School of Public Health

Work-related Traumatic Fatal Injuries Involving Confined Spaces

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DECLARATION

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Ethics approval for this study was granted through Curtin University Human Research Ethics Committee (HR 18/2013), the Victorian Department of Justice Human Research Ethics Committee (for access to the NCIS) – CF/13/6856, the Coroner's Court of Western Australia (for access to West Australian data in the NCIS) – EC 13/13, and the Coroner's Court of New Zealand (for access to New Zealand data in the NCIS). Copies of these ethics approvals are in appendices 1 to 3.

Jason Stuart Selman ____________________________

Date ____________________________

ABSTRACT

Many workers die in Australia and overseas each year as a result of workplace incidents. Confined space work is an ongoing source of workplace fatalities. Confined spaces are generally defined as enclosed or partially enclosed spaces, which are not intended or designed primarily for human work, and which have a risk of a hazardous atmosphere; or a risk of engulfment by a free-flowing solid or liquid (such as grain or other agricultural products). The risk of a hazardous atmosphere includes toxic airborne contaminants, flammable airborne contaminants, and unsafe levels of oxygen. Physical risks such as electrocution and falls from height are also present within confined spaces.

Workplace fatalities may be either traumatic or chronic in nature. Traumatic fatalities typically result from physical injuries which have a sudden onset in response to the interaction with a hazard. Chronic fatalities typically result from as illnesses which have delayed onset and are usually in response to prolonged exposure to a hazard. While the link between traumatic injuries and the workplace hazards is usually clear, the relation between a chronic injury and the workplace or work activity may be difficult to establish due to the long latency period. Like any other workplace fatality, deaths as a result of confined space work can be traumatic or chronic, and in the case of traumatic fatalities, the nexus between any incident and the risks of confined space work can be confirmed.

The aim of this research was to quantify work-related traumatic confined space fatalities in Australia and the aetiologies involved. Specific objectives were to identify the rate of traumatic confined space fatalities in Australia and compare the rate with other countries at a similar level of economic development; to identify the range of factors that could be associated with traumatic confined space fatalities and evaluate the factors to assess the contribution each may have to the fatality rate; to determine what proportion of these confined space fatalities were rescuer fatalities; and to identify preventative measures to control the risks to confined space workers and rescuers in order to reduce the fatality rate.

The identification of confined space deaths in Australia and New Zealand was conducted through the National Coronial Information Service (NCIS) – an internet-based data storage and retrieval system of all deaths reported to a coroner. In both Australia and New Zealand, workplace deaths are compulsorily reportable to the relevant state coroner – usually by the police force. There are limitations in the use of the NCIS to identify the relevant fatalities, as the data can be of poor quality. Where necessary, individual state coroner's offices, workplace health and safety authorities, and other agencies were contacted for clarification as required.

Particular to Australia over the period 2000 – 2012, this research found that there were 59 confined space related deaths; with an average rate of 0.05 deaths per 100,000 workers. Two of these deaths were the result of unplanned rescue attempts. Most confined space deaths in Australia were found to have occurred in just three industry groups; being transport, postal & warehousing; and the manufacturing industry groups. Related to these industries, ship or boat hulls or holds were the most common vessel type in which the fatalities occurred. 57% of deaths were as a result of atmospheric hazards (toxic airborne contaminants, flammable airborne contaminants, and unsafe levels of oxygen), while the remainder of deaths resulted from physical circumstances such as electrocution, falls from height, and being trapped in moving machinery. Finally, 16 ceiling cavity deaths and 8 trench deaths were identified. Although these are not normally considered confined space deaths as separate legislation and standards apply to this work, they were included for completeness.

Confined space statistics and rates for other jurisdictions such as the US and Quebec were from existing published studies, or were calculated from fatality numbers provided by those studies. The confined space fatality rate for Singapore was calculated from the collation of data in the published annual Workplace Safety and Health National Statistics reports produced by the Workplace Safety and Health Council of Singapore. The few confined space deaths in the annual reports were cross-referenced to case studies, safety alerts, and media reports of confined space incidents in Singapore to determine a definitive number of deaths.

The rate of 0.05 deaths per 100,000 workers in Australia was found to be comparable to similar industrialised countries and jurisdictions where the fatality rate was found to vary between 0.05 (New Zealand and the United Kingdom), 0.07 (Province of Quebec, Canada), and 0.08 (United States and Singapore) deaths per 100,000 workers. While the exposure to confined space work can vary from jurisdiction to jurisdiction due to industry mix, across all selected industrialised countries the fatality rate for confined space deaths was similar, and there was little variation in the definition of a confined space and the requirements for safe confined space entry and work. While the rates of confined space fatalities were comparable, and confined space deaths remain relatively rare, there can be considerable difference in the absolute number of deaths between countries as a result of the differing population. All deaths are both costly and impose enormous pain and suffering on affected families and work colleagues.

Across all similar industrialised countries it was found that up to half of all confined space deaths were due to atmospheric hazards while the remainder were due to physical hazards, including engulfment – a significant hazard in agriculture in the US which has a substantial workforce in grain production, storage, and transportation. Up to 17% of the confined space fatalities were found to be those undertaking rescue, which were overwhelmingly as a result of hazardous atmospheres.

Across all similar industrialised countries the common root cause of death was found to be inadequate risk assessment prior to conducting confined space work stemming from inadequate application of the risk management process among those entering and those supervising confined space work. This exists across all levels – from management to supervisors to individual work groups. Confined space incidents can include multiple fatalities, both initial entrants and would-be rescuers. Unplanned rescue attempts were rarely successful and often resulted in additional fatalities. Due to the high risks associated with confined space rescue, a simplified rescue procedure suitable for on-site or in-house confined space rescue teams was developed in conjunction with experienced rescue professionals and rescue teams in regards to the hierarchy of rescue (self-rescue, non-entry rescue, and entry rescue – with an increasing level of difficulty and danger); including specific rescue procedures for confined space engulfment incidents. This research also noted that the need for confined space rescue can be all but avoided if adherence to all safe work procedures is undertaken prior to entry, and is much preferred to performing a rescue after an entry is made.

The most common mechanisms of confined space engulfment incidents were found to occur when a worker became entrapped or engulfed during unloading of a silo or other product storage facility, when a worker was covered by an avalanche of product, or when a worker fell into a hidden void in a product. Agricultural products were the most likely medium. Worker age (both very young and older workers were more at risk), fatigue, seasonal employment, lack of training; and lack of safe working procedures in the workplace were all contributory factors. While prevention of a confined space incident is always preferable, the improving availability and training in the use of specific rescue equipment such as grain rescue tubes was found to have great potential to reduce confined space engulfment fatalities.

To reduce confined space fatalities, recommendations include improved worker education, training and knowledge; compliance with safe work procedures (including the risk management system and legislation, codes of practice and standards); and the conduct of thorough atmospheric testing and monitoring, ventilation, and purging as required. In addition, the application of future and emerging technologies such as smart monitoring devices other wearable technologies can provide real-time environmental and worker condition and information to supervisors and managers, enhancing safety oversight.

There are a number of limitations to this work. The principal limitation is the lack and quality of the available data – there is no specific coding for confined space-related deaths in any of the jurisdictions in this study – and hence identification of confined space fatalities often requires manual review of large data-sets. The calculation of confined space fatality rates is also limited by data, with differences in factors such as the numbers of workers at risk, variation in the nature of confined space work, and the quantity of work done differing by jurisdiction. There are also dissimilarities in the legislation and standards between jurisdictions, which result in differing inclusions and exclusions. Finally, only fatal incidents are included. Incidents which do not result in one or more fatality may not be notifiable to authorities, and while such incidents may be tracked through workplace compensation claims (noting the lack of specific coding for confined space incidents), it is generally recognised that compensation data captures only approximately half of all workplace injuries. For similar reasons, only traumatic deaths can be reliably connected to a particular workplace or work task, including confined space entry, and chronic deaths are generally impossible to enumerate.

This research encourages and calls for further research to be conducted on this subject, particularly in the identification and enumeration of non-fatal confined space incidents including injuries and near-misses; in the identification of the factors which lead to confined space agricultural engulfment incidents; and into the safety beliefs and behaviours (safety culture) of personnel who undertake confined space work.

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My work colleagues who first alerted me to the lack of information on confined space fatalities in Australia and internationally – this was an itch that needed to be scratched. In particular I wish to thank my work colleagues Judey Browne, Mick Hibbett, and Rob Pickford.

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PUBLICATIONS

The following is the list of publications arising from this research:

Selman J, Spickett J, Jansz J, Mullins B. (2017) Work-related traumatic fatal injuries involving confined spaces in Australia, 2000-2012. *Journal of Health, Safety and Environment,* 33 (2): 197-215. ***Chapter 3 of this thesis.***

Selman J, Spickett J, Jansz J, Mullins B. (2018) An investigation into the rate and mechanism of incident of work-related confined space fatalities. *Safety Science,* 109 (2018): 333-343. ***Chapter 4 of this thesis.*** *Impact factor: 2.835*

Selman J, Spickett J, Jansz J, Mullins B. (2019) Confined space rescue: A proposed procedure to reduce the risks. *Safety Science*, 113 (2019): 78-90. ***Chapter 5 of this thesis.*** *Impact factor: 3.619*

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CHAPTER ONE –
INTRODUCTION AND OVERVIEW

1.1. INTRODUCTION

Occupational or workplace fatalities resulting from both incidents and hazardous exposures are a significant issue worldwide, with many thousands of work-related deaths occurring annually. Workplace injuries and fatalities can be immediate or traumatic[1] in nature; and exposures to workplace hazards[2] can also result in chronic[3] injuries and illnesses which often don't present until many years later. The difficulties in establishing the link between a work activity and a death from illness or injury many years later is particularly difficult; and as such data collections such as the European Statistics on Accidents at Work (ESAW) program exclude fatalities that occur more than 12 months after the event or exposure (European Union, 2012). Although considerable efforts have been undertaken by governments (often through regulatory agencies), worker advocacy organisations (such as unions), and industry; workplace deaths continue to occur. Workplace health and safety (WHS) or occupational health and safety (OHS)[4] is the term used to describe the efforts to protect workers and other stakeholders from exposure to hazards and the subsequent risks[5] while undertaking work.

Confined space work is one such example of an environment in which many workplace hazards are present. Confined space work can also result in traumatic injury (including death) and chronic injury and illness. Confined spaces are defined by a number of criteria and present substantial risks to workers undertaking tasks

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[1] A *traumatic* workplace incident is one which has immediate physical or health impacts (such as injury or death) and can be directly attributed to work-related activities. Bystanders can also be subject to traumatic injuries from work-related activities.

[2] A *hazard* is defined as a source or a situation with the potential for harm. Hazards include toxic atmospheres, chemicals, live electricity, workplace noise, or operating machinery.

[3] *Chronic* illnesses and injuries result from exposure to workplace hazards (including chemicals, noise, dust, and heavy loads) often with a long latency period, and a workplace nexus can be difficult to ascertain. Bystanders can also be subject to chronic injuries and illnesses from work-related activities.

[4] The term Workplace Health and Safety (WHS) is the more current usage as it refers to hazards arising from the general workplace environment rather than a specific task that workers may undertake at work – but both terms are generally used interchangeably.

[5] A *risk* is defined as the likelihood that a person may be harmed or suffers adverse health effects if exposed to a hazard. Risks have consequences such as human injury or ill-health, damage to property, damage to the environment, or a combination of these

within confined spaces or in the immediate vicinity of a confined space – including physical hazards, atmospheric hazards, and the danger of engulfment in a liquid or free-flowing solid. An additional risk with confined spaces is the risk to rescuers attempting to free or retrieve entrants after an incident has occurred. In some cases, rescuers are killed attempting to assist other workers. Confined space entry for work should only be made under strict safety conditions, with appropriate training and supervision; and confined space rescue should never be attempted by untrained personnel.

1.2 RESEARCH AIM

In 2012 I was working in the safety industry conducting safety training; performing high risk access work; and providing WHS consulting services to a range of industries including the construction, mining, water and waste, and manufacturing industry groups. My work included multiple confined space entries, rescue stand-by services, and confined space safe entry and rescue training. In order to advise on the risks of confined space entry and the gravity and difficulty of attempting a rescue, I sought to find published figures on the annual number or rate of confined space incidents. I discovered that there was no definitive number or rate of confined space fatalities published either in Australia or internationally. There were a number of studies limited by region, industry group, or other selection criteria both in Australia and internationally; and the few broad studies into confined space fatalities (only US) were all somewhat dated. This was the impetus to conduct this research. My original aim was to identify the number, rate, and aetiologies of work-related traumatic confined space fatalities in Australia.

Specific objectives were:

- To determine the rate of traumatic confined space fatalities in Australia and compare that with other countries at a similar level of economic development.
- To identify the range of factors that could be associated with confined space fatalities and evaluate the factors to assess the contribution each may have to the fatality rate.

- To determine what proportion of these confined space fatalities were rescuer fatalities.
- To identify preventative measures to reduce the risks to confined space workers and rescuers in order to control the fatality rate.

While these were my original objectives, as I undertook additional research I was able to expand on these further to develop a more international outlook; and I have now produced a far more comprehensive body of research into work-related confined space fatalities, both for Australia and internationally. By necessity, this work focuses on traumatic confined space fatalities as the link between the work undertaken (including confined space entry or associated tasks) and the subsequent injury can be ascertained with a high degree of confidence.

1.3. RESEARCH DESIGN

This investigation consisted of new research from source data for Australia and New Zealand, the collation and comparison of previously published studies for the United States (US) and Canada, the collection and cross-referencing of individual case reports, media reports, and safety alerts – often industry-driven – of confined space incidents in various jurisdictions, and the aggregation of a number of small data sets of rare event data to generate a sum of data for analysis. The selection of source data was necessarily restricted to English-speaking countries, with a high level of industrialisation and social development (and thus with appropriate WHS legislation and government regulatory agencies), and with records or reports which were available for interrogation and analysis. Unfortunately, many jurisdictions which otherwise meet the criteria (high level of industrialisation and social development) do not have either specific confined space clauses or standards contained in their WHS legislation, or do not have records which contain the data granularity required for the identification and analysis of confined space fatalities. As such, this work is primarily based on data from Australia, New Zealand, the US, Canada, Singapore, and the United Kingdom (UK).

1.3.1 Sources

Established in 2000, the National Coronial Information Service (NCIS) is an internet-based data storage and retrieval system of all deaths reported to a coroner in

Australia. Reportable deaths include those in which a person dies of unnatural causes (such as in a workplace death) or when the cause of death in unknown. Reporting such deaths is mandatory under Australian law. The NCIS is one of the three datasets used by Safe Work Australia to track and report on the annual workplace fatality rate (Safe Work Australia, 2017). It is the most comprehensive in the capture of all workplace deaths, however it has limitations as coding is a complex process and the data provided to the system is occasionally missing or incorrectly coded (Bugeja, Ibrahim, & Brodie, 2010; Lindquist, Yardley, & Champion de Crespigny, 2014).

The other datasets used are the National Data Set for Compensation-based Statistics (NDS), and the Notifiable Fatalities Collection (NFC). The NDS only records deaths in which a claim for compensation is made, and thus it does not account for self-employed persons, deaths without a claim for compensation, bystander fatalities, or Defence Force fatalities (Safe Work Australia, 2015). As such, the NDS is recognised as only capturing approximately one-half of all workplace deaths (Driscoll et al., 2003; Lindquist et al., 2014). The NFC dataset consists of work-related fatalities as notified by the 13 various state, territory, and the Commonwealth workplace health and safety authorities. The weaknesses with the NFC dataset are that data is only available from 2003, and work-related vehicle fatality data prior to 2013 is limited (Lindquist et al., 2014; Safe Work Australia, 2015).

The NCIS was the primary source of data used to determine the number and aetiologies of confined space fatalities which occurred in Australia over the period 2000-2012. The NCIS database is comprised of a number of fields including the date and time of death and a description of the basic circumstances related to the fatality. As there is no specific coding for confined space fatalities, a number of negative filters were applied to the database to reduce the tens of thousands of database entries to a manageable set of source data. The database has a number of existing check-box fields including whether an incident[6] was determined to be work-related, whether it involved intentional self-harm, resulted from an assault, was caused by terrorism or war, or was sports-related, amongst others. These boxes were unchecked and acted as broad negative filters to exclude those incidents which were not work-related and

[6] The term *incident* is generally used to refer to an unexpected event which does not necessarily include loss or damage of any kind, but can include a near miss or a close call. *Incident* is the dominant terminology used in this work.

could not have occurred in a confined space – such as vehicle accidents[7]. The exclusion of these records reduced the dataset to the source data to be scrutinised.

After the exclusions were applied, over 4,200 individual records remained to be individually examined. While many of the records could be discounted quickly based on the incident description field of the database (such as death from anaphylaxis following a bee sting), many required further analysis. The description field itself rarely used the term 'confined space'; however often reported the location of the incident and the circumstances of death. Description fields varied greatly in quality and quantity of information. In some older records, the description field consisted only of a single line of text. In newer records, the description field was often quite comprehensive and permitted the record to be either included or excluded as appropriate. Some records have additional attachments such as police reports, coroner's reports, and toxicology reports. While the police reports (usually the first emergency services personnel to arrive at the scene) varied greatly in quality, coroner's reports and toxicology reports were valuable additions to assist in the determination of inclusion or exclusion. Workplace fatalities in which a confined space could be clearly identified as a significant contributing factor were included.

Complicating the categorisation of a work-related death as a confined space fatality was that the NCIS uses the International Classification of External Causes of Injury (ICECI) coding system to classify fatalities, rather than the standard Type Of Occurrence Classification System (TOOCS) version 3.1 used in Australia (ASCC, 2008). In both classification systems, there are no specific classifications by agency or mechanism by which confined space injuries or fatalities can be readily determined. The lack of specific coding for confined space incidents is not limited to Australia or to the ICECI coding system and existed in all jurisdictions studied.

When an incident was identified but there were doubts as to its inclusion or exclusion status, individual state coroner's offices, workplace health and safety authorities, and other agencies (such as the Australian regulator for safety in the offshore oil and gas industry – the National Offshore Petroleum Safety and Environmental Management

[7] The term *accident* is generally used to refer to an unexpected event which is caused by error or chance, and which usually has some negative result – such as damage to plant or equipment, injury to a person, or loss of life.

Authority – NOPSEMA; and the Australian transportation safety regulator – the Australian Transport Safety Bureau – ATSB) were contacted for clarification as required. There were three requests made for clarification from state coroner's officers (one each from Queensland, New South Wales, and Victoria), and three requests made for clarification from state WHS regulators (two from South Australia and one from the Northern Territory). Upon receiving further information from these agencies, two were excluded and the remainder were included.

Workplace fatalities in which performing work in a confined space was a significant contributor to the fatality (such as workers welding the external surface of a confined space and were killed when it exploded) were also included.

Each confined space fatality identified was also cross-referenced to published case studies, safety alerts, and reports in the open media. There were a number of confined space deaths identified which occurred within the jurisdiction of the ATSB, and each had an available investigation report which confirmed the circumstances and justification for inclusion, and further details of the incident. Some incidents were also widely reported in the open media, while others remained obscure. Media reports were sometimes wildly inaccurate, but often provided context to the work circumstances which were not apparent in the NCIS database (such as work experience, length of employment, etc.).

NZ coronial data from 2007 was integrated into the NCIS in 2015 and this was also used as the primary source data for the number and aetiologies of confined space fatalities which occurred in NZ over the period 2007-2012. The same process was used as for determining Australian confined space fatalities, and over 400 individual records were manually reviewed. It should be noted that unlike Australia with eight different police and state coronial jurisdictions, the singular jurisdiction in New Zealand provided a far more consistent set of data to each record, and the police reports in particular contained detailed descriptions of each incident which reduced the requirement to seek further information. Consequently, no clarification from Work Safe New Zealand or Maritime New Zealand was required. Like the Australian data, each confined space fatality identified was also cross-referenced to published case studies, safety alerts, and reports in the open media; which generally confirmed the circumstances of the description of each incident.

Workplace Safety and Health National Statistics reports produced by the Workplace Safety and Health Council of Singapore were used to determine the number and aetiologies of confined space fatalities which occurred in Singapore over the period for which data was available: 2007-2014. These were cross-referenced to published case studies, safety alerts, and to media reports of confined space incidents in Singapore over the period. There were very few confined space deaths recorded in Singapore, including zero deaths in 2009 and 2012, and many of these incidents had case studies and lessons learned published by the Workplace Safety and Health Council (and available on their webpage) in order to avoid repeat incidents. With so few incidents, cross-referencing was relatively straightforward. There were differences between media reporting of three confined space incidents and their categorisation in the annual Workplace Safety and Health National Statistics reports; and clarification of the circumstances was sought directly with the Singapore Workplace Safety and Health Council who provided the information to ensure data accuracy. Uniquely, until 2012, Singapore recorded confined spaces as an *agency of incident*[8] (Workplace Safety and Health Council, 2011). That is no longer the case, and individual fatality reports now require interrogation to determine the relationship to confined spaces. The agency of incident classification is very useful to identify the type of work environment or conditions under which incidents occur, and can be used by researchers or WHS authorities to identify common circumstances or causal factors.

The calculation of the rate of confined space fatalities for Australia, New Zealand, and Singapore was undertaken using figures from government sources (Australian Bureau of Statistics, 2014; Government of Singapore, 2015; Statistics New Zealand, 2016) of the working population to determine the number of confined space fatalities per 100,000 of the working population per year. It must be acknowledged that this is only one measure of comparison, and does not account for differences in industry mix between countries, the likelihood of exposure to confined space work, or to hours worked; however work-related fatality rates are a commonly used means of evaluation of the effectiveness of WHS preventative measures (Wiatrowski & Janocha, 2014; Woolford, Bugeja, Driscoll, & Ibrahim, 2017).

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[8] The object or physical environment, which due to its hazardous nature or condition, leads to the occurrence of an incident. It is related to the incident, not the injury.

Although the numbers are a fraction of all workplace deaths, confined space fatalities can be shocking and can have lasting impacts. Like all workplace deaths, confined space fatalities are both costly and impose enormous pain and suffering on affected families and work colleagues with both short-term and long-term effects including mental health issues (Matthews, Johnstone, Quinlan, Rawlings-Way, & Bohle, 2019; Vivona & Ty, 2011).

Previously published studies from the US and Canada were used to ascertain the rate (Burlet-Vienney, Chinniah, & Bahloul, 2014; Meyer, 2003; Pettit, Braddee, Suruda, Castillo, & Helmkamp, 1996; Wilson, Madison, & Healy, 2012), *mechanism of incident*[9] (Burlet-Vienney, Chinniah, Bahloul, & Roberge, 2015a; Meyer, 2003; NIOSH, 1994; Pettit et al., 1996; Sahli & Armstrong, 1992; Suruda, Pettit, Noonan, & Ronk, 1994; Wilson et al., 2012), entrant / rescuer fatality ratio (Burlet-Vienney et al., 2014; Meyer, 2003; Sahli & Armstrong, 1992; Suruda & Agnew, 1989; Wilson et al., 2012), and rescuer mechanism of incident (McManus, 1998; Sahli & Armstrong, 1992; Suruda et al., 1994). In addition, available published data from a number of Canadian provinces was used for mechanism of incident identification, and a review of the FACE case data from the 1994 NIOSH confined space monograph (NIOSH, 1994) was undertaken to assist in the determination of the mechanism of incident for confined space rescuer fatalities. The confined space fatalities were grouped into four main categories in accordance with the major hazards of confined space work – which are also the major mechanisms of incident. The fatalities were sorted into categories of toxic atmospheres, flammable atmospheres including fire and explosion, engulfment, and a further group combining other physical hazards that have substantial risk.

A number of published studies revealed common casual factors[10] which led to confined space fatalities (Beaver & Field, 2007; Burlet-Vienney et al., 2014; MacCarron, 2006; Manwaring & Conroy, 1990; McCann & Zaleski, 2006; McManus,

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[9] The action, exposure or event that best describes the circumstances that resulted in the most serious injury or disease. For a confined space incident, the mechanism of incident could be asphyxiation (the cause of death), but the agency of incident would be confined space.

[10] Causal factors are the primary reasons behind an incident and include human factors (fatigue, unsafe actions), mechanical factors (faulty or inappropriate tools or equipment), environmental factors (heat and weather conditions, or poor lighting), and group or social factors (supervision or safety culture).

1998; Pettit et al., 1996; Ross, 2007; Sahli & Armstrong, 1992; Suruda et al., 1994). These were largely procedural in nature and included lack of confined space entry training, failure to follow specified safe work procedures, failure to test the atmosphere of the confined space before entry, and a lack of effective isolation (lockout/tagout) procedures. The common root cause [11] has been identified as inadequate application of the risk management process for confined space entry and work. These results are discussed in more detail in *Chapter 6 – Confined Space Engulfment* in this work. Further studies recommended that a more detailed and specific risk assessment for confined space entry be carried out due to the nature of the hazards (Botti, Duraccio, Gnoni, & Mora, 2018; Burlet-Vienney et al., 2015a; Wilson et al., 2012).

The recommended rescue procedure for in-house or on-site confined space rescue teams was developed by the author, who is professionally experienced in confined space risk management, rescue planning, emergency standby tasks, and confined space rescue training. The proposed procedure has developed incrementally over several years and has been used successfully by a number of on-site rescue teams. The recommended rescue procedure has been developed with regard to published confined space rescue resources, albeit that they are aimed at professional emergency services personnel (CMC Rescue, 2012; NFPA 350, 2019; Rekus, 2018; Rhodes, 2003; Roop, Vines, & Wright, 1998; Sargent, 2000; Veasey et al., 2005).

1.3.2 Inclusion and Exclusion Criteria

Due to the difficulty in identifying the nexus between confined space work and chronic injury or illness – often with delayed onset of signs and symptoms – this work only considers traumatic work-related traumatic fatal injuries involving confined spaces.

All work-related fatalities which occurred in a confined space fitting the common definition of a confined space were included. The common definition used was that a confined space is an enclosed or partially enclosed space, which is not intended or designed primarily for human work, and which has a risk of a hazardous atmosphere;

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[11] The root cause is the fundamental reason for the occurrence of a problem. In accident analysis, the root cause is the initiating cause of either an action or a condition that leads to an incident.

or a risk of engulfment by a free-flowing solid or liquid. The risk of a hazardous atmosphere includes toxic airborne contaminants, flammable airborne contaminants (including gases, vapours and dusts), and unsafe levels of oxygen (Commonwealth of Australia, 2016b; Government of Canada, 2017; Government of Singapore, 2009a; Government of the United Kingdom, 1997; OSHA, 2011c; Standards Australia, 2009). Confined spaces include vats, tanks, pits, pipes, ducts, silos, sewers, pressure vessels, interiors of machines or plant, and some shipboard spaces. Workplace fatalities in which performing work in a confined space was a significant contributor to the fatality (such as a worker falling into a confined space and dying as a result of the fall) were also included.

Confined spaces do not include the workings of underground mines (such as tunnels, shafts, drives, and stopes), which are intended as a place of work and are specifically excluded as confined spaces by some jurisdictions (Commonwealth of Australia, 2016b; Government of the United Kingdom, 1997; Standards Australia, 2009), or which have other specific safety legislation or standards (Government of New Zealand, 2016; Government of Queensland, 1999). Confined spaces such as tanks, pipes, and the interiors of machines or plant may exist in a mine however, whether underground or on the surface, and work requiring entry into these spaces would be considered to be confined space work.

Ceiling cavities and trenches are also not confined spaces, unless they are expected to contain atmospheric hazards, as they often have other specific safety legislation or standards (Commonwealth of Australia, 2016b; Government of the United Kingdom, 1997; OSHA, 2011c, 2016). Work-related ceiling cavity deaths and work-related trench deaths in Australia were identified and included separately as there were no other studies in which such fatalities were identified.

1.3.3 Published Results

The number, rate, and aetiologies of confined space deaths in Australia were published as Selman J, Spickett J, Jansz J, Mullins B. (2017) Work-related traumatic fatal injuries involving confined spaces in Australia, 2000-2012. *Journal of Health, Safety and Environment,* 33 (2): 197-215; which is included as Chapter 3 in this work.

A comparison of the rate of confined space fatalities between similarly industrialised countries, the mechanism of incident for confined space entrant fatalities and rescuer fatalities (classified into four major categories), and the proportion of rescuer fatalities was published as Selman J, Spickett J, Jansz J, Mullins B. (2018) An investigation into the rate and mechanism of incident of work-related confined space fatalities. *Safety Science*, 109 (2018): 333-343; which is included as Chapter 4 in this work.

The common causal factors which lead to confined space incidents and fatalities, implementation of the hierarchy of controls for confined space work, and the presentation of a simplified confined space rescue procedure for in-house or on-site confined space rescue teams was published as Selman J, Spickett J, Jansz J, Mullins B. (2019) Confined space rescue: A proposed procedure to reduce the risks. *Safety Science*, 113 (2019): 78-90; which is included as Chapter 5 in this work.

1.4. LIMITATIONS

The primary limitation in this research was the lack or incompleteness of available data. All WHS authorities or regulatory bodies in industrialised countries have specific regulations or codes of practice for confined pace entry and work – which indicates that these bodies recognise there are specific hazards involved in confined space work – yet there is no specific tracking of confined space incidents or injuries (including fatality) as a separately coded category of incident (McManus, 1998; Pettit et al., 1996; Riedel & Field, 2013; Sahli & Armstrong, 1992). The aforementioned categorisation of incidents by agency of incident is one solution, but is rarely used. The identification of confined space fatalities often requires manual review of large data-sets.

Although this research compared and contrasted confined space fatalities in similarly industrialised countries, variations in industry mix between the countries (and thus the likelihood of exposure to confined space work), the hours worked, and the size of the working population (calculated confined space fatality rates are more sensitive to single incidents in smaller populations) can also be factors and are a limitation to the results.

Another limitation is the differing legislation and standards between jurisdictions. Although there are more commonalities than differences, there are differing exclusions and inclusions in the datasets used in the research, and the age of the data in previous studies was variable. These limitations have been identified in prior confined space fatality research (Burlet-Vienney et al., 2014; McManus, 1998; Pettit et al., 1996; Sahli & Armstrong, 1992; Suruda et al., 1994).

The final limitation is that this research only includes confined space incidents which resulted in one or more fatality. Non-fatal incidents are impossible to numerate for a number of reasons. While mandatory reporting of workplace deaths is often required (Dong et al., 2011; Gunby, 2011), incidents which result in less-than-fatal injuries or even no injuries (such as near-misses) may not be notifiable to WHS regulators or authorities. In Australia for example, an incident is only notifiable if it results in a fatality, a *serious injury* (defined as requiring immediate treatment for an injury such as an amputation, a serious head injury, or a spinal injury, etc.), or a *dangerous incident* (defined as an immediate or imminent exposure to an uncontrolled explosion, an electrical shock, or the collapse or partial collapse of a structure). Incidents that do not meet these criteria such as minor injuries or near-misses are not notifiable to WHS regulators or authorities (Commonwealth of Australia, 2016a). If an injury results from a non-notifiable incident, it may be tracked through a claim for compensation, however it is generally recognised that compensation data captures only approximately half of all workplace injuries (de Castro, 2003; Driscoll et al., 2003; McKenzie, Mitchell, Scott, Harrison, & McClure, 2009; Probst & Graso, 2013); and the same lack of specific confined space coding exists.

1.5 Significance

As noted above, confined space fatalities have been investigated in previous international studies across whole countries, limited by jurisdictions within a country (such as by state or province), or limited by industry group or the type of work conducted. The significances of this body of work are that:

- No previous study of work-related confined space fatalities including the aetiologies and mechanisms of incident has been undertaken across Australia.

- No previous study of work-related confined space fatalities has been undertaken in New Zealand.

- No previous comparison of confined space fatality rates (fatalities per 100,000 workers) has been made between different countries.

- No previous study has attempted to identify the proportion of confined space fatalities which were as a result of physical hazards.

- No previous study has identified the mechanism of incident of confined space rescuer fatalities.

- No previous analysis of confined space rescuer fatalities across a broad range of data has been undertaken; and the result of 17% of fatalities being rescuer fatalities was much lower than the previously published and often-referenced figure of 60%.

- No simplified rescue procedure suitable for in-house or on-site rescue teams has previously been developed and published.

1.6 THESIS STRUCTURE

This is a hybrid thesis comprised of an introductory chapter; a chapter containing a literature review and history of the problem; separate chapters outlining the methodology, results and discussion (comprised of both published manuscripts and unpublished information); and a final chapter containing points of discussion, conclusions and recommendations arising from this research. This thesis contains three peer-reviewed publications to help address the objectives, of which the candidate was the primary author. These manuscripts have not been included in any other PhD thesis. All published work has been replicated with permission from respective publishers and such authorisations and authorship declarations signed by each co-author are in appendices 4 to 7. Chapters 3, 4, and 5 contain the published papers. The published manuscripts address all of the research objectives, and are presented in separate chapters. A summary of the published manuscripts and the significant findings of each is outlined in table 1. One single reference list appears at the end of this thesis and is inclusive of all citations.

Table 1. Published manuscripts and significant findings

Publication	Significant Findings
Selman J, Spickett J, Jansz J, Mullins B. (2017) Work-related traumatic fatal injuries involving confined spaces in Australia, 2000-2012. *Journal of Health, Safety and Environment,* 33 (2): 197-215.	• 59 confined space deaths in Australia over the period 2000-2012 • Rate of 0.05 confined space deaths per 100,000 workers in Australia • 2 deaths were rescuer deaths • Highest number of deaths in transport, postal & warehousing; and manufacturing industry groups • One Australian state, Western Australia, had a disproportionate number of deaths • 57% of deaths as a result of atmospheric hazards and remainder of deaths from physical hazards • Half of confined space deaths were among those aged under 35 • Ship or boat hulls or holds were the most common vessel type related to confined space fatalities • In addition, 16 ceiling cavity deaths and 8 trench deaths (not confined spaces) were identified
Selman J, Spickett J, Jansz J, Mullins B. (2018) An investigation into the rate and mechanism of incident of work-related confined space fatalities. *Safety Science*, 109 (2018): 333-343.	• Although there is no universal definition of confined space between various countries, there are few differences overall • Different countries have similar occupational exposure limits (for atmospheric hazards which may exist in confined spaces) • Rate of 0.05 confined space deaths per 100,000 workers in New Zealand • Rate of 0.08 confined space deaths per 100,000 workers in Singapore • Across all selected industrialised countries, the fatality rate for confined space deaths was similar – 0.05 to 0.08 per 100,000 workers • Up to half of all confined space deaths were due to atmospheric hazards • The remainder of confined space deaths were due to physical hazards, including engulfment • Engulfment is a significant hazard in the agricultural industry • No more than 17% of confined space fatalities are rescuer fatalities, and are almost exclusively the result of atmospheric hazards

Selman J, Spickett J, Jansz J, Mullins B. (2019) Confined space rescue: A proposed procedure to reduce the risks. *Safety Science*, 113 (2019): 78-90.	• Confined space incidents can result in multiple fatalities • Confined space incidents all stem from inadequate risk assessment and failure to apply the risk management system • Attempted rescue of personnel involved in an confined space incident is rarely successful • Confined space rescue consists of three broad levels: self-rescue, non-entry rescue, and entry rescue – with an increasing level of difficulty and danger • A simple five-step rescue procedure is suitable for on-site or in-house confined space rescue teams • While the same procedure is suitable for engulfment incidents, special equipment and techniques are required • Confined space rescue should be deliberately planned and conducted by trained and competent people • Prevention of the need for confined space rescue is preferable.

CHAPTER TWO –
LITERATURE REVIEW AND HISTORY

This chapter details the development of the confined space safety body of knowledge. This is necessarily intertwined with the progress of knowledge on workplace (or occupational) health and safety matters and the efforts by governments and worker advocacy organisations (such as unions) to reduce workplace hazards; reduce workplace injuries, illnesses and fatalities; and protect workers' rights. This chapter includes a review of the development of confined space safety legislation, regulations, and standards; an examination and comparison of international workplace fatalities and statistics; and a literature review of previous work concerning confined space fatalities.

2.1. HISTORY

While the risk of injury or fatality in the workplace has always been present, the specific dangers of working in confined spaces have also been observed for over 2000 years. The British surgeon Charles Thackrah (1832, p. 83) wrote of the Roman emperor Trajan (98 – 117 AD) 'punishing a certain class of offenders by appointing them to the cleaning of sewers', some of whom 'died from the choking fumes' (Leyerle, 2009, p. 339). In 1556, Agricola (translated 1912) wrote of stagnant air in mines producing difficulties in breathing for those who worked within. Importantly, he also identified that work activity increased the dangers 'because the foul air from both lamps and men make the vapours still more heavy' (p. 155); and that suitable actions could be taken to improve the conditions – 'the remedies for this evil are the ventilating machines' (p. 251). Thackrah also identified the maladies suffered by workers in various occupations such as well-sinkers and sewer-cleaners who were 'frequently obliged to respire carbonic acid' (p. 43) and were subject to 'fetid gases' (p. 83) during the conduct of their work – in circumstances which would be considered to be confined spaces today. In 1921 *The Lancet* reported research undertaken to determine permissible limits for carbon monoxide exposure in confined spaces (Sprigge, 1921). The health and safety risks to workers, including those involved in confined space work, eventually resulted in governments passing safety legislation for protection from workplace hazards.

