures, and required signatures. Idem for a permit cancellation.

Table 4.5 : Challenges observed and possible improvements concerning audits

Challenges [organization where it was discussed]	**Possible improvements** [found in which section in CSA Z1006-10; organizations where it was observed]
No formal audits of the enforcement of the rules regarding confined space entry in two-third of the organizations visited [A-G, J, K and O].	- Respect general normative recommendations [s.8]. - Incorporate the audits into the supervisor's responsibilities. Prepare a checklist for this purpose [L, M and N]. - Introduce a safety-minded corporate culture with the presence of on-site supervisors with experience related to confined spaces (Huang *et al.*, 2014). - Record and consult gas detection readings by means of a centralized docking station [D, G, N and L].

4.3.2.6 Challenges with the subcontracting

Managing occupational health and safety of subcontractors is a legal obligation in Quebec, and the principal contractor must prove due diligence in this regard (Quebec Government, 1979). Confined space interventions are frequently subcontracted, particularly for major or specialized work requiring specific competencies. Thirteen of the 15 organizations visited in fact had external personnel (i.e. subcontractors) or themselves worked as subcontractors for some confined space interventions. Judging from the management programs obtained and the semi-structured interviews, in virtually all cases, the subcontractors were obliged to follow the same rules as the host organization and received specific information on the confined spaces. Their training was also verified on site. However, according to the on-site foremen, the subcontractors did not always follow the rules if they were not monitored during their activities and the training certification card is not enough to assess competencies. Recommendations on these points are presented in Table 4.6.

4.3.2.7 Challenges with the rescue measures

The management of residual risks in confined spaces is based on rescue with or without entry. Rescue plans were developed in this regard by the organizations visited. However, the implementation of these rescue measures poses many of its own challenges (Table 4.7).

Two-thirds of the organizations visited relied on the intervention of municipal firefighters for rescues with entry. However, for the most part, the rescue procedures provided by the municipal fire department had not been tested, as required in the Quebec regulation.

Table 4.6 : Challenges observed and possible improvements concerning subcontracting

Challenges [organization where it was discussed]	**Possible improvements** [found in which section in CSA Z1006-10; organizations where it was observed]
- Inadequacies regarding the actual use made by subcontractors of the entry permits, monitoring of gas concentrations, adherence to ventilation times, and use of the recommended personal protective equipment [D, F, H and N].	- Audit subcontractors [s.5.4.2].
- Subcontractor's training certification card is not enough to assess its competencies (Hardison *et al.*, 2014). For example, in some cases, subcontractor's administrative personnel did theoretical training sessions online on behalf of its field personnel to save time [D].	- Verify the actual integration of the knowledge acquired during training through observation of the subcontractor's work during the first contract [s.7.1.13]. One effective approach is that of the host organization issuing the permit in the subcontractor's presence, taking the first gas readings, verifying that everything is properly in place prior to entry, and remaining available to the subcontractor during the work, as needed [H and O].

In addition, some organizations estimated that there was a minimum delay of 60 to 90 minutes before victims were actually removed by municipal firefighters, taking into account the various delays detailed by Wilson *et al.* (2012).

This delay is often incompatible with emergency situations, particularly given that not all Quebec municipalities have firefighters trained in confined space rescue procedures. To reduce intervention delays, all the organizations visited have spent money in recent years to ensure that the supervisor can perform external rescues. This translates mainly into the provision of a davit arm or tripod equipped with a retrieval winch for use during vertical entries, combined with the obligation to wear a safety harness (Figure 4-3). However, external rescues are not always possible. Issues and recommendations are presented in Table 4.7.

4.3.2.8 Challenges with the use of risk reduction measures

Challenges linked to gas monitoring, ventilation, fall protection, respiratory protection and special configurations when compared to accepted practices are presented in

Table 4.8. It confirms the need for regular audits (section 4.3.2.5) and points to certain aspects requiring control. During visits, means providing an alternative to entry (e.g. camera; magnetized tools; devices for taking readings, greasing, or isolating from outside a confined space) were not yet in use. Lastly, the practice of involving the OHS coordinator at the confined space structure design stage was only just beginning in some organizations.

Table 4.7 : Challenges observed and possible improvements concerning rescue

Challenges [organization where it was discussed]	**Possible improvements** [found in which section in CSA Z1006-10; organizations where it was observed]
Rescue with entry	
- Delay for firefighters to remove victims is often incompatible with emergency situations [A-C, F, G, and J-O].	- Better communication between the organizations and their municipal emergency services department. Test of rescue procedures all together [ss. 6.6.3 and 6.6.4] - Rely on a share or on-site, properly equipped and trained, professional firefighting team, who developed and tested the rescue procedures [D, E, H and I]. However, it demands financial outlays that are difficult for the smallest organizations to assume.
External rescue	
- External rescue cannot take place if moving the victim would aggravate his or her condition. - The worker cannot always attach his or her harness to the winch because of obstacles, the work to be performed, the shape of the confined space, and the penetration distance. - Horizontal entries pose different rescue constraints than vertical entries and are sometimes neglected.	- Define in the management program the criteria for deciding whether to allow an external rescue or wait for the arrival of first aiders and rescuers [I]. - Train supervisor to perform external rescue and manage the organization of this intervention [ss. 7.1.9 and 7.1.10]. - Define more clearly the measures required to prepare for the first aiders' arrival and to stabilize the victim's condition, whether inside or outside the confined space.
- Less costly Class A harness is often used (dorsal D-ring; victim bent during removal) [In almost all organizations].	- Use Class E safety harnesses (shoulder D-rings) that allows both to keep the victim straight during a vertical rescue and to remove the person through a restricted entry (CSA, 2012).

Figure 4-3 : Tripod and winches for fall protection and external rescue; wearing of a Class A harness

Table 4.8 : Challenges observed and possible improvements concerning the use of risk reduction measures

Challenges [organization where it was discussed]	**Possible improvements** [found in which section in CSA Z1006-10; organizations where it was observed]
Gas monitoring	
- No measurements (i) of flammable gases, before opening the confined space, or (ii) during entry after the lunch break [B, C, F and I].	In order to manage these issues, the maintenance and use of detectors should be centralized in the hands of a small, trained, experienced team within an organization [ss.7.2.8 and A.14; H].
- Calibration not up to date (e.g. standard reference gas expired) [C, G and N].	
- No respect of the length of time required for measuring gas [I and L]	
- Insertion of the detector into the confined space instead of using a probe [In almost all organizations].	
- Workers not always aware that only four gases are measured by the current detectors, and that a difference of only a few tenths of a percentage relative to the standard 20.9% oxygen concentration can mean a serious source of contamination by a gas not targeted [F, K, M and N].	
- Workers relied mainly on the alarms sounding and not on variations in the gas concentrations (e.g. gas detector left all day long in the confined space with no readings taken and no battery checks) [K, J and N].	
- Very little use of the complementary photoionization detectors, designed mainly for volatile organic compounds such as solvents [D, E, G and M].	
Ventilation	
- No information available on the configuration required, ventilation time needed prior to entry and the continuous ventilation needed to control air quality [In almost all organizations].	- Carry out analysis of the ventilation configuration to be put in place for optimal purging and elimination of pockets of contaminants [ss.7.2.9.3 and A.15]. - If changes are planned, consider integrating permanent ventilation ducts into the structure, taking the space configuration into account and the types of work anticipated [ss.6.2.1.3, 6.4.2.3, A.3 and A.7].
Fall-protection	
- Difficulties during the installation of davit arms and guardrails due to the volume and the weight of equipment [B, D, F, G, K, L and N].	- Integrate bases and anchor points directly into the structure (Figure 4-4) [ss.6.2.1.3, 6.4.2.3, A.3, and A.7). Use a dedicated cart [G and H].
- Harness not worn or not attached during the intervention [B, C, E, F, H and I].	- Carry out regular audits [ss.4.5 and 8.2].
- Possible falling objects [C and K].	- Clean the area next to the entry, protect openings, and plan a method for lowering tools into the space [s.7.2.3].

Table 4.8 : Challenges observed and possible improvements concerning the use of risk reduction measures (cont. and end)

Respiratory protection	
- Uncertainties about the need to wear a half-facepiece respirator and its fit (e.g. with glasses or men not clean-shaven) [A, D and E].	- Risk evaluation [ss.6.3, 6.4 and 7.2.10]. - Carry out regular audits [ss.4.5 and 8.2].
- Storage of partially used in the open air [A and D].	- Follow manufacturer's instructions. [s.7.2.10]. Use a zipper storage bag [A and D] .
Special configurations	
Ensuring communication, rescue and gas monitoring in big penetration space (e.g. crawl spaces) or a confined space within a confined space (e.g. an oil tank in an underground technical room) [A, C, D, H, I and J].	Place a supervisor with first-aider training who could relay information between entrants and the surface supervisor in the confined space [I and J].

Figure 4-4 : Integration of a davit arm base, as well as a permanent ladder and guardrail

4.4 Conclusion

Our analysis of the 32 investigation reports and 40 fatalities associated with confined spaces in Quebec between 1998 and 2011 allowed us to identify a number of risk factors. The number of fatal incidents attributable to a problem with controlling hazardous energies related to machinery in the confined space revealed the prevalence of mechanical hazards in these spaces. On this topic, Chinniah (2015) proposes prevention strategies based on the analysis of serious and fatal accidents related to moving parts of machinery. Thus, it would be in the interests of OHS personnel and workers involved in confined space work to expand the scope of their actions beyond atmospheric hazards. Moreover, the conditions under which confined spaces are to be used and the tasks to be performed there must be envisaged right from the design stage in order to eliminate or limit the hazards at that time (CSA, 2010; ANSI/ASSE, 2011a; Bluff, 2014; Fadier & De la Garza., 2006). Access conditions and adequacy of the equipment control system are examples of potential problems identified in our accident analysis. Lastly, it is absolutely clear that the lack of an entry and rescue procedure translates into poor knowledge of the hazards on the part of the workers. Risk management, with the implementation of a program, training, permits, and other elements, thus appears to be a necessary exercise. However, as shown by our analysis of risk management for confined space interventions in 15 Quebec organizations, an additional permit system is not an end in itself. A safety culture is required to make the administrative procedures really efficient and to minimize risks. For example, direct manager and worker participation in the process of implementing the procedures ensures a greater level of commitment and adherence to procedures (Antonsen *et al.*, 2008). Audits are also a means to achieve this. Those points are consistent with Kletz (1998) who reports that many accidents have occurred when people were working inside confined spaces, either because the procedures for entering confined spaces were inadequate or were not enforced.

Our observations revealed that the organizations appear to have neglected, in terms of both prescribed directives and actual practices (i) the management of subcontractors, (ii) audits focusing on the use of risk reduction means and (iii) the integration of prevention through design. Furthermore, the lack of guidelines limited the actual effectiveness of measures related to training, rescue, and the preparation of entry permits. The preparation work prior to issuance of the permits (e.g. risk assessment) should normally reduce subjective decision-making and allow any two different permit issuers to take equivalent risk reduction measures in a given situation. This article therefore proposes a permit that consolidates all the information needed to prepare for a confined space entry and allows for follow-up on training verification, gas monitoring and measurement, risk assessment, emergency response measures, and possible feedback. It also recommends to optimize the use of ventilation, assist subcontractors and to provide clearer guidelines regarding the use of external rescue, which has gained importance in emergency response plans in recent years. Work is currently being carried out to formalize more systematic tools for assessing and communicating information on the risks associated with confined space interventions.

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CHAPITRE 5 ARTICLE 3: DESIGN AND APPLICATION OF A 5 STEP RISK ASSESSMENT TOOL FOR CONFINED SPACE ENTRIES

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Abstract: Many serious accidents related to work in confined spaces still occur. Despite all the regulatory and standard-setting efforts that have been made, organizations seem to have difficulties with risk assessment for interventions in confined spaces. Risk identification and estimation were not carried out in most of fatal accidents. This paper proposes a 5 step risk assessment tool for confined spaces based on risk management standards. The tool was tested by 22 experts in managing entries in confined spaces, including experts during 10 visits in different organisations. Step 1 consists of a questionnaire to describe the configuration of the selected confined space, its environment and the work situations. The answers generate predefined types of risk such as mechanical, atmospheric, falling, chemical, biological, etc. Step 2 describes the components of risks (i.e., hazards, hazardous activity, hazardous event, harm). Step 3 estimates risk using adapted risk parameters and matrix. Step 4 categorizes the intervention by class and level of risk. Step 5 is a feedback loop for estimating residual risks after risk reduction measures have been taken. This tool enables to (i) carry out comprehensive risk identification by analyzing all the risk factors during an intervention in a confined space, (ii) categorize interventions and rescue conditions by using specific criteria, (iii) determine if two situations are indeed identical in terms of risks, (iv) decide if intervention planned meets the permit required confined spaces definition, (v) evaluate if external rescue is feasible, and (iv) decide if the residual risks are acceptable. This tool applies both to the design of confined spaces and to the assessment of existing ones.

Keywords: Confined space, Risk assessment, Risk estimation, Risk reduction

5.1 Introduction

Many industrial processes involve work in confined spaces. Reservoirs, silos, vats, manholes, pits, sewers, piping, crawl spaces and tanks are all common examples of confined spaces in industry (NIOSH, 1994). A confined space is defined in the United States Occupational Safety and Health Administration (OSHA) regulation as “a space that: (1) is large enough and so configured that an employee can bodily enter and perform work; (2) has limited means of entry or egress; and (3) is not designed for continuous employee occupancy” (U.S Department of Labor, OSHA, 1993). A more or less similar definition can be found in regulations from different countries and from different provinces in Canada. For example, the Quebec Regulation on Occupational Health and Safety (ROHS) defines an enclosed area as “any area that is completely or partially enclosed, […], which has the following inherent conditions: (1) is not designed for human occupation, nor intended to be, but may occasionally be occupied during work; (2) access to which can only be made 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; (b) its atmosphere or insufficiency of natural or mechanical ventilation; (c) the materials or substances that it contains; (d) or other related hazards” (Quebec Government, 2014). Workers who enter these confined spaces are exposed to potentially high risks because of the confinement, inadequate natural ventilation, and access, rescue and communication problems (CSA, 2010). Studies have pointed out the risks of poisoning in the agricultural, construction and transportation sectors (Fuller and Suruda, 2000; Dorevitch *et al.*, 2002; Svedberg et al, 2008; Riedel and Field, 2013). Between 1992 and 2005, an average of nearly 38 deaths occurred per year in the United States due to poisoning or asphyxiation in confined spaces. Twenty percent of these events resulted in several deaths (Wilson *et al.*, 2012). An exhaustive analysis of the fatal accidents that have occurred in confined spaces in Quebec also illustrates the major role played by other hazards. For instance, moving parts of machinery count for 20% of the fatalities involving confined spaces, engulfment for 15%, fall from height for 12,5% and falling objects for 12,5% (Burlet-Vienney *et al.*, 2014).

If there is a potential serious hazard in a confined space, then an employer in the United States must comply with the Permit-Required Confined Space (PRCS) regulations, which cover the implementation of a management program, employee qualifications, risk identification, atmospheric monitoring, mandatory supervision and rescue procedures (U.S Department of Labor, OSHA, 1993). Serious hazards are defined in ANSI/ASSE Z117.1-2009 as conditions which may cause death, temporary impairment, functional disorder, or an inability to exit the space (e.g., hazardous atmosphere, engulfment, internal configuration such that an entrant could be trapped or asphyxiated, any other recognized serious safety or health hazard) (ANSI/ASSE, 2009). The information on the risks and the preventive measures must be available in writing at the work premises and explained to the worker(s) before entering a confined space. Canadian standard CSA Z1006-10 and the American ANSI/ASSE Z117.1-2009 on confined space risk management provide additional guidelines regarding roles and responsibilities of those involved, related planning (e.g. training, emergency response plan), program implementation (e.g., entry permits), and risk assessment (CSA, 2010; ANSI/ASSE, 2009). Risk management for confined space entries in other countries is described in a literature review by Burlet-Vienney *et al.* (2014) where 77 peer-review documents were analysed. Several technical guides have been published in Europe and Australia (Health and Safety Executive, 2013; Guilleux and Werlé, 2014; Government of South Australia, 2011) and there is also one standard on confined space management from Australia (Standards Australia, 2001).