2.2 General Safety Legislation

As the world rapidly shifted from a primarily agrarian society to a manufacturing economy, the industrial revolution was characterised by a large-scale change from manual and animal-based labour to machine power which brought many new hazards to the workplace. These hazards also brought about an increase in the injuries and fatalities suffered by process workers – including children – many of whom worked under terrible conditions (Winder, 2009). Commencing in the early 1800's, governments commenced passing laws (various *Factories Acts*) which required employers to protect the health and safety of workers through the application of specific standards with detailed and technical rules (Hofmann, Burke, & Zohar, 2017; Johnstone, 1999). Initially passed to protect women and children in the textile industry, these laws eventually expanded into other areas such as mining (Hutchins & Harrison, 1911).

2.2.1 Duty of Care Legislation

Progress on protecting the health and safety of workers continued to be based on exhaustive regulations and rules and safety innovation stagnated until after World War II, when the US passed the *Occupational Safety and Health Act of 1970*. This legislation commenced the shift away from detailed, technical specification standards and introduced general duty of care requirements (US Government, 1970). This was the first government legislation to introduce a two-pronged approach whereby an employer had a generic, legislated *duty of care*[12]; and was also required to follow certain standards where decreed.

Following the US, in 1970 the UK established the Committee on Safety and Health at Work under Lord Alfred Robens. The committee found workplace accidents and fatalities to be 'serious and disturbing'; and following the initiatives of the US and Canada recommended that a new system of workplace self-regulation be introduced, including involvement by workers and their representatives. The new system proposed to establish an employer's general duty of care in law, and to also enable specific requirements through subordinate legislation such as regulations and codes

[12] A moral or legal obligation to ensure the safety or well-being of others.

of practice (Robens, 1972). The government of the day agreed, and enacted the *Health and Safety at Work etc Act 1974*.

2.2.2 Australia

Australia followed suite, and the states and territories independently enacted their own workplace health and safety (or occupational health and safety) legislation. Each of these jurisdictions followed the three-tiered Robens recommendation of an Act, regulations, and codes of practices; and with the same general duty of care provisions placed on employers as in the UK model (Bluff & Johnstone, 2005; Winder, 2009). Although based on the same principles, each of the states and territories is responsible for their own workplace health and safety legislation, as it is not a Commonwealth responsibility under Section 51 of the Australian Constitution. An initiative to 'harmonise' workplace health and safety legislation across Australian states and territories commenced in 2008, and legislation based on the model laws was implemented in the Commonwealth jurisdictions, in both territories (the Australian Capital Territory and the Northern Territory), and in two states (Queensland and New South Wales) in January 2012. Two further states (Tasmania and South Australia) followed suit in January 2013; however the final two states (Victoria and Western Australia) have not implemented new WHS legislation based on the model laws at this stage. (MacDonald, Driscoll, Stuckey, & Oakman, 2012; Windholz, 2013). It is expected that Western Australia will implement new WHS legislation sometime in 2020, with a Bill prepared for debate in the state parliament (Government of Western Australia, 2019); while Victoria has no plans to review the current WHS legislation.

2.2.3 United States

The current state of legislation is no less complex in the United States. Although the Occupational Health and Safety Administration (OSHA) was established and appointed as the WHS regulator by the *Occupational Safety and Health Act of 1970*, (the National Institute for Occupational Safety and Health – NIOSH – was established under the same legislation as a WHS research and education agency), individual states are permitted to pass their own safety legislation for workers and appoint their own state regulator. 21 of the 50 states and the territory of Puerto Rico have passed independent safety legislation, and an additional five states and the territory of the Virgin Islands have passed independent safety legislation for public sector workers only. Further, self-employed persons and farm workers who are family members or who work on farms with less than eleven employees are exempt from all OSHA regulations (OSHA, 2011b; US Government, 1970).

2.2.4 Other Industrialised Countries

Of the other similarly industrialised countries referred to in this research, Canada has a WHS legislation and regulatory structure similar to that of Australia with separate jurisdictions; including a federal agency, ten provincial agencies, and three territorial agencies (Government of Canada, 1985). The UK's WHS legislation continues to operate within the Robens framework and has a single regulator, the Health and Safety Executive (the HSE). In the European Union, there is no common regulation or standard, but an overarching Framework Directive which guarantees minimum safety and health requirements throughout Europe (European Union, 1989); and a series of EU issued directives establish binding minimum WHS standards for specific tasks, hazards, and workplaces. Member states may enact legislation with higher safety standards into their own national legal framework. There is no EU directive on confined space work and thus the procedures for safe confined space entry and work are defined by the country in which the work takes place (Botti et al., 2018).

New Zealand's WHS legislation also operates with the Robens framework, and New Zealand has recently passed new WHS legislation based in part on the model Australian WHS legislation (Government of New Zealand, 2015; Windholz, 2016). New Zealand, like the UK, has a single WHS regulator.

Singapore likewise has a single regulator and has legislation which operates under a Robens-like framework (Government of Singapore, 2009c). Following a number of serious workplace accidents in 2004 which claimed 13 lives, Singapore embarked on a safety reform program which introduced new WHS legislation; strengthened the powers of the regulator (the Ministry of Manpower); employed more WHS inspectors; and increased engagement with employers, unions, service providers and other stakeholders (Doh, 2012). Many migrants on working visas are employed in higher-risk occupations in Singapore, and often have different safety perceptions to local employees given the poorer safety standards and practices in their countries of origin (Chan, Wong, Hon, Lyu, & Javed, 2017). Singaporean WHS legislation is therefore generally more prescriptive in higher risk work tasks than the aforementioned countries, with additional regulations for WHS officers (requiring registration, qualifications, and experience), construction, ship-building and repair, abrasive blasting and confined space work, among others. All specific regulations for high risk work require, for example, that workers attend a safety and health training course approved by the regulator (Government of Singapore, 2008b, 2009b). Specific to confined space work, areas in which the Singaporean legislation is more prescriptive than other industrialised countries are the requirement for a workplace to record the description and location of all confined spaces, to appoint specific managers to authorise confined space work, and for all confined space entrants to display name and identification badges at the point of entry of the confined space (Government of Singapore, 2009a).

2.2.5 Legislation, Codes of Practice, and Standards

Many industrialised and developed countries have explicit WHS legislation which includes the requirements for the control of various risks in the workplace. These typically include working with hazardous chemicals, working at height, electrical work, noise, and working in confined spaces. Some of these hazards have explicit and detailed control measures to be applied, while the implementation of control measures for other hazards requires application of the risk management system. Codes of practice and standards have been developed which provide more detailed guidance on minimising the risks from the hazards explicitly described in the legislation. Due to the general duty of care requirement to provide a work environment in which workers are not exposed to undue hazards, additional codes of practice and standards which aim to minimise the risk from other workplace hazards *not detailed* in the legislation have also been developed. These standards are often produced by organisations or industry associations, and represent ‘best practice’ for controlling risk.

In some cases, a code of practice or standard is specifically referenced in legislation and is thus enforceable by law. For example, most Australian state and territory WHS legislation references 16 Australian or joint Australian / New Zealand Standards (Government of New South Wales, 2017; Government of Queensland, 2011; Government of Victoria, 2017). In other cases, code of practices or standards may not be referenced by legislation, but compliance with such documents by a workplace can demonstrate adherence to a safe system of work and thus assists in meeting the general duty of care requirement. Unfortunately, this can result in an array of different documents which, although describing similar safe work procedures, do differ in their application and recommendations. For example, the Australian state of Western Australia requires that confined space entry complies with Australian Standard 2865:2001; although the standard has been revised and reviewed since, and the current edition of that standard was published in 2009 (Government of Western Australia, 1996; Standards Australia, 2009). The availability, relevance (by jurisdiction, by industry, or by confined space type), and legal worth of these guidelines can vary by jurisdiction. This issue applies to confined space safety legislation in many of the industrialised countries referred to in this research.

2.3 Confined Space Safety Legislation

It was recognised by legislators that working in confined spaces with the characteristic hazards of poor ventilation, the potential for hazardous atmospheres to accumulate, and the risk of engulfment in material was one of those areas which required specific safety control measures such as legislation.

2.3.1 Early Confined Space Regulations

Previous regulations which sought to specify safety requirements for confined space work had existed in earlier state legislation in Australia – such as in the Western Australian *Act Relating to Factories 1904* in which Section 27 required employers to ‘supply efficient appliances to carry off and render harmless all gases, fumes, dust, and other impurities.’ (Government of Western Australia, 1904) and the South Australian *Factories Act Amendment Act 1910* in which Section 39 required of employers that space was ‘to be kept clear in the vicinity of any engine, machine, or machinery therein as is sufficient to enable any person to work, attend to, and clean the same without risk or injury to himself or any other person.’ (Government of South Australia, 1910). Certain spaces within factories and workplaces began to be recognised as having particular hazards and specific regulations were enacted to protect workers, with the NSW *Factories, Shops and Industries Act 1962* requiring workers to be protected from the hazards of ‘dangerous containers’ (Government of New South Wales, 1962).

2.3.2 Confined Space Standards

The first confined space standard produced internationally under the tiered legislative system was the *Safety Requirements for Working in Tanks and Other Confined Spaces* produced by the American National Standards Institute (ANSI) in the US in 1977. This standard, although a voluntary industry standard (essentially a code of practice), sought to set the minimum requirements for safe entry, continued work in, and exit from tanks and other confined spaces at normal atmospheric pressure (ANSI, 1977).

Following on from the ANSI standard, NIOSH issued the criteria document *Working in Confined Spaces* in 1979. This document, a recommendation only (as per the legal status of NIOSH publications), recommended a number of procedures as ‘a means of protecting the health, and significantly reducing accidental injury and death associated with entering, working in, and exiting from confined spaces.’ (NIOSH, 1979, p. 1).

NIOSH followed this with *A Guide to Safety in Confined Spaces* in 1987, a document providing advice to workers and supervisors who may need to undertake confined space work (NIOSH, 1987b). OSHA, responsible for the issue and enforcement of legal safety standards, issued a number of interim alerts and guides, and issued the enforceable standard (an earlier version of the current 2011 standard) in 1993 (OSHA, 1993).

2.3.3 From Standards to Legislation

In the UK, the HSE published *Guidance Note GS5 Entry into Confined Spaces* in 1980 (Government of the United Kingdom, 1980). This was eventually superseded with *The Confined Space Regulations* in 1997 (Government of the United Kingdom, 1997).

Standards Australia first published the voluntary industry standard Australian Standard (AS) 2865 *Safe Working in a Confined Space* in 1986, with a second edition published in 1995 (Standards Australia, 1995). This second edition was adopted by the Australian National Occupational Health and Safety Commission (which became the Australian Safety and Compensation Council and is now Safe Work Australia) as a consistent approach to confined space entry and work and which could be used as regulations or a code of practice under state or territory jurisdiction. By way of example, the Queensland Workplace Health and Safety Regulations 1997 called up certain sections of this Standard that were compliance requirements. Other states and territories used the Australian Standard as a basis for the relevant sections in their workplace health and safety regulations.

Currently in Australia, each state which has adopted the model WHS legislation have common requirements for confined space safety and use the code of practice produced by Safe Work Australia and the standard for confined space work and safety (Safe Work Australia, 2016). Difficulties arise in the other states such as in the state of Western Australia, which continues to use AS 2865:2001 *Safe working in a confined space* as the code of practice, despite that standard being superseded by AS 2865:2009 *Confined spaces* (Government of Western Australia, 1996; Standards Australia, 2009). The state of Victoria has its own code of practice – the Compliance code: Confined spaces (Government of Victoria, 2018). There are subtle differences in both the Australian Standard and the Victorian Compliance code to the model code of practice produced by Safe Work Australia, including the definition of what constitutes a confined space and the requirements for emergency preparedness, including confined space rescue.

A timeline of confined space safety publications showing the increasing emphasis over time is provided in figure 1.

1904	*An Act Relating to Factories* (Western Australia)
1910	*Factories Act Amendment Act* (Government of South Australia)
1977	*Safety Requirements for Working in Tanks and Other Confined Spaces* (ANSI – United States)
1979	*Working in Confined Spaces* (NIOSH – United States)
1980	Guidance Note GS5 – *Entry into Confined Spaces* (HSE – UK)
1986	*Safe Working in a Confined Space* (Standards Australia)
1987	*A Guide to Safety in Confined Spaces* (NIOSH – United States)
1993	*Permit-required confined spaces* (OSHA – United States)
1995	*Safe Working in a Confined Space* ed. 2 (Standards Australia)
1997	*The Confined Space Regulations* (HSE – UK)
2009	*Confined Spaces* ed. 3 (Standards Australia)
2009	*Safety Requirements for Confined Spaces* ed. 2 (ANSI – United States)
2011	*Permit-required confined spaces* ed. 2 (OSHA – United States)
2011	Code of Practice – *Confined Spaces* (Safe Work Australia)
2014	Code of Practice – *Confined Spaces* ed. 2 (Safe Work Australia)
2016	Code of Practice – *Confined Spaces* ed. 3 (Safe Work Australia)
2018	Compliance Code – *Confined Spaces* (Victoria, Australia)
2018	Code of Practice – *Confined Spaces* ed. 4 (Safe Work Australia)

Figure 1. Timeline of confined space safety publications

Based on the review of confined space legislation between jurisdictions where many regions follow the practices and paradigms of others, and the similarly industrialised nature of the countries in this study, comparisons of confined space injuries and fatalities can be confidently made. A key component of this is the comparison between jurisdictions of the definition of a confined space.

2.3.4 Confined Space Definition

Exactly what constitutes a confined space varies by jurisdiction, with different countries holding different definitions for confined spaces. The definition of a confined space may even differ by jurisdiction within a country, such as is the case in Australia and Canada. In addition, although still meeting the criteria to be classified as a confined space, the safe procedures for confined space entry and work may differ according to industry sector in some countries such as the US.

For the purposes of this research, a confined space was defined as an enclosed or partially enclosed space, which is not intended or designed as a regular place of work, and which has a risk of a hazardous atmosphere; or a risk of engulfment by a free-flowing solid or liquid. Hazardous atmospheres include toxic airborne contaminants such as gases, fumes, mists, biological agents, and vapours; flammable airborne contaminants such as flammable gases, vapours, and dusts; and unsafe levels of oxygen – usually low levels of oxygen.

It should be noted that the US has two classifications of confined spaces. A *confined space* is large enough for a person to enter and perform work, has limited means of entry and exit, and is not designed for continuous occupancy. This is also known as a non-permit confined space. A *permit required confined space* (PRCS) is a confined space that may also contain (or has the potential to contain) a hazardous atmosphere, a material with the potential for engulfment, internally sloped walls that may lead to entrapment, or any other serious safety or health hazard (OSHA, 2011c). For the purposes of this research and to ensure consistency across different jurisdictions, only PRCS are considered confined spaces.

A consolidated list of the definitions of a confined space from a range of industrialised countries as referenced in this work is at appendix 8.

2.4 WORKPLACE FATALITIES

Prior to determining and discussing the rate of work-related confined space fatalities and making comparisons between various countries or jurisdictions, it is prudent to examine the differences in the rate of overall workplace deaths between countries. It is difficult to make direct comparisons between countries as different injury, mechanism of incident, and industrial classifications are used, and workplace injury data lacks accuracy and completeness regardless of where it is collected (Koehoorn et al., 2015; OECD, 1990; Probst & Graso, 2013; Takala, 1999). Fatality data is likely to be more complete and accurate than injury data due to often mandatory reporting of workplace deaths and simpler classification systems (Dong et al., 2011; Driscoll et al., 2003; Gunby, 2011).

2.4.1 Australia and New Zealand

Safe Work Australia (formerly known as the Australian Safety and Compensation Council – ASCC; and prior to that known as the National Occupational Health and Safety Commission – NOHSC) collates work-related fatal incidents through the Traumatic Injury Fatalities (TIF) dataset which is populated from data tracked by the 13 various state, territory, and Commonwealth workplace health and safety authorities; and from the NCIS, which is a record of all deaths reported to a coroner in Australia (Lindquist et al., 2014). Safe Work Australia reported that 182 workers (including bystanders) were fatally injured at work in 2016, representing a fatality rate of 1.5 fatalities per 100,000 workers. The overall workplace fatality rate in Australia has decreased over time from 3.0 in 2007 to 1.5 per 100,000 in 2016 (Safe Work Australia, 2017).

The rate of work-related fatalities in New Zealand (NZ) over the period 2008 to 2016 shows a decrease from 3.9 to 2.1 fatalities per 100,000 workers (Statistics New Zealand, 2017). This is an improvement in comparison to the period 2005 to 2008, where Lilley, Samaranayaka, and Weiss (2013) found the rate to average 4.2 fatalities per 100,000 workers.

Both Australia and NZ assign each fatality an industry group in accordance with the Australian and New Zealand Standard Industrial Classification (ANZSIC) system. In both Australia and NZ, a small number of industry groups – notably agriculture, forestry and fishing; construction; and the transport, postal and warehousing industry groups – had much higher rates of work-related fatalities than the other industry groups (Gunby, 2011; Lilley et al., 2013; Safe Work Australia, 2017; Statistics New Zealand, 2017). Agriculture in particular continues to have a high work-related fatality rate and has shown little reduction in the fatality rate since 2007 (Lower, Rolfe, & Monaghan, 2017).

2.4.2 North America

Like Australia and NZ, the US has seen a decrease in workplace fatalities, falling from 5,734 in 2003 to 5,190 in 2016 – despite the working population increasing by 10.5% over this period (US Bureau of Labor Statistics, 2018). Historically, the rate of worker fatalities initially demonstrated a decreasing trend from 4.0 to 3.5 fatalities per 100,000 workers over the period 2003 to 2010. The annual report of workplace fatalities produced by the US Bureau of Labor Statistics (BLS) shows that the rate has levelled off since and no further decreases are evident (US Bureau of Labor Statistics, 2017). In the same BLS report, transportation accidents were found to account for almost 40% (2,083) of workplace deaths in 2016.

Aggregated data from the Association of Workers Compensation Boards of Canada (AWCBC) drawn from the provincial and territorial worker's compensation boards in Canada found the fatality rate to range from 0.8 per 100,000 workers to 4.5 across the provinces and territories (Tucker & Keefe, 2018); however a major limitation in drawing data from Canada is that unlike most other countries included in this research, there is no national database of work-related fatalities (Grant, 2017).

2.4.3 Singapore

The Occupational Health and Safety Division of Singapore's Ministry of Manpower reported 42 fatal work-related injuries in 2017 (Government of Singapore, 2017), 12 (29%) of which occurred in construction and 7 (17%) each in transport and storage, and manufacturing; for an overall worker fatality rate of 1.2 per 100,000 workers. This is a significant and rapid decrease in the fatality rate from 4.9 fatalities per 100,000 in 2004 (Government of Singapore, 2008a).

2.4.4 Europe

The UK has among the lowest rate of workplace deaths amongst all industrialised countries, at 0.51 per 100,000 workers. In raw figures, 144 people were killed at work in 2017/2018, with a five year average of 141 deaths (Government of the United Kingdom, 2018). Although there have been changes to the inclusion and exclusion criteria, the rate of work-related fatal injuries in the UK has fallen from 2.3 in 1982 to 0.51 per 100,000 in 2017/2018 . Notably, data collected by the UK's Health and Safety Executive (HSE) – the governmental department responsible for workplace health, safety, and welfare in England, Scotland, and Wales – does not include fatal accidents involving workers travelling by air or sea; or travelling to and from work by road (Government of the United Kingdom, 2018).

The European Union is made up of 28 member states which have considerable variation in their economic and financial activity; population, education and society; industry and trade; and agriculture, forestry and fishing. Accordingly, the member countries of the European Union show a considerable variation in the rate of fatal work-related injuries, from more than 3.5 in Romania, Lithuania, Belgium, and Portugal; to less than 1.0 per 100,000 in Germany, the UK, Sweden, and the Netherlands (European Union, 2018; Government of the United Kingdom, 2017). These rates are often standardised to account for countries which have relatively more workers in higher risk industries (such as construction and agriculture), compared to those which have relatively more workers in lower risk industries (such as health care and financial services). Other studies have concluded that higher income level countries have statistically significantly lower work-related fatality rates than lower income level countries (Hämäläinen, Takala, & Kiat, 2017; Wilson et al., 2007).

A comparison of the most-recent work-related traumatic fatal injuries rates between Australia, NZ, Singapore, the US, and the UK, is shown in Figure 2. It should be noted that due to the differing inclusion and exclusion criteria, these figures are useful for comparison purposes only. Feyer et al. (2001) found that the biggest influence in the difference in the fatality rate between Australia, New Zealand, and the US was the proportion of workers by industry – with the highest fatality rate in the countries with more workers in higher risk industry groups of agriculture, forestry & fishing; transport, postal & warehousing; construction; and mining.

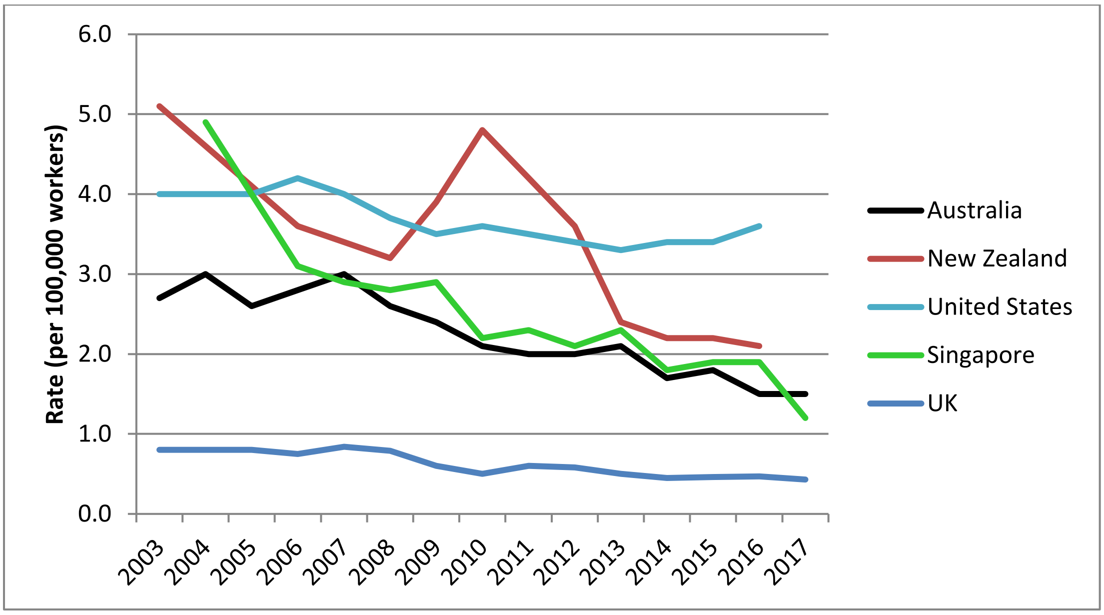

Figure 2. Rate of work-related fatalities (per 100,000) across similar industrialised countries, 2003–2017

2.5 Confined Space Fatalities

There have been a number of studies of confined space fatalities published within the literature, chiefly from the US. In addition to published research, there are also many magazine articles, in print and online, as well as marketing and promotion material and non-traditional media such as blogs, which on the whole do not contain any original research, but often present information from published studies.

2.5.1 Early Studies

The first comprehensive study into confined space injuries and fatalities was undertaken by NIOSH which examined accident reports over the period 1974 – 1977, and which led to the production of the aforementioned recommended standard (NIOSH, 1979). This study also listed the mechanism of incident for each fatality. These selected incidents can be categorised into the four major mechanisms of incident. Of the 276 selected incidents examined, 78 of the 193 fatalities (40%) were as a result of toxic or oxygen deficient atmospheres, 47 (24%) were as a result of fire or explosion, 26 (14%) were engulfed in free-flowing solids or liquids, and 42 (22%)

died as a result of physical hazards such as electrocution, falls from height, and temperature extremes. The breakdown into these four categories based on the data provided by this study is shown in figure 3. It was also noted that in 65% of the cases, atmospheric hazards existed prior to the confined space entry, and that would-be rescuers were injured or killed in 76% of attempted rescues (Campbell, 1990; McManus, 1998).

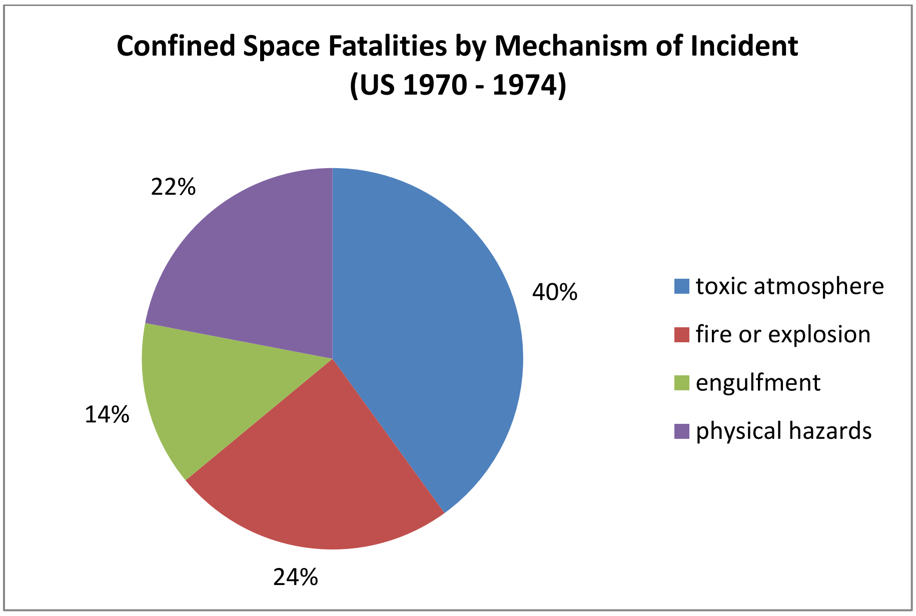

Figure 3. Percentage of fatality by mechanism of incident (Adapted from NIOSH, 1979)

Six reports were issued by OSHA over the period 1982 – 1990 which examined fatalities in certain industries or involving particular hazards. Some of these included fatalities which occurred in confined spaces, although these were not always identified as a separate factor. Of the six reports, one examined selected incidents over the period 1974 – 1982 in which toxic or asphyxiating atmospheres (such as toxic or poisonous gases and low levels of oxygen) resulted in a workplace death. Of the 122 incidents, there were 173 fatalities, including incidents in which there were multiple fatalities and incidents in which would-be rescuers were killed. Of the other reports in this series, up to 36% occurred in workplaces which would normally be considered to be confined spaces. These OSHA reports are of varying overlapping timeframes, and some incidents are utilised in more than one report – hence an aggregate of the figures is not appropriate. Of note, the authors of the OSHA reports also identified incomplete reports, data, and lack of specific coding for various incident factors (MacCarron, 2006; McManus, 1998).

2.5.2 United States

In 1986 NIOSH issue an alert titled 'Preventing Occupational Fatalities in Confined Spaces'. This alert investigated 8 confined space incidents in which 16 people were killed. It concluded that 'More than 60% of confined space fatalities occur among would-be rescuers; therefore a well-designed and properly executed rescue plan is a must.' (NIOSH, 1986). The alert provided sound advice to prevent confined space fatalities, however the proportion of deaths attributed to rescuers was produced from a very small sample size and no selection criteria for the sample were provided.

The Fatal Accident Circumstances and Epidemiology (FACE) program was commenced by NIOSH in 1982. It contains incident data from sources such as the National Traumatic Occupational Fatalities (NTOF) database – based on information from death certificates); and the Census of Fatal Occupational Injuries (CFOI) database – based on WHS regulator (OSHA) reports. While these and other datasets such as compensation claim data and medical examiner reports is useful for data statistical purposes; the FACE program consists of an in-depth examination (including site visits and interviews) of a selected subset of workplace fatalities (Higgins, Casini, Bost, Johnson, & Rautiainen, 2001) and the circumstances of each incident can be examined in detail. FACE investigations of confined space incidents which occurred from December 1983 to December 1989 were analysed by Manwaring and Conroy (1990). Of the 55 events which resulted in 88 deaths, water, wastewater, and sewerage systems were the most common confined space type, accounting for 58 (66%) of fatalities. This analysis also categorised the fatalities by cause of death, with 58 (66%) of the fatalities as a result of toxic or asphyxiating atmospheres, and 18 (21%) were a result of drowning – which is a reflection of the type of confined space in which the incidents occurred.

Research undertaken through the manual examination of death certificates in the US state of Virginia over the period 1979 – 1986 identified 41 confined space incidents resulting in 50 fatalities. A key finding of this research was that hazardous atmospheres resulting in asphyxiation and poisoning accounted for 31 (62%) confined space fatalities; and that while a wide range of atmospheric hazards including argon, carbon monoxide (CO), Freon (CCl_2F_2), hydrogen sulphide (H_2S), and methane (CH_4) were involved; the study also notes that in 6 of the incidents involving toxic atmospheres, the hazard was absent at the time of first entry into the confined space. Rescuers accounted for 3 (6%) of the fatalities, 15 personnel were injured attempting rescue, and an additional 7 bystanders were injured from these incidents. The majority of fatalities occurred amongst blue-collar occupations, frequently conducting inspection, repair, and maintenance work. Of note, 12 of the fatalities occurred in ship compartments – a reflection of one of the major industries in Virginia during the time period; and the researchers also acknowledged the difficulty of identifying confined space fatalities due to the lack of specific coding for confined space incidents (Sahli & Armstrong, 1992).

An analysis of death certificate data from NTOF between 1980 and 1988 identified 803 deaths in 681 confined space incidents. 499 (62%) of deaths were attributed to atmospheric hazards, while 223 (28%) of deaths were attributed to engulfment. The final 81 (10%) died as a result of physical hazards. The fatality data from this study was again classified into the four categories of mechanisms of incident is shown in Figure 4, although it should be noted that deaths from fire and explosion are included in the 'atmosphere' category. Most of the casualties were from the manufacturing industry; followed by the agriculture, forestry and fishing industry group (Suruda et al., 1994). The same study also analysed NIOSH FACE data which examined 62 confined space incidents in detail over the period 1982 – 1991 which resulted in 97 deaths. Of note, 35 (36%) of the decedents were rescuers (31 of whom were would-be rescuers – typically untrained work colleagues), and all rescuers bar one died as a result of a hazardous atmosphere. Much of the same FACE data was used to produce a NIOSH report in 1994, which included case data from 109 deaths in 70 incidents over the ten year period between 1983 and 1993. This report also noted that 39 (36%) of the deaths were rescuers, and that 38 of those died as a result of atmospheric hazards, with the final attempted rescuer drowning in rising water in a well. Of the rescuers who died, 4 were professional emergency services personnel (NIOSH, 1994; Pettit et al., 1996).

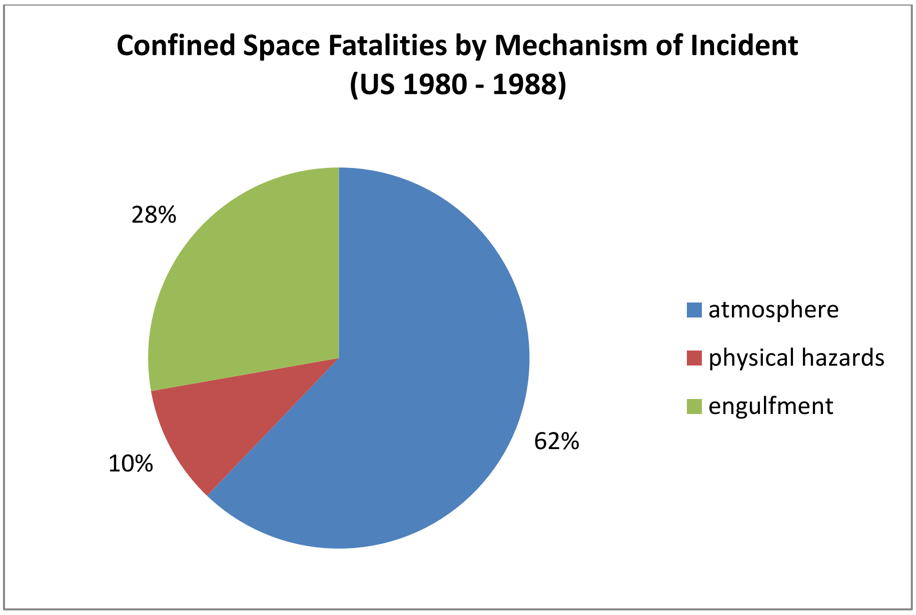

Figure 4. Percentage of fatality by mechanism of incident (Adapted from Suruda et al., 1994)

Data from the US CFOI program was used by Meyer (2003) to identify and examine 458 confined space fatalities over the five year period from 1997 to 2001. The CFOI is a database produced by the US Government's Bureau of Labor Statistics (BLS) rather than by NIOSH. The CFOI database covers all 50 states and the District of Columbia (and the US territories of Puerto Rico, Virgin Islands, Guam and American Samoa from 2011). The database is developed from multiple sources including death certificates and worker's compensation reports, and codes workplace fatalities through data elements such as industry group, occupation, and cause of death. The CFOI database is analogous to the Australian TIF database. Key findings from this study were that hazardous atmosphere was the causal factor in 101 (22%) deaths, engulfment in a further 130 (28%) deaths, and 25 (5.5%) of deaths were would-be rescuers attempting the rescue of others. This study also identified that 54% of fatalities occurred during repair and maintenance, and cleaning and washing; and that the greatest risk was to those working in the agriculture, forestry, and fishing industry group.

The CFOI database was interrogated for atmospheric-related confined space fatalities for the period between 1992 and 2005 to reveal 530 deaths in 431 incidents; with 39 deaths in 29 incidents occurring in California (Madison & Wilson, 2008). 20% (n=87) of the incidents US-wide resulted in multiple fatalities of which 47 (9%) were rescuers. The most common toxic atmospheres across the series were carbon monoxide, hydrogen sulphide, and methane. As has been found in other studies, inspection, repair, cleaning, and maintenance work accounted for almost half (47%) of fatalities. Further research using this data also identified that reliance on professional emergency services to respond to a confined space incident may be insufficient due to response and travel times of such services (Wilson et al., 2012).

2.5.3 Focused Studies

There have been a number of published studies focused on particular industry sectors, mechanisms of incident, or other criteria which also identify high numbers of confined space fatalities.

Suruda and Agnew (1989) examined 4756 work-related deaths from the OSHA database between 1984 and 1986 in which 423 (9%) were found to be as a result of work-related poisoning or asphyxiation (including as a result of engulfment). 146 of these occurred in confined spaces; and 17 (12%) of the confined space fatalities were co-workers or professional emergency services personnel attempting rescue. While the study found the type of confined space to be varied, most involved the entry into an unventilated space below ground level.

In a study of work-related deaths of painters in the construction industry, Suruda (1992) found that of the 129 deaths investigated between 1982 and 1986, six painters died from toxic atmospheres while working in a confined space; three from asphyxiation (nitrogen causing oxygen displacement) and three from toxic contaminants (methylene chloride, chlorine, and nitropropane). One additional painter fell from a scaffold while painting the interior of a confined space and was killed.

The US Mine Safety and Health Administration (MSHA) issued an alert in 1988 concerning the dangers of engulfment in confined spaces, principally bins, hoppers, and stockpiles; noting that there had been 44 fatalities in 38 incidents over the period 1980-1986. A subsequent hazard information alert published in 1994 reported that the number of fatalities had risen to 57 by the end of 1993 (MSHA, as cited in McManus, 1998, p. 6). Mines themselves are not normally deemed to be confined spaces, however confined spaces such as bins, tanks, hoppers and pipes may exist in a mine or quarry, and entry into these spaces would be considered to be a confined space entry.

Fuller and Suruda (2000) searched through the OSHA investigation database to find 80 fatalities from hydrogen sulphide poisoning in 57 incidents over the 11 year period between 1984 and 1994 in the US. 69 (86%) of the deaths occurred in confined spaces, and 19 (24%) of the 80 deaths were to workers attempting to rescue others. A further 36 workers received non-fatal injuries in these attempted rescues. Of concern, the authors noted that up to 77 (96%) of the 80 deaths may have been avoided had a portable gas detector been used. As there are exemptions over which OSHA does not have jurisdiction, such as self-employed persons and farms with less than eleven employees, the authors consider the figures to be an undercount.

Concerned at the disproportionally high number of workplace fatalities amongst construction workers, Dorevitch, Forst, Conroy, and Levy (2002) conducted a review of OSHA data between 1990 and 1999 and found 87 construction workers in the US died after the inhalation of toxic substances, accounting for 1.3% of all construction fatalities. Most (n=54, 62%) of these incidents occurred in confined spaces. The toxic substances associated with the most fatalities were carbon monoxide (19.5%), hydrogen sulphide (18.4%), and nitrogen (10.3%). Asphyxiation due to oxygen deficiency was the mechanism in a further 20.7% of cases. Again, these figures were assumed by the authors to be an undercount due to the dataset (the OSHA investigation database) used.

Approximately 14 work-related deaths occur in elevator shafts in the US each year, of whom approximately 70% are persons installing, inspecting, or repairing elevators; according to research conducted using CFOI data over the period 1992-2003 by McCann and Zaleski (2006). While the most common cause of death was falling from height into an elevator shaft (49%, n=84), 36 workers were killed when trapped in moving machinery (21%), and 26 were struck by moving objects – elevator cars (15%). Under most jurisdictions elevator shafts would not be considered to be confined spaces, however under the unique US legislation elevator shafts would be considered to be non-permit confined spaces (OSHA, 2011c).

2.5.4 Agricultural Confined Space Fatalities

A workplace-specific study of manure storage facilities over the period 1975 – 2004 identified 77 confined space fatalities in 56 incidents; and in most cases the cause of death was hazardous atmospheres – often hydrogen sulphide gas (Beaver & Field, 2007). The data was drawn from Purdue University's Agricultural Entrapment and Injury Database – a sub-set of the multiple-source database built from NIOSH data, death certificates, trade journals, media reports, and other sources. 17 (22%) of the 77 fatalities were those attempting the rescue of others. Although a common issue among all studies, under-reporting was believed to be worse in the agriculture industry due to exemptions from OSHA legislation for farms with less than eleven employees (OSHA, 2011b, 2011c).

Purdue University in Indiana, US, maintains a number of databases of specific types of agricultural industry injuries and fatalities, including a database which includes all agricultural confined space incidents. Multiple sources such as death certificates, police reports, and media reports are cross-referenced to capture these incidents and add to the database – known as the Purdue Agriculture Confined Spaces Incident Database (PACSID). An interrogation of the database for the period 1964 – 2010 identified 821 confined space fatalities in 1255 incidents (Riedel & Field, 2013). Unlike most other studies, the incident count includes non-fatal injuries. Engulfment and entrapment in flowing agricultural materials was found to be the mechanism for most fatalities, accounting for up to 62% of fatalities. 132 (10.5%) of incidents involved livestock manure storage or handling facilities which resulted in 110 fatalities, 24 (22%) of whom were attempting to rescue others. The study also acknowledged the lack of reliable data; however more aggressive data collection since 2008 has resulted in greater incident identification and incident aetiology information.

An update was published in 2016, which brought the total number of agricultural confined space fatalities from 1964 to 2013 up to 1036 in 1654 total incidents; with fatalities occurring in 62.6% of cases. The majority of cases continued to involve engulfment or entrapment in free-flowing materials, principally grain, with 62% of incidents; although falls from height in confined spaces were found to have an increased proportion of cases (Issa, Cheng, & Field, 2016). Annual updates continue to be published by Purdue University via an annual report derived from the PACSID database each year. In the most recent annual report, 23 (43%) of 54 incidents resulted in a fatality in 2017, 43% of which involved engulfment in a free-flowing solid or liquid (Cheng, Nour, & Field, 2018). Due to agricultural exemptions applying to up to half of agricultural facilities, and the lack of adequate reporting mechanisms for non-fatal incidents, the researchers believe that the true number of incidents could be up to 30% higher than those reported.

Cheng, Field, et al. (2018) conducted a search on the PACSID database and found 174 (8.8%) of the 1,968 incidents between 1964 and 2016 involved confined spaces within grain transport vehicles such as rail wagons and truck-pulled grain trailers. 64.3% (n=112) incidents resulted in at least one fatality, with one incident having five fatalities. Unfortunately, most fatalities (60.7%) occurred among children playing in and around the vehicles. This and other studies (Bahlmann et al., 2002; Cheng, Field, et al., 2018; Freeman, Kelley, Maier, & Field, 1998; Issa, Nour, & Field, 2018; Issa & Field, 2017; Issa, Field, Schwab, Issa, & Nauman, 2017; Issa, Schwab, & Field, 2015; Kingman, Deboy, & Field, 2003; Riedel & Field, 2013; Roberts, Deboy, Field, & Maier, 2011; Roberts, Field, Maier, & Stroshine, 2015; Russell, 2015) have examined the causative factors and aetiologies of agricultural confined space engulfment incidents and fatalities and have investigated rescue practices and procedures, which are examined and discussed in more detail in *Chapter 6 – Confined Space Engulfment* in this work.

2.5.5 Other Industrialised Countries and Jurisdictions

A study of confined space fatalities which occurred in the state of Western Australia between 1980 and 2004 was undertaken in order to identify the aetiologies and determine a rate of fatal accidents. It found 15 fatalities over the 24 year period, of which eight (53%) were as a result of electrocution, two (13%) each from hazardous atmospheres and engulfment, and a single fatality (7%) from oxygen deficiency, falling from height, and being struck by a falling object (MacCarron, 2006). This study identified, as had previous studies, the majority of the fatalities occurred among tradespersons and labourers including electricians, welders, and plumbers. It should be noted that this study included six deaths which occurred in ceiling spaces, an area not normally considered to be a confined space under most jurisdictions.

Burlet-Vienney, Chinniah, Bahloul, and Roberge (2015b) examined the worker's compensation database (which covers approximately 85% of workers) for the Canadian province of Quebec between 1998 and 2011 and identified 32 confined work-related space incidents in which 40 workers were killed. Key findings of this research were that hazardous atmospheres accounted for 14 (35%) of the confined space fatalities, and 26 (65%) fatalities were the result of physical hazards. The data from this research was also categorised by mechanism of incident and is shown in figure 5. Six (15%) of the fatalities were would-be rescuers. The authors also found the identification of non-fatal injuries resultant from confined space incidents was impossible to numerate. Additional literature produced by the same authors includes a comparison of legislation and standards, an analysis of the mechanisms of incident, presentation of a specific risk assessment, and recommendations for risk reduction in confined space work (Burlet-Vienney et al., 2014; Burlet-Vienney et al., 2015a; Burlet-Vienney, Chinniah, Bahloul, & Roberge, 2016).

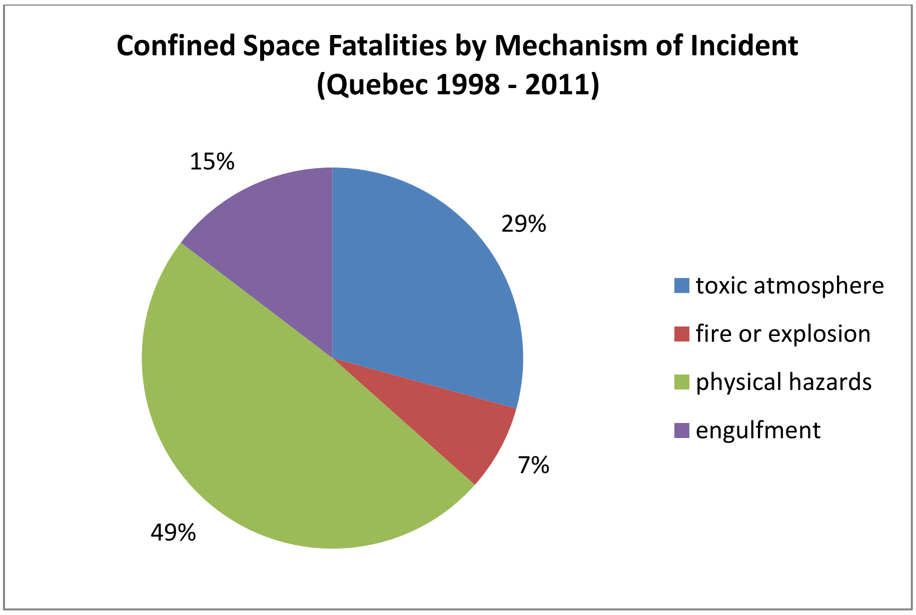

Figure 5. Percentage of fatality by mechanism of incident (Adapted from Burlet-Vienney et al., 2015b)

An analysis of Italian workplace accident statistics from 2001 to 2015 found 20 confined space incidents resulting in 51 fatalities – a high rate of fatality per accident. Of these, 38 (75%) were the result of hazardous atmospheres, and 9 (18%) were the result of physical hazards. One third (33%) occurred in the wastewater industry (Botti, Duraccio, Gnoni, & Mora, 2015). The authors also noted that there is no specific confined space legislation in Italy, and workplaces must instead comply with the general European Union (EU) directive 89/391/EEC '*on the introduction of measures to encourage improvements in the safety and health of workers at work*' which establishes a duty of care but which provides no specific regulations on confined space work (European Union, 1989). Other jurisdictions within the EU have passed their own legislation or standards such as Germany's BGR 117-1:2008 *Behälter, Silos und enge Räume* (Containers, Silos, and Confined Spaces).

An analysis of confined space fatalities in Jamaica over the period 2005 – 2017 by the Jamaican Institution of Engineers revealed 11 incidents resulting in 17 deaths, with a further 6 workers hospitalised as a result of injuries received. 9 (53%) died as a result of hazardous atmospheres, 5 (29%) from engulfment, and the remainder (18%, n=3) from physical hazards (Stennett, 2018).

Finally, in Australia there have been a number of confined space fatalities historically that have occurred within the Australian Defence Force which have not been captured by the various datasets which make up the TIF database. Although outside of the study period, they are included here for completeness. In 1985, three sailors died and 62 were injured on board HMAS Stalwart (D 215) off the coast of Darwin when hydrogen sulphide gas leaked from the sewerage system into maintenance compartments into which workers later entered. The subsequent inquiry found that two of those killed were medics attempting to rescue their shipmates, and that many others were injured entering contaminated compartments to perform rescues (Cassells, 2000; Midson, 2011). In an earlier incident on HMAS Tobruk (L 50) in 1981, a Naval Cadet was killed when hydrogen sulphide and carbon monoxide gases leaked from the sewerage system into the accommodation area (Doolan, 2007; Midson, 2011). More recently, four sailors died in 1998 from carbon monoxide inhalation inside a ship's compartment on HMAS Westralia (O 195) (Royal Australian Navy, 1998), and four sailors were again injured by gases from leaking sewerage systems on board HMAS Maitland (P 88) in 2006. Several hundred Royal Australian Air Force have also suffered chronic illness – with some resulting in death – from confined space work related to fuel tank servicing on Australia's F-111 jet aircraft (Royal Australian Air Force, 2001).

2.5.6 Confined Space Rescue

While some of the previous studies provide data on the number of persons killed attempting the rescue of others, describe the hazards of unplanned rescue, and categorise the cause of death of rescuers (both professional rescuers and would-be rescuers); few provide recommendations for the safe conduct of a confined space rescue. The time required for professional emergency services to arrive and perform a confined space rescue may be inadequate to preserve life in many cases (Burlet-Vienney et al., 2015b; Wilson et al., 2012), and there are also many challenges in maintaining an internal confined space rescue team. Other researchers have made recommendations on the training requirements for confined space rescue by professional emergency services (Smith et al., 2018; Yoshimura, Kako, & Satoh, 2007), but provide few recommendations on developing an in-house or on-site rescue capability. There are a number of books dedicated to the subject of rescue – and confined space rescue in particular – which do emphasise the need for safe rescue procedures and often quote the statistics of the previously published research (CMC Rescue, 2012; Rekus, 2018; Rhodes, 2003; Roop et al., 1998; Sargent, 2000; Veasey et al., 2005); however these are also written for professional emergency services.

A summary of the literature, including findings, is listed in chronological order by publication date in table 2 below.

Table 2. A summary of significant findings in the literature by publication date

Study jurisdiction and period	Authors	Incidents and fatalities	Significant findings
US (1974 – 1977) *selected data*	NIOSH (1979)	193 deaths in 276 incidents	• 40% hazardous atmosphere, 24% fire or explosion, 14% engulfment, 22% physical hazards • Would-be rescuers killed in 76% of attempted rescues • Up to 5% of all accidents in the shipbuilding and maintenance industry were confined space-related.
US (1974 – 1982) *atmospheric hazards only*	OSHA, McManus (1998)	173 deaths in 122 incidents	• Estimated 200 confined space deaths per year in the US • Some incidents with multiple fatalities including would-be rescuers • Up to 36% of all OSHA investigated deaths occurred in confined spaces • Incomplete data and lack of specific confined space coding
US (1984 – 1986) *asphyxiation or poisoning*	Suruda and Agnew (1989)	146 deaths	• Up to 9% of all work-related deaths were as a result of asphyxiation • Of 233 total deaths from asphyxiation and poisoning, 146 occurred in confined spaces • Additional 42 deaths from engulfment in various circumstances • 12% of confined space deaths were would-be rescuers
US (Dec 1983 – Dec 1989) *selected incidents (FACE data)*	Manwaring and Conroy (1990)	88 deaths in 55 incidents	• 66% of deaths in water treatment and sewerage systems • 66% hazardous atmospheres, 21% drowning • 39% of confined space deaths were would-be rescuers
Virginia (1979 – 1986)	Sahli and Armstrong (1992)	50 deaths in 41 incidents	• 62% hazardous atmosphere • 6% of confined space deaths were would-be rescuers • 24% of deaths occurred in the shipbuilding and maintenance industry • Lack of specific confined space coding

US (1982 – 1986) *painters in construction*	Suruda (1992)	7 deaths	• 6 died from asphyxiation and 1 died from a fall in confined spaces
US (1980 – 1988)	Suruda et al. (1994)	803 deaths in 681 incidents	• 62% hazardous atmosphere, 28% engulfment • 14% of incidents included multiple fatalities • 24% manufacturing, 16% agriculture, forestry and fishing, 13% construction, 12% utilities industries • Lack of specific confined space coding
US (1982 – 1991) *selected incidents (FACE data)*	Suruda et al. (1994)	97 deaths in 62 incidents	• 36% of confined space deaths were rescuers • All rescuers died of a hazardous atmosphere, except 1 fire & explosion • Lack of specific confined space coding
US (1980 – 1986) *mining only*	MSHA, in McManus (1998)	44 deaths in 38 incidents	• Majority of fatalities from engulfment
US (1983 – 1993) *selected incidents (FACE data)*	NIOSH (1994) Pettit et al. (1996)	109 deaths in 70 incidents	• 80% hazardous atmosphere • 36% of deaths were rescuers - 4 were professional rescuers • All rescuers died of a hazardous atmosphere, except 1 drowning
US (1984 – 1994) *hydrogen sulphide only*	Fuller and Suruda (2000)	80 fatalities in 57 incidents	• 86% of the deaths occurred in confined spaces • 24% of confined space deaths were rescuers • 96% may have been avoided with portable gas detectors
US (1990 – 1999) *atmospheric hazards in construction only*	Dorevitch et al. (2002)	87 deaths	• 62% occurred in a confined space • 21% oxygen deficiency, 20% carbon monoxide, 18% hydrogen sulphide, 10% nitrogen • 23% of deaths in water treatment, sewerage and utilities

US (1997 – 2001)	Meyer (2003)	458 deaths	• 22% hazardous atmosphere, 28% engulfment • 5.5% of deaths were would-be rescuers • 54% of fatalities occurred during repair and maintenance, and cleaning and washing • Agriculture, forestry and fishing is the most dangerous industry group
US (1992 – 2003) *elevators*	McCann and Zaleski (2006)	173 deaths	• 49% falls from height, 21% trapped in moving machinery, 15% struck by moving objects – all physical hazards
Western Australia (1980 – 2004) *included ceiling spaces*	MacCarron (2006)	15 deaths	• 20% hazardous atmosphere, 13% engulfment, remainder physical hazards (53% electrocution, 7% falling from height, 7% struck by a falling object) • 33% construction, 33% water treatment, sewerage and utilities, 27% agriculture, forestry and fishing
US (1975 – 2004) *manure storage facilities*	Beaver and Field (2007)	77 deaths in 56 incidents	• 22% of deaths were would-be rescuers • 34% of fatalities occurred while conducting repair or maintenance • 55% dairy cattle, 45% swine
US (1992 – 2003) *atmospheric hazards only*	Madison and Wilson (2008) Wilson et al. (2012)	530 deaths in 431 incidents	• 20% of incidents resulted in multiple deaths • 10% of incidents involved the death of at least one rescuer • Most common hazardous atmospheres were carbon monoxide, hydrogen sulphide, and methane. • 39 deaths in 29 incidents in California
US (1964 – 2010) *agricultural incidents only*	Riedel and Field (2013)	821 deaths in 1255 incidents	• 71% in grain storage facilities (77% engulfment), 11% in manure storage facilities, 9% in agricultural transport vehicles • Up to 20% of fatalities were under 16 years old • Incomplete data and lack of specific confined space coding

Quebec (1998 – 2011)	Burlet-Vienney et al. (2015b)	40 deaths in 32 incidents	• 35% hazardous atmospheres, 65% physical hazards • 15% of confined space deaths were rescuers • Non-fatal incidents were impossible to determine
Italy (2001 – 2015)	Botti et al. (2015)	51 deaths in 20 incidents	• 75% hazardous atmospheres, 18% physical hazards • 33% occurred in the wastewater industry
US (1964 – 2013) *agricultural incidents only*	Issa et al. (2016)	1036 deaths in 1654 incidents	• 76% in grain storage facilities • 62% engulfment
US (2017) *agricultural incidents only*	Cheng, Nour, et al. (2018)	23 deaths in 54 incidents	• 43% engulfment • Estimated that up to 30% of incidents are unreported
US (1964 – 2016) *agricultural grain transport vehicles only*	Cheng, Field, et al. (2018)	112 deaths in 174 incidents	• 64% of incidents resulted in at least one fatality • 61% of fatalities occurred among children
Jamaica (2005 – 2017)	Stennett (2018)	17 deaths in 11 incidents	• 53% hazardous atmospheres, 29% engulfment, 18 physical hazards

CHAPTER THREE –

WORK-RELATED TRAUMATIC FATAL INJURIES INVOLVING CONFINED SPACES IN AUSTRALIA, 2000-2012

FEATURE ARTICLE

Work-related traumatic fatal injuries involving confined spaces in Australia, 2000–2012

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Conflict of interest

The authors of this paper declare no conflict of interest.

Abstract

Occupational fatalities remain a significant issue in Australia and worldwide. Confined space fatalities are a particular subset. Confined spaces are defined by a particular set of hazards and often have poor ventilation, which can permit hazardous situations to develop. Confined space fatalities have been investigated in previous international studies; however, no contemporary Australian study specific to work-related confined space fatalities has been undertaken. This study conducted an analysis of work-related traumatic fatal

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injuries involving confined spaces in Australia based on coronial data. This study aimed to quantify the number of deaths and to provide a detailed description of the personal, industry, nature of the work, and mechanism-specific factors involved. Fifty-nine confined space related deaths were identified over the period 2000–2012; an average rate of 0.05 deaths per 100,000 workers across Australia. This rate is comparable to contemporary US (0.07) and Quebec (0.07) fatality rates.

Keywords: fatality, confined space, Australia, mechanism of incident.

Introduction

Occupational fatalities are a significant issue, both in Australia and worldwide. Despite considerable efforts by governments and industry, workplace fatalities continue to occur. Understanding and studying these fatalities provides a means to improve both policy and work practices, to ensure such fatalities are reduced or (ideally) eliminated.

Confined space fatalities in Australia

The exact definition of a confined space varies by legislation and jurisdiction. A confined space is generally defined as an enclosed or partially enclosed space, which is not intended or designed primarily for human occupancy, and which has a risk of an unsafe level of oxygen, toxic airborne contaminants, flammable airborne contaminants, or a risk of engulfment by a free-flowing solid or liquid.[1,2] Examples of confined spaces include vats, tanks, silos, pits, pipes, pressure vessels and sewers. Underground mines are not considered to be confined spaces, as they are intended as a place of work.[2] Many mines have mineral processing equipment such as vats, tanks, and pipelines; and work requiring entry into processing equipment, whether underground or on the surface, would be considered to be confined space work. Ceiling cavities in domestic or commercial premises are not normally considered to be confined spaces.

Safe Work Australia (formerly the Australian Safety and Compensation Council) and the various state, territory, and Commonwealth workplace health and safety authorities track and analyse work-related fatal incidents. Safety precautions for particularly hazardous work (with higher risk of injury or fatality) are specifically detailed by the authorities, and are included in the three-tiered Robens system of an Act, regulations, and codes of practices.[3,4]

The extent of work-related fatalities is that 191 workers died as a result of injuries received at work in Australia in 2013. This equates to a work-related fatality rate of 1.64 deaths per 100,000 workers — the lowest rate since Safe Work Australia commenced producing the Traumatic Injury Fatalities (TIF) dataset in 2002 to track work-related fatalities.[5] Prior to 2002, the National Occupational Health and Safety Commission (NOHSC — the forerunner to the Australian Safety and Compensation Council) recorded and reported work-related fatalities. The number of Australians killed at work has averaged out at approximately 260 workers per year for the past 11 years, but at the same time has shown a decreasing trend since 2004, which had the highest recent fatality rate of 2.94 per 100,000 workers.[6] This data includes fatalities in confined spaces.

However, despite the emphasis placed on confined space safety by the responsible authorities; as evidenced by specific regulations and codes of practice, and a range of confined space safety training and information materials; there is *no known definitive number or rate of confined space fatalities* in Australia.

The reasons behind the lack of confined space fatality data are twofold: first, fatalities are coded by workplace health and safety authorities using the Type Of Occurrence Classification System (TOOCS) version 3.1.[7,8] Under this system, injuries and fatalities are coded by a suite of five classifications: the nature of the injury or disease, the bodily location, the mechanism of the incident, the breakdown agency, and the agency of the injury.[7] Of interest to this study of confined space fatalities are the mechanism of the incident and the breakdown agency.

The mechanism of the incident is the "action, exposure or event that best describes the circumstances that resulted in the most serious injury or disease".[7] Of note, this study investigates traumatic confined space injuries, and therefore diseases are not included. The mechanism of the incident includes classifications, such as falls from a height, being hit by moving objects, contact with electricity, and being bitten by an animal.[7] However there is no classification from which confined space injuries or fatalities can be determined. This is because *confined spaces, by nature, do not cause harm or death*. Rather, they may contain unsafe levels of oxygen or atmospheric contaminants that are hazardous to life and health, or may have an increased risk of injury or death due to physical hazards within the confined space.[2]

The breakdown agency identifies the "object, substance or circumstance principally involved at the point at which things started to go wrong".[7] Breakdown agencies include classifications such as machinery and fixed plant, mobile plant and transport, powered equipment and tools, and chemicals. Again, there is no classification from which confined space injuries or fatalities can be determined. Some of the breakdown agencies may point towards a confined space fatality, such as code 2249 cement mixer;[7] but it is impossible to determine from the coding whether a fatality occurred as a result of being killed on the outside of the vehicle or inside the agitator — indicating entry into a confined space.

The second reason behind the lack of confined space fatality data is that the TIF database compiled by Safe Work Australia is limited as it is collected and collated from three datasets, with supplementary information from sources such as the Australian Transportation Safety Bureau (ATSB), the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA), and the media.[8]

The primary data for the TIF database is obtained through the National Data Set for Compensation-based Statistics (NDS). Although the most directly relevant of the datasets used, it does not account for self-employed persons, deaths without a claim for compensation, bystander fatalities, or Defence Force fatalities.[6,8] As such, the NDS only captures approximately one-half of all workplace deaths.[8,9] Data is also collated from the Notifiable Fatalities Collection (NFC) — which is populated by work-related fatalities if they have been notified as such from the 13 various state, territory, and the Commonwealth workplace health and safety authorities.[6,8] The final dataset used is the National Coronial Information System (NCIS), which is a record of all deaths reported to a coroner in Australia. Reportable deaths include when a person dies from unnatural causes, or when a cause of death is unknown. Searches of the NCIS can be filtered by whether or not the death was work-related. While the NCIS captures all reportable deaths, it also has limitations since the coding of deaths is a complex process, and while NCIS staff attempt to ensure each case is accurately coded, data is occasionally missing or incorrectly coded.[6,8] The NCIS uses the International Classification of External Causes of Injury (ICECI) to classify fatalities. Like TOOCS 3.1, there is no classification from which confined space injuries or fatalities can be readily determined.[10]

The first comprehensive analysis of work-related traumatic fatalities in Australia was conducted by Harrison, Frommer, Ruck and Blyth (1989) using coronial records for the period 1982–1984. That study identified 1,544 work-related fatalities over the period, with a fatality rate of 8.06 deaths per 100,000 workers. Of those, 910 fatalities actually occurred in a workplace. The remainder were either commuting fatalities or deaths that resulted from traffic-related injuries on public roads while working. The fatality rate in the workplace was 4.75 deaths per 100,000 workers.[11] This study also broke the information down into occupational group, age, cause of death and mechanism of incident; but it is impossible to draw a conclusion on the number of confined space-related fatalities.

In 1998, the NOHSC published the results of a study into workplace fatalities over the four-year period from 1989 to 1992.[12] The information presented in this report was also provided by coronial data. This NOHSC report included the mechanism of incident and the breakdown agency for workplace fatalities; and while not a specific study on confined space fatalities, it identified 53 worker fatalities in 48 confined space incidents. Of these identified confined space incidents, 43% occurred in construction and 21% occurred in the manufacturing industry. An overview of the NOHSC report calculated the overall worker fatality rate to be 5.5 deaths per 100,000 workers. [13]

Despite confined spaces being prevalent in many industries, there have been very few specific studies into the injury or fatality rates of confined space incidents. A study to numerate and ascertain the aetiologies of confined space fatalities in Australia examined 15 fatalities that occurred in Western Australia during the period 1980–2004.[14] Of these fatalities, eight (53%) died as a result of electrocution, two (13%) from engulfment, two (13%) from the inhalation of toxic contaminants, and one each (7%) from oxygen deficiency, falling from a height, and being struck by a falling object. It must be noted that of the eight electrocution deaths, six took place in ceiling cavities; an area which would not normally be considered to be a confined space under most Australian legislation.

Confined space fatalities in the United States

There have been a number of studies undertaken into the number and rate of work-related confined space fatalities in the United States. Sahli and Armstrong[15] studied the frequency and characteristics of confined space fatalities in the US state of Virginia over the period 1979 to 1986. They found the exact number and circumstances of confined space fatalities difficult to determine due to data collection methods and under-reporting. Through the manual review of death certificates for likely confined space incidents, the study identified a total of 50 fatalities from 41 confined space incidents in the state. Confined space deaths represented 5.1% of all workplace fatalities, with a mean fatality rate of 0.37 confined space deaths per 100,000 workers.[15] This figure seems very high in comparison to later studies.

A further study undertaken into confined space fatalities in the US using the National Traumatic Occupational Fatalities (NTOF) data from December 1983 to September 1993 was undertaken by Pettit, Braddee, Suruda, Castillo and Helmkamp.[16] They identified that such studies were difficult, with "epidemiological studies to assess deaths in confined spaces have been hampered by data that does not specifically identify this type of fatality". During the 10-year period, 585 fatal incidents were identified, which resulted in 670 fatalities. There were an average of 67 confined space deaths per year, at an average rate of 0.08 per 100,000 workers.[16]

An examination of US Bureau of Labor Statistics Census of Fatal Occupational Injuries (CFOI) data between 1997 and 2001 found a total of 458 confined space fatalities, at a rate of 0.07 fatalities per 100,000 workers.[17]

Other international confined space fatalities

As with Australia, many other workplace health and safety authorities track the number of work-related fatalities and report annually, but do not record the number of confined space deaths. One notable exception is Singapore, where the Workplace Safety and Health Council has been reporting the number of confined space fatalities recorded as the agency of incident since 2007.[18] Over the period 2007–2014, Singapore recorded 505 workplace fatalities, 18 (3.6%) of which occurred in confined spaces.[19] The small number of confined space fatalities in Singapore discounts the identification of a fatality rate. It should also be noted that the procedures for confined space work in Singapore are very prescriptive.

The only other international statistics available were a recent study conducted in the Canadian province of Quebec which identified 41 confined space-related fatalities over the period 1998–2011; an average of 3.2 deaths per year at a rate of 0.07 fatalities per 100,000 workers.[20,21]

Purpose

The purpose of this study was to determine the actual number and rate of work-related traumatic fatal injuries involving confined spaces in Australia; and to provide a detailed description of the personal, industry, nature of work, and mechanism-specific factors involved. This provides the dual role of updating knowledge on Australian confined space fatality rates, as well as inform policies and practices related to reducing confined space incidents.

Method

Ethics approval for this study was granted through the Curtin University Human Research Ethics Committee (HR 18/2013), the Victorian Department of Justice Human Research Ethics Committee (for access to the National Coronial Information System (NCIS) — CF/13/6856, and the Coroner's Court of Western Australia (for access to Western Australian data in the NCIS) — EC 13/13.

Identification criteria

The primary source of data for this study was the coronial reports of work-related fatalities produced by the state and territory coroners from 2000 to 2012. These records were reviewed through data stored in the NCIS. The NCIS is a national internet-based data storage and retrieval system of all deaths reported to a coroner in Australia since July 2000 (and January 2001 for Queensland). The NCIS provides a specific filter for work-related fatalities, and this was applied, but it does rely on the correct coding of the fatality at the time of data entry.

As data for each record is rarely identifiable as a confined space-related fatality through standard coding of mechanism of incident or breakdown agency, a number of negative filters were applied to exclude fatalities which were not specifically work-related (such as suicides), or which were highly unlikely to have occurred within a confined space (such as motor vehicle accidents or forestry accidents). After such exclusions, approximately 4,200 individual records were manually reviewed. In addition to the coded data, the individual records in the NCIS may also contain police reports, autopsy and toxicology reports, inquest results, and coronial findings. These records were examined to determine if the fatality occurred involving a confined space. If the records contained in the NCIS were insufficient to include or reject the fatality being confined space-related then further information was sought from the individual coroners, workplace health and safety authorities, or other authorities such as the ATSB and NOPSEMA — according to jurisdiction.

Inclusion and exclusion criteria

All work-related fatalities which occurred in a confined space fitting the definition of a confined space as specified by the current version of Australian Standard 2865 and the Code of Practice[1,2] were included. The current workplace health and safety legislation, as reflected in the Code of Practice, requires that risks are eliminated or minimised for work involving entry and work inside a confined space, as well as for work on or in the vicinity of a confined space, including the possibility of inadvertent entry.[2] Hence workplace fatalities in which the confined space was a *significant contributing factor* for the deaths was also included. In one such example, a worker fell into a confined space (inadvertent entry) and died as a result of the fall. In another, two workers inadvertently ignited fumes while conducting hot work on an oil silo and were killed when thrown off the silo in an explosion.

The examination of NCIS records identified 16 fatalities which occurred in ceiling cavities which, as noted above, are not normally considered a confined space. Ceiling cavities do not meet the commonly understood definition of a confined space. Ceiling cavities would not, under all but the most exceptional circumstances, have the risk of containing an unsafe atmosphere or a risk of engulfment.[1] These noted fatalities include the four deaths attributed to the Commonwealth government's economic stimulus home insulation program.[22] While not considered confined space deaths, a brief analysis is included for completeness.

There were eight fatalities which occurred while working in a trench which would not have been considered to be a confined space. There was one fatality which occurred while working in a trench which could have been considered a confined space. Similar to the ceiling cavities, trenches would *not normally be considered to be confined spaces.* Although trenches have a substantial risk of engulfment; trenches would not, under all but the most exceptional circumstances, have the risk of containing an unsafe atmosphere. The model Code of Practice for confined spaces states "Trenches are not considered confined spaces based on the risk of structural collapse alone, but will be confined spaces if they potentially contain concentrations of airborne contaminants that may cause impairment, loss of consciousness or asphyxiation."[2] The risk of engulfment from a trench collapse and the required control measures are dealt with separately in most state or territory workplace health and safety legislation. As for the ceiling cavity deaths, a brief analysis of trench fatalities is included for completeness.

Incident categorisation

Each confined space fatality identified was assigned an age group in accordance with the ABS Age Standard.[23] In order to provide a comparison by age group with the total number of Australian workplace fatalities, the distribution of all workplace fatalities by age group was obtained from Safe Work Australia's annual Traumatic Injury Fatalities report.[5] Each fatality was assigned an industry group in accordance with the Australian and New Zealand Standard Industrial Classification (ANZSIC) system;[24] and the state in which each confined space fatality occurred was recorded. The mechanism of incident (which best describes the circumstances which caused the incident) was assigned for each confined space fatality in accordance with TOOCS 3.1.[7] While there is no specified classification for the *type* of confined space, the authors grouped the fatalities by similar confined space types such as tanks, ship or boat hulls or holds, and industrial vessels. The total number of confined space fatalities identified was calculated against the Australian working population as provided by the Australian Bureau of Statistics (ABS)[25] to determine the rate of confined space deaths per 100,000 workers per year.

Results

Confined space fatalities

There were 59 traumatic fatal injuries in 46 incidents involving confined spaces in Australia over the period 2000–2012. All casualties were male. The relatively low number of confined space fatalities results in volatility in this measure if any misclassification should exist due to lack of information. Undercounting is highly unlikely, therefore the numbers presented here should be considered to be a lowest estimate.

The rate of confined space fatalities calculated against the Australian working population is shown in Figure 1. It reveals a generally steady trend with a mean rate of 0.05 deaths per 100,000 workers from 2000–2012. It must be noted that a single incident in 2001 resulted in nine fatalities — by far the largest mass casualty event in the dataset.

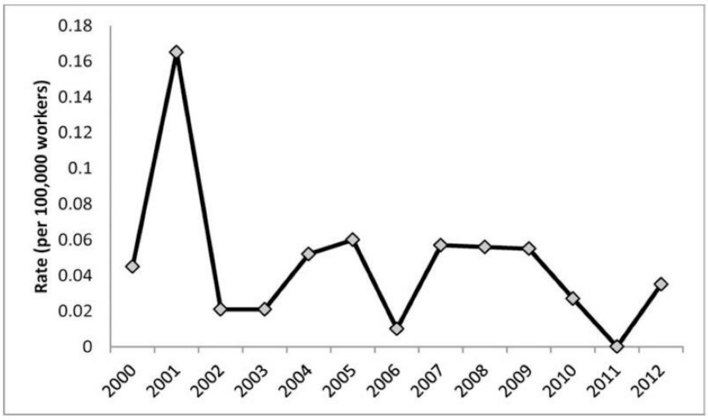

Figure 1. Rate of traumatic confined space fatalities (per 100,000) working population in Australia, 2000–2012.

Figure 2 shows the distribution of Australian workplace fatalities and confined space fatalities by age group. There were a significantly higher number of confined space casualties in the 25–34 years age group.

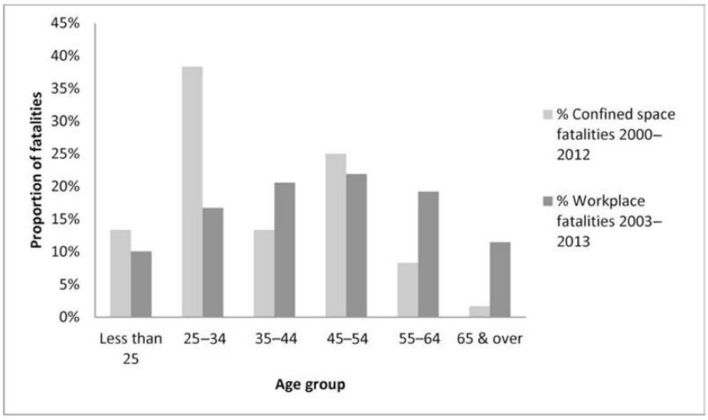

Figure 2. Traumatic confined space fatalities by age group in Australia, 2000–2012.

Figure 3 shows the distribution of confined space fatalities by industry group. The two industry groups which had the highest number of workers who died in confined spaces were the transport, postal & warehousing industry group; and the manufacturing industry group. There were many industry groups which did not record a confined space fatality; however they are included for completeness.