CSA (2010) defines risk assessment 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." When confronted with the actual constraints and limited resources in the field, risk assessment (i.e., risk identification, risk estimation and risk evaluation) and procedures can prove difficult to implement. Chinniah (2015) reports the same issues with risk assessment for industrial machines. For example, in most of the fatal confined space accidents in Quebec between 1998 and 2011, the investigation report clearly mentioned a problem with identifying the hazards or underestimating the risks (Burlet-Vienney *et al.*, 2014). Kletz (1998) also reports that many accidents have occurred when people were working inside confined spaces, either because the procedures for entering confined spaces were inadequate or were not enforced. Moreover, a study on 15 organizations that have implemented a confined space entry management policy reveals that over half of them did not conduct any preparatory analysis (e.g., risk fact sheets) before issuing an entry permit and relied solely on the experience of the permit issuer. In certain circumstances this approach can lead to poor risk assessment (e.g., omission or underestimation) and possibly to inadequate risk reduction measures. These field visits also revealed that most rescue procedures had neither been tested nor made available to the local fire department (Burlet-Vienney *et al.*, 2015a).

In addition, a literature review on confined space risk management reveals that some concepts present in regulations and standards are imprecise or difficult to use (Burlet-Vienney *et al.*, 2014). For example, the concepts of serious risk (i.e., PRCS), similar confined space and classes of confined spaces lack precise and objective criteria to reach a decision. Besides, these concepts have not been studied. Risk estimation as referred in standards apart from atmospheric hazards was not carried out. None of the organizations quantified the identified risks. On the 77 peer-review documents retained, only 22 tackled overall risk estimation. Other documents are limited to risk identification or atmospheric risks. Of these 22 papers, 9 suggest practical tools for estimating risks. These tools are either matrices or risk scales (e.g., low, medium, high). The main problem of scales is that there is no criterion to choose the level of a risk (Maritime and Coastguard Agency, 2010; Government of South Australia, 2011). Moreover, if a list of risks is suggested, it is often incomplete (NIOSH, 1994; British Compressed Gases Association, 2009). Matrices suggested gives more guidance to estimate risks but remain generic (Rekus, 1994; UK Ministry of Defense, 2010; Standards Australia, 2001). Definitions used are vague and parameters are not adapted to the particular characteristics of confined spaces (e.g., multiple types of risks, real rescue conditions, interactions among hazards) and no list of hazard suggested. ISO 31010 (2009) recommends that a matrix should be designed to be appropriate for the circumstances. The architecture of these matrices also contains flaws (e.g., not even distribution of risk levels in the matrix) (Gauthier *et al.*, 2012; Duijm, 2015).

The most essential roles in accident prevention are played by organizational factors, such as safety management and operations planning (Lind, 2008). A safety culture is required to make the administrative procedures really efficient and to minimize risks. For small and medium sized enterprises, Reinhold *et al.* (2015) suggest that using a supportive tool to assess the hazards and following the hierarchy of safety control measures could be an element for success. Caputo *et al.* (2013) and Blaise *et al.* (2014) are recent example of development of supportive approach for selecting safety devices of industrial machines and safe maintenance operation respectively. The objective of this study is therefore to design a risk assessment tool for confined spaces that addresses the deficiencies observed in the literature and on the field. This tool should allow carrying out multidisciplinary and comprehensive risk identification, estimating risks, categorizing interventions, predetermining rescue conditions and evaluating impact of risk reduction measures with objective criteria. This tool is based on five main stages prescribed in risk management standards: (i) characterization of the situation, (ii) hazard identification, (iii) risk estimation, (iv) risk evaluation and (v) risk reduction. It can be used as preparatory work done prior to the issuing of an entry permit.

5.2 Method

Risk management standard ISO 31010:2009 as well as ANSI/ASSE Z690.3 were used as guidelines during the development of the tool (ISO, 2009; ANSI/ASSE, 2011b). The standard on machine safety ISO 12100 (2010) and occupational hazards from the model developed by Aneziris *et al.* (2013) for managing risk owing to contact with moving parts of machinery were also used, as they include additional concepts related to mechanical and physical risks. To meet the identified requirements, a list of questions is needed to characterize the confined space work; an exhaustive list of hazards and related accident processes are required to identify hazards; an adapted method for estimating risks is required; and summary of the results of the risk estimation is needed.

Five experts in confined spaces from Quebec provided feedback during the development of the tool. They were in charge of managing confined space at their respective organizations, provide training on risks associated with confined spaces and entry permits, provide technical support to various organizations, validate permits and investigate accidents linked to confined spaces. Moreover, the tool was tested in 10 organizations in Quebec having confined spaces and which manage such entries. The tests were conducted between September and December 2014, and participant confidentiality was guaranteed. Most of the organizations that agreed to take part in the study were large (> 100 employees), private-sector (8/10) organizations. A variety of economic sectors and types of confined spaces were chosen (Table 5.1). The 17 safety professionals from those 10 organizations applied the tool to 10 confined spaces. They were guided by two members of the research team. The tool was implemented using Excel spreadsheet software. A questionnaire consisting of open-ended questions was also used by the researchers. The questions mainly concerned the structure, logic and complexity of the tool, the parameters used at the different stages, the results obtained and possibilities for improvement. Validation of the tool was done iteratively. From one test to the next, the tool was improved on the basis of the comments received from the organizations. Thus, the version of the tool presented in this paper incorporates inputs from 22 experts/practitioners in confined spaces. Details on how the tool was designed are presented in each of the 5 steps in the next section.

5.3 Results and discussions

To provide a concrete example of the tool, an accident investigated under the Fatality Assessment and Control Evaluation (FACE) program, run by the National Institute for Occupational Safety and Health (NIOSH), was selected (NIOSH, 2014). In brief, this workplace accident involved a welding repair job inside a truck tank compartment (Figure 5-1). The worker died following an explosion in the compartment next to the one where he was working. Only the worker's compartment was ventilated. Beforehand, the tank had been steam-rinsed and allowed to cool following a diesel delivery. As no work procedure was established during the work, the recommendations issued at the end of the investigation referred to the regulatory principles associated with the PRCS. The proposed tool is applied to this case study in the following sections.

Table 5.1 : Sample of the 10 organizations visited for the application of the risk assessment tool designed

	No. employees	**Sector of activities**		**Type of confined space**	**Work covered**
A	>1000	Private	Construction	Trench	Equipment installation
B	50-100	Private	Transportation	Truck tank	Cleaning
C	>1000	Private	Transportation	Manhole (sewer)	Replacing pump
D	>1000	Private	Equipment manufacturing	Reservoir	Welding
E	>1000	Private	Pulp and paper	Pulp mixer	Replacing bearings
F	>1000	Private	Oil and gas	Distillation column	Welding
G	>1000	Private	Transportation	Reservoir	Cleaning
H	>1000	Public	Municipal	Reservoir	Cleaning
I	100-500	Private	Construction	Manhole (electrical)	Demolition
J	>1000	Public	Municipal	Incinerator smokestack	Inspection

Figure 5-1 : Tanker wash facility (NIOSH, 2014)

5.3.1 Step 1. Characterization of confined space work

To identify all the root causes of confined space work hazards, cause-and-effect diagrams were used (Ishikawa, 1979). This method proposes reviewing the causes of an event on the basis of five categories: machine, material, environment, method and manpower. When this technique was adapted to the context of confined space work, the aspects considered in the tool were (a) general information, (b) the configuration of the confined space (machine), (c) its environment, (d) the work to be done (material, method) and (e) the workers (manpower). For each of these aspects, closed-ended questions with a choice of possible answers were developed to characterize all risk situations and not just those related to the structure of the confined space. The questions, applied to the selected accident example, are presented in Table 5.2.

Table 5.2 : Questionnaire for characterizing risk situations for confined space work applied to the 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 a 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 it 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): 12 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 the confined space have? What are the dimensions of each entrance?**
   ☒ 1 ☐ 2 ☐ 3 ☐ > 3
   Shape: ☒ Round ☐ Rectangular; Dimensions: ☒ < 610 mm (24 in) 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 ☐ N/A
   ☐ Horizontal
   - Means of access:
   - Condition of means of access: ☐ Good ☐ Poor ☐ Very poor ☐ N/A

Table 5.2: Questionnaire for characterizing risk situations for confined space work applied to the example (cont.)

5. Does the design of the confined space involve one or more of the following risk situations?
   ☒ Inadequate natural or mechanical ventilation**
   ☒ Restricted interior volume, limiting possible movements in the 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 significant slope*
   ☐ Presence of confining areas because of converging walls or funnel shape**
   ☐ Presence of structural weaknesses such as cracks, collapse, corrosion, offset entrance**
   ☐ Presence of sharp, pointed structural features**
   ☒ Inadequate light (see Schedule VI, Quebec Government, 2014)**
   ☐ Extreme temperature/humidity (see Schedule V, Quebec Government, 2014)
   ☐ High noise level (without work) (see sections 131 and 134, Quebec Government, 2014)**
   ☐ Other:
   ☐ None of the above

6. Does the habitual use of the confined space involve one or more of the following risk situations?**
   ☒ Presence of toxic agents or asphyxiants
   ☒ Presence of flammable products or explosives, of combustible dust
   ☒ Presence of corrosives, irritants, reagents or carcinogens
   ☐ Presence of decomposition products, sediments, residues, slow oxidation products (e.g., rust)
   ☐ Presence of mould/fungus or various biological pathogens (e.g., dirty objects)
   ☐ Presence of animals, insects, allergens
   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 piping or drains that must be locked out or blocked off (i.e., blanking to reduce risk of uncontrolled introduction or return of products, risk of drowning, equipment upstream/downstream)?**
   ☒ Yes ☐ No If so, specify: Openings for drainage locked in open position

8. Is there any equipment permanently installed in (or running through) the confined space 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 engulfment?**
   ☐ Yes ☒ No If so, specify:

C. Environment (section to be filled in once)

10. Is the access to the confined space... ?** (Check all that apply)
   ☐ 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 risky restricted access room
   ☐ None of the above

11. Is the work area around the entrance... ? (Check all that apply)
   ☐ Exposed to road traffic or to a roadway within a facility
   ☐ Exposed to other workers
   ☐ Exposed to the public
   ☐ Exposed to weather conditions (e.g., bad weather, outdoor temperatures)
   ☐ In a work area (e.g., workstation with stationary or mobile machine in operation)
   ☒ 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 might have an impact on the conditions in the confined space?
   ☒ Yes ☐ No If so, specify: Vehicle repairs

13. Are hazardous materials being stored in an adjacent reservoir/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], etc.)?**
   ☐ Yes ☐ No If so, specify:

Table 5.2: Questionnaire for characterizing risk situations for confined space work applied to the example (cont. and end)

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:
Work description: 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

17. Does the job (entrance to space and work) require any particular experience/expertise?
☒ Yes ☐ No If so, specify: Welding

18. Does the job (entrance to space and work) require any particular physical condition or mental health? Examples: 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 a year ☐ Annually
☐ 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 time, < 30 minutes ☒ Less than one shift ☐ Longer than one shift
☒ Day ☐ Night

22. Are there time constraints on the work (e.g., very short, other department waiting, essential public service) that put pressure on the people performing it?
☐ 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 work is to be done?*
☒ Vertical only ☐ Horizontal 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 risks? (Check all that apply)
☐ High-pressure cleaning**
☒ Hot work (e.g., welding)**
☐ Working at heights**
☒ Using specific tools [excluding those for hot work](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 PPE (e.g., visibility, sweating)
☐ Other:
☐ No additional risk

26. During the work, can the worker's harness be fastened at all times to a lifeline solidly secured to an anchoring point outside the confined space?*
☒ Yes ☐ No

The concepts and vocabulary used in the Quebec Regulation, which is equivalent to the OSHA regulations in the United States, were given priority (Quebec Government, 2014). The questions about confined space configuration mainly concern entry and egress, internal configuration, past content, mobility, natural ventilation, equipment contained in the space and piping. The questions about the environment refer to the conditions of access to the confined space, the configuration of the area around the entrance, adjacent work and changing conditions. Lastly, the questions about the work to be done and the people doing it focus on the material and human resources required for performing it. Some answers could be subjective without measures (e.g., noise, lightning, temperature). The answers provide a comprehensive profile of the situation.

This first stage then serves to generate a list of potential situation-related risks using a conversion table that associates each answer with potential hazards (Table 5.3; hazards related to the selected accident example indicated in italic). The conversion table was created on the basis of a consensus among the members of the research team. The hazards were grouped into 7 classes: atmospheric, chemical, biological, falling, mechanical, physical and ergonomic. This breakdown is based on the hazard-related accident process and the relative importance of certain kinds of hazards in the accidents (e.g., mechanical, falling) (Burlet-Vienney *et al.*, 2015a).

Table 5.3 : Mapping between answers given at work characterization stage and potential risks

Q.	**Answers**	**Risk class**	**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*
5	*Limited interior volume*	*Ergonomic*	*Work posture, psychology/stress*
	Hard to move around	*Falling*	*Fall on same level*
		Ergonomic	*Internal layout*
	Presence of converging walls	Ergonomic	Internal layout
	Presence of structural weaknesses	Mechanical	Structural failure
	Presence of sharp structural features	Mechanical	Sharp objects
	Inadequate light	*Ergonomic*	*Inadequate light/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 corrosives, irritants, etc.	*Chemical*	*Irritants/corrosives, 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 biological pathogens	Biological	Viruses, bacteria, protozoa, toxins, parasitic and other worms, moulds, fungi
	Presence of animals, insects, etc.	Biological	Viruses, toxins, bites
		Ergonomic	Psychology/stress
7	*Yes (piping, drains)*	*Chemical*	*Irritants/corrosives, reagents, toxic or carcinogenic products*
		Physical	*Drowning, heat (temp. of material)*

Table 5.3: Mapping between answers given at work characterization stage and potential risks (cont. and end)

8	Yes (lockout)	Mechanical	Moving parts, flying particles, parts 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, ambient pressure*
		Falling	*Fall from height*
	Entrance in another confined space	Ergonomic	Access, inadequate light/visibility
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 constructed	*Falling*	*Fall on same level*
12	*Yes (work nearby)*	*Atmospheric*	*Poisoning, asphyxiation, explosion/fire*
		Chemical	*Irritants/corrosives*
		Mechanical	*Flying particles, outside traffic, structural failure*
		Physical	*Heat, noise*
13	Yes (hazardous materials stored)	Atmospheric	Poisoning, asphyxiation, explosion/fire
		Chemical	Irritants/corrosives, reagents, toxic or carcinogenic products
14	Yes (changeable conditions)	Atmospheric	Poisoning, asphyxiation, explosion/fire
21	Night work	Ergonomic	Inadequate light/visibility
	Work is not short in duration	*Ergonomic*	*Physical exertion*
22	Yes (time constraints)	Ergonomic	Psychology/stress
25	High-pressure cleaning	Mechanical	Flying particles
	Hot work (e.g., welding)	*Atmospheric*	*Poisoning*
		Physical	*Electricity, Heat, optical and ionizing radiation, Noise*
	Working at heights	Falling	Fall from height
	Use of specific tools [excluding hot work]	*Mechanical*	*Moving parts, sharp objects, parts with potential energy, flying particles*
		Physical	*Electricity, optical and ionizing radiation, heat, noise*
	Setting up temporary lighting	*Physical*	*Electricity*
	Use of a generator	Atmospheric	Poisoning
		Physical	Noise
	Use of chemicals	*Chemical*	*Irritants/corrosives, 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*

Answers to the questions also suggest a characterization of rescue conditions based on two concepts: (1) rescue without entry is possible or not, and (2) the prevailing conditions make a rescue with entry more complex or not. Based on the work of Wilson *et al.* (2012), for a rescue without entry to be possible, penetration into the confined space must be primarily vertical, the path obstacle-free, the contact between worker and attendant must be maintained at all times, and the workers must be secured at all times by their harnesses to a lifeline. The questions related to these aspects (Q. 4, 5, 23, 24, 26) are marked with an asterisk in Table 5.2. The presence of complex conditions affecting a rescue operation requiring entry is dealt with under 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 risks in the confined space (Q. 5–9, 14, 25). These aspects are marked with a double asterisk in Table 5.2. In the accident used as an example, a rescue without entry seems possible, provided the compartments are not an obstacle to retrieval of the victim.

Lastly, this first step help determine, by means of precise criteria (i.e., comprehensive list of risks, recue conditions), whether two situations (i.e., confined space, environment and work) are indeed identical in terms of risks.

5.3.2 Step 2. Identification of hazards and related accident process

From the list of hazards generated in the previous step, 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, Appendix C) to descriptions of the events and circumstances that led to the accident, used in machine safety (i.e., hazard, hazardous situation, hazardous event, possible harm) (ANSI/ASSE, 2009). It was concluded that a checklist was not an effective way of determining in what context a hazard might have an impact. Providing a full description of the events and circumstances that led to the accident may be too complex a task, if no supervision is available. A table based on the accident description approach was therefore developed by simplifying the information required (splitting up one complex column into several simpler ones) and supplying lists of possible choices in order to obtain standardized answers (Table 5.4). The lists of possible answers were drawn up on the basis of Annex B of standard ISO 12100:2010 on the safety of machinery (ISO, 2010). Interactions between hazards can be dealt with by means of the “Hazardous event” (initiating event) column. Workers implied are also specified. The result is presented in simplified form in Table 5.4 for a few hazards relating to the accident example and especially for those relating to welding and the presence of diesel residue (Carlton and Smith, 2000; Flynn and Susi, 2009). The information related to hazards (i.e., origin, class, type, specifics) is automatically extracted from the conversion table (Table 5.3).

Table 5.4 : Identification of risks and related accident processes applied in part to the selected confined space accident example

Hazards				**Activities**			
Origin	Class	Type	Specifics	Hazardous action	Who	Hazardous event	Harm
	(filled in automatically)			- Position: Being nearby; Being in; Being in the path of; Being exposed to - Action: Go up/down; Use a tool; Carry a load	- Entrant - Attendant - All workers	3 possibilities: - Sudden event - Access, contact with hazard - Abnormal exposure	See ISO 1210 Annex B(14)
Confined space	Atmospheric	Poison	Diesel residue	Being in tank	Entrant	Abnormal concentration	Headache
Confined space	Fall	Fall from height	Entry at height	Climbing on tank Being on tank	Entrant Attendant	Slip	Fracture, death
Confined space	Ergonomic	Entry/ egress	Opening < 24"	Being in tank	Entrant	Having to strain too much to enter	MSD, bruising
Confined space	Mechanical	Mobile space	Space fixed to a vehicle	Being on, in or near the tank	All workers	Accidental start-up	Bruising, fracture
Work to be done	Atmospheric	Explosion/ fire	Welding-related energy	Being in tank	Entrant	Concentration > 10% LEL	Death
Work to be done	Physical	Optical radiation	Welding	Being exposed to radiation	Entrant	Abnormal exposure	Visual disorder

5.3.3 Step 3. Risk estimation

As mentioned in introduction, risk estimation tools available in the literature on confined spaces can be improved in particular by providing criteria to manage specific issues like the diverse nature of risks to take into account for the severity, influence of the rescue conditions, real exposure to hazards (Burlet-Vienney *et al.*, 2014).

As the risk estimation matrix presented in the Australian standard AS/NZ 2865:2001, is the only one proposed in a standard on confined spaces (Table 5.5), this tool served as a starting point and was modified (Standards Australia, 2001). The matrix was generic and not necessarily adapted to confined spaces. Recommendations for designing risk estimation tools from the literature were used. They cover a large range of issues like the architecture of the matrices (ISO, 2010; Duijm, 2015; Chinniah *et al.*, 2011; Gauthier *et al.*, 2012; Cox, 2008), the subjective assessment of parameters and the scaling of the discrete likelihood and consequence categories (Carey and Burgman, 2008; Patt and Schrag, 2003; Hubbard and Evans, 2010). The criteria used for the parameters were: (i) keep the estimating process simple; (ii) avoid defining levels too strictly, 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., most likely or potential consequence;

time reference for the probability of occurrence); (iv) use between three and five levels for the severity and probability of occurrence of the harm; (v) avoid discontinuities or gaps between the levels for each parameter; (vi) avoid using vague, unexplained terms to define levels; (vii) select all the risks on the same scale of severity and probability to ensure consistent estimates. Table 5.6 and Table 5.7 give the details of the modified severity and likelihood scales. For the severity of the harm, the definitions of the levels are made clearer with a description and some examples. The severity of harm was considered unlike the matrix from the standard with combined harm to workers and damage to the site (i.e. environmental consequences). In addition, references based on international regulatory values, or values adapted to the Quebec context, have been added for each type of hazard to ensure consistent estimates using actual values for variables whenever possible, as shown in Table 5.6. For the probability of occurrence of harm, the duration of work was used as the time reference, to reduce the number of factors to be considered. In addition, the level of probability *Moderate* has been removed in order to better break down answer choices (i.e., reduce overlapping). Finally, in machine safety the probability of harm is a combination of frequency and duration of exposure to the hazard, probability of occurrence of the hazardous event and possibility of avoiding or limiting the harm. A similar approach is used to suggest additional factors to take into account as shown in Table 5.7.

Table 5.5 : Risk matrix proposed in the Australian standard on the management of risks in confined spaces (Informative Appendix)

	Consequences				
Likelihood	**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 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.

Table 5.6 : Proposed severity of harm scale with 5 levels defined more clearly and factors associated with each type of hazard

Harm level	**Description** – Most severe harm that could result
Negligible	Not requiring first aid
Minor	Requiring medical treatment without loss time Examples: scratches, bruises, slight irritation
Serious	Requiring medical treatment with loss time Examples: sprain, simple fracture, vomiting, burn
Major	Major trauma, long-term disability Examples: multiple fractures, amputation, acute respiratory system damage
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 m (Quebec Government, 2014).

Mechanical

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

Note: For example, standard ISO 14120 (2002) on guards suggests forces (max.) of 75–150 N and kinetic energy of 4–10 J to reduce the risk of injury (ISO, 2002).

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 vibration

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 1 second or more (CSA, 2015).

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

Noise: The ROHS gives regulatory values for Quebec (e.g., max. 90 dBA for 8 hours' exposure) (Quebec Government, 2014).

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, 2013). 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 hour. It is 4 m/s^2 for 4 to 8 hours' exposure (ACGIH, 2013).

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 (Quebec Government, 2014).

Table 5.7 : Proposed probability of harm scale with 5 levels defined more clearly and factors to consider

Probability	**Description** – Likelihood of harm occurring during work
Very likely	Harm is almost inevitable during the work.
Likely	Harm may occur during the work.
Unlikely	Harm should not occur during the work.
Very unlikely	Harm not foreseen.

Factors to take into account

- Exposure to hazards
  - Total length of work (e.g., atmospheric, biological, chemical, ergonomic risks)
  - Length of use of certain equipment (e.g., mechanical, physical risks)
  - Expected number of times entering and exiting (e.g., risk of falling)
  - Number of workers exposed
- Probability 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 content
  - Possibility of changeable conditions
- Possibility of avoiding or limiting harm
  - Knowledge acquired about confined space and work to be done
  - Maintenance of confined space
  - Physical and psychological conditions required of entrant

The results given by the Australian matrix (i.e., estimated level of risk) were also adjusted, taking into account recommendations about the breakdown of risk levels in a matrix (e.g., even distribution of risk level in the matrix; leaps between risk levels in the matrix should be no more than one risk level change between adjacent cells) (Cox, 2008; 2009; Gauthier *et al.*, 2012). However, rather than take a totally theoretical/quantitative approach, the breakdown took into account the actual definitions of the different levels of the two parameters (Table 5.8). For instance, a severity estimates *Negligible* cannot correspond to a high risk level (i.e., levels 3 and 4). Finally, the denomination of the 4 levels of risk in the Australian matrix (i.e., low to high) was replaced by numbers for not influencing the risk evaluation step (i.e., acceptable risk).

Table 5.8 : Proposed risk estimation matrix

Probability 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

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, depending on whether a rescue without entry is possible or not. In fact, the rescue process can only occur after the risk has materialized.

5.3.4 Step 4. Summary of estimation

The purpose of the summary stage was to allow quick communication of the risks associated with the work in question. The chosen approach provides a comprehensive presentation of the situation using the data on the risk classes involved, their risk levels and origin. This categorization is a mix of those suggested in the literature (e.g., by risk level or nature of risk). Thus, the radar chart was chosen for the visual representation of the data. The radar spokes correspond to the 7 classes of risk as shown in Table 5.3. The value associated with a risk class (i.e., 1 to 4) corresponds to the maximum risk level reached among the risks it includes. The maximum approach is the strictest, because it means that all the risks of a risk class associated with the highest level must be reduced in order to bring down the risk level of that class. Figure 5-2 shows the summary for the accident example presented earlier. Without risk reduction measures, the predominant forms of risk in this example are atmospheric (explosion, poisoning), falling from heights, mechanical (mobility of the space) and physical (radiation, heat, noise). The chart could be split into two that break down the risks depending on whether they are (i) inherent to the confined space and its environment (Table 5.2, Q. 1–14), or (ii) related to the work to be done (Table 5.2, Q. 15–26). As additional information, an index keeps track of the risk classes among the seven that exceed an acceptable risk threshold set by the organization and for which action will have to be taken (e.g., greater than level 2). A (+) is added to this figure if a rescue without entry is not possible. The index value therefore ranges from 0/7 to 7/7+. As soon as the index is greater than 0/7 without risk reduction measure, the case should be considered as a PRCS. This index therefore provides an objective criterion to meet the concept of serious risk outlined in the US regulation (which allows differentiating between a PRCS and a Non-PRCS). For the selected accident example, if the acceptable risk is set at level 2 and if rescue without entry is possible, the index would be 4/7 (atmospheric, trips and falls, mechanical, physical).

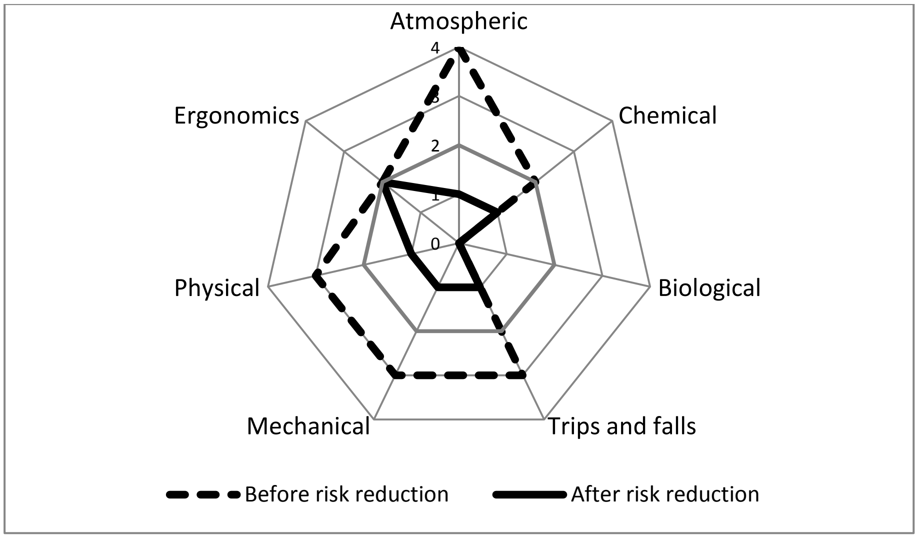

Figure 5-2 : Summary of risk estimation before and after risk reduction measures applied to confined space accident example

5.3.5 Step 5. Risk reduction and feedback

The hierarchy of risk reduction strategies commonly used for confined space work are presented in Table 5.9 (ISO, 2010; ANSI/ASSE, 2011a; AIHA, 2014). Their impact on the components of the risk (i.e., severity and probability of occurrence) is also detailed. Eliminating or reducing risk at its source by working on the design of the confined space is most effective. In addition, the risk should always be reduced as much as possible.

After risk reduction measures have been taken, feedback is needed to estimate the residual risk. The results regarding these residual risks are presented in the same way as earlier (Figure 5-2). The risks, before and after risk reduction, can thus be compared. For the selected accident example, in order to have an index of 0/7 following risk reduction, it was required that the tank be cleaned, but also that the following measures be taken: assign an attendant, provide dilution ventilation in several compartments and extraction ventilation in the compartment where the welding is done, gas detection, personal protective equipment for welding (e.g., gloves, welding 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.

Table 5.9 : Risk reduction principles for confined spaces and impact on risk components

Risk reduction measures	Impact on risk reduction	
	Severity	Probability
1. Eliminate risk at design stage	++	++
For example, eliminate confined space, a source of energy, hazardous shapes, use of a toxic product; eliminate possibility of entry.	Hazard or possibility of exposure is eliminated.	
2. Reduce hazard intensity through design	++	0
For example, limit drive forces, speeds, amperage, decibels, radiation, vibrations, concentrations of hazardous materials; substitute safer products; increase size of space for entrant, etc.	The strength/intensity of the hazard is reduced intrinsically by design. Exposure remains the same.	
3. Reduce need to enter through design	0	++
For example, move some elements inside the confined space outside the confined space; use tools, robots, cameras from the outside; preventive maintenance, such as (i) self-cleaning systems, (ii) durable materials, structures, surface treatments.	The hazard itself is not dealt with, but exposure to the hazard is reduced to a minimum.	
4. Incorporate collective means of protection	+	+
For example, guards, railings, adapted ladders/platforms, anchor points, permanent ventilation.	A collective means of protection can help limit hazard intensity and exposure. However, the source of the hazard is not dealt with.	
5. Apply technical procedures	+	+
For example, lockout, isolation of piping, portable ventilation, cleaning/draining of confined space before entry.	If followed properly, a technical procedure can help limit hazard intensity and exposure. However, the source of the hazard is not dealt with.	
6. Apply administrative procedures	0	+
For example, gas readings, warnings, pictograms, communication, monitoring, less time spent in confined space, worker rotation.	If followed properly, an administrative procedure can help limit risk exposure. However, the source of the hazard is not dealt with.	
7. Use personal protective equipment (PPE)	0	+
For example, harness, respirator, hearing protection, safety footwear, hard hat, gloves, eye protection and coveralls.	If used properly, PPE can help limit hazard exposure, but has no effect on the hazard itself.	

5.3.6 Validation

When the application of the risk assessment tool proposed in this paper was presented to 22 safety professionals in 10 organizations, its appropriateness and originality, but also its limitations, were noted.

The first safety specialists who took part in the testing while giving positive reviews on the underlying principles criticized the exhaustiveness and degree of precision of some aspects of the tool. Their suggestions focused on the wording of the questions, the criteria for determining the rescue conditions and the exhaustiveness of the lists and possible answers. These aspects were corrected and implemented as the tool was refined and tested.

According to the safety specialists, the tool meets their needs for structure when preparing for confined space entries. The characterization of situations specific to confined space work was the aspect they found most useful and most easily transposable to an organizational setting (Table

5.2). The other points, according to the safety professionals, are (i) the list of potential risks, which makes the user's job easier, (ii) the categorisation of the intervention based on the risk estimation results that can be used to justify certain requests to decision makers, (iii) the predetermined rescue conditions that force workers to think about this point, (iv) the visual summary for informing 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 when issuing calls for tenders.

The proposed tool seeks to address the complexity of confined space work. This tool is intended only for qualified people who are knowledgeable about confined space work and risk management. Only people with this knowledge will be able to give appropriate answers to the questions in the first stage so as not to bias the results. Similarly, the method is not to be used just prior to entry into a confined space because it takes time to complete.

The safety professionals questioned unanimously agreed that the viability of the tool in an organizational setting, especially organizations that manage a large number of confined spaces, depends on the development of software to make it easier to apply and use the data collected. For example, the data obtained could be transferred to other documents (e.g., entry permits).

Furthermore, the impact of the changes made to the risk estimation tool of the Australian standard is hard to evaluate at this stage. The proposed version corrects certain deficiencies and is more specific to confined space work, but it is impossible to conclude, with the tests that were run, whether it is really better than the old version. Lastly, it should be noted that several studies on qualitative matrices have highlighted issues of reliability and interpretation of results (Cox, 2008; Ball and Watt, 2013; Hubbard and Evans, 2010). However, matrices provide support in cases where explicit quantification cannot be agreed upon (Duijm, 2015).

5.4 Conclusion

Many accidents related to work in confined spaces still occur. Despite all the regulatory and standard-setting efforts that have been made, organizations seem to have difficulties with risk assessment for interventions in confined spaces. Risk identification and estimation were not carried out in most of fatal accidents. This paper proposes a 5 step risk assessment tool for confined spaces based on risk management standards. The tool was tested by 22 experts managing entries in confined spaces, including experts during 10 visits in different organisations. Step 1 consists of a questionnaire to describe the configuration of the selected confined space, its environment and the work situations. The answers are linked to predefined types of risk. Step 2 describes the components of risks (i.e., hazards, hazardous activity, hazardous event, harm). Step 3 estimates risks using adapted risk parameters and matrix. Step 4 categorizes the intervention by class and level of risk. Step 5 is a feedback loop for estimating residual risks after risk reduction measures have been taken. This tool addresses the following needs: to carry out a comprehensive risk identification by questioning and analyzing all the factors influencing the risks during an intervention in a confined space, and to categorize interventions and rescue conditions by using objective criteria. In particular, it allows determining if (i) two situations are indeed identical in terms of risks, (ii) the intervention planned meets the PRCS definition, (iii) external rescue is feasible, and (iv) the residual risks are acceptable. This tool applies both to the design of confined spaces and to the assessment of existing ones. The risk assessment method proposed here for confined space work has the following distinguishing features: (i) its multidisciplinary approach, (ii) the fact that the environment of the confined space and the work to be done are taken into account in the risk analysis, (iii) the detailed description of the accident process when identifying risks, (iv) the use of recognized design criteria for risk estimation, (v) an a priori method of rescue characterization and (vi) a summary by risk classes and levels. However, the tool must be used by a qualified person, and to ensure optimum use in an organizational setting, a software application of the tool would have to be developed.