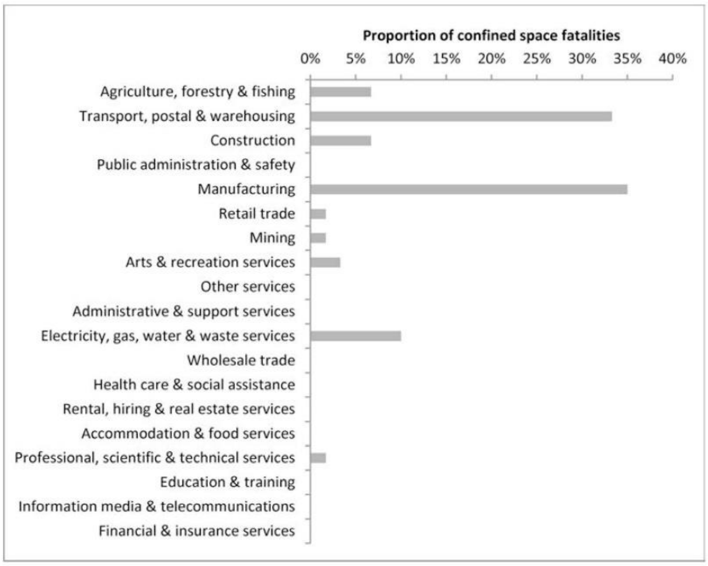

Figure 3. Proportion of traumatic confined space fatalities by industry group in Australia, 2000–2012.

The more populous states of New South Wales, Victoria, and Queensland had a higher incidence of confined space fatalities with 16.9%, 15.3%, and 22% of deaths respectively; however 39% of deaths occurred in Western Australia.

The mechanism of incident for the confined space fatalities identified by this study are shown in Figure 4. The mechanism "single contact with chemical or substance" includes all atmosphere-related fatalities which were short-term or traumatic in nature; and was the leading mechanism of incident. Figure 4 shows that "falls from a height" and "being trapped by moving machinery or equipment" were also major contributors to confined space deaths. Two of the 59 fatalities had the mechanism of incident as "slide or cave-in"; and involved entrapment and engulfment in grain and occurred in the agriculture, forestry and fishing industry group.

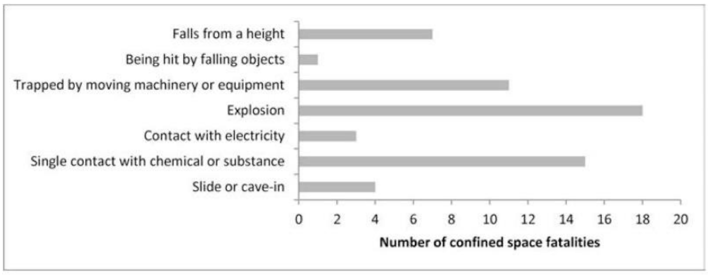

Figure 4. Mechanism of incident of traumatic confined space fatalities in Australia, 2000–2012.

Finally, while there is no specified type classification of confined spaces as noted above, the authors have grouped the fatalities by similar confined space types as shown in Figure 5. Ship or boat hulls or holds (which includes ballast and fuel tanks and other on-board compartments) is the category with the greatest number of deaths by far. Even accounting for the single 2001 incident on board a ship which resulted in nine fatalities, ship or boat hulls or holds remain the confined space type with the greatest number of casualties attributed.

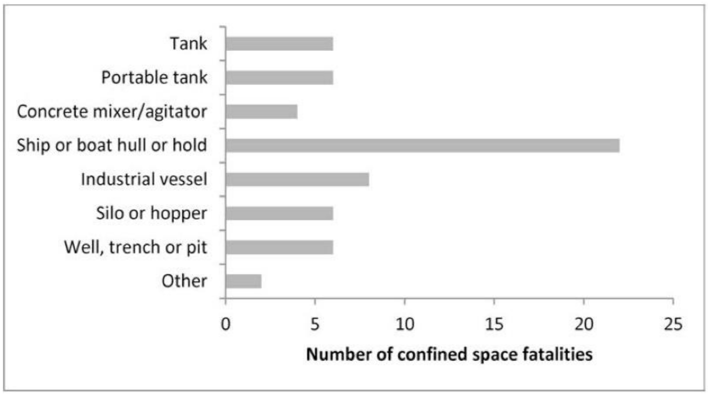

Figure 5. Confined space type for traumatic confined space fatalities in Australia, 2000–2012.

Ceiling cavities

A brief analysis of the ceiling cavity fatalities during the study period is provided for completeness. 16 work-related fatalities were identified as having occurred in ceiling cavities during the period 2000–2012. Of these, all the casualties were male, and all incidents occurred in the construction industry. All fatalities were single fatalities, and all fatalities bar one were of the mechanism of incident "contact with electricity". The remaining incident was "exposure to environmental heat". 63% (10) of the casualties were electricians, 31% (5) were labourers, and the remaining casualty was a plumber. The distribution of age of death was evenly distributed between the under 25-year-old group and the 45–54-year-old group. There was no notable distribution of incident by state — states with a larger working population (New South Wales, Victoria, Queensland, and Western Australia) had a greater number of fatalities.

Trenches

There were eight fatalities in trenches during the study period and a brief analysis is provided here for completeness. All casualties were male. Seven of the eight incidents occurred in the construction industry, with the remaining incident occurring on a farm and thus a part of the forestry, fishing and agriculture industry group. All fatalities were single fatalities, and 62% (five) of the eight deaths resulted from a slide or cave-in. There were no other discernible commonalities within the small number of incidents identified.

Discussion

This study attempted to identify the contemporary number and rate of work-related traumatic fatal injuries involving confined spaces in Australia. The study included an epidemiological investigation of the circumstances and causal factors involved.

Limitations

A limitation of the primary data source was that only "closed" coronial reports were available for examination. Closed coronial reports are those which the investigation has been completed by the coroner and the record closed in the NCIS. The more recent the time period, the more likely that a case would be open, and hence the time period was selected to minimise the potential of confined space fatalities remaining open and thus unavailable to the authors.

Number and rate of fatalities

As shown in Figure 1, the rate of confined space fatalities against the working population[25] shows a generally steady trend with a mean rate of 0.05 deaths per 100,000 workers from 2000–2012. A total of 59 traumatic work-related confined space fatalities were identified over the period 2000–2012. The rate of 0.05 fatalities per 100,000 workers was found to compare favourably to the overall workplace fatality rate in Australia of 1.64 per 100,000 workers.[5] It also compares favourably to studies undertaken in the US and Canada, which found confined space fatality rates to be between 0.07 and 0.08. [16,17,20]

Age distribution

The age groups distribution of the confined space deaths was at odds with the typical age group distribution of workplace deaths in Australia. There were a significantly higher number of casualties in the under 25 and 25–34 years age groups (total of 51%) in comparison to the fatality rate by age for all Australian workplace fatalities, which has a more normal distribution, with the 45–54 years age group containing the most fatalities.[5]

MacCarron[14] found 60% of Western Australian confined space fatalities to be between 16 and 30 years of age; although, as previously noted, the sample size was very small and included incidents which occurred in ceiling cavities. Similarly, a number of US studies into confined space fatalities have found that younger workers make up the majority of confined space fatalities. 40% of confined space fatalities were aged under 30 years in 88 deaths over the period December 1983 to December 1989;[26] 24% were aged under 30 years in 50 deaths in the US state of Virginia over the period 1979 to 1986;[15] 37% were aged under 30 years in 670 deaths over the period December 1983 to September 1993;[16] and 42% were aged under 35 years in 530 deaths over the period 1992 to 2005.[27] Young workers have a disproportionate rate of workplace injury and death in Australia. Young workers in higher-risk industry groups due to their exposure and factors such as lack of experience, inadequate training, and undeveloped personal risk identification skills.[28] The higher rate of confined space fatalities among younger workers is thought to result from many confined space entries — which can be small or tight or unpleasant tasks — performed by more junior employees such as apprentices, or by lower-skilled personnel who may be of a younger age.

Industry group and location

Of the identified fatalities, approximately 1/3 (35% — 21 fatalities) occurred in the manufacturing industry, and 1/3 (33% — 20 fatalities) occurred in the transport, postal & warehousing industry. This latter figure is skewed by a single incident which took place in 2001 in which there were nine fatalities on a sea-going ship. When confined space type is identified, ship or boat holds or hulls remain likely confined spaces in which fatalities occur, accounting for 22 (37%) of fatalities. Ship or boat holds or hulls may be the confined space type in either of the two industry groups noted above. The proportion of worker deaths in each industry group should be taken with care as workers in some industry groups are less likely to enter confined spaces in the course of their employment.

MacCarron[14] identified 3 out of 15 (20%) fatalities to have occurred in ship or boat holds or hulls. It is difficult to make direct comparisons with US studies, as a different industry classification code is used;[29] however commonalities remain. Of the 88 fatalities investigated by Manwaring & Conroy,[26] manufacturing was the third-most common industry with 15 (17%) fatalities, and chemical storage tanks the most common confined space type with 14 (26%) of incidents. Shipbuilding was the most common industry represented in the US state of Virginia, accounting for 6 (10%) of deaths, and ship holds accounted for 20% (12) of deaths across all industry groups.[15] Meyer,[17] in contrast, identified 111 of 458 fatalities (24%) occurred in the agriculture, forestry and fishing industry group; and 92 fatalities (20%) occurred in the manufacturing industry. In this study, silos and grain bins were the most frequent type of confined space involved, accounting for 111 fatalities (24% of all confined space fatalities). The construction industry accounted for 20% (106) and the manufacturing industry accounted for 19% (101) in 530 deaths over the period 1992 to 2005. [30]

Fatalities by state

Safe Work Australia[5] notes that over the past 11 years, New South Wales accounted for 30% of total worker fatalities, followed by Queensland with 24%, Victoria with 20%, and Western Australia with 12%. This generally correlates with the working population of each state as shown in Figure 6.[25] While the most populous states accounted for the majority of the confined space fatalities, New South Wales is under-represented with 17% of confined space fatalities, and Western Australia is over-represented with 39% of confined space fatalities. Even accounting for the nine-person incident, Western Australia is over-represented in confined space fatalities in respect to the working population of that state.

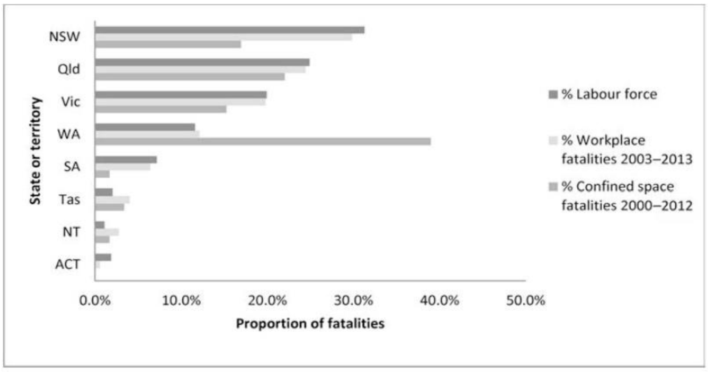

Figure 6. Proportion of fatalities by state or territory in Australia, 2000–2012.

It is difficult to account for this discrepancy. Of the industry groups with the highest proportion of confined space fatalities as depicted in Figure 3 (the transport, postal & warehousing industry group, and the manufacturing industry group), Queensland and Western Australia have a lower proportion of working population employed in these industry groups in comparison to New South Wales and Victoria. Queensland has 7.4% of the working population employed in manufacturing and 6.0% of the working population employed in transport, postal & warehousing. Western Australia has 7.2% of the working population employed in manufacturing and 4.6% of the working population employed in transport, postal & warehousing. New South Wales has 8.8% and 5.6% respectively; and Victoria has 9.9% and 5.0% respectively. [31]

Mechanism of incident

The mechanism of incident for the confined space fatalities in this study confirmed that atmospheric hazards (oxygen deficiency, toxic airborne contaminants, and flammable airborne contaminants) are the most prevalent mechanisms of incident, accounting for 34 (57%) of the 59 fatalities. Physical mechanisms including being trapped by moving machinery or equipment (18%), falls from a height (12%), and engulfment (7%) were also significant factors. There were two fatalities as a result of oxygen deficiency, and 13 fatalities caused by toxic airborne contaminants, referred to as "single contact with chemical or substance" under TOOCS 3.1.[7] No particular chemical or atmospheric hazard could be identified as a significant contributor to such deaths.

A review of all deaths investigated by the US Occupational Health and Safety Administration (OSHA) between 1984 and 1986 found that of the 4756 workplace fatalities; 233 were the result of asphyxiation or poisoning. This study was not limited to confined space deaths. Of these fatalities, 27 (12%) were due to an oxygen deficient atmosphere, 48 (21%) were due to simple asphyxiants (resulting in oxygen deficiency), 109 (47%) from toxic gases and solvents, and 42 (18%) as a result of mechanical asphyxiation — engulfment.[32] In studies of confined space fatalities, deaths as a result of atmospheric hazards feature prominently, and bear further analysis. It must be noted that deaths resulting from oxygen deficiency may also be coded as deaths resulting from simple asphyxiants such as non-toxic inert gases including carbon dioxide and nitrogen.

Previous studies from the US have identified atmospheric hazards (oxygen deficiency and toxic contaminants) to be the cause from 22%[17] to 43%[16] of deaths. More recently, Burlet-Vienneyab, Chinniahb[20] identified 33% of confined space deaths in Quebec during the period 1998–2011 to be as a result of atmospheric hazards. The particular atmospheric hazard causing death varies considerably by industry, and even in general studies, oxygen deficiency (including simple asphyxiants) ranges from 25%[27] to 46%[16] to 59%.[15] Other common toxic contaminants responsible for confined space fatalities include methane, carbon monoxide, and hydrogen sulphide.[15,16,17,20,26,27,32,33,34]

Both the relevant current version of Australian Standard 2865 and the Code of Practice[1,2] require atmospheric testing before entry into a confined space; and both specifically mention the dangers of oxygen deficient atmospheres, carbon monoxide, hydrogen sulphide, and flammable gases such as methane.

Grain entrapment

Of the four fatalities with the mechanism of incident being "slide or cave-in", two of these (50%) occurred in the agriculture, forestry and fishing industry group, and involved entrapment and engulfment in grain. As noted above, a study of confined space deaths in the US over the period 1997 to 2001 identified 130 engulfment fatalities out of 458 deaths, with 111 fatalities occurring in silos or grain bins. The same study classified 65% (71) of the 109 deaths in the agriculture, forestry and fishing industry to have occurred in silos or grain bins.[17] This is not the only source of confined space fatality in the agriculture sector, with another study recording 77 fatalities over the period 1975 to 2004 to have occurred in livestock manure storage and handling facilities;[33] however grain entrapment is an issue in US confined space fatalities. In 2010, there were 51 reported grain entrapment cases in the US, 26 (51%) of which resulted in a fatality. Reporting is acknowledged to be non-compulsory and thus incomplete. Of concern, the trend of both grain entrapments and fatalities is increasing, from 19 incidents in 2001 through to 51 incidents in 2010.[35,36]

Ceiling cavities

Ceiling cavities, in all but the most exceptional circumstances, would not normally be considered confined spaces. That does not mean that hazards are not present when working in ceiling cavities. This study identified 16 work-related fatalities which occurred in a ceiling cavity during the period 2000–2012. All incidents occurred in the construction industry, and all fatalities were due to electrocution except for one due to heat illness. 63% (10) of the 16 casualties were electricians. Of the 15 confined space deaths identified in WA between 1982 and 2004 by MacCarron,[14] six occurred in ceiling cavities. All six fatalities were as a result of electrocution, and all six were electricians or apprentice electricians. As with Australia, the US legislation and standards do not usually consider ceiling cavities to be confined spaces; and no further data collected in any available study could be found. A reduction in electrocution deaths in ceiling cavities could be achieved through a more rigorous risk assessment before work is undertaken, and the implementation of control measures such as the isolation of the electrical supply, or the use of residual current devices.

Trenches

Unless a trench has a risk of containing an unsafe atmosphere, it would not normally be considered to be a confined space. The major risk to workers in a trench is that of engulfment, whereby the trench walls slide or cave-in. As such, the required control measures for working in trenches are dealt with separately in most state or territory workplace health and safety legislation. Specifically, there is a requirement in all trenches greater than 1.5 m deep to minimise the risk through shoring, benching, or battering. There were eight fatalities identified as having occurred in trenches during the study period and seven of those incidents occurred in the construction industry. Five of the eight deaths (62%) resulted from a slide or cave-in. A specific study into slide or cave-in fatalities in trenches or excavations in the US construction industry identified 306 fatal cases between 1974 and 1986; an average of over 25 fatalities per year, most of which were due to inadequate trench wall shoring or bracing.[37] A follow-up study conducted after the introduction of new safety legislation in 1990 found a decrease in fatalities from the five years before the new legislation to the five years after the introduction of the new safety legislation to be 50%.[38] An examination of US Bureau of Labor Statistics CFOI data between 1995 and 1999 found a total of 231 fatalities resulting from excavation or trench cave-ins.[39] Trenches and other excavations are clearly of risk to workers, but should be examined separately to confined space fatalities.

Non-fatal injuries

Without formal identification as a confined space incident, non-fatal incidents and injuries which occur in a confined space are impossible to numerate. There are two data sets for workplace injuries. The first is the aforementioned NDS, which is compiled from 10 workplace health and safety authorities: each state and territory, the Commonwealth (Comcare), and Seacare. As noted above, the NDS accounts for only approximately half of all workplace fatalities.[5,8,9] A subset of the injuries recorded, those for which a claim for compensation has been accepted and paid, and for which an absence of more than one working week was required (defined as a serious claim), is published annually by Safe Work Australia. The most recent publication

(2012–2013) found 11.1 serious injury claims per 1000 workers over the time period.[40] This series is coded under TOOCS 3.1, and thus confined space injury numbers are irresolvable.

The second data set for workplace injuries is that which is produced by the ABS. While not limited to compensable injuries or serious injuries, the data is extrapolated from a sample survey. Members of the Australian Defence Force are again excluded. The latest dataset produced sampled 27,300 households and determined a gross workplace incident injury rate of 43 workplace injuries (of all type) per 1000 workers.[41] This data is also coded under TOOCS 3.1, and again confined space injury numbers cannot be determined. Workplace injuries are known to be under-reported[42,43] for various reasons; and even at the point of admission, an investigation revealed hospital records alone under-enumerating work-related admissions by 32%.[44] Without specific additions to TOOCS 3.1, the rate of confined space injuries is impossible to determine.

Coding recommendations

The primary objective of this study was to ascertain the number and rate of work-related traumatic confined space fatalities in Australia and to examine the aetiologies involved. The primary source of data was the manual review of coronial records of work-related fatalities produced by the state and territory coroners from 2000 to 2012 which were accessible from the NCIS. The major difficulty in identifying confined space fatalities from Safe Work Australia's TIF database (comprising the NDS, NFC, and the NCIS) is the lack of a specific coding for confined space injuries and fatalities in the classification system used.

Under TOOCS 3.1, the primary system used to produce the NDS and NFC datasets, the final two steps in coding an incident are the breakdown agency, which is what was *most closely associated with the incident when things started to go wrong*; and the agency of the injury or disease, which is what was *directly involved in inflicting the injury or disease*.[7] Both the breakdown agency and the agency of the injury or disease use the same four-digit code system. There is no code for a general confined space incident. It would be entirely possible to include a code for "confined space" under Group 7 "Environmental Agencies" in the four-digit agency codes without negatively affecting the integrity of the system. This would most likely apply to the breakdown agency. For example, a worker who is electrocuted while welding inside a confined space could have the mechanism of the incident as "contact with electricity" (code 57); the breakdown agency as "confined space" (new code 7599); and the agency of the injury or disease as "arc welding equipment" (code 3149). This permits identification of the incident having occurred in a confined space without affecting the correctness of other incident data, and complies with rule 13: "For all occurrences, the whole of the agency should be coded and not just the component part."[7]

Conclusion

In conclusion, it was found that over the period 2000–2012, there were 59 fatalities in 46 incidents in confined spaces in Australia, at a fatality rate of 0.05 deaths per 100,000 workers, which is a little better than comparative deaths in the US and Quebec at between 0.07 and 0.08. It is also better than the overall Australian workplace fatality rate of 1.64 fatalities per 100,000 workers. In addition to the confined space deaths, there were 16 work-related fatalities which occurred in a ceiling cavity during the period, and eight fatalities occurred in trenches during the study period 2000–2012.

Identification of confined space fatalities is difficult, and it is strongly recommended that additional coding is added to the TOOCS 3.1 system to assist in the identification of not only confined space fatalities, but all reported injuries and illnesses and near misses involving confined spaces. This will permit a better tracking of confined space injuries and fatalities across all datasets and will also inform the TIF database.

Government workplace health and safety authorities, businesses, industry associations, unions, and researchers can all make use of this research. In particular, the results will inform of the risks arising from working in and around confined spaces, and will contribute to increasing the understanding and recognition of the hazards in working in confined spaces; and reduce incidents, injuries, and fatalities.

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References

1 Standards Australia. Confined Spaces. Sydney, Australia: SAI Global; 2009.

2 Safe Work Australia. Code of Practice: Confined Spaces. Canberra, ACT: Commonwealth of Australia; 2014.

3 Robens, AL. Report of the committee on safety and health at work, 1970–1972. Her Majesty's Stationery Office: London; 1972.

4 Winder, C. The development of OHS legislation in Australia. Journal of Occupational Health and Safety, Australia and New Zealand. 2009; 25(4):277–287.

5 Safe Work Australia. Work-related Traumatic Injury Fatalities, Australia, 2013. Canberra, ACT: Commonwealth of Australia; 2014.

6 Safe Work Australia. Work-related Traumatic Injury Fatalities, Australia, 2012. Canberra, ACT: Commonwealth of Australia; 2013.

7 Australian Safety and Compensation Council. Type of Occurrence Classification System. Canberra, ACT: Commonwealth of Australia; 2008.

8 Lindquist, SI, Yardley, AJ and Champion de Crespigny, FE. Estimating the true number of work-related fatalities due to injury: The traumatic injury fatalities dataset. Journal of Health and Safety, Research and Practice. 2014; 6(6):8–14.

9 Driscoll, T et al. Coverage of work related fatalities in Australia by compensation and occupational health and safety agencies. Occupational and Environmental Medicine. 2003; 60:195–200.

10 World Health Organization. International Classification of External Causes of Injury (ICECI). ICECI Coordination and Maintenance Group. Geneva, Switzerland: Consumer Safety Institute, Amsterdam, The Netherlands and AIHW National Injury Surveillance Unit, Adelaide, Australia; 2004.

11 Harrison, JE et al. Deaths as a result of work-related injury in Australia. Medical Journal of Australia. 1989; 150(3):118–125.

12 National Occupational Health and Safety Commission. Work-related traumatic fatalities in Australia, 1989 to 1992. Sydney: Commonwealth of Australia; 1998.

13 Driscoll, T et al. Work-related fatalities in Australia, 1989 to 1992: an overview. Journal of Occupational Health and Safety, Australia and New Zealand. 2001; 17(1):45–66.

14 MacCarron, C. Confined Space Fatalities. Perth, Western Australia: Edith Cowan University; 2006.

15 Sahli, B and Armstrong, C. Confined Space Fatalities in Virginia. Journal of Occupational Medicine. 1992; 39(9):910–917.

16 Pettit, TA et al. Worker deaths in confined spaces. Professional Safety. 1996; 41(11):22–25.

17 Meyer, S. Fatal occupational injuries involving confined spaces, 1997–2001. Occupational Health & Safety. 2003; 72(11):58–64.

18 Workplace Safety and Health Council. Workplace Safety & Health, 2008, National Statistics. Singapore: Singapore Government; 2008.

19 Workplace Safety and Health Institute. Workplace Safety and Health Report, 2014. Singapore: Singapore Government; 2014.

20 Burlet-Vienneyab, D, Chinniahb, Y and Bahloul, A. The Need for a Comprehensive Approach to Managing Confined Space Entry: Summary of the Literature and Recommendations for Next Steps. Journal of Occupational and Environmental Hygiene. 2014; 11(8):485–498.

21 Statistics Canada. Table 282-0001, Labour force characteristics, unadjusted, by province (monthly). Ottowa, Ontario: Government of Canada; 2014.

22 Hanger, I. Royal commission into the home insulation program. Report of the royal commission into the home insulation program. Canberra, ACT: Commonwealth of Australia; 2014.

23 Australian Bureau of Statistics. Age Standard. Canberra, Australia: Commonwealth of Australia; 2014.

24 Australian Bureau of Statistics. Australian and New Zealand Standard Industrial Classification. Canberra, Australia: Commonwealth of Australia; 2006.

25 Australian Bureau of Statistics. Report 6202.0, Labour Force, Australia. Canberra, Australia: Commonwealth of Australia; 2014.

26 Manwaring, JC and Conroy, C. Occupational Confined Space-Related Fatalities: Surveillance and Prevention. Journal of Safety Research. 1990; 21(4):157–164.

27 Wilson, MP, Madison, HN and Healy, SB. Confined Space Emergency Response: Assessing Employer and Fire Department Practices. Journal of Occupational and Environmental Hygiene. 2012; 9(2):120–128.

28 Ehsani, JP et al. Work-related fatal injury among young persons in Australia, July 2000–June 2007. Safety Science. 2013; 57(2013):14–18.

29 National Technical Information Service. North American Industry Classification System. Alexandria, Virginia: Department of Commerce, United States Government; 2012.

30 Madison, HN and Wilson, MP. Protecting Workers in Industrial Confined Spaces: California's emergency response requirements are ambiguous and less protective than the federal standard. Berkeley, California: School of Public Health, University of California; 2008.

31 Australian Bureau of Statistics. Report 6291.0, Labour Force, Australia, Detailed. Canberra, Australia: Commonwealth of Australia; 2014.

32 Suruda, A and Agnew, J. Deaths from asphyxiation and poisoning at work in the United States 1984–86. British Journal of Industrial Medicine. 1989; 46:541–546.

33 Beaver, RL and Field, WE. Summary of Documented Fatalities in Livestock Manure Storage and Handling Facilities — 1975–2004. Journal of Agromedicine. 2007; 12(2):3–23.

34 Fuller, DC and Suruda, AJ. Occupationally related hydrogen sulphide deaths in the United States from 1984 to 1994. Journal of Occupational and Environmental Medicine. 2000; 42(9):939–942.

35 Riedel, S and Field, B. 2010 Summary of Grain Entrapments in the United States. West Lafayette, Illinois: ASAH Program, Purdue University.

36 Riedel, SM and Field, WE. Summation of the Frequency, Severity, and Primary Causative Factors Associated with Injuries and Fatalities Involving Confined Spaces in Agriculture. Journal of Agricultural Safety and Health. 2013; 19(2):83–100.

37 Suruda, A, Smith, G and Baker, SP. Deaths from trench cave-in in the construction industry. Journal of Occupational Medicine. 1988; 30(7):552–555.

38 Suruda, A et al. Impact of the OSHA Trench and Excavation Standard on Fatal Injury in the Construction Industry. Journal of Occupational and Environmental Medicine. 2002; 44(10):902–905.

39 Drudi, D and Zak, M. Work-related multiple-fatality incidents. Monthly Labor Review. 2004; 127(10):20–37.

40 Safe Work Australia. Australian Workers' Compensation Statistics, 2012–13. Canberra, ACT: Commonwealth of Australia; 2013.

41 Australian Bureau of Statistics. Report 6324.0, Work-Related Injuries, Australia, Jul 2013 to Jun 2014. Canberra, Australia: Commonwealth of Australia; 2014.

42 de Castro, AB. Health & Safety: Barriers to Reporting a Workplace Injury. The American Journal of Nursing. 2003; 103(8):112.

43 Probst, TM and Graso, M. Pressure to produce = pressure to reduce accident reporting? Accident Analysis and Prevention. 2013; 59:580–587.

44 McKenzie, K et al. The reliability of information on work-related injuries available from hospitalisation data in Australia. Australian and New Zealand Journal of Public Health. 2009; 33(4):332–338.

CHAPTER FOUR –
AN INVESTIGATION INTO THE RATE AND MECHANISM OF INCIDENT OF WORK-RELATED CONFINED SPACE FATALITIES

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An investigation into the rate and mechanism of incident of work-related confined space fatalities

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ABSTRACT

Confined spaces are defined by a particular set of hazards which include oxygen deficiency, toxic airborne contaminants, flammable atmospheres, the risk of engulfment in free-flowing solids and liquids, and physical hazards such as working at heights, electricity, and moving parts and machinery. This study conducted an analysis of work-related traumatic fatal injuries involving confined spaces and compared the rate of confined space fatalities in the working population between similar industrialised countries; the rate of confined space entrant to confined space rescuer deaths; and identified the difference in the mechanism of incident between entrant and rescuer deaths. The confined space fatality rate can be estimated to vary between 0.05 and 0.08 deaths per 100,000 workers, of which no more than 17% were found to be those undertaking rescue; with most of these deaths the result of hurried and ad hoc rescue attempts. While the major causes of death among entrants were toxic atmospheric hazards and physical hazards; confined space rescuer deaths were overwhelmingly as a result of toxic atmospheres. It is likely that these figures are an underestimate of all confined space fatalities, as government WHS authorities rarely identify such incidents as having occurred in a confined space. The inclusion of engulfment and other physical hazards of confined space work in safety legislation, and the separate identification of confined space incidents will permit better analysis and recommendations for confined space work safety improvements.

1. Introduction

Confined space fatalities continue to be a significant cause of workplace death in Australia and internationally. A detailed investigation into the aetiologies of confined space fatalities, including the rate and differences between confined space entrant and confined space rescuer fatalities, will assist in the reduction of these workplace deaths.

1.1. *The dangers of confined spaces*

The dangers of working in confined spaces have been known for many years. While Ramazzini (translated 1983) was the first to examine the relationship between employment and malady, Thackrah (1832) identified the atmospheric hazards present in confined spaces and the effect on those employed to enter such places. He noted that well sinkers were 'frequently obliged to respire carbonic acid, and other gases found in wells', and that sewer workers were 'often affected by the fetid gases', sometimes to the point of unconsciousness or death (Thackrah, 1832, pp. 117–118). Confined space incidents also result in multiple fatalities, often when rescue is attempted by workmates and untrained personnel. As early as 1812, it is recorded that three men lost their lives when one after another they climbed down into a well to recover some stolen beef and were overcome by the atmospheric conditions (Kletz, 1996). Sewer workers attempting rescue of workmates suffered the same fate in 1895 in an incident in which five were killed, one after another (Bond, 1996). Hamilton (1929) discussed the dangers of hydrogen sulphide in confined spaces and gave examples of resulting worker and rescuer fatalities.

It is unknown how many workers enter confined spaces on a daily, routine, or irregular basis. The United States Occupational Safety and Health Administration (OSHA) – the US national regulatory body for health and safety – estimated in 1993 that there were about 1.6 M workers who entered approximately 4.8 M confined spaces each year (Office of the Federal Register, 1993, p. 4542). Other estimates include over 658,000 confined space entries per year in Western Australia alone (Worksafe WA, as cited in MacCarron, 2006, p. 2); and an estimate of 2.1 M workers entering confined spaces annually (CSUF, 2012).

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Confined spaces include vats, tanks, silos, pits, pipes, shafts, pressure vessels and sewers. There is no universal definition of a confined space. The definition varies by country, jurisdiction, legislation, and in some cases industry group, however there are few differences overall. For the purposes of comparison between jurisdictions, a common definition of a confined space has been used in this study. A confined space is defined as an enclosed or partially enclosed space, which is not intended or designed primarily for human occupancy, and which has a risk of an unsafe level of oxygen, toxic airborne contaminants, flammable airborne contaminants, or a risk of engulfment by a free-flowing solid or liquid (Government of Singapore, 2009; Government of the United Kingdom, 1997; Safe Work Australia, 2016; Standards Australia, 2009; Standards Singapore, 2005). It should be noted that some jurisdictions such as the US and Canada also define a confined space as having limited or restricted means for entry or exit (ANSI/ASSE, 2009; Canadian Standards Association, 2016; OSHA, 2011). The US also divides confined spaces into those which do not have substantial risks; and those which have a risk of a hazardous atmosphere or risk of engulfment as *Permit Required Confined Spaces* (PRCS) (OSHA, 2011). A summary of the definitions of a confined space by jurisdiction is provided in Table 1 (Government of Victoria, 2017; Government of Western Australia, 1996; OSHA, 2016).

Underground mines are not defined as confined spaces, as they are intended to be places of work. Vessels and equipment located at a mine such as vats, hoppers, and tanks which may be located either above ground or underground, would be considered to be confined spaces. Ceiling cavities do not generally have a risk of containing an unsafe atmosphere or a risk of engulfment, so are not normally considered to be confined spaces. In an Australian study which examined 15 fatalities that occurred in the state of Western Australia during the period 1980–2004, six of the eight electrocution deaths took place in ceiling cavities, which are not ordinarily considered to be confined spaces (MacCarron, 2006). Ceiling spaces are also not usually considered confined spaces in the UK (Government of the United Kingdom, 2014), and are usually regarded as non-permit confined spaces in the US (OSHA, 2011). Likewise, although trenches have a substantial risk of engulfment, trenches would not, under all but the most exceptional circumstances, have the risk of containing an unsafe atmosphere. The Australian model Code of Practice for confined spaces states ‘Trenches are not considered confined spaces based on the risk of structural collapse alone, but will be confined spaces if they potentially contain concentrations of airborne contaminants that may cause impairment, loss of consciousness or asphyxiation.’ (Safe Work Australia, 2016, p. 5). Trenches are not considered confined spaces in the UK unless ‘there is also the presence of or a reasonably foreseeable risk of one of the specified risks to the health and safety of those working in the space’ (Government of the United Kingdom, 2014, p. 10). The ‘specified risks’ are defined as fire or explosion; heat injury; asphyxiation from a gas, fume or vapour; or engulfment. Likewise, in the US, OSHA confined space regulations apply only when excavation or trenching work is related to sewerage construction (OSHA, 2015).

1.2. Confined space fatalities

There have been a few studies of confined space deaths in Australia and North America. Selman et al. (2017) identified 59 confined space fatalities Australia-wide over the period 2000–2012, with a mean rate of 0.05 deaths per 100,000 workers in the working population. Two of the 59 fatalities (3.4%) were persons attempting rescue. A study of confined space fatalities in the US using the National Traumatic Occupational Fatalities (NTOF) data for 1980 through 1989 was undertaken by Pettit et al. (1996) which found 670 fatalities from 585 incidents over the ten year period, with a rate of 0.08 fatalities per 100,000 workers. 72 (12%) of the incidents involved multiple fatalities, although the study could not differentiate between entrants and rescuers in these incidents. A later study using Census of Fatal Occupational Injuries (CFOI) data produced by the US Bureau of Labor Statistics found 458 confined space-related fatalities over the five year period 1997–2001 with a rate of 0.07 fatalities per 100,000 workers in which 25 (5.5%) were persons attempting rescue - most of whom were not professional rescuers. It was noted that engulfment was the most common mechanism of incident (Meyer, 2003). CFOI data was examined for the period 1992–2005 by Wilson et al. (2012) in which only atmosphere-related confined space incidents were included, and revealed 530 fatalities in 431 incidents with 47 (9%) of the fatalities identified as would-be rescuers. A recent study conducted into confined space fatalities in the Canadian province of Quebec identified 41 fatalities over the period 1998–2011 with a fatality rate of 0.07 per 100,000 workers in which 6 (15%) of the deaths were attributed to rescuers (Burlet-Vienney et al., 2015b; Statistics Canada, 2014).

Further published studies which considered confined space fatalities in the total workforce either in the US or in other similar industrialised countries were not found; however a number of studies from the US restricted by geographical area, industry sector, or other criteria were identified. An examination of confined space fatalities in the US state of Virginia between 1979 and 1986 identified 50 deaths, including 3 (6%) of whom were rescuers (Sahli and Armstrong, 1992). Worker deaths in the US as a result of asphyxiation and poisoning over the period 1984–1986 were investigated by Suruda and Agnew (1989) and it was found that of the 233 deaths recorded, 146 occurred in confined spaces – 17 (12%) of whom were rescuers. Also noted were 42 deaths from mechanical asphyxiation as a result of engulfment. A study of livestock manure handling and storage facility confined space-related fatalities in the US between 1975 and 2005 identified 17 rescuer fatalities out of 77 total fatalities (22%) in 56 incidents (Beaver and Field, 2007). The United States National Institute for Occupational Safety and Health (NIOSH) – a division of the Centers for Disease Control (CDC) – conducts investigations of fatal occupational injuries as a part of the FACE (Fatal Accident Circumstances and Epidemiology) program, which targets particular causes of death and publishes the investigations into selected incidents (Higgins et al., 2001; Manwaring and Conroy, 1990). Analysis of confined space FACE data between 1982 and 1991 was undertaken in which 62 incidents resulted in 97 fatalities, including 35 (36%) attempting rescue (Suruda et al., 1994). It must be noted, however, that the FACE dataset is a selected subset of all confined space incidents, and while useful for aetiology analysis, it is not representative of the rate of confined space deaths or of the division between entrant and rescuer deaths as a whole. Confined space fatality data in the literature is generally weighted towards deaths from atmospheric hazards (toxic substances and oxygen deficiency).