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CHAPITRE 6 ARTICLE 4: RISK ANALYSIS FOR CONFINED SPACE ENTRIES: CRITICAL ANALYSIS OF 4 TOOLS APPLIED TO 3 RISK SCENARIOS

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Abstract: Investigation reports of fatal confined space accidents nearly always point to a problem of identifying or underestimating risks. This paper compares 4 different tools for confined space risk analysis by applying them to 3 hazardous scenarios. These risk analysis tools were namely (i) a checklist without risk estimation (Tool A), (ii) a checklist with a risk scale (Tool B), (iii) a risk calculation without a formal hazard identification stage (Tool C) and (iv) a questionnaire followed by a risk matrix (Tool D). Tool D has been proposed recently. Tool structure, use and results were studied. Tools A and B gave crude results comparable to those of more analytic tools in less time. Their main limitations were lack of contextual information for the identified hazards and their greater dependency on the user's expertise and ability to tackle hazards of different nature. Tools C and D are more systematic approaches that support risk reduction by describing the risk factors. Tool D is distinctive because of (i) its comprehensive structure with respect to the steps suggested in risk management including risk reduction, (ii) its dynamic approach to hazard identification and (iii) its use of data resulting from the risk analysis.

Keywords: Confined space, Risk identification, Risk estimation, Risk analysis

6.1 Introduction

Confined space work is regulated in most industrialized countries (U.S. Department of Labor, OSHA, 1993; Government of Canada, 2014; Government of United Kingdom, 1997; Guilleux & Werlé, 2014; Standards Australia, 2001). A confined space is defined in the United States Occupational Safety and Health Administration (OSHA) regulation as “a space that: (1) is large enough and so configured that an employee can bodily enter and perform work; (2) has limited means of entry or egress; and (3) is not designed for continuous employee occupancy” (U.S. Department of Labor, OSHA, 1993). Regulations set out requirements regarding worker qualifications, hazard identification, atmospheric control, monitoring of entry and egress, and rescue procedures. In addition, standards respecting confined spaces provide guidelines on the management program to be set up, the roles and responsibilities of stakeholders, the associated planning (e.g., training, emergency response plans) and the application of work permits (CSA, 2010; ANSI/ASSE, 2009).

Confined space safety is an issue that applies to a wide range of sectors, including the municipal, manufacturing, chemical, military, agricultural and transportation sectors (Rekus, 1994). The distinguishing feature of confined space accident prevention is its multidisciplinary nature, including atmospheric hazards (i.e., poisoning, asphyxiation, explosion), as well as biological, physical (e.g., mechanical, electrical, engulfment, falling, lighting, vehicle traffic) and ergonomic hazards (NIOSH, 1994).

The consequences for confined space workers are potentially serious because of problems with access, rescue, communication and poor natural ventilation (CSA, 2010). Confined space fatalities are still frequent, as the statistics in the literature show. Between 1992 and 2005, there was an average of close to 38 deaths per year by poisoning or asphyxiation in confined spaces in the United States. Twenty percent of those incidents resulted in multiple fatalities (Wilson *et al.*, 2012). Between 1964 and 2010, an average of close to 27 deaths per year in confined spaces in agriculture in the United States were recorded (Riedel & Field, 2011). In Quebec, one study reported 3 confined space fatalities per year on average for the period from 1998 to 2011, i.e., approximately 3% of all fatal workplace accidents. 27.5% of the deaths were due to an atmospheric hazard, 20% to moving machinery, 15% to engulfment, 12.5% to falls from height and 12.5% to falling objects, offering clear evidence of the need for multidisciplinary prevention (Burlet-Vienney *et al.*, 2015a).

What most of these fatal accidents had in common was that the work activity was improvised and no work procedure was followed. As a result, risk reduction measures were inappropriate or inexistent. Furthermore, no rescue plan was available at the work site. Risk assessment and the implementation of a program, training, permits and other elements, thus appears to be important. Typically, risk assessment involves 2 stages, namely risk analysis (i.e., identification of hazards and risk estimation [gravity and probability of the injury]) and risk evaluation (i.e. judgement, on the basis of risk analysis, of whether the risk reduction objectives have been achieved) (ISO, 2010). Following a structured risk assessment method makes it possible to (i) be proactive when identifying and controlling potential losses, (ii) provide information for decision making and improve communication regarding risks, (iii) contribute to safe design and (iv) reduce risks to an acceptable level (Eaton & Little, 2011; IEC/ISO, 2009; Main, 2004; Manuele, 2008). According to a study of 15 organizations that had implemented a confined space entry management program, businesses seem to have trouble formalizing the hazard identification and risk estimation stages when preparing for confined space work. Indeed, half of the organizations did not conduct any preparatory analysis (e.g., risk fact sheets) before issuing an entry permit, and none of the organizations quantified the identified risks or classified the confined spaces in terms of risks (Burlet-Vienney *et al.*, 2015a).

A review of the literature on risk management for confined space work found that the main tools suggested for risk analysis are checklists, risk scales and risk matrices (Burlet-Vienney *et al.*, 2014). A number of problems have been associated with these tools, however. The checklists suggested are often incomplete. The main problem of scales is that there is no criterion to choose the level of a risk (Maritime and Coastguard Agency, 2010). Moreover, matrices suggested give more guidance to estimate risks but remain generic (Standards Australia, 2001; Rekus, 1994). Definitions used are vague and parameters are not adapted to the particular characteristics of confined spaces (e.g., multiple types of risks, real rescue conditions, interactions among hazards). Duijm sums up the main drawbacks associated with risk matrices (e.g., subjective classification; limited resolution) (Duijm, 2015). To our knowledge, so far no study has compared the use and effectiveness of different tools recommended in the literature for confined space risk analysis.

6.2 Research objective and method

The objective of this study was to compare 4 different tools recommended in the literature or in business for risk analysis applied to confined space work. The research team tested each tool on 3 risk scenarios. Tool structure, use and results were investigated.

6.2.1 Confined space work scenarios

The 3 scenarios developed for testing the 4 tools were based on work observed in business settings or documented in accident reports. The scenarios selected illustrate common workplace situations and include various types of risks. In addition, each scenario had to be associated with a distinct overall risk level (i.e., low, medium, high) in order to cover a wide range and to detect any bias in the risk estimating tools. No risk reduction measures were considered when applying the 4 tools to each of the 3 scenarios.

The 3 scenarios are set out in detail in Table 6.1. The information provided reflects the degree of detail available in the companies visited. Scenarios #1 and #2 concern the same confined space which is a manhole providing access to sewer system (Figure 6-1), but two different work assignments. This choice highlights the importance in risk analysis of considering not only the confined space, but also the work to be performed. Scenario #3 which is a tanker wash facility is illustrated in Figure 6-2.

Figure 6-1 : Manhole providing access to sewer system – Scenarios #1 and 2

Figure 6-2 : Tanker wash facility – Scenario #3 (NIOSH, 2014)

Table 6.1 : Description of the 3 confined space work scenarios used for testing 4 tools

	#1 Manhole/Inspection	**#2 Manhole/Installation**	**#3 Tank truck/Welding**
Use of confined space			
Type	Manhole – Sewer system		Tanker truck tank
Function	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. Near traffic lane		Shelter adjoining garage
Accessibility	Entrance easily accessible		Tank entrance (3 m high). Access by ladder
Description of interior	4 levels, each 5 m high. Levels made of metal grating (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/exits	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 entry. Appears to be in good condition.		Ladder to be placed in tank. Appears to be in good condition.
Contents	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
Chemicals nearby	None		None
Planned work			
Work	Visual inspection of concrete at 1st level. 1 worker	Installation of measuring instruments at 4th level. 2 workers	Welding to repair bottom of tank compartment. 1 worker
Tools	Conventional tools (e.g., hammer, trowel)	Power tools (120 V) and conventional tools (e.g., pliers). Basket and rope for lowering and raising them.	Welding equipment. Solution for cleaning surface to be repaired
Length, frequency	30 min., twice a year	1 h, 30 min. Once every 3 years. Several trips in and out anticipated	2 h. Once every 2 years
Miscellaneous	Open access to lower levels	Open access to lower levels. 8°C at 4th level	N/A

Scenario #1 was considered a priori to be a low-risk scenario, as the potential harm seemed minimal for a visual inspection of concrete at 1st level inside the confined space. It revealed a confined space without obvious immediate hazards. Scenario #2 was considered to be a medium-risk scenario, chiefly because of the high potential harm of a fall from one level to the next higher (4 levels). It consisted of 2 workers installing measuring instruments at the 4th level inside the confined space. Scenario #3 was considered a priori to be a high-risk scenario on account of the possibly fatal harm that can result from welding (e.g., poisoning). It consisted of one worker welding to repair the bottom of the tank compartment of a tanker.

6.2.2 Risk analysis tools

Four types of tools were selected: checklist (Tool A), risk scale (Tool B), risk calculation (Tool C) and a risk matrix (Tool D) (Entreprise X, 2014; Government of South Australia, 2011; UK Ministry of defense, 2014; Burlet-Vienney *et al.*, 2015b). Tools that dealt only with atmospheric risks and those listed in the same reference document as another tool were excluded from the selection process (Standards Australia, 2001; British Compressed Gases Association, 2009) For each of the 4 types, those clearly more comprehensive in terms of listed risks and selection criteria were selected. The tools also had to be as distinct as possible.

Only the risk analysis part (i.e., hazard identification, risk estimation) was tested on the risk scenarios. However, all the information presented in the tools was analysed. In the countries where these tools have been published, it was not mandatory to use them.

6.2.2.1 Checklist (Tool A)

Checklists are widely used for risk analysis by businesses and universities (University of Melbourne, 2015; University of Wollongong, 2010). The tool we selected is used by a major corporation whose confidentiality was guaranteed by our study's research ethics certificate (Enterprise X, 2014). To illustrate tool A and its application to the scenarios, Table 6.2 shows the checklist applied to scenario #1.

Table 6.2 : Company's risk analysis checklist (tool A) applied to scenario #1

Atmospheric/chemical hazards		**Biological hazards**		**Physical hazards**			
Lack of oxygen	☒	Pathogenic microorganisms	☒	Various power supplies	☐	Falling	☒
Oxygen enrichment	☐	Dirty/rusty parts	☒	Mechanical	☒	Slippery surface	☒
Flammable contaminants	☐	Other	☐	Electric shock	☐	Noise	☐
Toxic contaminants	☐			Thermal (heat)	☐	Entrapment	☐
Toxic chemicals	☐			Hot surface (contact)	☐	Engulfment, drowning	☐
				Chemical burns	☐	Internal layout	☐
				Pressure (stored)	☐	Worker isolated	☐
				Visibility (lack of)	☐	Falling object	☒
				Difficult access or egress	☐	Other	☐

6.2.2.2 Risk scale (Tool B)

With the selected risk scale tool, risks can be estimated according to 4 levels or rankings: extreme, high, moderate, low (Government of South Australia, 2011). Hazards are identified by means of a predefined list that corresponds to the first column of Table 6.3. The application of tool B to scenario #2 is presented in Table 6.3. A column for the main risk reduction measures is provided in the tool but not presented in Table 6.3.

6.2.2.3 Risk calculation (Tool C)

The tool we selected has 2 parameters for estimating risk: likelihood of injury and severity of injury (Table 6.4, Table 6.5) (UK Ministry of defense, 2014). Combining the 2 parameters leads to 3 risk ratings (Table 6.6). There is no formal part for identifying hazards. Once risk reduction measures have been chosen, the tool estimates the residual risks. The application of tool C to scenario #3 is presented in Table 6.7.

Table 6.3 : Risk scale (tool B) applied to scenario #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	

Table 6.4 : Likelihood of injury (tool C) (UK Ministry of defense, 2014)

Likelihood	**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

Table 6.5 : Severity of injury (tool C) (UK Ministry of defense, 2014)

Severity	**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

Table 6.6 : Risk rating and action required (tool C) (UK Ministry of defense, 2014)

Risk Rating (likelihood x severity)	**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

Table 6.7 : Confined space risk assessment form (tool C) applied to scenario #3 (UK Ministry of defense, 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

6.2.2.4 Questionnaire and risk matrix (Tool D)

A five-step risk assessment tool was applied to the 3 scenarios (Burlet-Vienney *et al.*, 2015b). To illustrate this tool and its application to scenario #3, Table 6.8 shows the step 1 which consists of a questionnaire to describe the configuration of the selected confined space, its environment and the work situations. The answers generate predefined types of risk split in 7 families: atmospheric, chemical, biological, falling, mechanical, physical, and ergonomics. Answers to the questions also suggest a characterization of rescue conditions based on two concepts: (1) rescue without entry is possible or not (questions marked with an asterisk), and (2) the prevailing conditions make a rescue with entry more complex or not (questions marked with a double asterisk). Table 6.9 shows the step 2 of tool D which describes the components of risks (i.e., hazards, hazardous activity, hazardous event, harm). Table 6.10 shows the step 3 of tool D which estimates risk using two risk parameters and matrix. Supplementary information or numbered references are provided for each risk parameter to help with decision making (ACGIH, 2013; International Commission on Non-Ionizing Radiation Protection, 2010; ISO, 2006). Table 6.11 shows the results obtained for step 3 of tool D applied to scenario #3. Following the risk analysis, step 4 summarizes risk families and ratings, in chart form (Figure 6-3). The value associated with a risk class (i.e., 1 to 4) corresponds to the maximum risk level reached among the risks it includes. An estimate and a summary of the residual risks following the choice of risk reduction measures are also available (step 5). These last few steps were not used for the testing.

Table 6.8 : Step 1 of Tool D: Characterization of risk situations for scenario #3 (Burlet-Vienney *et al.*, 2015b)

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 a 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 it 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): 12 m^3
Location (address, building): Washing station outside buildings

Table 6.8 : Step 1 of Tool D: Characterization of risk situations for scenario #3 (cont.)

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 the confined space have? What are the dimensions of each entrance?**
☐ 1 ☐ 2 ☐ 3 ☒ > 3
Shape: ☒ Round ☐ Rectangular; Dimensions: ☒ < 610 mm (24 in) 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 ☐ N/A

☐ Horizontal
- Means of access:
- Condition of means of access: ☐ Good ☐ Poor ☐ Very poor ☐ N/A

5. Does the design of the confined space involve one or more of the following risk situations?
☒ Inadequate natural or mechanical ventilation**
☒ Restricted interior volume, limiting possible movements in the 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 significant slope*
☐ Presence of confining areas because of converging walls or funnel shape**
☐ Presence of structural weaknesses such as cracks, collapse, corrosion, offset entrance**
☐ Presence of sharp, pointed structural features**
☒ Inadequate light **
☐ Extreme temperature/humidity
☐ High noise level (without work)**
☐ Other:
☐ None of the above

6. Does the habitual use of the confined space involve one or more of the following risk situations?**
☒ Presence of toxic agents or asphyxiants
☒ Presence of flammable products or explosives, of combustible dust
☒ Presence of corrosives, irritants, reagents or carcinogens
☐ Presence of decomposition products, sediments, residues, slow oxidation products (e.g., rust)
☐ Presence of mould/fungus or various biological pathogens (e.g., dirty objects)
☐ Presence of animals, insects, allergens
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 piping or drains that must be locked out or blocked off (i.e., blanking to reduce risk of uncontrolled introduction or return of products, risk of drowning, equipment upstream/downstream)?**
☒ Yes ☐ No If so, specify: Openings for drainage locked in open position

8. Is there any equipment permanently installed in (or running through) the confined space 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 engulfment?**
☐ Yes ☒ No If so, specify:

Table 6.8 : Step 1 of Tool D: Characterization of risk situations for scenario #3 (cont.)