The issue of multiple and rescuer fatalities in confined spaces was recognised as a growing problem in modern industry and in 1986 NIOSH issued an alert based on a number of fatal confined space incidents in which NIOSH concluded ‘More than 60% of confined space fatalities occur among would-be rescuers; therefore a well-designed and properly executed rescue plan is a must.’ (NIOSH, 1986). While much of the advice provided in the alert was pertinent and remains relevant today, the proportion of rescuer deaths attributed in the alert is very high and subsequent studies have identified much lower ratios (Beaver and Field, 2007; Burlet-Vienney et al., 2014; Meyer, 2003; Pettit et al., 1996; Suruda et al., 1994; Wilson et al., 2012).

1.3. Confined space hazards

The causes of confined space incidents, which may lead to injury and death, can generally be divided into four categories of mechanism of incident – defined as ‘The action, exposure or event that best describes the circumstances that resulted in the most serious injury or disease’ (Austalian Safety and Compensation Council, 2008). The first three of those mechanisms are toxic atmospheres, flammable atmospheres, and engulfment in free-flowing substances; which are the general causes for caution with confined space entry and work. The

Table 1
Comparison of the definition of a confined space between similar industrialised countries.

Country / Regulation / Standard \ Criteria	Limited means of entry or exit	Enclosed or partially enclosed	Not designed or intended for occupation	Normal atmospheric pressure during occupation	Potential hazards of a confined space: Toxic atmosphere (including unsafe oxygen levels)	Fire or explosion	Risk of engulfment	Risk of other physical hazards
Australia Code of Practice (Safe Work Australia, 2016)[1]		☑	☑	☑	☑	☑	☑	
State of Victoria, Australia Regulation (Government of Victoria, 2017)[1]	☑			☑	☑	☑	☑	
State of Western Australia, Australia Regulation (Government of Western Australia, 1996)[1]	☑	☑	☑	☑	☑	☑	☑	
New Zealand Australian / New Zealand Standard 2865 (Standards Australia, 2009)[2]		☑	☑	☑	☑	☑	☑	
Canada Regulation (Government of Canada, 2017)[3]	☑	☑	☑		☑	☑	☑	☑
Province of Quebec, Canada Regulation (Government of Quebec, 2017)[3]	☑	☑	☑		☑	☑	☑	☑
Province of Ontario, Canada Regulation (Government of Ontario, 2017)[3]		☑	☑		☑	☑		
Singapore Regulation (Government of Singapore, 2009)		☑			☑	☑	☑	
Singapore Standard (Standards Singapore, 2005)		☑			☑	☑		
United Kingdom Regulation (Government of the United Kingdom, 1997)		☑			☑	☑	☑	☑
United States Regulation (general) (OSHA, 2011) – PRCS Regulation (construction industry) (OSHA, 2016)[4]	☑	☑	☑		☑	☑	☑	☑

Notes:
1. Legislation can differ between jurisdictions in Australia. The Code of Practice is approved for all jurisdictions under the legislation.
2. The Australian/New Zealand Standard is the approved Code of Practice under New Zealand legislation.
3. Legislation can differ between jurisdictions in Canada.
4. Unique to the US, different legislation applies to confined spaces in the construction industry.

general definition of a confined space includes those hazards. Many studies also acknowledge that physical hazards, such as falls, electrocution, and being caught or crushed in machinery are significant causes of death in confined space incidents (Burlet-Vienney et al., 2015b; Meyer, 2003; NIOSH, 1994; Pettit et al., 1996; Sahli and Armstrong, 1992; Selman et al., 2017).

1.3.1. Toxic atmospheric hazards

Toxic atmospheres includes oxygen deficient atmospheres, in which causes asphyxiation as a result of low levels of oxygen – usually because the oxygen has been displaced or replaced by a non-toxic, low toxicity, or inert gas such as nitrogen or carbon dioxide. Toxic atmospheres also include those in which death occurs as a result of the inhalation of harmful airborne contaminants such as toxic gases, vapours, fumes and dusts (Safe Work Australia, 2016).

Among the countries included in this study, most confined space legislation, regulations and standards specify a minimal safe level of oxygen as 19.5% by volume, with the exception being Canada; which permits work in an atmosphere with oxygen as low as 18% by volume in certain circumstances (Burlet-Vienney et al., 2014; Government of Canada, 2017). In 2003, a safety bulletin was published by the US Chemical Safety and Hazard Investigation Board which warned of the dangers of nitrogen asphyxiation after 80 deaths were recorded from this hazard over the period 1992–2002 (US Chemical Safety and Hazard Investigation Board, 2003). Other than low levels of oxygen, workers may also be exposed to toxic contaminants such as fumes, gases and vapours in the course of their work inside a confined space. These contaminants have occupational exposure limits based on toxicity, which include the Time Weighted Average (TWA) – which is the maximum exposure for an eight hour working day for a five day week; the Short Term Exposure Limit (STEL) – a 15 min exposure which should not be exceeded at any time during the working day, even if the exposure is within the eight hour TWA (Reed et al., 2013); and the Peak or Immediately Dangerous to Life or Health (IDLH) exposure standard – which workers should not be exposed to without adequate respiratory protection (NIOSH, 2013). These occupational exposure limits are often expressed in parts per million (ppm), and are very similar from jurisdiction to jurisdiction, although differences in exposure limits do exist (Schenk et al., 2008). Common toxic contaminants in confined spaces, their source, and the maximum concentration for work are shown in Table 2 (American Conference of Governmental Industrial Hygienists, 2015; Government of the United Kingdom, 2011; OSHA, 2017; Safe Work Australia, 2013).

Oxygen deficiency and displacement of oxygen by inert gases was the biggest contributor (60%) to confined space atmosphere-related fatalities in Virginia between 1976 and 1986, followed by carbon monoxide (17.6%), and hydrogen sulphide and gasoline vapours (Sahli and Armstrong, 1992). Oxygen deficiency and inert gases were responsible for at least 132 of the 373 (35%) atmosphere-related confined space deaths in the US for the period 1980–1989, with hydrogen sulphide (13.7%), carbon monoxide (6.7%), and 'sewer gases' (a mixture of toxic contaminants possibly including hydrogen sulphide, methane, ammonia, carbon monoxide, sulphur dioxide, and nitrogen oxides) responsible for a further 6.7% (NIOSH, 1994). Wilson et al. (2012) identified 104 (26%) of the atmosphere-related confined space fatalities as resulting from carbon monoxide, 95 (18%) from oxygen deficiency, and 44 (11%) from hydrogen sulphide. Unfortunately the substance was not identified in 52% of incidents. The most common toxic atmosphere responsible for confined space fatalities in Quebec over the period 1998–2011 was hydrogen sulphide, accounting for 8 (19.5%) of all deaths (Burlet-Vienney et al., 2014). These studies demonstrate that there is a wide range of toxic contaminants which are hazards in confined spaces, but the majority of fatalities result from a few common gases (oxygen deficiency, carbon monoxide, and hydrogen sulphide).

1.3.2. Flammable atmospheric hazards

Flammable atmospheres may lead to fires and explosions, resulting in injury and death of confined space workers. Legislation, codes of practice and standards limit the exposure of workers to flammable atmospheres. The limitation is usually expressed as a percentage of the Lower Explosive Limit (LEL) – defined as 'the concentration of the gas, vapour or mist in air below which the propagation of a flame does not occur on contact with an ignition source' (Commonwealth of Australia, 2014, p. 30). Most confined space legislation, regulations and standards among the countries included in this study specify a minimal safe level of specify a maximum LEL of 10% or less for confined space entry and work (Burlet-Vienney et al., 2014; Commonwealth of Australia, 2014; Government of Canada, 2017; Government of Singapore, 2009; Government of the United Kingdom, 1997).

1.3.3. Engulfment

Engulfment results when a person is immersed in a liquid or free-flowing solid. This may result in drowning or asphyxiation, including physical asphyxiation from crushing. Materials with a propensity for engulfment include sewage, plastics, sand, sawdust, grain, and other agricultural products (NIOSH, 1987; Pettit et al., 1996; Safe Work Australia, 2016). Engulfment occurs when an unexpected introduction of a substance into the container occurs, or when a worker falls into the product. A particular danger results when stored materials form a crust above a void and a worker or workers walking on top of the crust, or working below the crust, are engulfed when the crust gives way (Safe Work Australia, 2016). While engulfment is a common-enough causative factor, certain industry groups such as agriculture have a much higher rate of engulfment fatality (Issa et al., 2016; Meyer, 2003; Riedel and Field, 2011, 2013).

1.3.4. Physical hazards

Physical hazards such as falls from height, being struck by falling objects, entrapment in machinery, and electrocution have also been found to contribute to a noteworthy number of confined space-related fatalities (NIOSH, 1994). Such physical hazards were found to be responsible for 22 (37%) of the 59 fatalities in Australia over the period 2000–2012 (Selman et al., 2017); and for 20 (49%) of the 41 confined space fatalities identified in Quebec in the 14 years between 1998 and 2011 (Burlet-Vienney et al., 2014, 2015b). Interaction among hazards are another important factor in confined space incidents as a combination of hazards may lead to synergistic risks (Lyon and Hollcroft, 2012); or risks may be consecutive (Burlet-Vienney et al., 2014) – in one such incident in Australia identified by the authors, a worker was descending a ladder into a well when he suffered oxygen deficiency as a result of carbon monoxide asphyxiation and fell into the liquid below and drowned.

1.4. Purpose

The purpose of this study was to develop a more current dataset on the rate of work-related traumatic fatal injuries involving confined

Table 2
Occupational exposure limits and sources for toxic airborne contaminants common to confined spaces.

Airborne contaminant	Source	TWA (ppm)	STEL (ppm)	Peak or IDLH (ppm)
Chlorine	Water purification, cleaning products	0.5	1	10
Sulphur dioxide	Wastewater treatment, preservatives, bleaching products	2	5	100
Hydrogen cyanide	Industrial processes, mining applications	10	10	50
Hydrogen sulphide	Sewage, rotting vegetation, industrial processes	10	15	100
Ammonia	Industrial processes, fertilisers, refrigerants	25	35	300
Carbon monoxide	Engines, furnaces, fuel combustion	30	200	1200
Carbon dioxide	Respiration, rusting	5000	30,000	40,000
Inert gases (argon, helium, nitrogen)	Usually from purging activities, or welding	Simple asphyxiants. Oxygen concentration above 19.5%		

spaces in selected industrialised countries, to identify the major mechanisms of incident, and to identify any difference in rate and mechanism of incident between confined space entrants and rescuers.

2. Method

Ethics approval for this study was granted through the Curtin University Human Research Ethics Committee (HR 18/2013), the Victorian Department of Justice Human Research Ethics Committee (for access to the National Coronial Information System (NCIS) – CF/13/6856, and the Coroner's Court of Western Australia (for access to Western Australian data in the NCIS) – EC 13/13, and the Coroner's Court of New Zealand (for access to New Zealand data in the NCIS).

2.1. Confined space fatality data

Data for Australian confined space fatalities was taken from MacCarron (2006) and Selman et al. (2017). Data for New Zealand (NZ) confined space fatalities was extracted from the coronial reports of work-related fatalities produced by the NZ coroner and reviewed through data stored in the National Coronial Information System (NCIS), which contains records of workplace deaths reported to a coroner in NZ since 2007. While the NCIS captures all reportable deaths, it also has limitations since the coding of deaths is a complex process, and case data is occasionally missing or incorrectly coded despite the attempts of the NCIS staff to ensure its accuracy (Lindquist et al., 2014). After exclusions using a number of negative filters as previously used by the authors to extract Australian work-related confined space fatality data (Selman et al., 2017), approximately 400 individual records were reviewed manually. All work-related fatalities which occurred in a confined space fitting the definition as specified by the current version of Australian Standard 2865 (Standards Australia, 2009) – the recognised Code of Practice under New Zealand's safety legislation – were included. The confined space fatalities identified between 2007 and 2012 were calculated against the NZ working population as provided by Statistics New Zealand (Statistics New Zealand, 2012) to determine the rate of confined space deaths per 100,000 workers per year.

All confined space fatality data for the US was from existing studies. (Pettit et al., 1996) calculated the rate of confined space fatalities to be 0.08 per 100,000 for the ten year period 1980–1989. The rate of confined space fatalities per 100,000 workers for the period 1997–2001 was calculated to be 0.07 per 100,000 by Meyer (2003). The rate of confined space deaths per 100,000 workers for the period 1992–2005 was calculated based on the fatality data from Wilson et al. (2012) and calculated against the US working population as provided by the US Bureau of Labor Statistics (US Bureau of Labor Statistics, 2018) to obtain a figure of 0.03 fatalities per 100,000 workers. It should be noted that the fatality data only includes atmosphere-related confined space fatalities, and that the working population figures excludes farm employees. Thus the figure is an estimate only. A complete review of the FACE case data (70 incidents resulting in 109 deaths over the period 1983–1993) from the 1994 NIOSH confined space monograph was undertaken to improve fidelity on the circumstances surrounding the confined space rescuer fatalities described (NIOSH, 1994).

Data for Singapore confined space fatalities was collated from the annual Workplace Safety and Health National Statistics reports produced by the Workplace Safety and Health Council of Singapore, and was cross-referenced to case studies, safety alerts, and media reports of confined space incidents in Singapore. Although the Workplace Safety and Health Council (now known as the Workplace Safety and Health Institute) has been reporting the number of confined space fatalities recorded as the agency of incident since 2007 (Workplace Safety and Health Council, 2008); a number of additional fatalities were identified through media reports, and it is suspected by the authors that the number of fatalities is likely to be under-stated by the annual reports. Fatalities which result from a physical mechanism of incident (such as 'falls from height' or 'struck by moving object') are recorded against that mechanism rather than as a confined space incident. The rate of confined space deaths per 100,000 workers was calculated through the number of identified confined space deaths against the Singapore working population as provided by the Singapore Ministry of Manpower (Government of Singapore, 2015), although it is acknowledged that this is likely to be a low estimate.

Data for Canadian confined space fatalities was compiled from individual provincial fatality statistics provided by the relevant workplace health and safety authorities for each province. While workplace injuries and fatalities are tracked by each of the individual provincial authorities, as for many other jurisdictions, confined space fatalities are not specifically recorded. An analysis of individual provincial fatality statistics was undertaken where data was available, although underreporting was expected. Based on the detailed data for Quebec produced by Burlet-Vienney et al. (2015b), the individual datasets provided by the major provinces (Alberta, British Columbia, Manitoba, and Saskatchewan) appear to show similar workplace fatality rates to Quebec and similar confined space fatality rates. Official statistics from the most populous province of Ontario record only four confined space deaths; which is highly likely to be an undercount. A contributing factor to the low figures for Ontario is likely that only atmospheric hazards are included in the definition of a confined space in Ontario legislation (Government of Ontario, 2017). Thus the data from the provinces of Canada was assessed as being suitable for mechanism of incident identification only. Data published by Burlet-Vienney et al. (2014) for the province of Quebec, which has a similar definition for a confined space (although known as an 'enclosed area') to the general definition used in this study (Government of Canada, 2017; Government of Quebec, 2017), and which was derived in that study from a manual review of all fatal accident data, was assessed to be suitable for the calculation of the fatality rate (against the working population) as well as entrant/rescuer ratios.

No data was available from the United Kingdom (UK). The Health and Safety Executive (HSE) is the governmental department responsible for workplace health, safety, and welfare in England, Scotland, and Wales. The HSE produces annual fatality statistics, and recorded just 142 workplace fatalities for 2014/2015 – a rate of 0.46 per 100,000 workers (Government of the United Kingdom, 2015). This is a very low rate in comparison to Australia (1.64 in 2013), the European Union (2.8 in 2010) and the US (3.1 in 2010) (Wiatrowski and Janocha, 2014). There are differences in the inclusions and exclusions and in the method of calculation; however the UK fatality rate remains very low. Like many jurisdictions, the HSE tracks the number of work-related fatalities and reports annually, but does not record the number of confined space deaths. One estimate for the UK was that there were around 15 confined space fatalities per year (Smith, 2013), which would indicate a confined space fatality rate of 0.05 deaths per 100,000 workers, but that figure cannot be substantiated. Approaches were made to the HSE for confined space fatality data, but no figures were made available.

2.2. Inclusion and exclusion criteria

The authors are aware that data quality is variable due to differing definitions of a confined space, differing definition and structures of the mechanisms of incident, and different emphasis on the subject matter investigated. The definition used for a confined space; although differing in detail among state, territory, Commonwealth, and international jurisdictions, was the commonly understood definition as per Australian Standard 2865 (Standards Australia, 2009) as described above. Data assessed as meeting the commonly understood definition of a confined space and including fatalities from all hazards (not just atmospheric hazards) was included in the calculation of confined space fatality rates, mechanism of incident, and rescuer fatalities – unless otherwise noted.

Where possible, workplace fatalities in which the confined space was a *significant contributing factor* for the deaths were also included. Examples included workers inadvertently igniting flammable gases or vapours which caused explosions while working on the outside of a confined space; and there were several fatalities identified in which workers fell into confined spaces (inadvertent entry) and were killed.

Studies which were restricted by industry sector, mechanism of incident, or other criteria were identified and were only used in the aggregation of the categorisation of mechanism of incident for rescuer deaths, or in specific discussion points, such as engulfment fatalities.

2.3. Mechanism of incident categorisation

As noted above, confined space fatalities can be grouped into four main categories in accordance with the major hazards of confined space work. An analysis of existing studies for which fatalities from all hazards were included (Australia, US, and Quebec) and the examination of new coronial data to produce the NZ data set was conducted. The fatalities were sorted into categories of toxic atmospheres, fires and explosions, physical hazards, and engulfment. Studies using selected datasets such as the FACE dataset or which were selective by industry or causative mechanism, or in which the data was suspected of being incomplete, were excluded.

2.4. Confined space rescuer deaths

'Rescuing a worker from a confined space is a low-frequency, high risk operation that is both time sensitive and technically challenging.' (Wilson et al., 2012, p. 121). The best confined space rescue is one in which no rescue is required. While there are always circumstances which cannot be planned, the far majority of the fatalities presented occurred because the hazards of working in or around confined spaces were not identified, the risks were not controlled, and when things went wrong there was either no emergency response plan, or the plan was inadequate (Burlet-Vienney et al., 2015b; NIOSH, 1986, 1994; Suruda et al., 1994). In all legislation and standards internationally, the risks are to be controlled and assessed before entry into a confined space is made, and emergency response is to be considered. Typical of such regulations, Australian Standard 2865 Confined Spaces states 'Appropriate emergency response and first aid procedures and provisions shall be identified, planned, established and rehearsed' and that 'appropriate and sufficient arrangements have been made for the initiation of emergency response and, where necessary, rescue of persons from the confined space'. Furthermore, untrained personnel attempting an improvised rescue can become secondary casualties, and 'In a confined space emergency, the spontaneous reaction to immediately enter and attempt to rescue a person from a confined space could lead to the death or serious injury of those attempting the rescue.' (Standards Australia, 2009, p. 12)

When data permitted, the authors divided confined space fatalities into confined space entrant fatalities and confined space rescuer fatalities. A confined space entrant was considered to be a worker who entered a confined space in order to conduct a work task. A confined space rescuer was considered to be a person who entered a confined space with the intent of rescuing or removing another person. Rescuers included both 'would-be rescuers' – untrained workers who attempt rescue; and 'professional rescuers' – emergency services or other personnel trained in confined space rescue and appointed as rescuers. It was found to be impossible to differentiate between would-be rescuers and professional rescuers as that data is rarely recorded. Only one study (Pettit et al., 1996) differentiated between the two, with four of the 39 (10%) rescuer fatalities being professional rescuers. There were no professional rescuers identified by the authors in either Australian or New Zealand confined space incidents. There are a number of confounding factors in attempting to identify the entrant/rescuer fatality ratio, not the least of which is that multiple casualties may or may not include rescuers – 'it could be incorrectly assumed that multiple fatality incidents within confined spaces imply one of the decedents was rescuing the other(s)' (Meyer, 2003, p. 64). Studies using selected datasets in which a restricted number of incidents were selected for further analysis such as those based on the FACE dataset were not included in the calculation of entrant/rescuer ratios due to the selective and therefore unrepresentative nature of the data.

Where data permitted, the authors also identified the differences in the mechanism of incident for the fatality between confined space entrants and confined space rescuers. These differences were identified through the NCIS data for Australia and NZ, and through a range of available data and published studies for the other countries included here. The mechanism of incident for confined space rescuer deaths was aggregated due to the small sample size in each study.

3. Results

3.1. Confined space fatality rate

There were only six identified work-related confined space deaths in four incidents in NZ over the period 2007–2012. There were an additional five deaths recorded as a result of engulfment or trench collapse, and one death in a ceiling cavity from electrocution, all of which are not regarded as confined space deaths. The confined space fatality rate for NZ was calculated to be 0.05 deaths per 100,000 workers, although it is acknowledged that the sample size is small.

There were 18 identified confined space deaths in Singapore over the period 2004–2014, at a rate of 0.08 deaths per 100,000 workers. The number of incidents in which these fatalities occurred was unable to be determined, and it is likely that the number of confined space fatalities is an under-count.

A comparison of the rate of work-related traumatic fatal injuries involving confined spaces in selected industrialised countries is shown in Fig. 1. The estimated UK confined space fatality rate is included for comparison purposes, although it cannot be substantiated.

3.2. Mechanism of incident of confined space fatality

Fig. 2 shows the breakdown of confined space fatalities into the four major categories described above (toxic atmospheres, flammable atmospheres, engulfment, and physical hazards). Studies which specifically exclude or which are suspected of excluding some mechanisms of incident; or have incomplete data have been omitted from the chart. While the proportions of mechanism of incident vary between studies, it is demonstrated that atmospheric hazards (oxygen deficient and toxic atmospheric conditions) are a significant factor in confined space fatalities, as are physical hazards which account for up to one half of work-related confined space deaths by proportion. Of fatalities as a result of toxic atmospheres, the toxic substance responsible (including oxygen deficiency) was quite variable, and no particular toxic substance was found to be a dominant cause of the fatalities identified; however the toxic substances causing death included all of the common contaminants in table 2. All fatalities, entrant and rescuer, are included. Engulfment is a far more prevalent mechanism of incident in the agricultural industry sector and will be discussed in further detail below.

3.3. Mechanisms of incident for confined space rescuer fatalities

It has proven to be difficult to differentiate between the mechanism of incident between entrant and rescuer fatalities due to incomplete data. Fig. 3 shows the distribution of the total number of confined space rescuer fatalities identified among all the studies categorised into in the four major categories as used above, where the cause or mechanism of incident was known. Studies which specifically exclude or which are suspected of excluding some mechanisms of incident were omitted. Selective incident studies (such as those based on US FACE data) were included.

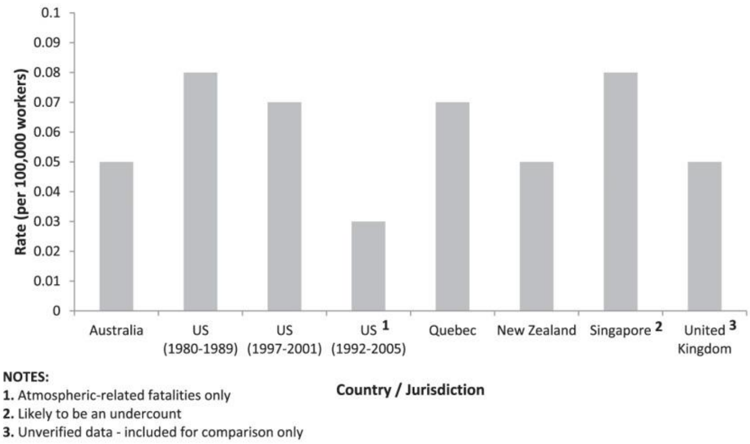

Fig. 1. Rate of traumatic confined space fatalities (per 100,000) in the working population in similar industrialised countries.

4. Discussion

This study attempted to compare the rate of work-related traumatic fatal injuries involving confined spaces in selected industrialised countries, to identify the major mechanisms of incident, and to identify any major difference in rate and mechanism of incident between confined space entrants and rescuers.

4.1. Limitations

The most significant limitation in this study was the availability and variability of the available data. Data sources were incomplete, of inconsistent quality, over variable periods, and data from some published studies may not have included all fatalities which occurred in a confined space regardless of mechanism of incident. Much of the data was also older, with many of the US studies using data prior to 2005. These limitations haves been acknowledged in previous studies of confined space fatality data (Burlet-Vienney et al., 2014; Pettit et al., 1996; Sahli and Armstrong, 1992; Selman et al., 2017; Suruda et al., 1994). Despite the inclusion of confined space safety requirements in specific regulations and codes of practice; and a range of confined space safety training and information materials; the collection and analysis of confined space incidents and fatalities by the responsible authorities is lacking.

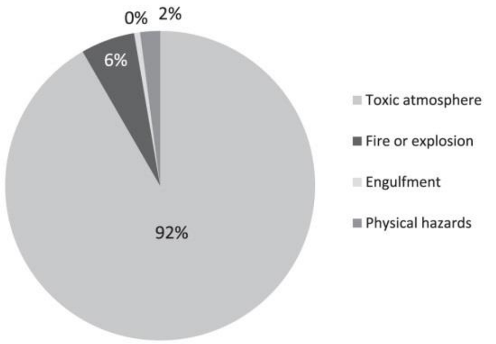

Fig. 3. Aggregated mechanism of incident for all confined space rescuer fatalities.

Further to the lack of available data on confined space fatalities,

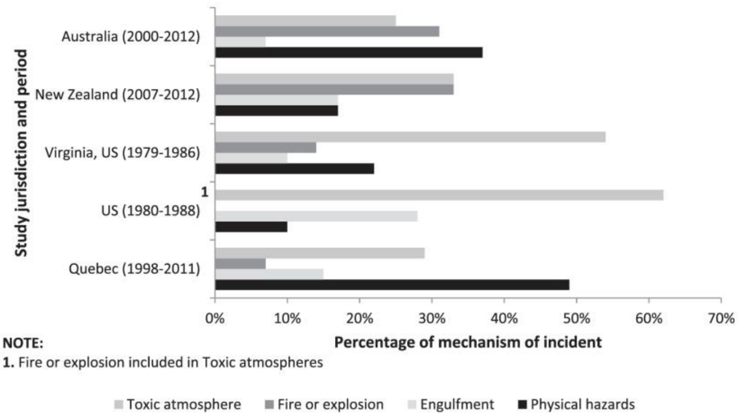

Fig. 2. Categorisation by mechanism of incident of confined space fatalities for selected studies.

non-fatal incidents and injuries which occur in a confined space are often impossible to numerate (Selman et al., 2017). This includes incidents in which rescuers, both would-be and professional, are injured attempting the rescue of confined space entrants.

4.2. Confined space fatality rates

The NZ Department of Labour issued an information sheet in which it stated 'It's been calculated that working in a confined space is 150 times more dangerous than doing the same job outside.' (New Zealand Department of Labour, p. 2). This figure is found referenced from time to time in the literature (Alberta OHS, 2009; Golbabaei et al., 2012). The confined space fatality rates in this study varied from 0.03 (US atmosphere-related fatalities only) to 0.05 (Australia and NZ) (Selman et al., 2017) and to 0.08 fatalities per 100,000 workers (Singapore, US, and Quebec) (Meyer, 2003; Pettit et al., 1996). This is in comparison to the overall workplace fatality rates which varied from 1.64 (Australia) (Safe Work Australia, 2014) to 4.2 (NZ) (Lilley et al., 2013) per 100,000 workers. While it is acknowledged that not all workers enter confined spaces as part of their work, other hazardous tasks are undertaken in many other workplaces. There appears to be little credence to the statement contained in the information sheet, and when contacted by the authors, the NZ Department of Labour could not provide any source data or evidence from which this statistic was calculated. Overall, the estimated confined space fatality rate was similar for all industrialised countries from which data could be obtained.

As noted above, in 1986 NIOSH issued an alert based on eight confined space incidents in which there were six entrant fatalities and ten rescuer fatalities for a total of 16 confined space deaths. Over 60% of deaths were attributed to rescuers. This alert was based on a very small sample size with no stated selection criteria for the collection of the incidents contained in the alert. This proportion of rescuer deaths in confined space fatalities has become accepted as fact (Fridlyand, 2007; Pitt and Gales, 2012; Sahli and Armstrong, 1992; WorkSafe BC, 2007), although that may not have been the original intention of the alert. Table 3 shows the total number of work-related confined space fatalities and the proportion of rescuer deaths. Studies which have incomplete or selective data (such as studies based on the US FACE dataset), and studies in which rescuer deaths were not specified have been excluded. With the exception of the small dataset of British Columbia, no more than 17% of confined space deaths were attributed to rescuers, and most studies reveal a rescuer fatality rate of 15% or less (Burlet-Vienney et al., 2015b; Meyer, 2003; Sahli and Armstrong, 1992; Selman et al., 2017; Wilson et al., 2012).

Table 3
Total work-related confined space fatalities and rescuer fatalities for selected studies.

Study jurisdiction and period	Confined space fatalities	Rescuer fatalities
Australia (2000–2012)	59	2 (3.4%)
New Zealand (2007–2012)	6	1 (17%)
Singapore (2007–2014)	18	0
Physical hazard fatalities excluded		
Quebec, Canada (1998–2001)	41	6 (15%)
British Columbia, Canada (2001–2010)	17	7 (41%)
US (1984–1986)	146	17 (12%)
Fatalities from poisoning and asphyxiation only		
Virginia, US (1979–1986)	50	3 (6%)
US (1997–2001)	458	25 (5.5%)
US (1992–2005)	530	47 (9%)
Fatalities from atmospheric hazards only		

4.3. Mechanisms of incident

Fig. 2 shows the mechanism of injury causing death can vary quite considerably between study, with atmospheric hazards (both oxygen deficiency and toxic airborne contaminants) and physical hazards the cause of up to 60% of fatalities. Of note, more contemporary studies have shown a lower proportion of atmospheric-related fatalities, and a greater proportion of physical hazard fatalities. This may be the result of the improved availability of simple-to-operate and inexpensive confined space gas monitors.

The mechanism of incident for rescuer fatalities was overwhelmingly atmospheric hazards (both oxygen deficiency and toxic airborne contaminants). This is unsurprising, as the hazards of an unsafe atmosphere may not be readily apparent to a rescuer (in comparison to moving machinery or flowing grain, for example) and a rescuer is more likely to attempt a rescue if unaware of the hazards of entry.

4.4. Engulfment fatalities

Engulfment as a mechanism of incident is far more prevalent in farming than any other occupation. Meyer (2003) identified 109 fatalities among farmers out of the 458 fatalities identified over the period 1997–2001. The same study classified 65% (71) of the 109 deaths to have occurred in silos or grain bins, almost all from engulfment. This is not the only source of confined space fatality in the agriculture sector, with another study recording 77 fatalities over the period 1975–2004 to have occurred in livestock manure storage and handling facilities (Beaver and Field, 2007); however grain entrapment is a considerable issue in US confined space fatalities. In 2010, there were 51 reported grain entrapment cases in the US, 26 (51%) of which resulted in a fatality, although reporting is acknowledged to be non-compulsory and thus likely incomplete (Riedel and Field, 2011). Additionally, workplaces with less than 11 employees or in which family members make up the workforce are exempt from OSHA confined space regulations and reporting requirements (Riedel and Field, 2013). A summary of all agricultural confined spaces cases from 1964 to 2013 revealed the majority of cases to be grain entrapment or engulfment-related; and which represented 52% of fatalities in 2013 (Issa et al., 2016). Outside the US, there has been very little study in this area. Selman et al. (2017) identified four Australian engulfment fatalities, half of which occurred in the agriculture sector. Of note, recent studies into engulfment fatalities have determined three primary causes of death; aspiration (obstruction of the respiratory tract by a substance), asphyxiation (insufficient supply of oxygen), and mechanical asphyxiation (force or weight of the substance prevents the expansion and contraction of the lungs) (Issa et al., 2017, 2015). Rescue from engulfment is a difficult endeavour; and like other mechanisms of incident, places rescuers at risk of injury and death (Roberts et al., 2011).

4.5. Confined space rescue

The emphasis for all confined space work should be the prevention of a confined space incident rather than the response to a confined space incident. Unfortunately, many confined space rescue attempts result in multiple fatalities. 'Had these spaces been properly evaluated prior to entry and continuously monitored while the work was being performed and had appropriate rescue procedures been in effect, none of the 16 deaths would have occurred.' (NIOSH, 1986). Studies of confined space fatalities continue to unearth incidents which result in the death or injury of rescuers – most of whom are not trained rescuers but workmates who attempt to save a fellow worker (Burlet-Vienney et al., 2014; NIOSH, 1986, 1994; Selman et al., 2017; Suruda et al., 1994; Wilson et al., 2012). In 1986, NIOSH (1986) recommended that rescue procedures be planned before entry to a confined space, and that rescue equipment be prepared and persons trained to use it. It recommended that rescue response should be planned and practised, and life-endangering rescue attempts be eliminated.

Those same principles have not changed; and in all legislation and standards internationally, emergency response is to be considered and planned. The number of persons killed attempting rescue of others from confined spaces indicates that rescue planning is not undertaken as a priority, and with atmospheric hazards the primary killer of rescuers, the risks of an unplanned rescue are not realised (Burlet-Vienney et al., 2015b). Thorough risk assessment, planning, and rehearsal of confined space rescue including an understanding of the difficulties of non-entry and entry rescue techniques is required to reduce the number of rescuers killed (Burlet-Vienney et al., 2015a; CMC Rescue, 2012; Roberts et al., 2011; Roop et al., 1998; Sargent, 2000; Silk, 1971). In many cases, relying on professional emergency services is insufficient to effect a rescue in the time required to remove an entrant from a confined space and workplaces in which frequent confined space entries are made should prepare for the eventuality of rescue using on-site personnel and resources (Burlet-Vienney et al., 2015b; Wilson et al., 2012).

Without doubt, an improved awareness of the dangers of confined spaces among workers and supervisors; the availability of confined space gas monitors and other technologies; and changes to legislation and standards – often brought about as outcomes of fatality investigations – have led to better safety improvements in the way confined space entry is conducted. However in all studies, there was the potential for many more rescuer deaths, injuries and illnesses; with many would-be rescuers injured attempting rescue, including 7 rescuers treated for carbon monoxide poisoning in one incident (NIOSH, 1994).

5. Conclusion

The rate of confined space deaths for similar industrialised countries can be estimated to lie between 0.05 and 0.08 fatalities per 100,000 workers. This is a fraction of the rate of overall workplace deaths. It is acknowledged that not every worker enters a confined space as a part of their work duties, and it would be ideal to report the number of confined space fatalities per confined space entry, however such data is impossible to obtain on a broad scale. It is recommended that government WHS authorities improve the fidelity of confined space fatality data collection, to be inclusive of all deaths that occur in confined spaces regardless of the mechanism of incident, in order to permit more detailed analysis and recommendations for safety improvements.

The statement made by NIOSH in 1986 ‘More than 60% of confined space fatalities occur among would-be rescuers’ is not substantiated by further studies. There are a number of limitations to the NIOSH alert, not the least of which was the compilation of a small sample of confined space incidents for which no selection criteria was apparent. Contemporary studies show the proportion of rescuer deaths to be no more than 17% of all confined space deaths. The proportion of confined space deaths attributed to rescuers is of great concern, with most of these deaths the result of hasty and unplanned rescue attempts. Workers must continue to be reminded that the prevention of confined space incidents should be the priority; and that should an incident occur, ill-conceived and hasty rescue attempts could lead to their injury or death.

It was identified that confined space entrants are killed by a range of mechanisms. Atmospheric conditions are the mechanism of incident for confined space entrants from 25% to 62% of the time, and physical hazards can account for up to 49%. Rescuer deaths however, are almost exclusively due to atmospheric hazards. Confined space rescue is a difficult undertaking, and is often initiated without proper planning or an assessment of the risks – leading to unnecessary fatalities. It is recommended that all government WHS authorities consider engulfment and other physical hazards of confined space work in their safety legislation to assist in the reduction of confined space fatalities.

Government WHS authorities, businesses, industry associations, unions, and researchers can all make use of this research. In particular, the results identify the major risks of confined space entry, and warn of the risks in unplanned rescue. All should take heed of the dangers of unplanned rescue attempts, and ensure confined space rescue is considered, planned, and rehearsed before it is required.

6. Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

7. Conflict of interest

None.

Appendix A

See Table A1.

Table A1
Rate of traumatic confined space fatalities (per 100,000) in the working population in similar industrialised countries.