C. **Environment** (section to be filled in once)

10. Is the access to the confined space... ?** (Check all that apply)
☐ 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 risky restricted access room
☐ None of the above

11. Is the work area around the entrance... ? (Check all that apply)
☐ Exposed to road traffic or to a roadway within a facility
☐ Exposed to other workers
☐ Exposed to the public
☐ Exposed to weather conditions (e.g., bad weather, outdoor temperatures)
☐ In a work area (e.g., workstation with stationary or mobile machine in operation)
☒ 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 might have an impact on the conditions in the confined space?
☒ Yes ☐ No If so, specify: Vehicle repairs

13. Are hazardous materials being stored in an adjacent reservoir/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], etc.)?**
☐ 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:
Work description: 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

17. Does the job (entrance to space and work) require any particular experience/expertise?
☒ Yes ☐ No If so, specify: Welding

18. Does the job (entrance to space and work) require any particular physical condition or mental health? Examples: 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: long and demanding

19. How frequently must such work be done?
☐ Daily ☐ Weekly ☐ Several times a year ☐ Annually
☒ 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 time, < 30 minutes ☒ Less than one shift ☐ Longer than one shift
☒ Day ☐ Night

22. Are there time constraints on the work (e.g., very short, other department waiting, essential public service) that put pressure on the people performing it?
☐ 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 work is to be done?*
☒ Vertical only ☐ Horizontal 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

Table 6.8 : Step 1 of Tool D: Characterization of risk situations for scenario #3 (cont. and end)

25. Does the work to be performed involve any additional risks? (Check all that apply)
    - ☐ High-pressure cleaning**
    - ☒ Hot work (e.g., welding)**
    - ☐ Working at heights**
    - ☒ Using specific tools [excluding those for hot work](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 PPE (e.g., visibility, sweating)
    - ☐ Other:
    - ☐ No additional risk
26. During the work, can the worker's harness be fastened at all times to a lifeline solidly secured to an anchoring point outside the confined space?*
    ☒ Yes ☐ No

Table 6.9 : Step 2 of tool D: Identification of risks and related accident processes (Burlet-Vienney *et al.*, 2015b)

Hazards				**Activities**			
Origin	Class	Type	Specifics	Hazardous action	Who	Hazardous event	Harm
Filled in automatically after the questionnaire and the validation of the actual risks				- Position: ▪ Being nearby ▪ Being in ▪ Being in the path of ▪ Being exposed to - Action: ▪ Go up/down ▪ Use a tool ▪ Carry a load	- Entrant - Attendant - All workers	3 possibilities: - Sudden event - Access, contact with hazard - Abnormal exposure	See ISO 1210 Annex B(13)

Table 6.10 : Step 3 of Tool D: Risk estimation matrix (Burlet-Vienney *et al.*, 2015b)

	Severity of harm (S)				
Probability of occurrence of harm (P)	Negligible Not requiring first aid	Minor Requiring medical treatment without loss time	Serious Requiring medical treatment with loss time	Major Major trauma, long-term disability	Catastrophic Death of one or more workers
Very likely Harm is almost inevitable during the work	2	3	3	4	4
Likely Harm may occur during the work	1	2	3	4	4
Unlikely Harm should not occur during the work	1	2	2	3	4
Very unlikely Harm not foreseen	1	1	1	2	3

Table 6.11 : Step 3 of Tool D: Results of the risk estimation step (without the activities part) for scenario #3

Origin	**Class**	**Type**	**Source**	**S**	**P**	**Risk**
Confined space	Atmospheric	Oxygen deficiency	Welding	Serious	Likely	3
Confined space	Atmospheric	Explosion/fire	Flammable product (gas)	Catastrophic	Likely	4
Confined space	Chemical	Corrosive product	Gas	Minor	Unlikely	2
Confined space	Falling	Fall from height	Vertical access	Serious	Unlikely	2
Confined space	Falling	Fall from height	Access at height	Catastrophic	Likely	4
Confined space	Ergonomic	Inadequate light	No light	Minor	Likely	2
Confined space	Ergonomic	Entry/egress	Opening <610mm	Minor	Likely	2
Confined space	Ergonomic	Work posture	Small internal volume	Minor	Likely	2
Confined space	Mechanical	Mobility of space	Confined space on a truck	Serious	Likely	3
Confined space	Physical	Drowning	Wastewater pipe	Minor	Very unlikely	1
Work to be done	Atmospheric	Poisoning	Welding gas	Catastrophic	Likely	4
Work to be done	Chemical	Corrosive product	Welding product	Minor	Unlikely	2
Work to be done	Falling	Falling on the same level	Curved surface	Serious	Likely	3
Work to be done	Ergonomic	Physical exertion	Duration of work	Minor	Likely	2
Work to be done	Ergonomic	Heat stress	Welding	Minor	Likely	2
Work to be done	Physical	Noise	Tools	Serious	Likely	3
Work to be done	Physical	Electricity	Tools	Major	Unlikely	3
Work to be done	Physical	Electricity	Temporary light	Major	Unlikely	3
Work to be done	Physical	Optical radiation	Welding	Major	Very likely	4
Work to be done	Physical	Heat	Welding - Surface	Serious	Very likely	3

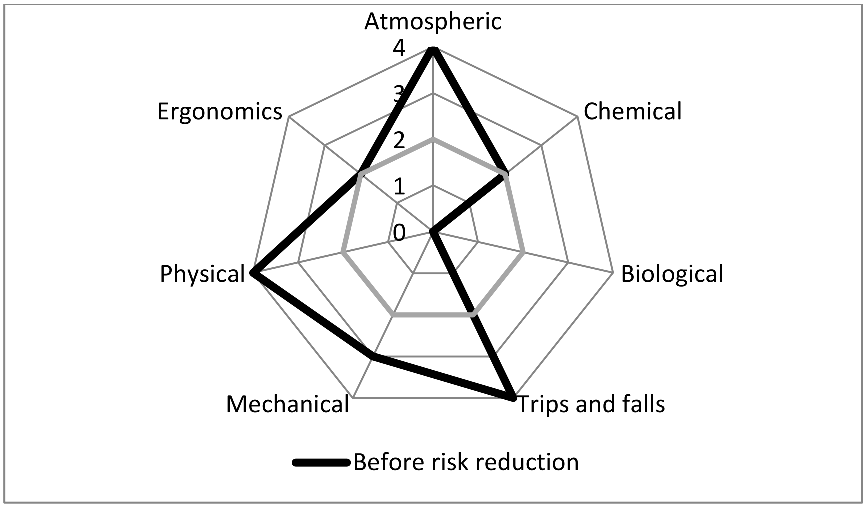

Figure 6-3 : Tool D: Summary of risk estimation before risk reduction measures applied to scenario #3 (Burlet-Vienney *et al.*, 2015b)

6.2.3 Comparison criteria

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

- Comparison with risk management steps recommended in standards (IEC/ISO, 2009)
- Means to ensure risk analysis is exhaustive and systematic
- Summary and measurement for communicating estimated risks (e.g., categorization of risks)
- Construction of risk estimation and criticism in relation to chosen architecture (ISO, 2010; Duijm, 2015; Chinniah *et al.*, 2011; Gauthier *et al.*, 2012; Cox, 2008)

Then, the time required for each analysis, ease of use (i.e., easy, difficult), the list of hazards, as well as the subjectivity and precision of the possible answers were noted to assess the usability of the tools.

6.3 Results and discussion

6.3.1 Tests

The results obtained by the research team over the 12 tests (4 tools on 3 scenarios) are presented in Table 6.12. The first column of the table shows all the different hazards identified with the 4 tools for the 3 scenarios. When a box is empty, it implies that the risk has not been identified when using that tool for the scenario. Thus, this table allows comparing both the risks found with each tool and the estimation of the risks for tool B, C and D. The risk levels obtained are specified in the form “estimated risk level/number of risk levels in tool”. In absolute terms, the risk level obtained for a risk in a scenario should be equivalent from one tool to the next.

The structure of the 4 tools selected and the characteristics of their usability are presented in Table 6.13. These results are discussed in the following sections.

Table 6.12 : Risk outcomes over possible outcomes or classes for scenarios 1, 2 and 3 for different hazards described in the tools

	Scenario #1				**Scenario #2**				**Scenario #3**			
Hazards	**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
Pathogenic microorganisms	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 (movement, cut)			2/3	2/4	X	2/4	1/3	2/4				
Animals (bite, 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
Intro. of 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 temperatures					X	2/4	1/3	2/4	X	1/4	1/3	2/4
Noise					X				X		3/3	3/4
Restricted entrance/exit									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
Restricted entrance/exit									X	2/4	1/3	2/4
Physical exertion												2/4

Table 6.13 : Structure and usability of four types of tools

	Tool type Checklist	Risk scale	Risk calculation	Questionnaire + Matrix
Context definition	Information required about targeted confined space and work to be done			
Hazard identification	List of possible answers	Set list of hazards	N/A	Questionnaire and validation
Risk estimation	N/A	Choice among 4 risk levels/ratings	2 parameters that lead to 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 possible answers			
Other steps	N/A	N/A	Estimation of residual risks	– Estimation of residual risks – Work categorization – Characterization of rescue, in principle
Time per scenario	< 5 min	5 min	10 min	20 min
Ease of use and understanding of tool	Easy: checkboxes	Easy: tick off risk level/rating	Demanding: no help for identifying hazards	Demanding: very detailed

6.3.2 Checklist

A checklist is a hazard identification tool. Its main advantages are its speed and ease of use, which is why businesses prefer it. But the disadvantage of its simplicity is its lack of precision for risk reduction purposes. The tool does not provide any context for the identified hazards and their origin (e.g., related to the specific work or the confined space). For example, in the case of scenario #1, a risk of falling is indicated, but the tool does not specify that there are two different risk situations: entry and access to the second floor. In addition, the proposed list of hazards is incomplete when compared with the other tools. Ergonomic hazards and rays or radiation are not included, for instance, and mechanical hazards (e.g., nip points, mobile confined spaces) are not specified.

Another issue was that tool did not define from what level the presence or absence of a risk need to be indicated. According to our tests, a risk will be mentioned if it is not deemed acceptable by the user. “Risk acceptance is the deliberate decision to assume a risk that is low enough with respect to the probability of a hazard-related incident or exposure occurring and the severity of harm or damage that may result, and which is considered tolerable in a given situation” (Manuele, 2008). This decision depends on many factors, including training, experience and resources available. When checklists are used, the reasoning behind and basis for selecting or not a hazard is not documented. It can lead to repeatability issues for the same user or different users for the same situation.

6.3.3 Risk scale

The risk scale tested had, on the whole, the same advantages and disadvantages as the checklist for identifying hazards. In comparison with tool A, the fact that hazards are not classified into families (e.g., atmospheric, biological) in tool B means that the exercise is more tedious. Lastly, some of the potential hazards listed are hard to interpret, such as “lack of PPE” because no PPE had been defined, or too general, such as “method of work selected.” In the case of “lack of PPE”, any risk estimation has been made.

The difference between the risk scale and the checklist is that the former uses an ordinal scale to estimate risks (Stevens, 1946). An evaluation of this scale based on the construction rules proposed by Chinniah *et al.* (2011) for risk estimation tools shows that it suffers from “poor definition.” This problem consists in using single words or vague terms to define the levels of risk, of likelihood of harm or of severity of harm. Vague language like this can lead to bias in the estimation process and significantly influence the final result (Carey & Burgman, 2008; Patt & Schrag, 2003). During testing, the choices proved to be completely intuitive and therefore depended on the person who was doing the estimation. The results of the estimation, on the other hand, were comparable to those of tools C and D, except for falling from height, falling objects and traffic risk, which were underestimated. In these cases, severity of harm seemed to be underestimated compared to tools C and D. For the purposes of a professional risk assessment, the problem would therefore seem to be not the accuracy of the estimation, but rather the identification and documenting of the factors contributing to the risk.

6.3.4 Risk calculation

Tool C does not include a formal hazard identification step. In this form, the tool is based on the user’s experience or on an additional description of the confined space at this stage. This configuration can lead to some hazards being overlooked, especially considering that confined space accident prevention is a multidisciplinary problem. It’s an important point because if risk identification is not practiced well, then all that follows including risk reduction is crippled

(Cantrell & Clemens, 2009). It is an acknowledged fact that, if no preventive measures are taken, a hazard will sooner or later cause harm (ISO, 2010).

This tool takes longer and is more complex to use than the two others discussed above because its risk estimation stage is more developed. The estimation of the two parameters that make up risk is qualitative. The two parameters and the risk index obtained provide guidance for risk reduction by highlighting certain risk factors, such as exposure and severity. The tool can also be used to estimate residual risks once risk reduction measures have been taken. Risk assessment is no longer completely intuitive, as it is for a risk scale, but partly analytic (rule based). The results are easier for a business to use because it can standardize the risk estimation step and focus on the risk reduction measures (Eaton & Little, 2011).

When the tool is presented in a matrix form (Table 6.14), however, it can be seen that the risk estimation process does have some shortcomings. First, the definitions for the two highest levels of the two parameters are inconsistent. For instance, it is hard to distinguish between *high possibility of injury* and *probable injury* or between *urgent hospital treatment* and *major trauma.* Nevertheless, this drawback seems to be attenuated by the fact that, regardless of the degree of likelihood, choosing between *serious* or *major* severity has no effect on the risk rating. Similarly, regardless of the severity, choosing an occurrence likelihood of *likely* or *most likely* has no influence on the result. In fact, this matrix should simply be a 3 x 3, with the two highest levels being merged for the two parameters. To conclude, the severity of the injury should be presented and chosen before the likelihood of injury, as the injury needs to be known in order to be able to assess its likelihood of occurrence.

Table 6.14 : Tool C presented in form of matrix

	Severity			
Likelihood	Trivial (1)	Slight (2)	Serious (3)	Major (4)
Most likely (4)	4	**8**	**12**	**16**
Likely (3)	3	**6**	**9**	**12**
Unlikely (2)	2	4	**6**	**8**
Most unlikely (1)	1	2	3	4

6.3.5 Questionnaire and risk matrix

Tool D is based on existing tools and seeks to combine their strengths and eliminate their weaknesses (Standards Australia, 2001). It has a distinctive structure, which formally goes through all the steps suggested in risk management standards.

Another feature that distinguishes this tool from the others is its dynamic hazard identification stage. The questionnaire includes a detailed list of hazards. This aspect ensures that the hazard identification stage, which, as explained earlier, is absolutely essential, will be handled systematically. Of the four tools, this one produced the most complete list of identified hazards (e.g., ergonomic hazards, radiation, animals and stress). Another advantage of the questionnaire is that it also provides a means of contextualizing risks, as it pinpoints the origin of the hazard and the physical source. As a result, in scenario #3, for example, it is possible to itemize the different situations related to the risk of falling from height (e.g., when climbing down into the tank or down from the roof of the tank) and the risk associated with toxic chemicals (e.g., diesel and cleaning solution residues). Questions 1 to 14 deal with space configuration risks, while questions 15 to 26 concern risks related to the specific work to be done. This separation means that the first part of the questionnaire remains valid when only the work assignment is changed, as was the case with scenario #2.

As mentioned in Table 6.9, the activities can be specified by the user. This stage proved useful for anticipating the actual step-by-step details of the work and facilitating severity and probability choices when estimating risks. However, this specification step takes a lot of time, which explains the average tool use time of around 20 minutes. The risk estimation stage has the same general characteristics as tool C, and the risks obtained are comparable. However, the term "unlikely" has a different meaning in tool C (positive i.e. injury is conceivable case) and in tool D (negative i.e. harm should not occur during the work). This point illustrates the importance of clearly defining the levels of parameters in order to limit interpretations by the user.

Nevertheless, certain structural problems raised regarding matrix (e.g., inconsistent definitions) are correctly addressed and selection criteria for severity and likelihood have been added to make the process more systematic from one user to the next (Piampiano & Rizzo, 2012). “A good risk estimation tool is one that encourages those doing the ranking to systematically consider all relevant information and ensures that participants understand the procedures and feel satisfied with both the process and outcome" (Florig *et al.*, 2001).

Lastly, the tool is distinctive in the way it allows the user to visualize the risk estimation results and communicate them more easily (Figure 6-3). This tool also details how the different strategies used to reduce risks for interventions in confined spaces (i.e., eliminate risk at design stage, reduce hazard intensity or need to enter through design, incorporate collective means of protection, apply technical or administrative procedures, use PPE) impact the severity and the probability of occurrence of harm.

6.3.6 Tool comparison

Table 6.15 compares the four tools at the hazard identification and risk estimation stages. Tools that have the same advantages and limitations are grouped together. Checklists and risk scales are quick to use and give acceptable results in comparison with other tools, but provide only a relatively superficial analysis of a situation. They rely more on a user's instinct and experience. Tools C and D offer more precise information about the risk factors involved. Tool D is also more systematic thanks to its questionnaire. This is a significant advantage in the context of confined spaces, where the wide variety of risks requires multidisciplinary expertise. The risk analysis takes much longer than with the other tools, however.

Checklists and risk scales with checklists provide an initial overall analysis and could conceivably be used in the field, just before work begins by experts familiar with the confined space where the intervention will occur. Risk calculation and risk matrices allow a more in-depth analysis of a situation and should preferably be used by an accident prevention specialist in an office setting when a company is preparing for confined space work or at the design stage of the confined space.