Study jurisdiction and period	Authors	Inclusions and exclusions	Confined space fatalities	Confined space fatality rate (per 100,000 workers)
Australia (2000–2012)	Selman et al. (2017)	All identified confined space fatalities included. No exclusions.	59	0.05
New Zealand (2007–2012)	Included in this study	All identified confined space fatalities included. No exclusions.	6	0.05
Singapore (2007–2014)	Included in this study	*Fatalities from physical hazards excluded.*	18	0.08
Quebec, Canada (1998–2001)	Burlet-Vienney et al. (2015b)	All identified confined space fatalities included. No exclusions.	41	0.07
US (1980–1989)	Pettit et al. (1996)	Numbers “to be considered a minimum”. No known exclusions.	670	0.08
US (1997–2001)	Meyer (2003)	No known exclusions.	458	0.07
US (1992–2005)	Wilson et al. (2012)	*Fatalities from atmospheric hazards only.*	530	0.03
UK	Smith (2013)	*Estimate only*	15 per year	0.05

References

Alberta OHS, 2009. Occupational Health and Safety Code Explanation Guide *Part 5 Confined Spaces*. Alberta Ministry of Labour, Government of Alberta, Edmonton, Alberta, Canada.
American Conference of Governmental Industrial Hygienists, 2015. Threshold Limit Values and Biological Exposure Indicies. ACGIH, Cincinnati, United States.
ANSI/ASSE, 2009. Safety Requirements for Confined Spaces, vol. Z117.1. American National Standards Institute/American Society of Safety Engineers, Washington, D. C., United States.
Australian Safety Compensation Council, 2008. Type of Occurrence Classification System. Commonwealth of Australia, Canberra, ACT.
Beaver, R.L., Field, W.E., 2007. Summary of Documented Fatalities in Livestock Manure Storage and Handling Facilities - 1975–2004. J. Agromedicine 12 (2), 3–23. http://dx.doi.org/10.1300/J096v12n02_02.
Bond, J., 1996. The Hazards of Life and All That: A Look at Some Accidents and Safety Curiosities, Past and Present. Institute of Physics Publishing, Bristol, United Kingdom.
Burlet-Vienney, D., Chinniah, Y., Bahloul, A., 2014. The need for a comprehensive approach to managing confined space entry: summary of the literature and recommendations for next steps. J. Occup. Environ. Hyg. 11 (8), 485–498. http://dx.doi.org/10.1080/15459624.2013.877589.
Burlet-Vienney, D., Chinniah, Y., Bahloul, A., Roberge, B., 2015a. Design and application of a 5 step risk assessment tool for confined space entries. Safety Sci. 80, 144–155. http://dx.doi.org/10.1016/j.ssci.2015.07.022.
Burlet-Vienney, D., Chinniah, Y., Bahloul, A., Roberge, B., 2015b. Occupational safety during interventions in confined spaces. Safety Sci. 79, 19–28. http://dx.doi.org/10.1016/j.ssci.2015.05.003.
Canadian Standards Association, 2016. Management of Work in Confined Spaces, second ed., vol. Z1006-16. CSA Group, Toronto, Canada.
CMC Rescue, 2012. Confined Space Entry and Rescue Manual. FSP Books and Videos, Goleta, California, US.
Commonwealth of Australia, 2014. Model Work Health and Safety Regulations. Safe Work Australia, Commonwealth of Australia, Canberra, ACT.
CSUF, 2012. Confined Space Program. Retrieved from. California State University, Fullerton, Fullerton, California, United States. https://ehis.fullerton.edu/_documents/programs/confined%20space%20program.pdf.
Fridlyand, S., 2007. The dangers of confined spaces. Mach. Equip. 23 (2), 23–25.
Golbabaei, F., Seyedsomea, M., Ghahri, A., Shirkhanloo, H., Khadem, M., Hassani, H., Dinari, B., 2012. Assessment of welders exposure to carcinogen metals from manual metal arc welding in gas transmission pipelines, Iran. Iranian J. Pub. Health 41 (8), 61–70.
Government of Canada, 2017. Canadian Occupational Health and Safety Regulations (SOR/86-304). Part XI - Confined Spaces. Department of Justice, Government of Canada, Ottowa, Canada.
Government of Ontario, 2017. Ontario Regulations 632/05 - Confined Spaces, vol. Ontario Regulations 632/05. Queen's Printer for Ontario, Government of Ontario, Toronto, Ontario.
Government of Quebec, 2017. Regulation Respecting Occupational Health and Safety. Publications Quebec, Government of Quebec, Quebec, Quebec (Chapter S-2.1, r.13).
Government of Singapore, 2009. Workplace Safety and Health (Confined Spaces) Regulations 2009. Ministry of Manpower, Government of Singapore, Singapore.
Government of Singapore, 2015. Singapore Yearbook of Manpower Statistics 2015. Ministry of Manpower, Government of Singapore, Singapore.
Government of the United Kingdom, 1997. The Confined Spaces Regulations. Health and Safety Executive, Government of the United Kingdom, London, England.
Government of the United Kingdom, 2011. Workplace Exposure Limits, vol. EH40. Health and Safety Executive, Government of the United Kingdom, London, England.
Government of the United Kingdom, 2014. Safe Work in Confined Spaces - Approved Code of Practice and Guidance. Health and Safety Executive, Government of the United Kingdom, London, England.
Government of the United Kingdom, 2015. Statistics on Fatal Injuries in the Workplace in Great Britain 2015. Health and Safety Executive, Government of the United Kingdom, London, England.
Government of Victoria, 2017. Occupational Health and Safety Regulations 2017. Government of Victoria, Melbourne, Victoria, Australia.
Government of Western Australia, 1996. Occupational Safety and Health Regulations. Government of Western Australia, Perth, Western Australia, Australia.
Hamilton, A., 1929. Industrial Poisions in the United States. The Macmillan Company, New York.
Higgins, D.N., Casini, V.J., Bost, P., Johnson, W., Rautiainen, R., 2001. The fatality assessment and control evaluation program's role in the prevention of occupational fatalities. Inj. Prev. 7 (Suppl 1), 27–33.
Issa, S.F., Cheng, Y.H., Field, W.E., 2016. Summary of agricultural confined-space related cases: 1964–2013. J. Agric. Saf. Health 22 (1), 33–45.
Issa, S.F., Field, W.E., Schwab, C.V., Issa, F.S., Nauman, E.A., 2017. Contributing causes of injury or death in grain entrapment, engulfment, and extrication. J. Agromedicine 22 (2), 159–169. http://dx.doi.org/10.1080/1059924X.2017.1283277.
Issa, S.F., Schwab, C.V., Field, W.E., 2015. A review on the environmental impact and physiological conditions on the human body during an engulfment, entrapment and extrication. In: Paper Presented at the 2015 ASABE Annual International Meeting, New Orleans, Louisiana, United States.
Kletz, T.A., 1996. Dispelling Chemical Engineering Myths, third ed. Taylor & Francis, London, England.
Lilley, R., Samaranayaka, A., Weiss, H., 2013. International Comparison of International Labour Organisation Published Occupational Fatal Injury Rates: How Does New Zealand Compare Internationally? Injury Prevention Research Unit, Department of Preventive and Social Medicine, Dunedin School of Medicine, University of Otago, Dunedin, New Zealand.
Lindquist, S.L., Yardley, A.J., Champion de Crespigny, F.E., 2014. Estimating the true number of work-related fatalities due to injury: the traumatic injury fatalities dataset. J. Health Saf., Res. Pract. 6 (6), 8–14.
Lyon, B.K., Hollcroft, B., 2012. Risk assessments - top 10 pitfalls & tips for improvement. Prof. Saf. 57 (12), 28–34.
MacCarron, C., 2006. Confined Space Fatalities. PhD. Edith Cowan, Perth, Western Australia.
Manwaring, J.C., Conroy, C., 1990. Occupational confined space-related fatalities: surveillance and prevention. J. Saf. Res. 21 (4), 157–164. http://dx.doi.org/10.1016/0022-4375(90)90023-5.
Meyer, S., 2003. Fatal occupational injuries involving confined spaces, 1997–2001. Occup. Health Saf. 72 (11), 58–64.
New Zealand Department of Labour. Safe Working in a Confined Space. Occupational Safety and Health Service, New Zealand Department of Labour, Government of New Zealand, Wellington, New Zealand.
NIOSH, 1986. Preventing Occupational Fatalities in Confined Spaces. National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government, Morgantown, West Virginia, United States.
NIOSH, 1987. A Guide to Safety in Confined Spaces. National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government, Washington, DC, United States.
NIOSH, 1994. Worker Deaths in Confined Spaces - A Summary of NIOSH Surveillance and Investigative Findings. National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government, Cincinnati, Ohio, United States.
NIOSH, 2013. Current Intelligence Bulletin 66 - Derivation of Immediately Dangerous to Life or Health (IDLH) Values. National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government, Cincinnati, Ohio, United States.
Office of the Federal Register, 1993. Preamble for permit required confined spaces, 29 CFR Part 1910.146. US Government Printing Office, Washington, D.C., United States. Retrieved from https://www.govinfo.gov/content/pkg/FR-1993-01-14/pdf/FR-1993-01-14.pdf.
OSHA, 2011. Permit-Required Confined Spaces, vol. Code of Federal Regulations Title 29, Part 1910.146. Occupational Safety and Health Administration, Department of Labor, Washington, D.C., United States.
OSHA, 2015. Confined Spaces in Construction; Final Rule. Occupational Safety and Health Administration, Department of Labor, Washington, D.C., United States.
OSHA, 2016. Confined Spaces in Construction, vol. Code of Federal Regulations Title 29, Part 1926, Subpart AA. Occupational Safety and Health Administration, Department of Labor, Washington, D.C., United States.
OSHA, 2017. Toxic and Hazardous Substances, vol. Code of Federal Regulations Title 29, Part 1910, Subpart Z. Occupational Safety and Health Administration, Department of Labor, Washington, D.C., United States.
Pettit, T.A., Braddee, R.W., Suruda, A.J., Castillo, D.N., Helmkamp, J.C., 1996. Worker deaths in confined spaces. Prof. Saf. 41 (11), 22–25.
Pitt, M., Gales, R., 2012. Managing the hazard of asphyxiant gases. Loss Prevent. Bull. 228, 25–28.
Ramazzini, B., translated 1983. De morbis artificum diatriba (Diseases of workers) (W. Wright, Trans.). Classics of Medicine Library, Gryphon Publications, New York, United States.
Reed, S., Pisaniello, D., Benke, G., Burton, K. (Eds.), 2013. Principles of Occupational Health and Hygiene, second ed. Allen and Unwin, Sydney, NSW, Australia.
Riedel, S., Field, B., 2011. 2010 Summary of Grain Entrapments in the United States. Purdue University, West Lafayette, Illinois.
Riedel, S.M., Field, W.E., 2013. Summation of the frequency, severity, and primary causative factors associated with injuries and fatalities involving confined spaces in agriculture. J. Agric. Saf. Health 19 (2), 83–100.
Roberts, M.J., Deboy, G.R., Field, W.E., Maier, D.E., 2011. Summary of prior grain entrapment rescue strategies. J. Agric. Saf. Health 17 (4), 303–325. http://dx.doi.org/10.13031/2013.39804.
Roop, M., Vines, T., Wright, R., 1998. Confined Space and Structural Rope Rescue. Mosby-Year Book, St Louis, Missouri, US.
Safe Work Australia, 2013. Workplace Exposure Standards for Airborne Contaminants. Commonwealth of Australia, Canberra, ACT.
Safe Work Australia, 2014. Work-related Traumatic Injury Fatalities, Australia 2013. Commonwealth of Australia, Canberra, ACT.
Safe Work Australia, 2016. Code of Practice: Confined Spaces. Commonwealth of Australia, Canberra, ACT.
Sahli, B., Armstrong, C., 1992. Confined space fatalities in Virginia. J. Occup. Med. 39 (9), 910–917. http://dx.doi.org/10.1016/0022-4375(93)90011-B.
Sargent, C., 2000. Confined Space Rescue. Fire Engineering Books and Videos, Saddlebrook, New Jersey, US.
Schenk, L., Hansson, S.O., Rudén, C., Gilek, M., 2008. Occupational exposure limits: a comparative study. Regul. Toxicol. Pharmacol. 50 (2), 261–270.
Selman, J., Spickett, J., Jansz, J., Mullins, B., 2017. Work-related traumatic fatal injuries involving confined spaces in Australia, 2000–2012. J. Health Saf. Env. 33 (2), 197–215.
Silk, S., 1971. Manhole Access into Enclosed Plant. Department of Employment, Her Majesty's Stationary Office, London.
Smith, K., 2013. Indecent enclosure. Saf. Health Pract. 31 (9), 48–50.
Standards Australia, 2009. Confined Spaces, vol. 2865. SAI Global, Sydney, Australia.
Standards Singapore, 2005. Entry into and Safe Working in Confined Spaces, vol. CP 84:2000. SPRING Singapore, Singapore.

Statistics Canada, 2014. Table 282–0001, Labour Force Characteristics, Unadjusted, by Province (monthly). Government of Canada, Ottowa, Ontario.
Statistics New Zealand, 2012. Household Labour Force Survey (series). Government of New Zealand, Wellington, New Zealand.
Suruda, A., Agnew, J., 1989. Deaths from asphyxiation and poisoning at work in the United States 1984–86. Br. J. Ind. Med. 46, 541–546.
Suruda, A.J., Pettit, T.A., Noonan, G.P., Ronk, R.M., 1994. Deadly rescue: the confined space hazard. J. Hazard Mater. 36 (1), 45–53. http://dx.doi.org/10.1016/0304-3894(93)E0051-3.
Thackrah, C.T., 1832. The Effects of the Principal Arts, Trades, and Professions on Health and Longevity, second ed. Longman, Rees, Orme, Brown, Green, & Longman, London, England.
US Bureau of Labor Statistics, 2018. All Employees, Total non-farm, Seasonally Adjusted, Time series CES0000000001. (CES0000000001). Bureau of Labor Statistics, Department of Labor, Washington, D.C., United States. Retrieved from https://beta.bls.gov/dataViewer/view.
US Chemical Safety and Hazard Investigation Board, 2003. Safety Bulletin: Hazards of Nitrogen Asphyxiation. US Government, Washington DC, United States.
Wiatrowski, W., Janocha, J., 2014. Comparing fatal work injuries in the United States and the European Union. Monthly Labor Review June 2014, 7-1A,2A,3A,4A,5A,6A,7A.
Wilson, M.P., Madison, H.N., Healy, S.B., 2012. Confined space emergency response: assessing employer and fire department practices. J. Occup. Env. Hyg. 9 (2), 120–128. http://dx.doi.org/10.1080/15459624.2011.646644.
Workplace Safety and Health Council, 2008. Workplace Safety & Health, 2008, National Statistics. Singapore Government, Singapore.
WorkSafe BC, 2007. Confined Space Entry Program: A Reference Manual. (ISSN 1715-4189). WorkSafe BC, Vancouver, British Columbia, Canada. Retrieved from https://www.worksafebc.com/en/resources/health-safety/books-guides/confined-space-entry-program-a-reference-manual?lang=en&origin=s&returnurl=https%3A%2F%2Fwww.worksafebc.com%2Fen%2Fsearch%23q%3Dconfined%2520space%2520manual%26sort%3Drelevancy%26f%3Alanguage-facet%3D%5BEnglish%5D.

CHAPTER FIVE –

CONFINED SPACE RESCUE: A PROPOSED PROCEDURE TO REDUCE THE RISKS

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Confined space rescue: A proposed procedure to reduce the risks

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ABSTRACT

Each year, workers are killed in incidents involving confined spaces. To minimise and control the risks so far as reasonably practicale, confined space work should be thoroughly considered and carefully planned before any entry. Unfortunately, when would-be rescuers attempt the rescue of fellow workers, multiple fatalities can result. Confined space rescue should always be a deliberate undertaking, planned prior to the confined space entry taking place, and conducted by trained personnel. This paper proposes a five step procedure to safely undertake confined space entry rescue, mindful of the hierarchy for protection (rescuers, bystanders, and casualties); and of the hierarchy of the level of confined space rescue (self-rescue, non-entry rescue, and entry rescue). The proposed confined space rescue procedure is a simplified and broad-based process for the preparation and conduct of a confined space rescue by on-site or in-house rescue teams, and is an adaptation of the procedures used by professional emergency services. The five step procedure is described by the acronym REALE. Step 1 is Reconnaissance of the rescue task. Step 2 is Elimination or reduction of hazards. Step 3 is Accessing the casualty, in which a minimal number of rescuers enter the confined space and make contact with the casualty. Step 4 is the provision of Life-saving first aid to the casualty. Step 5 is the Extrication of the casualty as required. The proposed procedure is suitable for adoption by rescue teams regardless of country or jurisdiction as it meets the requirements for all regulations and standards.

1. Introduction

Each year, workers are killed in incidents involving confined spaces. In similarly industrialised countries, the rate of confined space fatalities varies between 0.05 and 0.08 per 100,000 workers (Burlet-Vienney et al., 2014; Meyer, 2003; Pettit et al., 1996; Selman et al., 2017, 2018; Smith, 2013). The mechanism of incident for these fatalities can be categorised into toxic atmospheres, fire and explosion, engulfment in free-flowing solids or liquids; or as a result of other physical hazards such as falls from height or entrapment in machinery (Selman et al., 2018). Such hazards and the risks of confined space entry should be thoroughly assessed and eliminated or minimised before any confined space entry is made, and the need for rescue should be avoided.

A significant body of research (Burlet-Vienney et al., 2015a; Meyer, 2003; NIOSH, 1986; Pettit et al., 1996; Selman et al., 2018; Suruda et al., 1994; Wilson et al., 2012) demonstrates that due to the nature of confined spaces; with their risks of physical hazards, atmospheric hazards, and the danger of engulfment; rescuers are also at risk and in some cases are killed attempting to free other workers. Confined space rescue should never be attempted by untrained personnel as it is a difficult undertaking which should be deliberately planned and conducted. Many workplaces rely on professional emergency services to conduct confined space rescue; however in a time-sensitive situation their arrival may be too late. On-site or in-house rescue teams and personnel can react more quickly, and provided they are appropriately trained, they can successfully retrieve or extricate a casualty from a confined space. An examination of the hazards of conducting a confined space rescue, the planning of the rescue procedure(s) *before* workers enter a confined space, and the conduct of a rescue in accordance with the proposed rescue procedure will assist in the reduction of the risks associated with confined space rescue. In addition, the use of specialised rescue equipment and techniques for rescue of a person engulfed in a free-flowing solid are recommended.

1.1. Confined spaces

The definition of a confined space varies by legislation and jurisdiction, and in some cases industry group; however the key elements

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Table 1
Summary of confined space fatality statistics.

Jurisdiction	Period	Fatalities	Rescuer fatalities
US	1980–1989	670 fatalities in 585 incidents	72 (12%) multiple fatalities[1]
US	1997–2001	458 fatalities	25 (5.5%) rescuers
US	1992–2005	530 fatalities in 431 incidents	47 (9%) rescuers
British Columbia	2001–2010	17 fatalities in 8 incidents	7 (41%) rescuers
Quebec	1998–2011	41 fatalities in 31 incidents	6 (15%) rescuers
Australia	2000–2012	59 fatalities in 45 incidents	2 (3.4%) rescuers
New Zealand	2007–2012	6 fatalities in 4 incidents	1 (17%) rescuer
Singapore	2004–2014	18 fatalities	Figures not available
Italy	2001–2015	51 fatalities in 20 incidents	Figures not available
Jamaica	2005–2017	17 fatalities in 11 incidents	4 (36%) multiple fatalities[2]

NOTES:
1. No differentiation made between entrant and rescuer fatalities.
2. No differentiation made between entrant and rescuer fatalities.

of the definition of a confined space – also known as a *Permit Required Confined Space* (PRCS) in the US – are similar and relate to the hazards of confined space entry and work (Selman et al., 2018). The common elements of a confined space are that it is an enclosed or partially enclosed space, which is not intended or designed primarily for human work, and which has a risk of a hazardous atmosphere; or a risk of engulfment by a free-flowing solid or liquid. The risk of a hazardous atmosphere includes toxic airborne contaminants, flammable airborne contaminants (including gases, vapours and dusts), and unsafe levels of oxygen (Commonwealth of Australia, 2016b; Government of Canada, 2017; Government of Singapore, 2009; Government of the United Kingdom, 1997; OSHA, 2011c). In the US and Canada, an additional element is that a confined space has a restricted means of entry or exit (ANSI/ASSE, 2009; Canadian Standards Association, 2016; Government of Canada, 2017; OSHA, 2011c); and in both Australia and New Zealand a confined space is to be at normal atmospheric pressure during work – which excludes caissons and other over-pressure vessels (Safe Work Australia, 2016, 2017; Standards Australia, 2009).

Confined spaces include pressure vessels, tanks, vats, silos, pits, pipes, sewers, shafts, interiors of machines or plant, and some shipboard spaces. Underground mines are not considered to be confined spaces, as they are intended as a place of work, and are specifically excluded by some jurisdictions (Government of the United Kingdom, 1997; Safe Work Australia, 2016, 2017; Standards Australia, 2009). Mines may however contain confined spaces such as vats, tanks, and pipelines; and work requiring entry into these spaces, whether underground or on the surface, would be considered to be confined space work. Ceiling cavities and attics (Government of the United Kingdom, 1997; OSHA, 2016); and trenches, except when they are likely to contain atmospheric contaminants (OSHA, 2015; Safe Work Australia, 2016); are not usually considered to be confined spaces.

1.2. *Confined space fatalities*

There have been a few studies which have attempted to numerate the number of confined space fatalities, although identifying and analysing confined space fatalities has proven to be difficult due to issues such as under-reporting (Martinkus, 1996; Probst and Graso, 2013; Quinlan and Mayhew, 1999; Sahli and Armstrong, 1992), lack of specific coding for confined space incidents (McManus, 1998; Pettit et al., 1996; Selman et al., 2017), and collation of statistics from different regulatory authorities by employment or industry group (McManus, 1998; Riedel and Field, 2013; Selman et al., 2017, 2018). Nonetheless, these studies remain a valuable resource for research.

Pettit et al. (1996) conducted a study of confined space fatalities in the US using the National Traumatic Occupational Fatalities (NTOF) data for the ten year period 1980–1989 which revealed 670 fatalities in 585 incidents. Of these incidents, 72 (12%) involved multiple fatalities, although there was no reported differentiation between entrant and rescuer deaths. An analysis of Occupational Safety and Health Administration (OSHA) data from the US during the period 1974–1990 determined a fatality rate of 64 confined space deaths per year, 41 of which were the result of hazardous atmospheric conditions (McManus, 1998). Meyer (2003) used Census of Fatal Occupational Injuries (CFOI) data from the US to ascertain 458 confined space fatalities over the five year period 1997–2001; of which 25 (5.5%) of these fatalities were workers attempting rescue. A later study also used the CFOI data over the period 1992–2005 to identify atmosphere-related confined space incidents. It was found that there were 530 confined space fatalities in 431 incidents over the period, with 47 (9%) of those being rescuer fatalities (Wilson et al., 2012). Work-related fatalities in the province of Quebec, Canada, were analysed by Burlet-Vienney et al. (2015b) who found 41 fatalities in 31 confined space incidents over the period 1998–2011. Of these deaths, 6 (15%) were identified as rescuers. Research into Australian confined space fatalities was conducted by Selman et al. (2017) for the period 2000–2012, in which there were 59 identified fatalities in 45 incidents – 2 (3.4%) of whom were rescuers. An investigation of New Zealand (NZ) coronial records identified six work-related confined space deaths in four incidents over the period 2007–2012 with one (17%) death being a rescuer; and a collation of open source reports identified 18 fatalities over the period 2004–2014 (rescuer deaths unknown) in Singapore and 17 fatalities over the period 2001–2010 with 7 (41%) of deaths being rescuers in the province of British Columbia, Canada (Selman et al., 2018). A recent study which analysed Italian workplace accident statistics from 2001 to 2015 found 20 confined space incidents resulting in 51 fatalities – a high rate of fatality per accident by current comparison (Botti et al., 2015); and a further study of confined space fatalities in Jamaica found 17 fatalities in 11 incidents over the period 2005–2017 (Stennett, 2018). These figures are summarised in Table 1.

Further published studies restricted by geographical area, industry sector, or other criteria also identify high numbers of confined space fatalities. Sahli and Armstrong (1992) identified 50 deaths, including 3 (6%) of whom were rescuers in confined space fatalities in the US state of Virginia between 1979 and 1986. Of the 233 asphyxiation and poisoning deaths of workers in the US over the period 1984–1986, 146 occurred in confined spaces, including 17 (12%) of whom were rescuers (Suruda and Agnew, 1989). Between 1975 and 2005, there were 77 confined space fatalities in 56 incidents in livestock manure handling and storage facilities in the US, with 17 (22%) of the fatalities attempting rescue of another person (Beaver and Field, 2007). A study of agricultural material engulfment incidents in confined spaces over the period 1964–2006 identified 686 incidents in which 74% resulted in a fatality. This study identified 14 instances of secondary entrapment of a rescuer (although suspected to be under-reported), 6 (43%) of whom were also killed in the rescue attempt (Roberts et al., 2011).

Both OSHA and NIOSH (the National Institute for Occupational Safety and Health – a division of the Centers for Disease Control (CDC) –

which conducts research and delivers information, education, and training in workplace health and safety) conduct investigations of fatal occupational injuries which include a detailed analysis of the aetiology and epidemiology of selected incidents. The Fatal Accident Circumstances and Epidemiology (FACE) program conducted by NIOSH, in particular, attempts to identify common factors and develop recommendations to prevent future deaths (Higgins et al., 2001; Manwaring and Conroy, 1990). The FACE program is a selected subset of all workplace fatalities and while useful for analysis, as a selected subset it is not valid as a source of the overall number or rate of confined space deaths, or for the distinction between entrant and rescuer deaths. Suruda et al. (1994) conducted an analysis of FACE data between 1982 and 1991 and identified 62 confined space incidents which resulted in 97 fatalities, including 35 (36%) rescuers. A similar study of FACE data between December 1983 and December 1989 identified 88 deaths in 55 incidents, of whom 34 (39%) were persons attempting rescue (Manwaring and Conroy, 1990).

1.3. Multiple fatalities

While the overwhelming majority (96%) of work-related fatalities occur in incidents in which there is a single decedent (Drudi and Zak, 2004; Pierce, 2016), multiple fatality workplace incidents do occur. De Vaney asserted that 'other than vehicular accidents, more multiple fatalities occur during confined space entry work than any other type of work performed in the United States today' (as cited in MacCarron, 2006, p. 1). Contemporary studies show that while confined space incidents can result in multiple fatalities, other mechanisms of incident are more likely to produce multiple deaths. 1109 multiple fatality workplace incidents resulted in 2949 fatalities in the US over the period 1995–1999. While only 4% of all workplace fatal incidents were multiple fatality incidents, they accounted for almost 10% of all workplace deaths over this period. In descending order, road transport accidents, vehicle accidents in the workplace, aircraft accidents, assault and homicide, fire and explosion, and confined spaces were the leading mechanisms of incident for multiple fatalities (Drudi and Zak, 2004). Similar figures were obtained for the period 2005–2010, in which 3.8% of all fatal workplace accidents (n = 86,032) were multiple fatality accidents, accounting for 9.8% of workplace deaths. For the year 2010, the most common mechanisms of incident were (in descending order) road transport accidents, aircraft accidents, fire and explosion, assault and violent acts, and confined spaces (6% of all deaths in multiple fatality incidents) (Pierce, 2016).

Confined space incidents most often result in multiple fatalities when rescue is attempted by workmates and/or untrained personnel. A memorial to Constable Patrick Sheahan stands in Burgh Quay, Dublin, which was erected to recognise his efforts in 1905 to rescue a worker who entered a sewer and was overcome by the toxic atmosphere within. Unfortunately, the unsuccessful rescue cost Constable Sheehan his life. Confined space rescues have been notoriously unsuccessful and have resulted in many rescuer fatalities. The outcomes of bystander or untrained rescuers attempting rescue are seldom good. A study based on OSHA data of selected confined space incidents involving hazardous atmospheres between 1974 and 1982 found that rescue was attempted in 75% of all confined space atmosphere-related incidents, that it was successful in only 15% of all rescue attempts, and that in those rescue attempts, nearly half of the would-be rescuers died in the attempt (McManus, 1998). The same study also identified that there were no successful rescues in confined space events involving physical hazards in which entrants were killed; but that there were also no rescuers who died in these events.

In 1986 NIOSH issued an alert titled 'Preventing Occupational Fatalities in Confined Spaces' which concluded 'More than 60% of confined space fatalities occur among would-be rescuers; therefore a well-designed and properly executed rescue plan is a must.' (NIOSH, 1986). Subsequent studies have identified much lower ratios (Beaver and Field, 2007; Burlet-Vienney et al., 2014; Meyer, 2003; Pettit et al., 1996; Suruda et al., 1994; Wilson et al., 2012), with a conclusion by Selman et al. (2018) that rescuer deaths account for up to 17% of all confined space deaths. While entrant deaths were due to a range of mechanisms including atmospheric hazards, fires and explosions, and physical hazards (including engulfment); rescuer deaths have been found to be almost exclusively the result of atmospheric hazards (McManus, 1998; Selman et al., 2018).

As previously mentioned, there are difficulties in numerating confined space fatalities due to under-reporting, the absence of specific confined space coding, and differences in areas of responsibility for regulatory authorities (Martinkus, 1996; McManus, 1998; Pettit et al., 1996; Probst and Graso, 2013; Quinlan and Mayhew, 1999; Riedel and Field, 2013; Sahli and Armstrong, 1992; Selman et al., 2018). More difficult is the identification of confined space incidents in which entrants suffer non-fatal injuries, or who are successfully rescued. While fatalities in the workplace are reportable to WHS authorities, most injury data is collected through compensation agencies, and workplace injuries are well-known to be under-reported (de Castro, 2003; Probst and Graso, 2013; Quinlan and Mayhew, 1999; Selman et al., 2017). In addition, different jurisdictions may have quite dissimilar reporting thresholds for incident or injury notifications. A confined space incident in which rescue by emergency services personnel was required, and in which considerable resources were expended, but only minor injuries resulted, may not meet WHS authority notification criteria (Commonwealth of Australia, 2016a; Government of the United Kingdom, 2013; OSHA, 2014). Thus only confined space incidents which result in a fatality – to an entrant and/or a rescuer – are generally available for study of this topic.

1.4. Risk management for confined space entry

An analysis of a range of confined space fatality studies has identified that atmospheric hazards (oxygen deficient and toxic atmospheric conditions) are a significant mechanism of incident in confined space fatalities. Physical hazards (such as falls, electrocution, being caught or crushed in machinery, and engulfment) are also significant mechanisms of incident, accounting for up to half of all confined space fatalities in some studies – with engulfment being the most common physical mechanism in the agricultural sector (Issa et al., 2016; Riedel and Field, 2013; Selman et al., 2018). The hazards are only identified and risks controlled if correct confined space procedures are undertaken.

All regulatory information accessed by the authors in respect to confined space entry had common safety requirements to be undertaken before any confined space entry. Some jurisdictions require that workplaces comply with legislation such as regulations (Government of Canada, 2017; OSHA, 2011c, 2016), while others provide more detailed Codes of Practice (Government of the United Kingdom, 2014; Safe Work Australia, 2016). Some jurisdictions permit workplaces to comply with national or industry standards (Standards Australia, 2009; Standards Singapore, 2005). In all designated systems of work, confined space entry is controlled using the risk management process, with some specific safety provisions as a result of the nature of confined space hazards. In general, the risk management process requires that hazards are identified, the risk from these hazards assessed (both the likelihood of the hazard causing harm and the expected consequences should that harm occur), control measures are adopted and implemented, and then reviewed and evaluated to reduce the risks so far as is reasonably practicable (ISO 31000, 2009). Particular to confined space entry, common requirements of regulations and standards include: ensuring isolation of plant, services, and preventing product ingress; the conduct of atmospheric testing and/or monitoring; purging or ventilation of the space; training for all entrants and attendants; the completion of a permit and the posting of an attendant (or 'stand-by person'); and the establishment of emergency response procedures (ANSI/ASSE, 2009; Canadian Standards Association, 2016; Government of Canada, 2017;

Government of Singapore, 2009; Government of the United Kingdom, 1997; OSHA, 2011c, 2016; Safe Work Australia, 2016; Standards Australia, 2009; Standards Singapore, 2005). All of these requirements are designed to reduce the risks of confined space entry.

Common procedural factors which lead to confined space deaths include failure to identify the entry as a confined space (MacCarron, 2006; McManus, 1998; NIOSH, 1986; Suruda et al., 1994), no or inadequate risk assessment conducted (Burlet-Vienney et al., 2014; McManus, 1998; Meyer, 2003; Ross, 2007), a lack of safe confined space entry procedures or established procedures not followed (Burlet-Vienney et al., 2014; Kletz, 2009; MacCarron, 2006; Manwaring and Conroy, 1990; McManus, 1998; Suruda et al., 1994), no or inadequate confined space entry training for entrants and rescuers (Burlet-Vienney et al., 2014; MacCarron, 2006; Pettit et al., 1996), no atmospheric testing conducted before entry or no atmospheric monitoring carried out while undertaking work inside the confined space (Burlet-Vienney et al., 2014; Manwaring and Conroy, 1990; McManus, 1998; NIOSH, 1986; Sahli and Armstrong, 1992; Suruda et al., 1994), no ventilation of the confined space conducted prior to or during entry (Burlet-Vienney et al., 2014; Manwaring and Conroy, 1990; McManus, 1998), a lack of effective isolation (lockout/tagout) procedures (McCann and Zaleski, 2006; Ross, 2007; Sahli and Armstrong, 1992), and of course unplanned rescue attempts by would-be rescuers (Beaver and Field, 2007; McManus, 1998; Meyer, 2003; NIOSH, 1986; Sahli and Armstrong, 1992). Interestingly, Beaver and Field (2007) also identified a level of risk acceptance amongst confined space entrants – that decedents knowingly entered a confined space despite the risks – in which it is likely they assessed the benefits of completing a task to be greater than the potential costs of the risk of entry.

The identified common procedural factors all stem from inadequate assessment of the risks to enter or perform work in a confined space and inadequate application of the risk management system. The use of a generic risk assessment across all work processes does not address the multiple hazards of confined space work, and is counter to ISO 31010 (2009), which recommends that the selection of a risk assessment technique be applicable to a particular circumstance. Weaknesses in risk assessments can lead to weakness in the application of control measures to prevent incidents. The use of a confined space-specific risk assessment such as those proposed by Burlet-Vienney et al. (2015a) and Botti et al. (2018) can provide a more realistic and considered risk profile. Once a thorough risk assessment has been completed for a confined space task, control measures can be put in place to reduce the risk of the task so far as is reasonably practicable. There are, of course, inherent weaknesses in any risk assessment. Risk assessments conducted for comparatively simple tasks such as confined space tasks in which personal risks are of the greatest concern are inherently subjective, rely on informed judgement of both likelihood and consequences, are reflective of cultural or individual biases, and are reflective of the general safety culture of the workplace (Caponecchia and Sheils, 2011; Gadd et al., 2004; Joy, 2004). Unfortunately in some instances, risk assessment is 'seen as a paper exercise without practical importance' (Pinto et al., 2013, p. 410).

The risks involved should be reduced using the commonly understood hierarchy of controls: 1. Eliminate the hazard – which ideally eliminates the need to enter the confined space; 2. Substitute processes, substances, or methods of work for those less hazardous; 3. Isolate the hazards (electrical, mechanical, radiological, product ingress, etc.) – usually with a lock-out/tag-out system; 4. Engineer plant, equipment and processes to reduce risk; 5. Use administrative controls such as training and safe work procedures and restrict access; and 6. Fit personal protective equipment to reduce the exposure of confined space entrants to hazards (Botti et al., 2018; ISO 31000, 2009). As there are two elements from the risk management process in ascertaining the risk of harm – likelihood and consequences – the control measures adopted should also be designed to reduce both the likelihood and the consequences of a hazard. The regulatory common safety requirements for confined space work previously mentioned including ensuring isolation from mechanical and electrical hazards, prevention of product ingress, conducting atmospheric testing and monitoring, purging or ventilation of the space, training, and a permit to work system are primarily based on reducing the *likelihood* of an incident occurring; however the posting of a confined space attendant and the establishment of emergency response and rescue procedures are control measures which only reduce the *consequences* should an incident occur.

1.5. *Confined space rescue*

The regulations and standards, while specifying that emergency response and rescue procedures are to be in place, often lack detailed definitions. Terms such as 'appropriate emergency procedures' (Safe Work Australia, 2016) are used; and the regulations and standards lack practical advice for the provision and conduct of emergency response and rescue (Burlet-Vienney et al., 2014). All regulations and standards consulted require that emergency response and rescue be planned; and some also require that those performing the rescue be practised (OSHA, 2011c, 2016; Standards Singapore, 2005); yet no defined response time [eg. 'timely' (OSHA, 2011c, 2016; Standards Singapore, 2005), or 'immediately' (Government of Canada, 2017; Government of the United Kingdom, 1997)] is given. Beyond the requirements of regulations and standards, some published guidelines provide detailed information and best practice guideline for confined space emergency response and rescue, and are a valuable resource (NFPA 350, 2016; NFPA 1670, 2017; Workplace Safety and Health Council, 2014). A summary of the emergency response and rescue provisions required by regulations, standards, and guidelines is provided in Table 2. The original 1986 NIOSH alert also recommended that rescue procedures should be established before entry, that a standby person should be assigned and provided with the means to conduct non-entry retrieval, that rescue procedures should be practiced, and that life-threatening rescue attempts be eliminated (NIOSH, 1986).