Table 6.15 : Advantages and limitations noted for each tool with regard to hazard identification and risk estimation

	Advantages	Limitations
Hazard identification		
Checklist (tools A and B)	Quick, effective Intuitive Satisfactory overview Easy to use in the field	Not sufficiently exhaustive, systematic Interuser variability, depends on user competency, no well-defined hazards and hazardous situations No information on source and origin of hazard. Analysis must be completely redone if work changes
Questionnaire-suggestion (tool D)	Dynamic approach, more exhaustive and systematic Contextualized hazards. No need to redo analysis completely if work changes Usable at design stage	Fairly long process Must be used by qualified person, in part in office setting
Risk estimation		
Risk scale (tool B)	Quick, effective Risk levels determined close to those obtained with analytic tools Easy to use in the field	Risk factors not made explicit and documented Interuser variability, depends on user competency
Risk calculation (tool C), Risk matrix (tool D)	Questioning and documenting of risk factors Criteria for risk acceptability and assessment of effectiveness of risk reduction measures Better convergence of interuser results if risk matrix appropriate Usable at design stage	Lengthy process Estimation that is still qualitative and partly subjective, and should be regarded as such Must be used by qualified person, in part in office setting

6.4 Conclusion

The objective of this study was to compare different tools recommended in the literature or in business for confined space risk analysis by applying them to three risk scenarios. Four tools that take distinct approaches were tested: (i) a checklist without risk estimation, (ii) a checklist with a risk scale, (iii) a risk calculation tool without a formal hazard identification stage and (iv) a risk matrix with a questionnaire.

Checklist and risk scale tools, favoured by businesses, proved to be quick to use, relying on the user’s intuition, and gave acceptable results in relation to the other tools. Their limitations have to do with their lack of contextualization for identified hazards (e.g., no information about the source or origin of a hazard) and their greater reliance on the user’s competency for identifying hazards. The likelihood of overlooking risks is high, which limits the scope of these tools. They are therefore better suited for an initial overall analysis of a situation. Tools C and D represent more systematic approaches that make it possible to ask questions about risks, identify risk factors and document the analytic process. Their use offers support for the risk reduction process by providing criteria for assessing risk acceptability and residual risks. Using these tools can produce more homogeneous results from one user to the next (i.e. repeatable results), 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). These tools require devoting more time to analysis than the other tools do, which can limit their usefulness in business. Our results demonstrate, that the advantages of more analytic tools lie in their contextualizing of risks, their documenting of the analytic process and the guidance they provide for risk reduction decision making

Tool D has a distinctive structure, which formally goes through all the steps suggested in risk management standards. It also differs from the other tools in that its hazard identification stage is very exhaustive, questioning the user about risk factors related to the configuration of the confined space, the work environment and the work itself. The risk estimation results are comparable to those obtained with tool C. Tool D also makes use of hazard identification and risk estimation results by categorizing risks and rescue conditions. It also details the impact of the different strategies used to reduce risks for interventions in confined spaces on the component of the risk. These data could be useful at the design stage of the confined space.

Lastly, the results of our study illustrate the complementarity and the different scope of the intuitive and analytic approaches to risk analysis (Solvic & Peters, 2006).

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CHAPITRE 7 DISCUSSIONS GÉNÉRALES ET CONCLUSION

7.1 Synthèse des travaux

Malgré les normes et les règlements mis en place au fil des années, les accidents en espace clos restent nombreux. Cette thèse vise donc à réduire le nombre d'accidents en espace clos en ciblant la préparation et la gestion des risques lors de ces interventions. Les lacunes et les besoins liés à la gestion des risques en espace clos ont été identifiés dans les articles aux chapitres 3 et 4 par l'intermédiaire d'une revue critique de la littérature sur la gestion des risques en espace clos, l'analyse des rapports d'accidents mortels en espace clos au Québec et l'étude de la gestion des risques en espace clos menée dans 15 organisations. Le développement subséquent d'un outil d'appréciation du risque dédié aux interventions en espace clos ainsi que sa validation a été détaillé dans les articles aux chapitres 5 et 6. La contribution originale de cette thèse et la validation des hypothèses de recherche sont décrites ci-après.

Contribution 1 (hypothèse de recherche 1): Les travaux de recherche menés sur la littérature ou en entreprise ont mis en évidence le besoin d'une approche globale et multidisciplinaire pour l'étape d'identification des phénomènes dangereux en espace clos afin d'obtenir une meilleure représentation de la réalité lors des interventions. Le nombre d'accidents mortels dus à un problème de maîtrise des énergies liées à de la machinerie a en effet révélé l'importance des phénomènes dangereux mécaniques et de l'interaction entre les phénomènes dangereux dans les espaces clos. Jusqu'à présent, les phénomènes dangereux atmosphériques (c.-à-d. asphyxie, intoxication, explosion) monopolisent l'attention. Lors de l'identification des phénomènes dangereux, ce sont les plus cités et les plus longuement traités. Les check-lists proposées pour l'identification des dangers sont incomplètes concernant les phénomènes dangereux physiques (ex. chute, ensevelissement, mécanique, ergonomique). Également, les statistiques disponibles portent quasi exclusivement sur les phénomènes dangereux atmosphériques (ex. Wilson *et coll.*, 2012; Dorevitch *et coll.*, 2002). Cette approche s'explique par le fait que ces risques sont spécifiques au confinement des espaces clos. Néanmoins, les risques physiques peuvent eux aussi être sévères, complexifient les situations à risque, et impliquent des mesures de sauvetage adéquates. Par ailleurs, les dangers peuvent être présents en permanence dans l'espace clos, mais également se développer lors de l'intervention (ex. utilisation d'équipements de soudage, de meulage, etc.). Un tiers des accidents reliés aux phénomènes dangereux atmosphériques serait d'ailleurs introduit par l'activité de travail (WorkSafe BC, 2008). Ainsi, la gestion des risques devrait être menée de façon multidisciplinaire et globale pour prendre en compte la réelle complexité des interventions en espace clos. Les travaux de recherche ont permis de dresser une liste étendue des phénomènes dangereux pertinents lors d'une intervention en espace clos, et de répertorier les interactions possibles entre eux.

Contribution 2 (hypothèse de recherche 2): Les documents de référence sur la gestion des risques pour les interventions en espace clos manquent de formalisme par rapport aux règles de l'art énoncées dans les normes en gestion des risques, hormis pour les risques atmosphériques. La littérature sur les espaces clos permet avant tout d'identifier les phénomènes dangereux lors des différentes interventions. Les étapes d'estimation du risque et d'évaluation du risque sont largement négligées. Seuls neuf outils qui incluent une étape d'estimation globale des risques en espace clos ont été recensés parmi les 77 documents de référence retenus (NIOSH, 1994; Standards Australia, 2001; Maritime and Coastguard Agency, 2010; Standards Australia, 2003; UK Ministry of Defense, 2014; Rekus, 1994; BCGA, 2009; Government of South Australia, 2011; Workplace health and safety Queensland, 2010). Par ailleurs, les principaux outils suggérés dans la littérature pour l'analyse du risque en espace clos (check-lists, échelles de risque, matrices) sont souvent incomplets et ne tiennent pas compte de certains facteurs particuliers comme les caractéristiques physiques de l'espace clos, les conditions de sauvetage, les phénomènes dangereux de nature variée, ou encore la condition physique et psychologique de la personne qui entre. Enfin, l'architecture de ces outils d'estimation du risque contient des défauts tels que des définitions de niveaux de paramètres vagues ou une distribution non uniforme des niveaux de risques dans la matrice (Chinniah *et coll.*, 2011; Duijm, 2015).

Contribution 3 (hypothèse de recherche 2) : Les travaux de recherche ont également révélé un manque d'encadrement et de critères pour une utilisation adéquate de la notion d'espace clos similaire, utilisée pour alléger le travail de réduction du risque. Par exemple, la notion d'espace clos similaire est présentée sans critère pratique pour juger de la similarité (ex. « caractéristiques similaires », « mêmes risques », « en raison de leurs similarités », etc.). De plus, il est plus adapté de parler d'interventions en espaces clos similaires puisque la nature des travaux effectués influence les risques rencontrés. Il en est de même pour le concept de catégorisation des espaces clos qui peut être utile pour la communication et la réduction des risques. Les catégorisations des espaces clos présentés se basent soit sur la nature des risques soit sur le niveau de certains risques. Une méthode englobant ces deux notions donnerait une image plus complète des risques liés à l'intervention en espace clos.

Contribution 4 (hypothèse de recherche 3): Un bilan des accidents mortels en espace clos au Québec entre 1998 et 2011 et des mécanismes en cause a été établi. Il appert dans la plupart des accidents que les activités en espace clos étaient improvisées et qu'aucune procédure de travail n'a été appliquée, ce qui en fait un facteur de risque important. Les moyens de réduction du risque étaient par le même fait inadaptés, voire inexistants. Par ailleurs, aucun plan de sauvetage n'était disponible sur les lieux de travail. Enfin, les conditions d'utilisation et les travaux effectués dans les espaces clos n'avaient pas été envisagés lors de la conception. Une conception sécuritaire des espaces clos efficace devra passer par l'utilisation d'outils d'analyse du risque adaptés au contexte et à la complexité des espaces clos. Ce travail au niveau de la conception n'est pas encore totalement formalisé sur le terrain.

Contribution 5 (hypothèses de recherche 3 et 4): Les difficultés vécues par les organisations pour la gestion des risques en espace clos ainsi par rapport aux exigences réglementaires et normatives ont été identifiées. Les organismes visités ont semblé négliger tant au niveau prescrit que lors des interventions (i) l'estimation des risques, se basant uniquement sur l'expérience de l'émetteur de permis, (ii) la gestion des sous-traitants, (iii) les audits dédiés à l'utilisation des moyens de réduction du risque, et (iv) l'intégration de la conception sécuritaire. Le manque de lignes directrices limitait l'efficacité réelle des mesures liées à la formation, au sauvetage, à l'utilisation de certaines mesures de contrôle (ex. détecteurs de gaz) ainsi que la préparation des permis d'entrée. Un permis d'entrée qui regroupe toutes les informations nécessaires à la préparation d'une entrée en espace clos a ainsi été proposé.

Contribution 6 (hypothèse de recherche 5): Un outil d'appréciation du risque dédié aux interventions en espace clos a été développé en inspirant de la démarche utilisée dans les normes en sécurité des machines (ex. ISO 12100:2010 et ANSI/ASSE Z690.3-2011). Les 5 étapes de l'outil reprennent formellement les étapes de l'appréciation et de la réduction du risque prescrites dans ces normes (c.-à-d. définition du contexte, identification des dangers, estimation du risque, évaluation du risque et réduction du risque).

Contribution 7 (hypothèse de recherche 5): L'outil développé répond aux lacunes identifiées dans la littérature et dans les entreprises vis-à-vis de l'appréciation des risques et des conditions de sauvetage lors des interventions en espace clos. L'étape 1 de l'outil est une liste de 26 questions fermées pour caractériser l'espace clos, son environnement et les conditions d'intervention. Les réponses génèrent une liste de phénomènes dangereux répartis en sept familles (c.-à-d. atmosphérique, chimique, biologique, chute, mécanique physique et ergonomique). La table de conversion a été obtenue par consensus entre les chercheurs selon les principes de la méthode Delphi (c.-à-d. méthode visant à organiser la consultation d'experts sur un sujet précis). La deuxième étape permet de décrire les processus accidentels liés aux phénomènes dangereux retenus par l'utilisateur. Ces deux étapes assurent une identification rigoureuse et multidisciplinaire des phénomènes dangereux. Elles peuvent également soutenir le processus de conception sécuritaire. L'étape 3 permet d'estimer le risque avec une matrice, des paramètres et des critères qui tiennent compte du contexte des interventions en espace clos (ex. nature des phénomènes dangereux, plusieurs entrants, interactions des phénomènes dangereux, difficultés d'accès). La matrice de risque proposée prend également en compte les règles de construction formulées au cours des dernières années dans la littérature scientifique pour l'estimation du risque à l'aide d'un tel outil. L'étape 4 propose une catégorisation graphique de l'intervention en intégrant à la fois la nature et le niveau des risques. Enfin l'étape 5 est une boucle de rétroaction pour estimer les risques résiduels une fois les mesures de réduction du risque choisies. En outre, l'utilisation de cet outil permet de déterminer à l'aide de critères explicites (i) si deux espaces clos sont réellement identiques (étapes 1 et 2), (ii) si le sauvetage sans entrée est possible (étape 1), et (iii) si les risques sont acceptables (étapes 3 à 5). Tous ces éléments permettent de faciliter, de formaliser et de documenter le processus de réduction du risque mené par les organisations (exigences de diligence raisonnable). L'utilité et la pertinence de cet outil ont été confirmées lors de tests avec une version automatisée auprès de 22 experts en espace clos. L'outil répond à leur besoin de structuration et d'exhaustivité lors de la préparation des entrées en espace clos.

Contribution 8 (hypothèse de recherche 5) : 4 outils d'appréciation du risque préconisés dans la littérature ou en entreprise pour les interventions en espace clos ont été comparés. L'outil développé lors de cette thèse est inclus dans les 4 outils testés. Ces quatre approches sont une check-list sans estimation du risque, une check-list avec échelle de risque, un calcul du risque sans étape formelle pour l'identification des phénomènes dangereux et un questionnaire suivi d’une matrice de risque. Les quatre outils ont été testés sur 3 scénarios à risque. La structure des outils, leur utilisation et les résultats obtenus ont été étudiés. L’outil développé dans le cadre de cette thèse se distingue des autres outils par (i) son approche systématique qui permet de se questionner sur les risques, d’identifier les facteurs de risque, et de documenter le processus d’analyse, (ii) sa structure qui reprend formellement toutes les étapes suggérées dans les normes en gestion du risque, (iii) l’exhaustivité et la multidisciplinarité de l’étape de l’identification des phénomènes dangereux, (iv) les critères de choix détaillé et des définitions de niveaux de paramètres pour l’estimation du risque, (v) l’exploitation des résultats de l’identification et de l’estimation des risques en proposant une catégorisation des risques et des conditions de sauvetage et (vi) l’impact des mesures de réduction du risque dédiées aux espaces clos sur les paramètres du risque.

7.2 Limitations de la solution proposée et directions de recherche

Les échantillons d’entreprises et de participants qui ont été visés lors de la mise en place de la méthode de recherche n’ont pas de portée statistique. La méthodologie en place avait pour objectif d’explorer la variété des situations plus que leur représentativité. Le critère qui a été fixé pour le nombre d’entrevues (entre 10 et 15) est basé sur le principe de saturation (Gillham, 2000). La collecte de données est arrêtée lorsque les informations recueillies dans les différentes situations deviennent répétitives. Il convient également de mentionner que les organisations et les préventionnistes rencontrés lors de ces travaux de recherche proviennent uniquement de la province du Québec. Les besoins exprimés et pris en considération sont donc liés aux exigences réglementaires et aux conditions de travail de cette province.

Par ailleurs, la démarche proposée tente de répondre à la complexité des interventions en espace clos. Le corollaire est que la solution proposée ne peut pas trop simplifier l’analyse. Ainsi, cette démarche s’adresse uniquement à des personnes dites qualifiées selon la définition donnée à l’article 297 du RSST : « une personne qui, en raison de ses connaissances, de sa formation ou de son expérience, est en mesure d’identifier, d’évaluer et de contrôler les dangers relatifs à un espace clos » (Gouvernement du Québec, 2014). Ces connaissances doivent permettre de répondre adéquatement aux questions de la première étape pour ne pas biaiser les résultats qui en découlent. Aussi, l’utilisation de l’outil proposé ne dégage en aucun cas l’utilisateur de ses responsabilités en matière d’analyse des risques.

Par ailleurs, les interactions entre les phénomènes dangereux lors des interventions en espace clos, qui sont globalement négligées lors des analyses du risque, ont été traitées dans la démarche proposée lors de la précision de l'événement dangereux (c.-à-d. élément déclencheur de l'accident ; par exemple une intoxication qui conduit à une chute dans une échelle). Toutefois, cette proposition reste limitée puisque l'augmentation de la probabilité du dommage liée à l'interaction n'est pas automatiquement incluse lors de l'estimation du risque. Le choix de la probabilité du dommage est entièrement sous la responsabilité de l'utilisateur. Enfin, il aurait été possible de modéliser les interactions entre les dangers lors de la synthèse visuelle des risques en liant certaines familles de risque.

Dans le même ordre d'idée, l'outil proposé ne peut pas être utilisé juste avant une entrée dans un espace clos. Il doit l'être lors du processus de planification de l'intervention. Selon nos tests, la durée moyenne pour étudier un scénario à risque est d'une vingtaine de minutes. C'est une limitation dans le cadre d'une utilisation en entreprise. Les préventionnistes interrogés ont été unanimes sur le fait que la viabilité de la démarche en entreprise, surtout celles qui gèrent un grand nombre d'espaces clos, passe par un développement logiciel professionnel qui optimisera l'utilisabilité et le potentiel des données obtenues. Plusieurs avenues de développement sont possibles. Par exemple, une interface utilisateur dynamique basée sur des boîtes de dialogue successives pourrait faciliter les réponses au questionnaire ainsi que les choix et la saisie des étapes subséquentes. Également, la liste des phénomènes dangereux potentiels proposée suite au questionnaire pourrait être optimisée en effectuant des analyses croisées des réponses au questionnaire ou encore en utilisant un algorithme d'apprentissage incrémental[1] basé sur les données issues d'un nombre important d'analyses. Un tel algorithme d'apprentissage pourrait même à terme réduire le nombre de questions nécessaire pour passer en revue l'ensemble des facteurs de risque et orienter les choix du niveau des paramètres lors de l'estimation des risques. Enfin, le développement logiciel de l'outil pourrait s'intégrer dans le processus global de gestion des risques pour les entrées en espace clos. L'utilisation des résultats des analyses du risque pourrait permettre la génération automatique des permis d'entrée.

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[1] Algorithme qui apprend en recevant des données d'entrée et les résultats associés. L'algorithme peut à terme prédire le résultat optimal à partir des données d'entrées (Borodin & El-Yaniv, 1998).

Par ailleurs, les résultats obtenus au chapitre 6 illustrent que les analyses du risque avec une approche intuitive peuvent être complémentaires aux approches analytiques. Les outils de type check-list et échelle de risque privilégiés en entreprises se sont révélés être des outils rapides d'utilisation basés sur l'instinct qui donnent des résultats convenables par rapport aux outils plus analytiques. Les approches intuitives permettent une première analyse globale de la situation. La comparaison entre ces deux approches (c.-à-d. intuitive et analytique) mériterait d'être approfondie dans le cadre de la gestion des risques en espace clos en faisant appliquer à un groupe d'experts des outils de type échelle de risque (tendance intuitive) et des outils de type matrice de risque (tendance analytique). Afin de réduire les biais lors cette étude, les outils comparés à l'outil développé lors de ce travail de thèse devraient être des outils non consultés lors de cette étude. À terme, une telle étude permettrait d'explorer une fusion entre les deux approches dans un même outil afin d'être plus efficace tout en restant fiable. Les résultats de l'estimation du risque pourraient être étudiés en termes de convergence de l'indice de risque obtenu et de satisfaction.

Enfin, la conception sécuritaire étant le moyen le plus efficace de réduire les risques (Table 5.9), une autre avenue de recherche possible serait d'intégrer l'utilisation de notre outil, qui se distingue dans l'identification des facteurs de risque, dans les bureaux d'études de concepteurs d'espace clos (ex. silos, égouts, traitement des eaux). Il serait pertinent de mesurer l'impact de l'utilisation dès la conception d'un tel outil sur la prévention des risques en SST.

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ANNEXE A – GRILLE DE LECTURE UTILISÉE LORS DE LA REVUE DE LA LITTÉRATURE

Éléments d'étude	**Document 1**	**Document 2**	**…**
A/ Risques identifiés - Type, nature - Description, valeurs limites - Blessures liées - Interactions risques			
B/ Activités liées à l'entrée dans l'espace clos - Type - Description, matériel utilisé			
C/ Facteurs de risque (éléments pouvant influencer les risques) - Conception, configuration de l'espace clos - Utilisation de l'espace clos - Psychologie, physiologie du travailleur - Autres			
D/ Techniques d'analyse du risque - Méthode générale (ex., check-list, matrice, calcul, etc.) - Paramètres composant le risque (déf., nb de niveau, etc.) - Indice de risques (déf., nb. de niveau, etc.) - Utilisation des résultats, évaluation du risque			
E/ Catégorisation d'un espace clos - Type de catégorie - Critère de catégorisation			
F/ Conception sécuritaire des espaces clos, méthodes alternatives - Techniques suggérées			

ANNEXE B – GRILLE DE LECTURE POUR L'ANALYSE DES ACCIDENTS MORTELS EN ESPACE CLOS AU QUÉBEC

# Accident	**Accident #1**	**Accident #2**	**…**
Date accident : AA-MM			
Date rapport : AA			
Nom de l'entreprise			
Secteur d'activité			
Type d'espace clos			
Activité lors de l'accident			
Description sommaire de l'accident			
Nombre de décès			
Nombre de blessés			
Causes issues de l'enquête			
Agent causal primaire			
Fonctions travailleurs			
Travailleur seul ou en équipe?			
Méthode de travail adéquate appliquée (procédure)			
Méthode de sauvetage adéquate (plan de sauvetage)			
Éléments de conception			
Divers			

ANNEXE C – QUESTIONNAIRES UTILISÉS EN ENTREPRISES POUR ÉTUDIER LA GESTION DES RISQUES LORS DU TRAVAIL EN ESPACE CLOS

Cette annexe présente les 3 outils de collecte utilisés lors des visites en entreprises afin d'étudier leur gestion des risques lors des interventions en espaces clos:

A. une grille d'entretien pour les entrevues;
B. une grille de collecte pour les observations d'entrée en espace clos;
C. une grille pour la vérification du programme de gestion mis en place.

A. GRILLE D'ENTRETIEN

SYNTHÈSE DE LA VISITE

Compilé par	……………………………………………………………………………………
Coordonnées	Nom de l'organisme : …………………………………………………………… Adresse : ……………………………………………………………………………
Date de la visite	………../………../…………………
Personne contact	Nom : …………………………………………………………………………… Fonction : ………………………………………………………………………… Tél. professionnel : …………………………………………………………… Courriel : ………………………………………………………………………… Expérience (espace clos) : ……………………………………………………
Personnes interviewées	Nom : …………………………………………………………………………… Fonction : ………………………………………………………………………… Expérience (espace clos) : ……………………………………………………
	Nom : …………………………………………………………………………… Fonction : ………………………………………………………………………… Expérience (espace clos) : ……………………………………………………
Résumé de la documentation obtenue	…………………………………………………………………………………… …………………………………………………………………………………… ……………………………………………………………………………………

RENSEIGNEMENTS GÉNÉRAUX SUR L’ORGANISME VISITÉ

Organisme visité (10)

Raison sociale (100) : ……………………………………………………………………

Secteur d’activités économique (selon le portrait de l’établissement) (101) :

……………………………………………………………………………………………

Nombre de travailleurs dans l’organisme (102) : ………………………………………

Nombre et fonction des travailleurs concernés par les espaces clos (103) : ……

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Type de production / Services offerts (104) :

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Organigramme général en lien avec la SST (105) :

- ………………………………………………………………………………………
- ………………………………………………………………………………………
- ………………………………………………………………………………………
- ………………………………………………………………………………………
- ………………………………………………………………………………………

Y a-t-il un comité de SST? (106) ☐ Oui ☐ Non

Y a-t-il un sous-comité pour la gestion du travail en espace clos? (107)

☐ Oui ☐ Non

Y a-t-il un responsable SST ou de la prévention? (108) ☐ Oui ☐ Non

---

PARC D'ESPACES CLOS

Identification (20)

Qu'est-ce qui a déclenché l'identification des espaces clos? (200) ……………………

……………………………………………………………………………………………

Quelle définition d'un espace clos a été utilisée pour leur identification$^+$? (201)
☐ RSST ☐ CSTC (Code de la construction) ☐ Autre : ……………

……………………………………………………………………………………………

Par qui l'identification a été faite$^+$? (202) ☐ Personne qualifiée

☐ Autre : …………………………………………………………………………………

Quand? (203) ……………/……………………

Les espaces clos sont-ils physiquement identifiés, et leurs accès contrôlés$^+$?
(204) ☐ Oui ☐ Non ……………………………………………………………………

Si oui, comment? (205) ………………………………………………………………

……………………………………………………………………………………………

Avez-vous un processus qui permet de déclasser un espace clos en espace restreint (ou isolé à risque)? (206) ☐ Oui ☐ Non

Si oui, pouvez-vous préciser? (207) ……………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Parc (21)

Nombre d'espaces clos répertoriés (210) : ……………………………………………

……………………………………………………………………………………………

Avez-vous une liste des espaces clos, et est-elle disponible (211)

☐ Oui ☐ Non

<u>Si non</u>, quels types espaces possédez-vous (fonction, localisation)? (212) :

1. ……………………………………………………………………………………
2. ……………………………………………………………………………………
3. ……………………………………………………………………………………
4. ……………………………………………………………………………………
5. ……………………………………………………………………………………
6. ……………………………………………………………………………………
7. ……………………………………………………………………………………
8. ……………………………………………………………………………………
9. ……………………………………………………………………………………
10. ……………………………………………………………………………………

PROGRAMME DE GESTION DES ESPACES CLOS

Programme ou autre (30)	Avez-vous un programme de gestion des espaces clos+? (300) ☐ Oui ☐ Non Si non, quelles mesures de gestion avez-vous? (301) …………………………………………
Élaboration du programme de gestion des espaces clos (31)	Qu'est-ce qui a déclenché l'élaboration du programme? (310) ………………………… Par qui le programme a-t-il été élaboré? (311) …………………………………………… Date d'élaboration (312) : …………/……../………………… Quelles références ont été utilisées? (313) ☐ RSST ☐ CSA Z1006-10 ☐ CSTC (Code de la construction) ☐ Autres : …………………………………… La direction a-t-elle été impliquée? (314) ☐ Oui ☐ Non Les travailleurs ont-ils participé? (315) ☐ Oui ☐ Non Quels moyens ont été mis à disposition? (316) ……………………………………………
Utilisation du programme (32)	Comment le programme est-il rendu accessible aux employés? (320) ……………… Comment est-il intégré au système de gestion de la SST? (321) …………………… ……………………………………………………………………………………………………
Audit et revue du programme de gestion des espaces clos (33)	Le programme a-t-il déjà été audité? (330) ☐ Oui ☐ Non - Si oui, pour quelles raisons ou à quelle fréquence? (331) …………………………… …………………………………………………………………………………………… - Par qui? (332) …………………………………………………………………………… L'application du programme a-t-elle déjà été auditée? (333) ☐ Oui ☐ Non - Si oui, pour quelles raisons ou à quelle fréquence? (334) …………………………… …………………………………………………………………………………………… - Par qui? (335) ……………………………………………………………………………
Documentation développée (résumé) (34)	Quels documents avez-vous développés? (340) *Disponible* - Programme de gestion : ☐ Oui ☐ Non ☐ - Liste des espaces clos : ☐ Oui ☐ Non ☐ - Fiches descriptives des espaces clos : ☐ Oui ☐ Non ☐ - Fiches de contrôle (permis d'entrée) : ☐ Oui ☐ Non ☐ - Registre des interventions ☐ Oui ☐ Non ☐ - Liste des intervenants (dont sous-traitants) : ☐ Oui ☐ Non ☐ - Documents de formation : ☐ Oui ☐ Non ☐ - Audit et revue : ☐ Oui ☐ Non ☐ Les documents sont mis à jour selon quel mécanisme? (341) …………………………… ……………………………………………………………………………………………………

INTERVENTIONS EN ESPACE CLOS

Interventions effectuées (40)

Combien d'interventions en espace clos faites-vous par an (400) : ....

Sur quels espaces clos principalement? (401) ....

- ....
- ....
- ....
- ....

Durant quelles périodes de l'année? (402) ....

Pour quels types de travaux et à quelle fréquence (nombre/an)? (403) :

☐ Réparation : ....
☐ Déblocage / Ajustement / Dépannage : ....
☐ Construction / Démontage: ....
☐ Inspection : ....
☐ Récupération d'objet : ....
☐ Nettoyage: ....
☐ Autres :...

Planification des interventions et difficultés (41)

Quelle est la proportion d'interventions planifiées (par rapport à celles imprévues)? (410) ....

Y a-t-il des situations où vous n'appliquez pas de procédure avant d'entrer? (411) ☐ Oui ☐ Non

Si oui, pourquoi? (412)

- ....
- ....

Quelles sont les principales difficultés rencontrées lors des interventions en espaces clos? (413)

- ....
- ....
- ....

Avez-vous eu des incidents/accidents lors d'entrée en espace clos? (414)

☐ Oui ☐ Non Si oui, quelle en était la cause? (415)

- ....
- ....
- ....

INTERVENANTS

Organisation des intervenants
(50)

Quelle est la hiérarchie en place concernant la gestion des espaces clos? (500)

- ……………………………………………………………………
- ……………………………………………………………………

Quelle est la composition des équipes d’intervention? (501)

- Entrant
- Surveillant$^+$: ☐ Oui ☐ Non
- Surveillant de fond : ☐ Oui ☐ Non
- ……………………………………………………………………

À combien interviennent-ils au minimum? (502) ……………………………………

Formation / Information pour les interventions en espace clos
(51)

Les entrants sont-ils habilités$^+$? (510) ☐ Oui ☐ Non

Les différents intervenants sont-ils formés$^+$? (511) ☐ Oui ☐ Non

Formation (512): ☐ En interne ☐ En externe Durée : ……………………

La formation est-elle adaptée à leur rôle? (Pratique/Théorique, sauvetage, surveillance, analyse de risque, travail à chaud, cadenassage, etc.) (513)

☐ Oui ☐ Non ……………………………………………………

……………………………………………………………………

Les intervenants ont-ils reçu, avant que leur travail débute, des informations spécifiques aux espaces clos du lieu de travail$^+$? (514) ☐ Oui ☐ Non

Quelle est la fréquence des remises à niveau? (515) ……………………………

Sous-traitance
(52)

Y a-t-il des interventions en espace clos sous-traitées? (520) ☐ Oui ☐ Non

Si oui, pouvez-vous préciser (521) : ……………………………………………

- ……………………………………………………………………
- ……………………………………………………………………

Comment sont gérées les activités exécutées par les sous-traitants? Comment les pratiques sont-elles harmonisées? (522) ……………………………………

……………………………………………………………………

……………………………………………………………………

Les sous-traitants ont-ils reçu, avant que leur travail débute, des informations spécifiques aux espaces clos du lieu de travail$^+$? (523) ☐ Oui ☐ Non

Lors du devis, assurez-vous que les sous-traitants aient reçu une formation sur les interventions en espace clos? (524) ☐ Oui ☐ Non

Les activités des sous-traitants sont-elles documentées? (525) ☐ Oui ☐ Non

PROCÉDURES D'ENTRÉE EN ESPACE CLOS

Permis d'entrée	Avez-vous une procédure de travail générale pour les entrées en espace clos? (600) ☐ Oui ☐ Non
Fiches descriptives et de préparation à l'entrée (60)	Utilisez-vous des fiches de contrôle (permis d'entrée)? (601) ☐ Préparées d'avance ☐ Préparées juste avant l'entrée ☐ Non Sur quelles bases vos fiches de contrôle (permis) sont-elles élaborées et validées$^+$? (603) ☐ Fiches descriptives et de préparation à l'entrée ☐ Analyse de risques ☐ Autre : …………………………………… …………………………………………………………… Qui les prépare$^+$? (604) ☐ Personne qualifiée : …………………………… ☐ Autre : …………………………………………………… Comment la fiche de contrôle (permis d'entrée) et la fiche descriptive et de préparation à l'entrée sont-elles rendues accessibles? (605) ☐ Classeur papier ☐ Poste informatique ☐ Autre : …………………… Comment l'accès au matériel d'intervention est-il organisé (ÉPI, ventilation, instrument de mesure)? (606) …………………………………… ……………………………………………………………
Procédure de sauvetage (61)	Y a-t-il des mesures de sauvetage mises en place pour les interventions en espace clos$^+$? (610) ☐ En interne ☐ À l'externe ☐ Aucune Expliquez (en entrant, depuis l'extérieur, etc.) : …………………………… …………………………………………………………… …………………………………………………………… Ces mesures, sont-elles adaptées en fonction des dangers liés à l'intervention de sauvetage (ex. environnement contaminé)? (611) ☐ Oui ☐ Non Ces mesures ont-elles été éprouvées$^+$? (612) ☐ Oui ☐ Non Si à l'interne, comment les équipements de sauvetage sont-ils rendus accessibles$^+$? (613) …………………………………………… Pouvez-vous élaborer sur les équipements de sauvetage disponibles$^+$? (614) …………………………………………………………… ……………………………………………………………
Procédure de cadenassage (62)	Un programme de cadenassage a-t-il été développé en complément des interventions en espace clos? (620) ☐ Oui ☐ Non Si oui, pouvez-vous préciser (621) : …………………………………… ……………………………………………………………

GESTION DES RISQUES LORS DES ENTRÉES EN ESPACE CLOS

Identification des phénomènes dangereux^{+} (70)

Les phénomènes dangereux ont-ils été identifiés? (700)

☐ Par espace clos ☐ Par intervention ☐ Non

…………………………………………………………………………………………

Un formulaire a-t-il été utilisé pour effectuer ce travail (ex. check-list)?