Confined space rescue may be difficult due to the presence of hazards which have instigated a state of emergency; the number of entrants within the confined space (Wilson and Wang, 2013); or due to physical characteristics of the confined space itself such as the size and shape of the confined space, obstacles within, and the vertical depth or horizontal penetration that the entrants are within the confined space (Burlet-Vienney et al., 2015b). Confined space rescue is a difficult endeavour, may require technical expertise, is stressful upon the rescuers (Kitabayashi et al., 2016), and due to the risks and short time-frames required to remove entrants from a hazardous environment, it may not always be achievable without undue risk to the rescuers (NFPA 350, 2016). The arrival times of professional emergency services may also be beyond that required to preserve life (Burlet-Vienney et al., 2015b; Wilson et al., 2012). Accordingly, the best confined space rescue is one in which no rescue is required, and certainly in which no would-be rescuers have entered a confined space and put themselves at risk. A continual difficulty is asking fellow workers and bystanders to act against human nature and not attempt unplanned rescue, as 'people cannot stand idly by when an identified person's life is visibly threatened' (McKie and Richardson, 2003, p. 2408), but that 'the spontaneous reaction to immediately enter and attempt to rescue a person from a confined space could lead to the death or serious injury of those attempting the rescue.' (Standards Australia, 2009).

The objectives of this paper are to emphasise the need for proper risk assessment and implementation of control measures prior to any confined space entry to reduce the risks of entry and the possibility of a rescue being required; to stress the importance of rescue planning prior to a confined space entry; and to propose a simple and safe procedure for confined space rescue for on-site or in-house rescue teams and personnel which will reduce the risks in the conduct of a rescue and improve the success rate for the rescue of confined space entrants in difficulty.

Table 2
Emergency response and rescue provisions required by regulations, standards, and guidelines.

Country/regulation/ standard	Standby/attendant	Rescue procedure	Rescue equipment	Communications	Rescuer capabilities	Rescuer protection	Professional emergency services
Australia[1] Code of practice (Safe Work Australia, 2016)	'A standby person must be assigned to continuously monitor the wellbeing of those inside the space'	First aid and rescue procedures to be followed in an emergency must be established and practised as necessary	'Suitable rescue and resuscitation equipment in close proximity' and 'mechanical lifting equipment or emergency response equipment should … be on site before entry'	Continuous communication and monitoring from outside the confined space, and communications to summon help in an emergency	Rescuers properly trained, fit, and capable of using equipment provided for an emergency	'Rescuers must be provided with and wear appropriate respiratory protective equipment'	Provision for the notification of professional emergency services is required
New Zealand Australian/New Zealand Standard 2865 (Standards Australia, 2009)[2]	'Standby person' or another system of controls that will 'provide for an equal or better safety outcome'	'Appropriate emergency response and first aid procedures and provisions shall be identified, planned, established and rehearsed'	'Suitable rescue and resuscitation equipment in close proximity' and 'mechanical lifting equipment or emergency response equipment should… be on site before entry'	Continuous communication from within the confined space to outside; and the means to initiate emergency response procedures	Rescuers should be assessed to confirm their competency and should be reassessed at appropriate intervals	Personal Protective Equipment (PPE) requirements should be based on the risk assessment; and should be correctly fitted, cleaned, stored, and maintained	Emergency response may include professional emergency services
Canada Regulation (Government of Canada, 2017)[3]	Ensure that a person trained in entry and emergency procedures is in attendance outside the confined space. NOTE: Two or more persons must be 'in the immediate vicinity of the confined space to assist in the event of an accident or other emergency'	When there is a risk of a hazardous atmosphere, 'emergency procedures to be followed in the event of an accident or other emergency in or near the confined space' must be established	Every person entering, exiting or occupying a confined space 'must wear an appropriate safety harness that is securely attached to a lifeline' and 'where reasonably practicable, equipped with a mechanical lifting device'	The attendant is to remain in communication with persons inside the confined space	At least one of the persons in the immediate vicinity of the confined space is to be trained in emergency procedures, and is to hold a first aid certificate	Rescue personnel are to be provided with PPE and rescue equipment including a mechanical lifting device	No mention
Singapore Regulation (Government of Singapore, 2009)	A confined space attendant must be appointed before entry	A written rescue plan shall be established, appointing adequately trained rescuers	Sufficient supplies of breathing apparatus, harness and ropes, rescue equipment, and revival apparatus are to be readily available, maintained, and regularly examined	'maintain regular contact with the persons in the confined space' and alert rescue personnel in an emergency	All designated rescue personnel are to be adequately trained	All designated rescue personnel are to be adequately trained in the proper use of PPE	No mention
Singapore Standard CP84 (Standards Singapore, 2005)	'An attendant shall be appointed for entry into the confined space … between the opening of the cover and the time all the necessary safety measures have been put in place'	A written rescue plan shall be established, including names of rescuers, rescue method, rescue equipment required, and means of activation	Sufficient supplies of breathing apparatus, harness and ropes, and resuscitation equipment 'shall be provided and kept readily available'	The attendant is to maintain regular contact with entrants and be able to alert rescue personnel in an emergency	All designated rescue personnel are to be adequately trained and a drill is to be conducted every 12 months, recorded, and evaluated	All designated rescue personnel are to be adequately trained in the proper use of PPE	No mention
United Kingdom Regulation (Government of the United Kingdom, 1997) Code of Practice (Government of the United Kingdom, 2014)	Requirement for supervision by a competent person based on results of a risk assessment.	'The arrangements for emergency rescue … must be suitable and sufficient' and should be in place before any entry	Equipment for extracting workers from the confined space and first-aid equipment should be in place before entry	Between entrants, between entrants and those outside, and 'to summon help in case of emergency'	Rescue personnel should be trained, and refresher training conducted regularly (eg. annually)	Rescuers must be safeguarded against the cause of the emergency	Public emergency services should not be relied upon
United States Regulation (general) (OSHA, 2011c) – PRCS[4]	'Provide at least one attendant outside the permit space into which entry is authorized for the duration of entry operations'	Develop and implement procedures for rescue, for summoning rescue and emergency services, provide for rescued employees, and prevent unauthorised rescue attempts	'To facilitate non-entry rescue, retrieval systems or methods shall be used whenever an authorized entrant enters a permit space, unless the retrieval equipment would increase	Communications means between entrants and attendants, and communications means to rescue and emergency services who can be summoned	Select a proficient rescue service. If an in-house rescue team is selected, personnel require proficiency in rescue and CPR, and practice at least annually	'Provide affected employees with the PPE needed to conduct permit space rescues safely and train affected employees so they are proficient in the use of that PPE'	May be evaluated and selected as a workplace rescue and emergency service; or not

(continued on next page)

Table 2 (*continued*)

Country/regulation/ standard	Standby/attendant	Rescue procedure	Rescue equipment	Communications	Rescuer capabilities	Rescuer protection	Professional emergency services
			the overall risk of entry or would not contribute to the rescue of the entrant'				
Regulation (construction industry) (OSHA, 2016)[5]	'Provide at least one attendant outside the permit space into which entry is authorized for the duration of entry operations'	Develop and implement procedures for summoning rescue and emergency services, for rescuing entrants from confined spaces, providing services to rescued employees, and for preventing unauthorised rescue attempts	Non-entry rescue is required unless the retrieval equipment would increase the overall risk of entry or would not contribute to the rescue of the entrant'	Communicates with entrants as necessary to assess entrant status and summons rescue and other emergency services as soon as the attendant determines that it is necessary	Select a proficient rescue service. If an in-house rescue team is selected, personnel require proficiency in rescue and CPR, and practice at least annually.	'Provide affected employees with the PPE needed to conduct permit space rescues safely and train affected employees so they are proficient in the use of that PPE'	May be evaluated and selected as a workplace rescue and emergency service; or not

Notes:
1. Legislation can differ between jurisdictions in Australia. The Code of Practice is approved for all jurisdictions under the legislation.
2. The Australian / New Zealand Standard is the approved Code of Practice under New Zealand legislation.
3. Legislation can differ between jurisdictions in Canada.
4. PRCS - Permit Required Confined Spaces – those with actual or potential atmospheric hazards.
5. Unique to the US, different legislation applies to confined spaces in the construction industry.

2. Method

The authors are professionally experienced in confined space risk management, rescue planning, and emergency standby tasks; and the proposed procedure is one that has developed incrementally and has been used successfully by a limited number of on-site rescue teams over several years. A comprehensive international literature review was conducted in the preparation of this paper, which confirmed the procedural steps as generally common amongst the literature, although much of the existing literature is written for professional emergency services personnel. These resources contain comprehensive training programs and detailed checklists; however all are written to comply with the standards of the US National Fire Protection Association (NFPA), a non-government industry standards organisation, and are aimed at professional emergency services personnel (typically members of fire and rescue departments) (CMC Rescue, 2012; IAFC and NFPA, 2009; Rhodes, 2003; Sargent, 2000; Veasey et al., 2005). The contents described (organisation, equipment, training drills and outcomes, etc.) are generally beyond the scope of part-time in-house or on-site emergency response teams.

The procedure as presented in this paper is written for use by all rescue personnel, from part-time mine rescue teams through to professional emergency services personnel. While the term 'rescue' is used, the rescue itself is only part of the emergency response procedure. A confined space incident which requires the rescue of personnel from within may be part of a larger safety incident in a facility, or may require changes to the operation of a workplace. Withdrawing part-time rescue team members from their normal workplaces, shutting down sections of plant to make for a safe rescue environment, or calling professional emergency services to conduct or assist in a rescue will have impacts on the workplace; and post-emergency actions such as isolation of the incident site, investigation, and post-incident recovery and support should be included in the overall emergency response procedures (NFPA 1670, 2017; Veasey et al., 2005).

Although most legislation across the various jurisdictions requires that confined space entrants have suitable training before entry, that permits are issued by an authorised or responsible person, and that rescuers have suitable training, the emphasis placed upon these procedures and the training requirements vary considerably.

The authors are aware of the limitations of the data presented due to differing legislation and standards, exclusions and inclusions in the datasets, and the age of the data. These limitations have been acknowledged in previous studies of confined space fatality data (Burlet-Vienney et al., 2014; Pettit et al., 1996; Sahli and Armstrong, 1992; Selman et al., 2017; Suruda et al., 1994).

Ethics approval for this study was granted through the Curtin University Human Research Ethics Committee (HR 18/2013).

3. Results and discussion

Confined space rescues can be divided into a hierarchy of three main types or levels, with increased complexity and hazards. These are self-rescue, non-entry rescue, and entry rescue (NFPA 350, 2016; NFPA 1670, 2017; Ross, 2007; Veasey et al., 2005; Wilson et al., 2012; Workplace Safety and Health Council, 2014). In all cases, the hierarchy for protection should be safety of rescuers, safety to the scene (including bystanders), and then safety (provision of first aid and rescue) to the casualty/ies. Additional casualties amongst rescuers or bystanders only creates more problems (Greaves, 2006; Hogan and Burstein, 2007; Veasey et al., 2005). Planning for rescue prior to any confined space entry will also improve the safety of entrants and rescuers, as required by some jurisdictions (Government of Canada, 2017; Government of Singapore, 2009; Standards Singapore, 2005), and any pre-entry rescue planning should also conform to the hierarchy of the level of rescue – self-rescue, non-entry, and entry.

Self-rescue is simply the confined space entrants evacuating or exiting the confined space without assistance. This may be initiated by identifying a hitherto unforeseen hazard, reacting to the alarm on a confined space gas detector, or even assisting a fellow entrant who has received a minor injury or suffered a medical issue. Entrants should self-exit a confined space under such conditions. This action is more likely to end in a favourable outcome than ignoring an issue until rescue is required (NFPA 350, 2016; Veasey et al., 2005) – and is of minimal danger to the entrants, confined space attendants, bystanders, or any rescuers. Exit of the confined space may also be by order of the attendant or a supervisor if a danger is recognised, or for other reasons such as an incident in another part of the workplace which could inhibit emergency response timeliness.

Non-entry rescue (or retrieval) can often be performed by the confined space attendant with minimal training; however it usually requires that entrants are wearing safety equipment (such as full body harnesses) and are attached to systems (such as lines, ropes, and winches) which permit their retrieval by the attendant. These retrieval systems should be appropriately anchored, with no danger of failure, and contain a mechanical advantage if used in a vertical configuration or in which an entrant may be a short horizontal distance into a space (NFPA 350, 2016). Retrieval systems are only suitable if there are no obstacles between the entrant and the exit point, and the entrant can be retrieved in a straight-line pull by the attendant or rescuer from the point of entry. If a non-entry rescue is possible, the attendant or attending rescue team may attempt to eliminate or reduce the hazards present (as described below), but the retrieval of any entrants from within the confined space should not be delayed in order to do so.

Entry rescue (also known as contact rescue) requires that at least one rescuer enter the confined space, make contact with the casualty, and assist in extricating the casualty from the space (NFPA 350, 2016; Veasey et al., 2005). Entry rescue is not to be performed by the attendant, but rather the attendant is to raise the need for rescue via the procedures and contact information detailed on the entry permit. Entry rescue may be required when a casualty is not wearing a harness or has removed the harness, is injured and the injuries prevent the casualty being removed with a retrieval system, the confined space is horizontal in nature, or if the internals of the confined space do not permit effective retrieval from outside (NFPA 1670, 2017). A simple example is a truck tank compartment which has a single top entry, but which has baffles within the tank to prevent liquid surging. A casualty in a baffled area of the tank remote from the entry point will require an entry rescue as the casualty cannot be remotely retrieved due to the baffles acting as obstacles. Entry rescue is more difficult and dangerous as rescuers are exposed to the hazards of the confined space, and in many cases, rescuers are entering confined spaces to rescue entrants from hazards which should have been addressed before any entry was made. Entry rescue may require rescuers to wear retrieval and personal protective equipment (PPE) such as respiratory protection or breathing apparatus, harnesses, lifelines, and protective clothing. By using a defined space rescue procedure, the hazards can be minimised and the successful exit of all personnel safely from the space can be achieved.

The hierarchy of the level of rescue is shown graphically in Fig. 1.

3.1. Confined space rescue procedure

While confined space rescue procedures have been described in the literature previously, they have been written for professional emergency services personnel, and have focussed on the conduct of the technical elements (use of breathing apparatus, chemical protection, and mechanical advantage hauling systems) of confined space rescue and on the rapid removal of the casualty from the confined space (Rhodes, 2003; Sargent, 2000; Veasey et al., 2005). While some of these elements may be required, it is also possible that minimal technical rescue equipment is required, and in non-complex situations a number of rescuers may enter a confined space only to package a casualty into a litter to be walked out (Fig. 2).

The confined space rescue procedure is broken into five steps and described by the acronym **REALE**. Step 1 is **R**econnaissance of the rescue task. Step 2 is **E**limination or reduction of hazards. Step 3 is **A**ccessing the casualty. Step 4 is the provision of **L**ife-saving first aid to the casualty. Step 5 is the **E**xtrication of the casualty as required.

1. ***Reconnaissance.*** Often termed 'size-up' by fire and rescue services (CMC Rescue, 2012; NFPA 1670, 2017; Rhodes, 2003; Sargent, 2000; Veasey et al., 2005), the reconnaissance of the rescue task seeks to ascertain the hazards present and identify any further potential hazards. Much of this information can be obtained from the previously completed risk assessment for the confined space entry, from the confined space permit, and from questioning the confined space attendant. A walk-around is also conducted to discover any hazards that may have been missed on the original risk assessment or entry permit, or which have developed since the original entry. The atmosphere of the confined space must be tested using a confined space gas detector to identify any atmospheric hazards – and is required to be monitored throughout the whole period of the rescue.

2. ***Eliminate hazards.*** All identified hazards should be eliminated. If the hazards cannot be eliminated, they should be reduced so far as is reasonably practicable using the hierarchy of control. Up to half of confined space entrants die as a result of atmospheric hazards (Selman et al., 2018), which require a time-sensitive rescue (McManus, 1998). In a confined space in which the atmosphere is not hazardous (confirmed by atmospheric testing), the rescue may not be as urgent and other hazards such as physical hazards and engulfment risks must be controlled. The atmosphere within the confined space can be improved through fresh air forced ventilation – avoiding recirculation, short circuiting, and other ventilation issues (CMC Rescue, 2012; NFPA 350, 2016); and through the flushing of any liquids to remove sources of vapours and fumes. Purging is not normally an option when casualties remain inside the confined space. The confined space must be effectively isolated from operating plant, services, and product ingress; and other physical hazards to the rescuers such as the potential of falls from height must be controlled.

3. ***Access the casualty/ies.*** Only the minimum number of rescuers required to enter the confined space should do so, and only when it is safe to do so. Rescue personnel may enter a confined space under circumstances in which entry would not normally be permitted to conduct a work task in order to rescue a casualty, but the cost-benefit analysis of doing so must weigh up the risks of secondary casualties and the subsequent increase in rescue complexity should they occur. The rescue should be deliberately planned, the rescue personnel protected through appropriate control measures including PPE (NFPA 350, 2016; NFPA 1670, 2017; Sargent, 2000; Veasey et al., 2005), and planning for rescuer retrieval and backup should be made prior to entry. Although rescue teams are prone to over-commitment (Ash and Smallman, 2008), when the risk to rescuers is unreasonable, or the potential loss of life of rescuers is high for a low chance of rescue success, entry should not occur or the rescue attempt should be abandoned. Unreasonable risk includes situations in which hazards cannot be isolated or rescuers cannot be protected from those hazards (for example intense fire), or where it is clear and obvious that any casualties have perished (such as a casualty found after several hours in a non-respirable atmosphere). In the case of a perished casualty, urgency is not required and entry should only be made by the rescue personnel when conditions are completely safe. Rescue is not always possible (NFPA 350, 2016), and confined space rescues in hazardous conditions have a low rate of success (McManus, 1998). Each rescue team should develop their own go/no-go criteria; and undertake all actions in accordance with the hierarchy for protection (rescuers, bystanders, casualty/ies).

4. ***Life-saving first aid.*** First aid or emergency treatment should be given to the casualty as soon as possible, in accordance with first aid principles, procedures, and protocols (ANZCOR 8, 2016; Singletary et al., 2015). OSHA requires that at least one member of a confined space rescue team is a current first aider (OSHA, 2011c), so that person

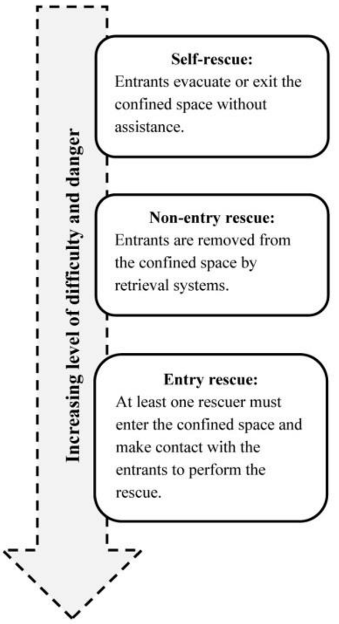

Fig. 1. The hierarchy of the level of rescue.

Fig. 2. Confined space casualty extricated by litter (Photo by Selman, 2009).

should be the first to enter. First aid may include treatment for injuries, fitting of PPE such as breathing apparatus, or moving a casualty out of immediate danger such as proximity to a source of electricity or heat. This is a critical step in the rescue procedure, and first aid can be provided by a rescuer immediately upon contact with the casualty while other rescue and retrieval equipment is being prepared or rigged. A rescue team member, for example, could enter a confined space while wearing breathing apparatus to gain access to a casualty, fit the casualty with PPE, and commence first aid while ventilation of the confined space is ongoing to bring the atmosphere to a safe level for the conduct of the rescue. Again, this should only be attempted when the risk to rescuers is not unreasonable. A problem arises when there are multiple casualties in a confined space. In a clinical setting, casualties are prioritised – known as *triage* – and those with the greatest need are provided the greatest care. When resources such as first aiders or medical supplies are insufficient to provide optimal treatment to all casualties simultaneously, the prioritising of first aid may be more difficult (O'Meara et al., 2007). A casualty with marginal survivability whose treatment might compromise the chances of survival of others may be permitted to expire so as to salvage the greatest number of lives (Frykberg, 2005). Obviously this decision can only be made in the most extreme of circumstances.

5. *Extrication (as required).* Not all confined space rescues will require the immediate or quick extrication of casualties. In a permissive environment (safe atmosphere, low-risk hazards), the casualty's treatment can be methodical and thorough and the extraction planned and rehearsed before the extrication of the casualty – which may be as simple as packaging the casualty into a litter to be walked out by the rescue team. If the mechanism of injury is such that a spinal injury is suspected (such as a fall from height within or into the confined space), the casualty can be maintained in position with spinal immobilisation until professional medical assistance can be obtained (ANZCOR 9.1.6, 2016); or in the case of massive trauma, the casualty can be treated and stabilised before extrication. The extrication of the casualty (and rescue personnel) from the confined space may require technical rescue techniques such as rope access practices, high angle rescue, or technical rescue skills; or may require an extraction method that includes protection of the spine if the mechanism of injury warrants, or the continuation of oxygen therapy during extraction. These skills also require thorough training and revision to maintain competency. As with the provision of life-saving first aid, in the event that there are multiple casualties in the confined space, extrication will need to be prioritised.

The proposed confined space rescue procedure is expressed graphically in Fig. 3.

As previously mentioned, the regulations and standards consulted from different jurisdictions (as summarised in Table 2) have differing requirements for confined space rescue planning. Some require that a rescue plan is established before each confined space entry (Government of Canada, 2017; Government of Singapore, 2009; Standards Singapore, 2005); however all require that arrangements for confined space emergency response and rescue be established. It is recommended by the authors and the existing rescue literature that pre-emergency preparation and planning is conducted before every confined space entry takes place (IAFC & NFPA, 2009; Rhodes, 2003; Sargent, 2000; Veasey et al., 2005). This planning-for-rescue may lead to changes in the conditions for entry (such as each entrant being fitted with a full body harness to assist in rescue if it is required), or the pre-rigging of retrieval or hauling equipment to save time and assist in the event that a rescue is required. The rescue plan may be established as a standard procedure or for each individual confined space in the workplace – which may need to be reviewed for each entry as the conditions or the work to be performed changes – or may be written from scratch for each entry. Conditions that must be met for the conduct of an entry rescue – and the levels of risk considered reasonable for rescuers – may be established.

For workplaces without an on-site or in-house confined space rescue team, or for small-medium enterprises for which the development of a rescue team is not practicable, it is recommended that liaison with professional emergency services is conducted and that they be invited to the workplace to gain some familiarity with the workplace should they ever need to attend for an emergency. In certain circumstances, such as a major plant maintenance period or shut-down, contracted confined space rescue may be engaged and located on-site for the duration. In all cases, *prevention* of the need for rescue through thorough risk assessment, job planning, compliance with procedures, confined space entry training, isolation of hazards, and atmospheric testing and monitoring should be prioritised before rescue is required. Atmospheric testing and monitoring through the use of portable gas detectors in particular will reduce the risks, and the price of such devices continues to fall as the accuracy continues to improve (Piedrahita et al., 2014). Manufacturers are also starting to connect portable gas detectors through wi-fi networks to applications on smart devices such as mobile telephones and tablets which can provide real-time observation by workplace supervisors (Achkar et al., 2013); and some testing in the placement of sensors within confined spaces to provide real-time monitoring of conditions such as oxygen concentration, ambient temperature, and airflow (which can also be recorded and time-stamped) and which can send notifications of hazardous conditions to smart devices via wireless networks has been conducted (Riaz et al., 2014).

It is recommended that a rescue plan is prepared prior to entry, and that the rescue plan is written in detail, containing the requirements for entry (such as isolations required, equipment required by each entrant); and emergency or rescue equipment required and a procedure and sketch or plan for the rescue. A suggested form for the recording of the confined space rescue plan is provided in Fig. 4.

3.2. Engulfment rescue

Engulfment occurs when a worker falls into a liquid or free-flowing solid, or when there is an unexpected ingress of such a substance into a container in which a worker is undertaking a task. Engulfment can also occur when a worker falls into the product. A particular danger results when stored materials form a crust above a void and a worker or workers walking on top of the crust, or working below the crust, are engulfed when the crust gives way (NIOSH, 1987; Safe Work Australia, 2016). The results of an engulfment can be drowning or asphyxiation, including physical asphyxiation from crushing; and common materials involved in confined space engulfment fatalities include sewage, plastics, sand, sawdust, grain, and other agricultural products (Issa et al., 2016; NIOSH, 1987; Pettit et al., 1996; Riedel and Field, 2013; Safe Work Australia, 2016). Certain industry groups such as agriculture have a much higher rate of engulfment fatality in confined spaces than others. Riedel and Field (2013) reported nearly 900 fatal and non-fatal incidents involving grain storage and handling over the period 1964–2010, resulting in 557 (61.8%) deaths. Entrapment or engulfment in agricultural materials occurred in 690 (76.7%) of those incidents. Grain entrapment or engulfments often occur when workers are walking on top of stored grain while it is flowing out of a silo or bin through a hatch below; the sudden collapse of a grain "bridge" which opens a void into which a worker falls; and the avalanche of a face of a grain stockpile onto a worker (Issa et al., 2018, 2017). Grain engulfments and entrapments average 30 incidents per year in the US, and continue to have a high fatality rate (S. Issa et al., 2017; Issa et al., 2016). Many of these engulfment incidents in the US occur on farms with less than ten employees which are exempt from OSHA confined space legislation (OSHA, 2011a, 2011b).

The rescue of a person trapped in grain or another free-flowing solid is best performed using specific equipment and procedures. A trapped casualty can be submerged very quickly in the flowing product, and the 'quicksand-like' effect of the product can prevent the casualty from being easily retrieved (Bahlmann et al., 2002; Roberts et al., 2015). Previously, the accepted method of rescue of a person trapped or engulfed in a product was to cut holes in the side of the container (such as a grain silo or bin) to expedite the emptying of the container of product and permit rescue of the casualty. This was not without risk, and was largely unsuccessful (Bahlmann et al., 2002; Roberts et al., 2011). The current best-practice is to use a rope or rescue strop to anchor the casualty to prevent further descent into the product; then a grain rescue tube – either improvised or designed for purpose – is placed around the casualty which acts as a coffer dam to prevent ingress of product, and the area immediately adjacent to the casualty is excavated (by hand, through a small auger, or through vacuuming) to reduce the pressure load on the casualty's body (Bahlmann et al., 2002; Roberts et al., 2011). The casualty can then climb out or be pulled free of the engulfment. It is important to note that if the product is not removed from the area adjacent to the casualty, the forces required to extract the casualty from the product can be life-threatening and attempting to pull a casualty buried greater than waist deep should not be undertaken (Issa and Field, 2017; Roberts et al., 2015). Rescuers who conduct rescues in a workplace with a high risk of engulfment should be trained and practised in engulfment rescue techniques. The same proposed five step procedure (REALE) can be used, however the hazards and the actual technical rescue techniques differ and training and rehearsal in the specific rescue techniques should be undertaken.

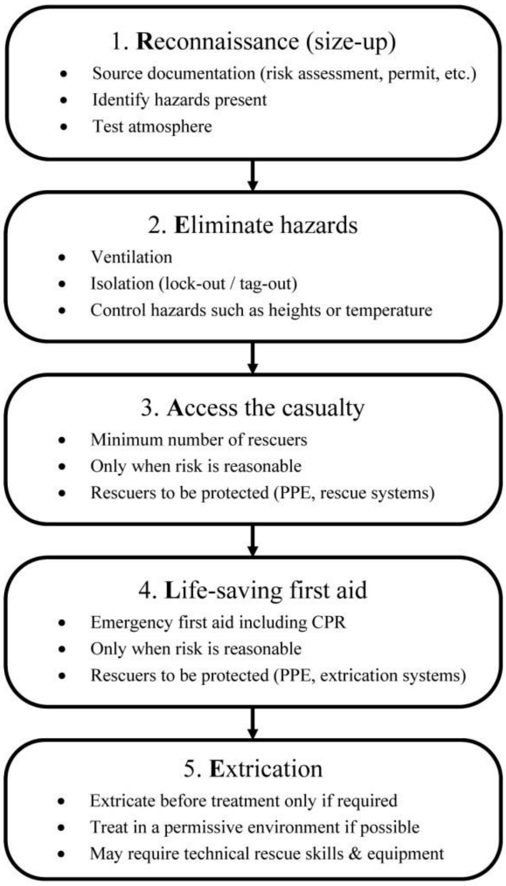

Fig. 3. Five step confined space rescue procedure REALE.

3.3. Example case studies

The following three case studies all involved a confined space incident in which the initial entrant required retrieval or entry rescue, and the outcomes were unsuccessful. In two of the cases, the attempted rescue resulted in further injuries, two of which were fatal. In each case study, the application of the REALE confined space rescue procedure is discussed with the likely more favourable outcomes.

3.3.1. Case study 1 (2005, Delaware, US)

Two workers removed a temporary cover from a reactor vessel and commenced cleaning the flange surface in order to re-install piping after work had been completed on the vessel. The vessel had been recently purged with nitrogen, was clearly marked as a confined space, and had additional red danger tape surrounding the opening. The workers noticed a roll of duct tape lying inside the vessel, about 1.6 m

Confined Space Name / Location:				**Date:**	
Communications:					
Entrants to Attendant:					
Attendant to Rescue Personnel:					

Isolations Required:	**Location / Method:**	**Atmospheric Testing Results:**				
Water / Gas / Steam / Chemical:		Instrument Make and Model:				
Mechanical / Electrical Services:		Instrument #:		Test Date:		
Hydraulic / Pneumatic:		Bump Test:		Yes / No		Pass / Fail
Stored Energy (gravity / pressure):		Performed By (Name):				
Auto Sprinkler Systems:		**Time**	**Oxygen**	**Flammable**	**Toxic**	
Sludge / Waste / Drains:		(24 hour)	> 19.5% < 23.5%	< 5% LEL	CO < 30 ppm	H2S < 10 ppm
Product / By-product Flow:						
Other:		:				
Other:		:				
Locks and tags to be fitted		Other:				

Method of Rescue:			
Rescue Equipment Required (and qty):			
Anchor straps / slings:	Karabiners:	Rigging Plates:	Pulleys:
Ropes:	Tripod:	First aid kits:	Stretcher / Litter:
Progress capture devices:		Hauling systems:	
Breathing apparatus:		Special PPE:	
Pre-rigging required?	Yes / No	Continuous Rescue Presence?	Yes / No
Rescue Procedure and Diagram:			

Rescue Plan Completed By:							
Name:	....	**Sign:**	....	**Date:**	......../........./.........	**Time:**	.... :.........

(caption on next page)

Fig. 4. Suggested confined space rescue plan.

below the opening. They attempted to retrieve the tape by hooking it with a long wire. This was unsuccessful and one worker either deliberately entered the vessel to retrieve the tape, or fell into the vessel while attempting to use the wire. The second worker immediately placed a nearby ladder into the vessel and climbed down to rescue the first worker. A supervisor raised the alarm and an in-house rescue team arrived within two minutes. The rescue team tested the atmosphere and found the oxygen content inside the vessel to be near zero. They donned breathing apparatus and entered the vessel to perform an entry rescue. Because the opening was narrow (24" – 600 mm), and the casualties were not wearing safety harnesses, the rescue was difficult. Nonetheless, both casualties were extricated within ten minutes. Unfortunately they could not be revived and both were later pronounced dead (CSB, 2006). Had the workers complied with safe confined space entry practices (risk assessment, permit, atmospheric testing, and ventilation), then the incident would not have occurred. The decision by the second worker to attempt rescue without a proper rescue procedure proved fatal. The conduct of the REALE confined space rescue procedure would have most likely prevented the second death. A full ***Reconnaissance*** (including atmospheric testing) would have revealed the presence of an unsafe atmosphere, the hazard would have been ***Eliminated*** through ventilation of the reactor vessel prior to the would-be rescuer's entry, and ***Access*** to the casualty would have been improved through the first entrant wearing a full body harness and attachment to a safety line. A proper risk assessment and rescue plan conducted before entry would have led to a non-entry rescue in which the first worker would have been retrieved from outside the vessel at the first sign of trouble. ***Life-saving first aid*** could then be administered in a safe environment and without delay.

3.3.2. Case study 2 (2007, Victoria, Australia)

A worker entered a silo filled with canola to clear a blockage inside the 20-metre high tower. He fell, plunging chest-deep into six metres of quicksand-like canola just above the narrow funnel of the 12-metre wide structure. Local volunteer rescue organisations attempted to rescue the man (who was wearing a harness) through ropes attached to stairs, ladders and overhead beams, but they could not prevent him sinking further. The man slipped further into the grain and the squad inside the silo attempted to shovel away seeds to keep his face clear of the grain, however their proximity to the trapped worker caused grain to flow towards the worker. Less than five hours after becoming trapped in the silo, the man disappeared from view under the surface of the canola and died shortly thereafter. There was much argument as to the rescue procedure to be used, with concerns that attempting to cut holes in the silo could lead to a grain or dust explosion [NOTE: In 686 cases of grain entrapment analysed by Roberts et al. (2011), there were no reports or evidence found of structural collapse or explosions resulting from cutting holes in grain storage vessels]. Rescue workers were able to retrieve the man's body the next day after drilling holes near the base of the silo to drain the grain (Coroners Court of Victoria, 2012). Had the rescuers followed a simple rescue procedure such as REALE, he would have likely been rescued. A full ***Reconnaissance*** would have revealed suitable anchor points for ropes to be attached from the anchors to the worker. The hazard would have been ***Eliminated*** through draining the grain either through a bottom hatch or holes once the worker was anchored, or through insertion of a grain rescue tube around the trapped worker. This would have permitted ***Access*** to the casualty by rescuers wearing safety equipment who could retrieve the worker once the grain level had drained to below the casualty's hips, or would have removed grain from inside the grain rescue tube. This would have cleared the area for ***Life-saving first aid*** and would have permitted ***Extrication*** of the casualty with little danger. It should be noted that the volunteer rescue organisations from the wheat belt in Victoria have now purchased grain rescue tubes, have undertaken specific grain rescue training, and have since successfully conducted grain entrapment rescues (Russell, 2015).

3.3.3. Case study 3 (2010, New York, US)

A sanitation worker descended through a manhole into a sewerage system located just to the rear of a fire station to clear a blockage. Two volunteer firefighters on location walked over to the manhole and saw the sanitation worker lying approximately 18 feet (6 m) below at the bottom of the vertical access shaft. Incorrectly assuming the worker had simply fallen, one firefighter commenced preparing a portable gas detector and rescue equipment while the other donned his boots and climbed down into the sewer system before the equipment had been made ready. He collapsed into the bottom of the shaft. The portable gas detector was lowered into the shaft on a rope and a low oxygen alarm was triggered. A tripod was set up over the manhole and fresh air forced ventilation was commenced. A firefighter wearing self-contained breathing apparatus (SCBA) was lowered into the shaft with an additional system to fit to the firefighter casualty and they were hauled back to the surface. The same system was used to extricate the sanitation worker. Both casualties were given emergency medical treatment and transported to hospital where they were pronounced dead (NIOSH, 2011). A full ***Reconnaissance*** (including atmospheric testing) would have revealed the presence of an unsafe atmosphere, commencement to ***Eliminate*** the hazard through ventilation of the shaft could have been commenced using mechanical ventilation before the first entry, and the initial rescuer would have worn breathing apparatus to safely ***Access*** the casualty. ***Life-saving first aid*** could have been administered to the casualty sooner, and ***Extrication*** of the initial casualty using the vertical technical rescue system could have been commenced with little delay.

4. Conclusion

Confined spaces pose a risk to entrants and to rescuers who attempt to retrieve or extricate casualties in an emergency. Confined space rescues can be divided into a hierarchy of three main types or levels being self-rescue, non-entry rescue, and entry rescue. Confined space rescue should be deliberately planned and conducted by trained and competent people – particularly entry rescue due to the complexity and hazards involved. The adoption of a simplified and broad-based rescue procedure for the preparation and conduct of a confined space rescue by on-site or in-house rescue teams and personnel, as an adaptation of the procedures used by professional emergency services, can provide a rapid and safe intervention in a confined space incident. For workplaces without an on-site or in-house confined space rescue team, or for small and medium enterprises without the ability to conduct a deliberate rescue, it is recommended that liaison with professional emergency services is conducted.