☐ Oui ☐ Non Si oui, précisez (701) : …………………………………………

Qui effectue ce travail d'identification des phénomènes dangereux? (702)

☐ Personne qualifiée ☐ Autre : …………………………………………………

A-t-il été fait en équipe? (703) ☐ Oui ☐ Non…………………………………

Les phénomènes dangereux suivants ont-ils été pris en compte? (704)

Coter la fréquence de leur présence avec 1 : peu présent, et 3 : très présent

Intoxication/Asphyxie	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Explosion, incendie, poussière	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Thermique (surface)	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Thermique (ambiance)	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Électrique	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Ensevelissement/Écoulement libre	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Chute de hauteur	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Pièce en mouvement	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Noyade/écoulement	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Bruit et vibration	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Introduction substance/Interconnexion	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Travail à faire (ex. travail à chaud)	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Biologique, animaux	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Chute de plain-pied	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Structure de l'espace (ex. stabilité)	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Éclairage/visibilité	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Chute d'objet	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Radiation	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Entrée/sortie restreinte	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Lié aux résidus : …………………………	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Circulation extérieure	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Environnemental/Météorologique	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Effort excessif/posture	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Accessibilité à l'espace clos	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Psychologie, stress	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3
Lié aux vêtements/ÉPI	☐ Oui ☐ Non	☐ 1 ☐ 2 ☐ 3

Autres : ………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

Estimation du risque* pour les interventions en espace clos (71)

* définition de la gravité probable d'un dommage et de la probabilité de ce dommage (ISO12100:2010)

Les risques lors des interventions en espace clos sont-ils estimés? (710)

☐ Oui ☐ Non

Combien d'estimations du risque ont-elles été faites? (711) ....

Un outil d'estimation du risque est-il utilisé? (712): ☐ Oui ☐ Non

Avez-vous intégré dans l'outil d'estimation du risque des particularités pour l'adapter au contexte des interventions en espace clos (ex. condition de sauvetage)? (713) ☐ Oui ☐ Non

....

Pouvez-vous justifier les choix qui ont été faits lors de la construction ou la sélection de cet outil (ex. paramètres, niveaux, définitions, etc.)? (714)

....

....

Quels sont, selon vous, les avantages et les inconvénients (difficultés) de votre outil d'estimation du risque? (715) ....

....

....

Qui effectue ce travail d'estimation du risque$^+$? A-t-il été fait en équipe? (716)

....

....

Évaluation du risque* pour les interventions en espace clos (72)

* jugement destiné à établir, à partir de l'analyse du risque, si les objectifs de réduction du risque ont été atteints (ISO12100:2010)

Les risques résiduels sont-ils évalués (ex. inacceptable/acceptable)? (720)

☐ Oui ☐ Non Si oui, selon quels critères? (721)

- ....
- ....
- ....
- ....

Quels critères sont nécessaires pour autoriser l'entrée en espace clos$^+$?

Pouvez-vous justifier les choix de ces critères? (722)

- ....
- ....
- ....
- ....

Quelles sont les principales difficultés lors de l'évaluation du risque? (723)

- ....
- ....

Réduction du risque pour les interventions en espace clos (73)

Y a-t-il des catégories d’espace clos qui ont été créées? (730) ☐ Oui ☐ Non

Si oui, selon quels critères? (731)

- ....
  ....
- ....
  ....

Travaillez-vous sur la conception des espaces clos pour éliminer les risques à la source? (732) ☐ Oui ☐ Non

Si oui, pouvez-vous nous donner quelques exemples? (733)

- ....
- ....
- ....

Quels sont les autres principaux moyens mis en place pour réduire les risques? (734)

- Ventilation+ : ☐ Oui ☐ Non ....
- Équipement de protection :
  - Harnais+ : ☐ Oui ☐ Non ....
  - Appareil respiratoire : ☐ Oui ☐ Non ....
  - Autres : ....
- Détecteur de gaz, test et relevés+ : ☐ Oui ☐ Non ....
- Moyen de communication : ☐ Oui ☐ Non ....
- Purge, dégazage, ou nettoyage : ☐ Oui ☐ Non ....
- ....

Avez-vous un programme d’entretien du matériel pour la réduction du risque? (735) ☐ Oui ☐ Non

Avez-vous mis en place des moyens pour faciliter la mise en place des mesures de réduction des risques? (736) ☐ Oui ☐ Non

Si oui, pouvez-vous nous donner quelques exemples? (737)

- ....
- ....

Quelles sont les principales difficultés lors de la réduction des risques? (738) ...

- ....
- ....
- ....

B. GRILLE D'OBSERVATION

Complété par	………………………………………………………………………………………
Organisme	………………………………………………………………………………………
Date de la visite	…………/…………/……………………

INTERVENANTS

Équipe d'intervention (A)	Nom : ……………………………… Fonction : ……………………………… Expérience (espace clos) : ………………………………………………
	Nom : ……………………………… Fonction : ……………………………… Expérience (espace clos) : ………………………………………………
	Nom : ……………………………… Fonction : ……………………………… Expérience (espace clos) : ………………………………………………
	Autres : …………………………………………………………………… ……………………………………………………………………………
Perception des risques (B)	Perception des risques avant et lors de l'intervention (ex. conscience, facteurs) : …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… Expériences concernant la récupération d'incidents ou de passés proches : …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… ……………………………………………………………………………

CONTEXTE

Espace clos concerné **(C)**	Type d'espace clos : …………………………………… Fonction : …………………………………… Localisation : …………………………………… Accessibilité à l'espace clos : …………………………………… Description générale de l'espace clos / Schéma: …………………………………… …………………………………… …………………………………… …………………………………… Nombre entrée/sortie : …………………………………… Dimensions des entrées/sorties : ………… / ………… / ………… Moyen d'accès à l'intérieur : …………………………………… Profondeur : …………m Distance de pénétration : ……………………m Contenu : …………………………………… Équipements présents à l'intérieur : ☐ Oui ☐ Non Si oui : …………… Présence d'obstacles : ☐ Oui ☐ Non Si oui : …………………… Préparation avant l'ouverture : ☐ Purge ☐ Nettoyage ☐ Ventilation
Environnement de travail extérieur **(D)**	T°C : ………… Conditions climatiques : …………………………… Bruit environnant : ☐ Très bruyant ☐ Bruyant ☐ Normal Luminosité : ☐ Suffisante ☐ Faible ☐ Très faible/Obscurité Divers : ☐ Travail en hauteur ☐ Véhicules circulant à proximité ☐ Travail isolé ☐ Présence de public à proximité ☐ Matières dangereuses à proximité ☐ Autres : ……………………
Raison de l'intervention **(E)**	☐ Réparation ☐ Déblocage ☐ Inspection ☐ Construction / Démontage ☐ Entretien préventif ☐ Nettoyage ☐ Récupération d'objet ☐ Sauvetage Détails : …………………………………… Durée : ☐ 15 min ☐ 30 min ☐ 1h ☐ 2h ☐ > 2h : …………………… Fréquence d'intervention : ……………………………………

INTERVENTION

Permis d'entrée (F) **Obtenu** ☐ Oui ☐ Non	Permis d'entrée préparé : ☐ d'avance ☐ juste avant l'intervention Utilisation réelle du permis : ☐ Oui ☐ Non Accès au permis : …………………………………………
Étapes observées lors de l'intervention – Activités de travail réelles (G)	1. ……………………… 8. ……………………… 2. ……………………… 9. ……………………… 3. ……………………… 10. ……………………… 4. ……………………… 11. ……………………… 5. ……………………… 12. ……………………… 6. ……………………… 13. ……………………… 7. ……………………… 14. ……………………… Difficultés et facteurs de risques lors de l'activité réelle : ……………… ………………………………………… ………………………………………… …………………………………………

Phénomènes dangereux présents (H)

Intoxication	☐	Produits, concentrations : ………………
Asphyxie	☐	% O_2 : ………………
Explosion, incendie	☐	Produits, %LIE : ………………
Thermique (ambiant)	☐	T°C : ……………… Humidité : ………………
Thermique (surface)	☐	T°C : ………………
Électrique	☐	Accès, Volt, Ampère : ………………
Ensevelissement	☐	Matière à écoulement libre : ………………
Chute de hauteur	☐	Hauteur : ……… Configuration : ………………
Pièce en mouvement	☐	Élément en mvt : ……………… Vitesse : ………………
Noyade/écoulement	☐	Matière: ……………… Profondeur : ………………
Bruit et vibration	☐	Source : ……………… dB :………………
Introduction substance	☐	Produits : ……………… Source : ………………
Activité	☐	Technique/Outils : ………………
Chute de plain-pied	☐	Surface/Obstacle : ………………
Structure de l'espace	☐	Stabilité, configuration interne : ………………
Éclairage	☐	Lux : ………………
Chute d'objet	☐	Mvt de charge, protection : ………………
Radiation	☐	Source : ………………
Entrée/sortie restreinte	☐	Nombre/Dimensions/Accès : ………………
Lié aux résidus	☐	Produits: ………………
Circulation extérieure	☐	Route/Piéton : ………………
Environnemental	☐	Météo : ……………… Équip. adjacent : ………………
Effort excessif	☐	Manutention : ……………… Posture : ………………
Accessibilité de l'entrée	☐	Accès/Isolement/Contrôle : ………………
Psychologie, stress	☐	État psychologique : ………………
Lié aux vêtements/ÉPI	☐	Confort/Visibilité :……………… Élec. statique : ………………

Détails : ……………………………………………………

……………………………………………………

……………………………………………………

Différences entre le permis d’entrée et l’activité de travail réelle : ………

……………………………………………………

……………………………………………………

……………………………………………………

Réduction des risques (complément d’information) (I)

Moyens utilisés pour réduire les risques :

- ……………………………………………………
- ……………………………………………………
- ……………………………………………………

Accessibilité du matériel : ……………………………………

……………………………………………………

Difficultés lors de l’utilisation du matériel pour l’intervention : ………

……………………………………………………

……………………………………………………

Mesure d’urgence (J)

Procédure d’urgence en vigueur : ……………………………………

1. ……………………………………………………
2. ……………………………………………………
3. ……………………………………………………

Matériels utilisés pour assurer un éventuel sauvetage :

- ……………………………………………………
- ……………………………………………………

Adaptés aux types de risques : ☐ Oui ☐ Non ……………………

……………………………………………………

……………………………………………………

Commentaires ……………………………………………………

……………………………………………………

……………………………………………………

……………………………………………………

C. GRILLE DE VÉRIFICATION DES PROGRAMMES DE GESTION DES ENTRÉES EN ESPACE CLOS

PROGRAMME DE GESTION DES ESPACES CLOS

Contenu du programme de gestion des espaces clos	Les thèmes suivants sont-ils présents dans le programme?		
	Informations générales (date, objectifs, références)	☐ Oui	☐ Non
	Définition espace clos	☐ Oui	☐ Non
	Rôles et responsabilités	☐ Oui	☐ Non
	Composition des équipes d’intervention	☐ Oui	☐ Non
	- Surveillant	☐ Oui	☐ Non
	Formation et communication	☐ Oui	☐ Non
	Inventaire des espaces clos	☐ Oui	☐ Non
	Signalisation et accès	☐ Oui	☐ Non
	Conception des espaces clos	☐ Oui	☐ Non
	Identification des dangers	☐ Oui	☐ Non
	Estimation des risques	☐ Oui	☐ Non
	Évaluation des risques	☐ Oui	☐ Non
	Mesures de réduction des risques	☐ Oui	☐ Non
	- Ventilation	☐ Oui	☐ Non
	- ÉPI	☐ Oui	☐ Non
	- Détecteur de gaz et relevé	☐ Oui	☐ Non
	- Cadenassage	☐ Oui	☐ Non
	Procédures de travail	☐ Oui	☐ Non
	Permis d’entrée/Fiche de contrôle	☐ Oui	☐ Non
	Gestion des permis d’entrée	☐ Oui	☐ Non
	Mesures d’urgence, de sauvetage	☐ Oui	☐ Non
	Achat et gestion du matériel	☐ Oui	☐ Non
	Gestion de la sous-traitance	☐ Oui	☐ Non
	Documentation et gestion des changements	☐ Oui	☐ Non
	Revue du programme	☐ Oui	☐ Non
	Audit de l’application	☐ Oui	☐ Non

OUTILS D’ESTIMATION DU RISQUE

Estimation du risque* pour les interventions en espace clos * définition de la gravité probable d'un dommage et de la probabilité de ce dommage (ISO12100:2010)	Outil sous forme de matrice : ☐ Oui ☐ Non Paramètres utilisés : ☐ Gravité du dommage ☐ Probabilité d’occurrence du dommage ☐ Autres : …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… Chaque paramètre est-il associé à une définition? ☐ Oui ☐ Non Y a-t-il 3 à 5 niveaux par paramètres? ☐ Oui ☐ Non Niveaux des paramètres sont-ils définis et continus? ☐ Oui ☐ Non Un paramètre a-t-il été privilégié? ☐ Oui ☐ Non Y a-t-il au minimum 4 niveaux de risque? ☐ Oui ☐ Non La distribution est-elle uniforme? ☐ Oui ☐ Non L’outil est-il calibré (ex. morts multiples)? ☐ Oui ☐ Non

ANNEXE D – QUESTIONNAIRE UTILISÉ LORS DU TEST DE L’OUTIL D’ANALYSE DU RISQUE DÉVELOPPÉ POUR LES INTERVENTIONS EN ESPACE CLOS

Cette annexe présente le questionnaire qui a été utilisé pour recueillir les impressions et commentaires des participants lors du test en entreprise de l’outil d’analyse du risque développé pour les interventions en espace clos.

INFORMATION SUR LA VISITE

Compilé par	…………………………………………………………………………………………
Coordonnées	Nom de l’organisme : …………………………………………………………… Adresse : ……………………………………………………………………………
Date de la visite	…………/……………/……………………
Personnes rencontrées	Nom : ……………………………………………………………………………… Fonction : ……………………………………………………………………………
	Nom : ……………………………………………………………………………… Fonction : ……………………………………………………………………………

IMPRESSIONS GÉNÉRALES

Structure de la démarche $_{(10)}$ 5 étapes : 1. Caractérisation de l'intervention 2. Identification des processus accidentels 3. Estimation du risque 4. Synthèse 5. Boucle de rétroaction	Pertinence/Utilité de l'approche $_{(100)}$: …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… Adaptation à une multitude de réalités (dont la vôtre) $_{(101)}$: …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… Apport en comparaison de vos méthodes d'analyse du risque en place $_{(102)}$: …………………………………………………… …………………………………………………… …………………………………………………… Complexité de la démarche $_{(103)}$: …………………………………………………… …………………………………………………… ……………………………………………………
Suggestions sur la structure/ l'approche $_{(11)}$	Points forts, points faibles $_{(110)}$: …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… Éléments d'amélioration ou manques $_{(111)}$: …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… ……………………………………………………

VALIDATIONS PRÉCISES

Étapes 1-Caractérisation de la situation (20)	Validation des questions (formulation, manque, superflue) (200) : …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… Validation de l'approche sur les conditions de sauvetage *a priori* (201) : …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… Validation de la notion d'interventions similaires (202) : …………………………………………………… …………………………………………………… …………………………………………………… ……………………………………………………
Étape 2 – Identification des processus accidentels (21)	Validation des colonnes du tableau et des listes de choix (210) : (type de risques; situation dangereuse; événement dangereux; dommage) …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… ……………………………………………………

Étape 3 – Estimation du risque (22)	Validation de l'échelle de gravité et des critères de choix (221) : …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… Validation de l'échelle de probabilité et des critères de choix (222) : …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… Validation de l'échelle de la matrice de risque (223) : …………………………………………………………………………………… …………………………………………………………………………………… ……………………………………………………………………………………
Étape 4 – Synthèse (23)	Validation du principe de synthèse avec le graphique radar (risque max. par famille ; décomposition par origine du risque) (230) : …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… Validation du principe de catégorisation (231) : …………………………………………………………………………………… …………………………………………………………………………………… ……………………………………………………………………………………
Étape 5 – Boucle de rétroaction (24)	Validation du principe de fonctionnement de la boucle de rétroaction (240) : …………………………………………………………………………………… …………………………………………………………………………………… ……………………………………………………………………………………