The preparation of a rescue plan prior to a confined space entry, as required by some jurisdictions, is a key factor in reducing the risks in conducting a rescue, and should be completed for all confined space entries. By preparing a rescue plan and following the proposed five step procedure (REALE), which is suitable for all countries and jurisdictions, a confined space rescue may be performed with minimal risk to rescuers and bystanders, and with due regard to the safety of the casualty/ies. Efficient and effective rescue requires individual and collective skills; revision training and practice; and specialised rescue tools, techniques, and equipment are required for workplaces with particular hazards such as confined spaces with internal obstacles or risks of engulfment. By following the proposed procedure, the number of multiple fatalities including rescuer fatalities involved in confined space rescues can be reduced.

Although this paper focuses on the conduct of a confined space rescue, the authors note that the best confined space rescue is one in which no rescue is required. Prevention of the need for rescue through the safe conduct of confined space work through thorough hazard identification, risk assessment, and the implementation of control measures in accordance with the hierarchy of control measures is always preferred.

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Conflict of interest

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References

Achkar, R., Haidar, C.A., Makhoul, N., Osseili, H., (2013, 17-20 Nov 2013). Gas ascertainment via smartphone. In: Paper Presented at the 2013 7th IEEE GCC Conference and Exhibition, Doha, Qatar.

ANSI/ASSE, 2009. Safety Requirements for Confined Spaces (Vol. Z117.1). American National Standards Institute/American Society of Safety Engineers, Washington, D.C., United States.

ANZCOR 8, 2016. Cardiopulmonary Resuscitation. Melbourne, Victoria, Australia: Australia New Zealand Committee on Resuscitation (ANZCOR), Vol. 8, pp. 5.

ANZCOR 9.1.6., 2016. Management of Suspected Spinal Injury. Melbourne, Victoria, Australia: Australia New Zealand Committee on Resuscitation (ANZCOR), Vol. 9.1.6, pp. 6.

Ash, J.S., Smallman, C., 2008. Rescue missions and risk management: highly reliable or over committed? J. Conting Crisis. Manag. 16 (1), 37–52. https://doi.org/10.1111/j.1468-5973.2008.00528.x.

Bahlmann, L., Klaus, S., Heringlake, M., Baumeier, W., Schmucker, P., Wagner, K.F., 2002. Case report: Rescue of a patient out of a grain container: the quicksand effect of grain. Resusc 53 (2002), 101–104. https://doi.org/10.1016/S0300-9572(02)00009-6.

Beaver, R.L., Field, W.E., 2007. Summary of documented fatalities in livestock manure storage and handling facilities - 1975–2004. J. Agromed. 12 (2), 3–23. https://doi.org/10.1300/J096v12n02_02.

Botti, L., Duraccio, V., Gnoni, M.G., Mora, C., 2015. A framework for preventing and managing risks in confined spaces through IOT technologies. In: Paper Presented at the Safety and Reliability of Complex Engineered Systems: ESREL 2015, Zurich, Switzerland.

Botti, L., Duraccio, V., Gnoni, M.G., Mora, C., 2018. An integrated holistic approach to health and safety in confined spaces. J. Loss Prev. Process Ind. 55 (2018), 25–35. https://doi.org/10.1016/j.jlp.2018.05.013.

Burlet-Vienney, D., Chinniah, Y., Bahloul, A., 2014. The need for a comprehensive approach to managing confined space entry: summary of the literature and recommendations for next steps. J. Occup. Environ. Hyg. 11 (8), 485–498. https://doi.org/10.1080/15459624.2013.877589.

Burlet-Vienney, D., Chinniah, Y., Bahloul, A., Roberge, B., 2015a. Design and application of a 5 step risk assessment tool for confined space entries. Saf. Sci. 80 (2015), 144–155. https://doi.org/10.1016/j.ssci.2015.07.022.

Burlet-Vienney, D., Chinniah, Y., Bahloul, A., Roberge, B., 2015b. Occupational safety during interventions in confined spaces. Saf. Sci. 79 (2015), 19–28. https://doi.org/10.1016/j.ssci.2015.05.003.

Canadian Standards Association, 2016. Management of work in confined spaces (edition 2), Vol. Z1006-16. CSA Group, Toronto, Canada.

Caponecchia, C., Sheils, I., 2011. Perceptions of personal vulnerability to workplace hazards in the Australian construction industry. J. Saf. Res. 42 (4), 253–258. https://doi.org/10.1016/j.jsr.2011.06.006.

Rescue, C.M.C., 2012. Confined Space Entry and Rescue Manual. FSP Books and Videos, Goleta, California, US.

Commonwealth of Australia, 2016a. Model Work Health and Safety Act. Safe Work Australia, Commonwealth of Australia, ACT, Australia.

Commonwealth of Australia, 2016b. Model Work Health and Safety Regulations. Safe Work Australia, Commonwealth of Australia, Canberra, ACT.

Coroners Court of Victoria, 2012. Finding into death without inquest. (2007 4950). Coroners Court of Victoria, Melbourne, Australia.

CSB, 2006. Case Study: Confined space entry - worker and would-be rescuer asphyxiated (2006-02-I-DE). Washington, D.C., United States: US Chemical Safety and Hazard Investigation Board, US Government Retrieved from https://www.csb.gov/valero-refinery-asphyxiation-incident/.

de Castro, A.B., 2003. Health & safety: barriers to reporting a workplace injury. Am. J. Nurs. 103 (8), 112.

Drudi, D., Zak, M., 2004. Work-related multiple-fatality incidents. Mon. Labor. Rev. 127 (10), 20–37.

Frykberg, E.R., 2005. Triage: principles and practice. Scan. J. Surgery 94 (4), 272–278. https://doi.org/10.1177/145749690509400405.

Gadd, S.A., Keeley, D.M., Balmforth, H.F., 2004. Pitfalls in risk assessment: examples from the UK. Saf. Sci. 42 (9), 841–857. https://doi.org/10.1016/j.ssci.2004.03.003.

Government of Canada, 2017. Canadian Occupational Health and Safety Regulations (SOR/86-304) Part XI - Confined Spaces. Department of Justice, Government of Canada, Ottowa, Canada.

Government of Singapore, 2009. Workplace Safety and Health (Confined Spaces) Regulations 2009. Ministry of Manpower, Government of Singapore, Singapore.

Government of the United Kingdom, 1997. The Confined Spaces Regulations. Health and Safety Executive, Government of the United Kingdom, London, England.

Government of the United Kingdom, 2013. Reporting of Injuries, Diseases and Dangerous Occurrences Regulations. Health and Safety Executive, Government of the United Kingdom, London, England.

Government of the United Kingdom, 2014. Safe work in confined spaces - Approved code of practice and guidance. Health and Safety Executive, Government of the United Kingdom, London, England.

Greaves, I., 2006. Emergency Care: A Textbook for Paramedics, second ed. Elsevier, Edinburgh, UK.

Higgins, D.N., Casini, V.J., Bost, P., Johnson, W., Rautiainen, R., 2001. The Fatality Assessment and Control Evaluation program's role in the prevention of occupational fatalities. Inj. Prev. 7 (Suppl 1), 27–33.

Hogan, D.E., Burstein, J.L., 2007. Disaster Medicine, 2nd ed. Lippincot, Williams & Wilkins / Wolters Kluwer, Philladelphia, Pennsylvania, US.

IAFC & NFPA, 2009. Fundamentals of Technical Rescue. Jones & Bartlett Learning, Sudbury, Massachusetts, United States.

ISO 31000., 2009).. Risk management - Principles and guidelines (Vol. 31000). International Organization for Standardization (ISO), Geneva, Switzerland.

ISO 31010, 2009).. Risk Management - Risk Assessment Techniques. International Organization for Standardization (ISO), Geneva, Switzerland.

Issa, F.S., Nour, M.N., Field, W.E., 2018. Utilization and effectiveness of harnesses and lifelines in grain entrapment incidents: preliminary analysis. J. Agric. Saf. Health 24 (2), 59–72. https://doi.org/10.13031/jash.12170.

Issa, S., Cheng, Y.H., Field, B., 2017a. 2016 Summary of US Agricultural Confined Space-Related Injuries and Fatalities. Purdue University, West Lafayette, Illinois.

Issa, S.F., Cheng, Y.H., Field, W.E., 2016. Summary of agricultural confined-space related cases: 1964–2013. J. Agric. Saf. Health 22 (1), 33–45.

Issa, S.F., Field, W.E., 2017. Determining the pull-forces required to extricate a victim entrapped at various angles in a grain mass. Safety 3 (1), 11–19. https://doi.org/10.3390/safety3010011.

Issa, S.F., Field, W.E., Schwab, C.V., Issa, F.S., Nauman, E.A., 2017b. Contributing causes of injury or death in grain entrapment, engulfment, and extrication. J. Agromed. 22 (2), 159–169. https://doi.org/10.1080/1059924X.2017.1283277.

Joy, J., 2004. Occupational safety risk management in Australian mining. Occup. Med. 54 (5), 311–315. https://doi.org/10.1093/occmed/kqh074.

Kitabayashi, T., Kudo, S., Kitajima, M., Takamaki, S., Chiba, T., Tachioka, N., Kudo, H., 2016. Stress of rescue team members working in confined spaces during a disaster: Effectivenss of individual wireless communication devices. Hirosaki Med. J. 66 (2016), 176–187.

Kletz, T.A., 2009. What Went Wrong? Case Histories of Process Plant Disasters and How They Could Have Been Avoided, fifth ed. Elsevier, Burlington, Massachusetts, US.

MacCarron, C., 2006. Confined Space Fatalities. (PhD), Edith Cowan, Perth, Western Australia.

Manwaring, J.C., Conroy, C., 1990. Occupational confined space-related fatalities: surveillance and prevention. J. Saf. Res. 21 (4), 157–164. https://doi.org/10.1016/0022-4375(90)90023-5.

Martinkus, J., 1996. Damn lies and statistics. Australia's national injury statistics are a joke. Aust. Saf. News 20-21, 23-24, 59.

McCann, M., Zaleski, N., 2006. Deaths and Injuries Involving Elevators and Escalators. The Center to Protect Worker's Rights, Silver Spring, Maryland, US.

McKie, J., Richardson, J., 2003. The rule of rescue. Soc. Sci. Med. 56 (2003), 2407–2419.

McManus, N., 1998. Safety and Health in Confined Spaces. CRC Press, Boca Raton, Florida, United States.

Meyer, S., 2003. Fatal occupational injuries involving confined spaces, 1997–2001. Occup. Health Saf. 72 (11), 58–64.

NFPA 350, 2016. Safe Confined Space Entry and Work (Vol. 350). National Fire Protection Association (NFPA), Quincy, Massachusetts, US.

NFPA 1670, 2017).. Standard on Operations and Training for Technical Search and Rescue Incidents (Vol. 1670). National Fire Protection Association (NFPA), Quincy, Massachusetts, US.

NIOSH, 1986. Preventing Occupational Fatalities in Confined Spaces. Morgantown, West Virginia, United States: National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government.

NIOSH, 1987. A Guide to Safety in Confined Spaces. Washington, DC, United States: National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government.

NIOSH, 2011. Volunteer fire fighter dies during attempted rescue of utility worker from a confined space - New York. (F2010-31). Cincinnati, Ohio, United States: National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government.

O'Meara, M., Porter, K., Greaves, I., 2007. Triage. Trauma 9 (2), 111–118. https://doi.org/10.1177/1460408607084180.

OSHA, 2011a. Grain handling facilities (Vol. Code of Federal Regulations Title 29, Part 1910.272). Occupational Safety and Health Administration, Department of Labor, Washington, D.C., United States.

OSHA, 2011b. Occupational Safety and Health Standards for Agriculture (Vol. Code of Federal Regulations Title 29, Part 1928). Occupational Safety and Health Administration, Department of Labor, Washington, D.C., United States.

OSHA, 2011c. Permit-required confined spaces (Vol. Code of Federal Regulations Title 29,

89

Part 1910.146). Occupational Safety and Health Administration, Department of Labor, Washington, D.C., United States.
OSHA, 2014. Occupational Injury and Illness Recording and Reporting Requirements (Vol. Code of Federal Regulations Title 29, Part 1904). Occupational Safety and Health Administration, Department of Labor, Washington, D.C., United States.
OSHA, 2015. Confined Spaces in Construction; Final Rule. Occupational Safety and Health Administration, Department of Labor, Washington, D.C., United States.
OSHA, 2016. Confined Spaces in Construction (Vol. Code of Federal Regulations Title 29, Part 1926, Subpart AA). Occupational Safety and Health Administration, Department of Labor, Washington, D.C., United States.
Pettit, T.A., Braddee, R.W., Suruda, A.J., Castillo, D.N., Helmkamp, J.C., 1996. Worker deaths in confined spaces. Prof. Saf. 41 (11), 22–25.
Piedrahita, R., Xiang, Y., Masson, N., Ortega, J., Collier, A., Jiang, Y., Shang, L., 2014. The next generation of low-cost personal air quality sensors for quantitative exposure monitoring. Atmos. Meas. Tech. 7 (10), 3325–3336. https://doi.org/10.5194/amt-7-3325-2014.
Pierce, B., 2016. How rare are large, multiple-fatality work-related incidents? Accid. Anal. Prev. 96 (2016), 88–100.
Pinto, A., Ribeiro, R.A., Nunes, I.L., 2013. Ensuring the quality of occupational safety risk assessment. Risk Anal. 33 (3), 409–419. https://doi.org/10.1111/j.1539-6924.2012.01898.x.
Probst, T.M., Graso, M., 2013. Pressure to produce = pressure to reduce accident reporting? Accid. Anal. Prev. 59, 580–587.
Quinlan, M., Mayhew, C., 1999. Precarious employment and workers' compensation. Intl. J. Law Psych. 22 (5), 491–520. https://doi.org/10.1016/S0160-2527(99)00023-0.
Rhodes, P., 2003. Technical Rope Systems, and Confined Space Rescue: Urban Technical Rescue, Volume 1 (3rd ed. Vol. 1). Premium Source Publishing.
Riaz, Z., Arslan, M., Kiani, A.K., Azhar, S., 2014. CoSMoS: A BIM and wireless sensor based integrated solution for worker safety in confined spaces. Automat. Constr. 45 (2014), 96–106. https://doi.org/10.1016/j.autcon.2014.05.010.
Riedel, S.M., Field, W.E., 2013. Summation of the frequency, severity, and primary causative factors associated with injuries and fatalities involving confined spaces in agriculture. J. Agric. Saf. Health 19 (2), 83–100.
Roberts, M.J., Deboy, G.R., Field, W.E., Maier, D.E., 2011. Summary of prior grain entrapment rescue strategies. J. Agric. Saf. Health 17 (4), 303–325. https://doi.org/10.13031/2013.39804.
Roberts, M.J., Field, W.E., Maier, D.E., Stroshine, R.L., 2015. Determination of entrapment victim extrication forces with and without use of a grain rescue tube. J. Agric. Saf. Health 21 (2), 71–83. https://doi.org/10.13031/jash.21.10150.
Ross, P., 2007. Confined space entry - mitigating risk in general industry. AAOHN J. 55 (6), 245–249.
Russell, D., 2015. Grain engulfment 2015 - case study Retrieved 13 Jul 18, from http://news-cfa-stage.data-solutions.com.au/news/grain-engulfment-2015-case-study.html.
Safe Work Australia, 2016. Code of Practice: Confined Spaces. Commonwealth of Australia, Canberra, ACT.
Safe Work Australia, 2017. Model Work Health and Safety Regulations. Commonwealth of Australia, Canberra, ACT.
Sahli, B., Armstrong, C., 1992. Confined space fatalities in Virginia. J. Occup. Med. 39 (9), 910–917. https://doi.org/10.1016/0022-4375(93)90011-B.
Sargent, C., 2000. Confined Space Rescue. Fire Engineering Books and Videos, Saddlebrook, New Jersey, US.
Selman, J., Spickett, J., Jansz, J., Mullins, B., 2017. Work-related traumatic fatal injuries involving confined spaces in Australia, 2000–2012. J. Health Saf. Env. 33 (2), 197–215.
Selman, J., Spickett, J., Jansz, J., Mullins, B., 2018. An investigation into the rate and mechanism of incident of work-related confined space fatalities. Saf. Sci. 109 (Nov 2018), 333–343. https://doi.org/10.1016/j.ssci.2018.06.014.
Singletary, E.M., Charlton, N.P., Epstein, J.L., Ferguson, J.D., Jensen, J.L., MacPherson, A.I., ... Zideman, D.A., 2015. Part 15: first aid: 2015 American heart association and american red cross guidelines update for first aid. S574–S589. Circ 132 (suppl 2). https://doi.org/10.1161/CIR.0000000000000269.
Smith, K., 2013. Indecent enclosure. Saf. Health Pract. 31 (9), 48–50.
Standards Australia, 2009. Confined Spaces. SAI Global, Sydney, Australia.
Standards Singapore, 2005. Entry into and safe working in confined spaces (Vol. CP 84:2000). SPRING Singapore, Singapore.
Stennett, A., 2018. Engineer's angle: dangers in confined work space. The Gleaner Retrieved from http://jamaica-gleaner.com/article/news/20180805/engineer-angle-dangers-confined-work-space, 5 Aug 18.
Suruda, A., Agnew, J., 1989. Deaths from asphyxiation and poisoning at work in the United States 1984–86. Br. J. Ind. Med. 46, 541–546.
Suruda, A.J., Pettit, T.A., Noonan, G.P., Ronk, R.M., 1994. Deadly rescue: The confined space hazard. J. Hazard. Mater. 36 (1), 45–53. https://doi.org/10.1016/0304-3894(93)E0051-3.
Veasey, D.A., McCormick, L.C., Hilyer, B.M., Oldfield, K.W., Hansen, S., Krayer, T.H., 2005. Confined Space Entry and Emergency Response. J. Wiley & Sons, Hoboken, New Jersey, US.
Wilson, M.P., Madison, H.N., Healy, S.B., 2012. Confined space emergency response: assessing employer and fire department practices. J. Occup. Env. Hyg. 9 (2), 120–128. https://doi.org/10.1080/15459624.2011.646644.
Wilson, P., Wang, Q., 2013. Development of a protocol for determining confined space occupant load. Process Saf. Prog. 33 (2), 143–147. https://doi.org/10.1002/prs.11619.
Workplace Safety Health Council, 2014. Technical Advisory on Working Safely in Confined Spaces. Singapore Government, Singapore.

CHAPTER SIX –
CONFINED SPACE ENGULFMENT

6.1. Introduction

While the exact definition of a confined space varies by jurisdiction, confined spaces are defined by a number of physical criteria and by the hazards they represent. Commonly, the physical description of a confined space is that it is an enclosed or partially enclosed space, not designed for occupancy as a workplace, which may or may not have restricted means for entry and exit (and rescue), and which is typically at a normal atmospheric pressure. The potential hazards of a confined space include unsafe level of oxygen, toxic airborne contaminants, flammable airborne contaminants, and the *risk of engulfment by a free-flowing solid or liquid*. These are by no means the only potential hazards in a confined space, with research finding that physical hazards contribute to up to half of all confined space deaths (Burlet-Vienney et al., 2015a; Issa et al., 2016; Meyer, 2003; NIOSH, 1994; Pettit et al., 1996; Sahli & Armstrong, 1992), as summarised in *Chapter 4 – An Investigation into the Rate and Mechanism of Incident of Work-Related Confined Space Fatalities* above, however engulfment is the only physical hazard explicit in the definition of a confined space.

While there are differences between *entrapment*[13] and *engulfment*[14], delineation between the two is rarely used and the term engulfment is more common. There are a number of mechanisms which result in injury and death in an engulfment scenario, including oxygen asphyxiation (where the oxygen level reduces until it reaches a point which is inadequate for life), asphyxiation through aspiration (where grain or other materials fill the casualty's mouth, nose, and lungs), mechanical asphyxiation (where the pressure of the grain or materials on the chest prevent the breathing process), cardiac arrest (due to the grain pressure reducing blood flow), and environmental exposures such as hypothermia (Issa et al., 2017; Moore & Jones, 2017).

[13] When a casualty is caught in a liquid or free flowing solid but the head remains clear of the engulfing material.
[14] When a casualty is completely covered by the liquid or free flowing solid and is no longer visible.

Despite the prevalence of physical hazards as a mechanism of incident in confined space fatalities, the original criteria for confined spaces only included atmospheric hazards (McManus, 1998), and many jurisdictions such as the provinces of Canada still do not include engulfment as a criteria in the definition (Government of Alberta, 2009; Government of Manitoba, 2006; Government of Ontario, 2017; Government of Sasketchewan, 1996); although the Canadian national regulations include that a confined space 'may become hazardous to any person entering it owing to … the materials or substances in it' (Government of Canada, 2017, part XI). Some studies into confined space incidents categorise a fatality as confined space-related only if the mechanism of incident was related to a hazardous atmosphere (Madison & Wilson, 2008; McManus, 1998; Wilson et al., 2012); while some jurisdictions such as Singapore only record an incident as confined space-related under the same criteria in accordance with the standard (Standards Singapore, 2005) – although the legislation includes the risk of engulfment (Government of Singapore, 2009a).

There is therefore a mismatch between the definition of a confined space and WHS regulators or authorities which do not categorise an engulfment fatality as a confined space incident. This includes jurisdictions which do not specifically include the hazards of engulfment, and jurisdictions such as South Africa which have regulations concerning engulfment hazards ('working in danger of engulfment') separate from confined space hazards (Government of South Africa, 1986). This chapter presents the hazards of engulfment in confined spaces, the risks and magnitude of the problem, and the means to both prevent and respond to a confined space engulfment incident.

6.2 Inclusions and Exclusions

It should be noted that not all engulfment fatalities are confined-space-related. Entrapment in a trench from collapsing materials – with the most likely causes of death being asphyxiation through suffocation (insufficient available oxygen to maintain life) or mechanical asphyxiation (pressure of materials on the chest preventing the breathing process) (Issa et al., 2017; Suruda, Smith, & Baker, 1988) – are not normally considered to be confined space-related, and explicitly excluded as confined space incidents in many jurisdictions. Other instances of collapsing materials, slides, and cave-ins may occur outside of confined spaces.

6.2.1 Trenches

Although not normally considered to be confined spaces, trenches may be confined spaces under certain circumstances. For example, under Australian legislation, trenches may be confined spaces if they ‘potentially contain concentrations of airborne contaminants that may cause impairment, loss of consciousness or asphyxiation’ (Safe Work Australia, 2016, p. 6); and may likewise be a confined space under US legislation when there is an atmospheric risk only (OSHA, 2016). While not considered confined spaces, the following analysis of trench fatalities is included for completeness.

As with many workplace hazards, the danger associated with working in trenches have been acknowledged for many years. During his period as the Home Secretary, in which his responsibilities included WHS, Winston Churchill commissioned a report ‘to inquire into the dangers attending deep excavations in connection with the construction of docks and other similar works’ (Harrison, 1912, p. 1). Among the recommendations of this report were that falls into excavations be prevented through the installation of rails, that adequate means of escape be provided through ladders, and that the sides of trenches and excavations be ‘timbered’ to prevent collapse (ibid, pp. vii-x).

In 1985, NIOSH issued an alert titled ‘Preventing Deaths and Injuries From Excavation Cave-Ins’. This alert examined BLS data over the period 1976 to 1981 and identified that excavation cave-ins resulted in up to 75 fatalities per year – nearly 1% of all US work-related fatalities (NIOSH, 1985), and recommended that shoring or sloping of the sides be used from a depth of 5 feet (1.5m) or more.

306 trench fatalities between 1974 and 1986 with complete reports were analysed by Suruda et al. (1988), who found that most incidents occurred in the construction of sewers, at relatively shallow depths with a mean depth of 11.4 feet (3.5m) and a SD of 4 feet (1.2m). In almost all cases examined, protective measures such as sloped sides or shoring were not used.

In 1989, OSHA issued a new standard for excavation and trenching, which simplified the requirements and added pictorial examples and a graphical summary of the requirements (OSHA, 1989). An analysis of the impact of the new standard and the conduct of an OSHA special emphasis and inspection program was undertaken through the comparison of fatality data before and after the introduction of the new standard. This found a 66% decrease in the number of fatalities in trench and excavation collapse-related incidents (Suruda, Whitaker, Bloswick, Philips, & Sesek, 2002). While the decrease in fatalities are unlikely to be solely as a result of the introduction of the new standard, the decrease in trench-related fatalities was much higher than the 27% decline in total fatalities across the construction industry during the same period. A supplementary amendment to the OSHA standard in 1984 required walkways crossing excavations greater than 6 feet (1.8m) deep to include handrails.

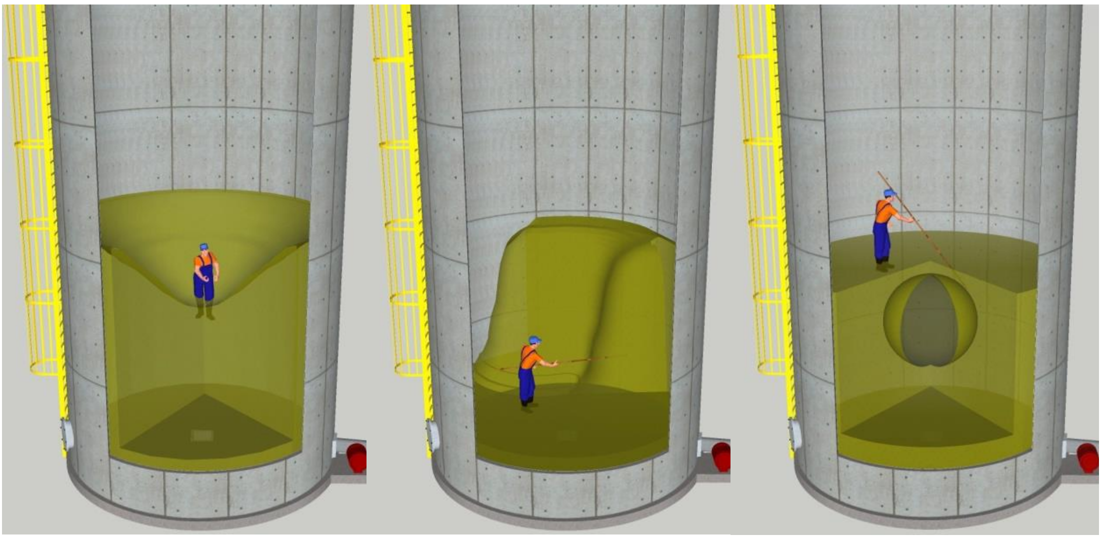
Trench fatalities are not confined to the US, with Fishwick (2007) identifying four fatalities as a result of trench or ditch collapse in the UK between 2002 and 2005; and Selman, Spickett, Jansz, and Mullins (2017 - Chapter 3 of this work) finding eight trench fatalities between 2000 and 2012 in Australia, and five trench fatalities between 2007 and 2012 in NZ (Selman, Spickett, Jansz, & Mullins, 2018 - Chapter 4 of this work).

6.2.2 Other Engulfment Fatalities

Trenches are not the only location where engulfment may occur outside of a confined space. Workplace fatalities can include the collapse of piled materials or natural formations (such as landslides), or when materials spill out of a transport or holding vessel with little or no warning. The author identified a number of instances of workers engulfed by materials without a confined space nexus while undertaking research through the NCIS for Chapters 3 and 4 of this work; and such fatalities have also been reported in the media. Examples include a worker killed when a pile of sand collapsed at a building site, and a worker who was killed working in a quarry when a large landslide engulfed him and the excavator he was operating in at the time.

6.3 THE MAGNITUDE OF THE PROBLEM

Typically, engulfment occurs in confined spaces when a material collapses onto workers below after being disturbed in some manner; when material is introduced into a confined space where work is taking place; or when a worker falls into a product – either from a place or safety or when a substance being walked upon unexpectedly gives way under a worker's feet (Safe Work Australia, 2016). The most common causes of engulfment in agriculture occur when a worker sinks into a mass of grain while a silo or other storage facility is being unloaded (normally via an auger), when a worker is covered by an avalanche of vertical grain (typically crusted damp or mouldy grain), or when a worker falls into a hidden void (usually bridged by damp or mould grain) (Kingman, 2005). These scenarios are depicted in figure 6. It is usually safe to walk on all stationery grain products that do not contain voids.



Sinking while unloading Vertical avalanche Hidden void

Figure 6. Common scenarios for engulfment in agricultural materials.

Common materials involved in engulfment incidents include sand and other minerals, sawdust, woodchips, plastic and other pelletised products. The most common materials are agricultural products, primarily grain (Issa et al., 2016; NIOSH, 1987b; Pettit et al., 1996; Riedel & Field, 2013). There were four identified engulfment fatalities in Australia over the period 2000 to 2012 – with two being from grain in storage silos, one from hot ash in a boiler, and one from cement clinker in a conveyor chute (Selman et al., 2017 - Chapter 4 of this work).

Engulfment in agricultural products, and in particular grain, has been a recognised issue in the US agriculture industry for many years. The hazards of grain engulfment were raised by Field (1980) after the number of engulfments and entrapments was noticed to be increasing annually. Contributing to this increase were faster and larger volume grain handling machinery, larger storage facilities, and extended grain seasons. NIOSH issued an alert in 1987 (NIOSH, 1987a) and an update in 1993 (NIOSH, 1993) which warned grain farmers, workers, and their families of the dangers of grain engulfment; and described the steps to be taken for prevention.

An attempt to numerate the number of confined space grain engulfment fatalities in commercial or depot facilities – as opposed to on-farm incidents – was made by Freeman et al. (1998), who identified and examined 71 cases of grain engulfment in US commercial grain facilities between 1969 and 1995. Unsurprisingly, the majority of engulfments occurred in states with higher grain production; and while a number of bulk materials including soybeans, rapeseed (canola), wheat, peanuts, milo (sorghum) were involved, corn was the engulfing product in 26 (37%) of all cases. Similarly, the Minnesota Department of Health identified corn as the engulfment material in six out of nine (67%) fatal grain engulfment incidents over the period 1992 – 1995 (CDC, 1996). A high rate of morbidity was also noted by Freeman et al., with death of the entrapped casualty the result in 80% (n=57) of incidents.

Of the study Meyer (2003) conducted into confined space deaths using CFOI data over the period 1997 to 2001, it was identified that of the 458 confined space-related fatalities, 130 occurred as a result of engulfment, and 111 occurred in grain storage facilities such as silos and grain bins. Of concern, it was calculated that the relative risk of a confined space fatality was nine times higher in the forestry, fishing, and agricultural industry group – a large industry group but of which crop production is a major part.

As previously described in Chapter 2 – *Literature Review and History*, the PACSID database maintained by Purdue University in Indiana contains consolidated data of all agricultural confined space incidents derived from multiple sources. An analysis of this database found engulfment and entrapment in flowing agricultural materials to account for 683 of the 891 of the incidents which occurred in grain storage and handling facilities through the period 1964 to 2010 (Riedel & Field, 2013). Agricultural products included soybeans, wheat, milo (sorghum), barley, rice, sunflower and peanuts; but again corn was the material involved in the majority of cases, accounting for over 38% of all engulfment cases.

The same report also identified 115 incidents which occurred in or around agricultural transport vehicles of various kinds; and the majority of incidents occurred when workers were inside the vehicle or performing vehicle unloading. When the material was included, corn was the agricultural material in 53% of cases. Unfortunately, 75% of the incidents occurred among children under the age of 16, many of whom were playing in the vehicle, and which resulted in death in 58% of cases (ibid).

Updates to this report published in 2016 and 2017 found that 62% of agricultural confined space incidents still involved engulfment or entrapment in flowing agricultural materials, with a nearly 50% fatality outcome, and it was again noted that US states with higher grain production had a greater number of incidents. (Cheng, Nour, et al., 2018; Issa et al., 2016). While commercial facilities have mandatory reporting requirements, many grain storage facilities on smaller farms remain exempt from OSHA safety regulations and reporting, and both updates estimate up to 30% under-reporting.

A thorough investigation into engulfment and entrapment in agricultural transport vehicles conducted by Cheng, Field, et al. (2018) through the PACSID database found the number of incidents totalled 174 over the period 1964 to 2016; 64% of which resulted in at least one person killed. Corn was the most common product involved in these cases, involved in 61.6% of cases. This study also identified a generally increasing trend of incidents over time; and suggested that one of the factors behind this trend is that smaller farms no longer store grain on the premises (over the ten year period between 2002 and 2012 farm storage capacity across the US decreased by just over 24%), but instead transport their agricultural products to commercial or cooperative facilities as they are harvested.

6.3.1 Prevention

Many of these studies have identified that small farm (farms with less than eleven employees or employing family members) exemptions from OSHA regulations (OSHA, 2011a, 2011b) result in under-reporting by up to 1/3 (Cheng, Field, et al., 2018; Field, 1980; Issa et al., 2016; Riedel & Field, 2013), but also that agriculture in general has a higher incident rate than many other industry groups (Feyer et al., 2001; Lower et al., 2017) with more than half of all incidents under-reported (Leigh, Du, & McCurdy, 2014). Reasons include:

- An older workforce which is statistically less likely to have an accident, but more likely for that accident to be fatal (CAIRS, 2011; Feyer et al., 2001; Grandjean et al., 2006; Jones, Routley, Trytell, Ibrahim, & Ozanne-Smith, 2012)
- Long work hours and fatigue (Day et al., 2009; Pawlak & Nowakowicz-Dębek, 2015; Reed, 2004; Walsh, 2000)
- Undocumented or seasonal workers, often working for low pay (Leigh et al., 2014; Reed, 2004)
- Individual reluctance to wear personal protective clothing (Reed, 2004; Walsh, 2000)
- Workers unaware of the dangers through lack of hazard-specific training, or who choose to ignore the risks (Leigh et al., 2014; Meyer, 2003; Pate & Dai, 2014).

Interestingly, training may not be the answer, as some studies have reported little evidence of the effectiveness of safety training for agricultural workers (McCurdy et al., 2004; Sprince et al., 2003).

Specific to the problem, agricultural workers may also be unaware of the risks of engulfment in a confined space, or of the hazards of working in a confined space in general. Common problems which lead to confined space deaths in general include both workplace factors such as lack of confined space procedures and inadequate training; and individual factors such as failure to identify the entry as a confined space, or entry in violation of workplace procedures. These are described and discussed in *Chapter 5 – Confined Space Rescue: A Proposed Procedure to Reduce the Risks* above. Specific to agricultural confined space hazards, workers may be unable to identify out-of-condition grain and the subsequent hazards, or may have a lack of knowledge of engulfment hazards. Poor communication between workers can be an additional causal factor (Kingman, 2005). Pate and Dai (2014) identified that workers with a higher level of education had a higher perception of risk; and those who had experience with an engulfment incident as a ‘close call’ or who had personal knowledge of an incident also had a higher perception of risk. Even with a thorough understanding of the risks, the issue of deliberate violations remains. Of the 71 incidents surveyed by Freeman et al. (1998), it was concluded that ‘nearly all could have been avoided if appropriate safe work practices procedures had been followed. In every case for which information concerning the activity at the time of entrapment was available, employees became entrapped while performing tasks in direct violation of recommended guidelines’.

6.3.2 Postvention (Emergency Response and Rescue)

The other side of the bowtie[15] for the prevention of confined space engulfment fatalities is the means to respond to an incident and perform a rescue if required after an incident has occurred. A general procedure for confined space rescue – particularly aimed at in-house or on-site rescue teams, was proposed by Selman, Spickett, Jansz, and Mullins (2019 - Chapter 5 in this work), which also noted that the employment of specialised equipment and procedures resulted in a greater chance of success. Rescue of a person entrapped or engulfed in a free-flowing solid requires such equipment and procedures.

A review of rescue strategies used to extricate casualties entrapped or engulfed in grain was made by Roberts et al. (2011), who reviewed the previous literature and examined the narratives of rescue attempts recorded in the PACSID database. Of all the cases in the database, only 52% (n=131) contained information concerning rescue attempts. The most common technique used was to cut holes in the side of the structure to allow the material to flow out and away from the casualty. Of the 118 cases in which this technique was recorded as being used, it was successful in 109 (92%) of cases. There were documented concerns that cutting holes could lead to structural collapse or could initiate a dust explosion; however there were no recorded instances of these risks ever being realised. In some cases, the trapped casualties were fitted with improvised harnesses or ropes to assist in the rescue, or attempts were made to pull the casualty out of the grain – sometimes with fatal outcomes.

[15] A risk analysis model in which control measures to reduce the likelihood of an incident (prevention) are to the left of the safety incident, and control measures to reduce the consequences of an incident (postvention) are to the right. The model looks like a bow tie in appearance when represented graphically.

It was also noted that grain rescue tubes (also variously known as grain retaining walls or cylinders) – either improvised or commercial – were used in 37 of the 131 cases. A grain rescue tube acts both as a source of handhold for the casualty and also acts as a small cofferdam[16] – preventing the backflow of grain in towards the casualty's body as the grain immediately surrounding the casualty is removed. The first reference of a commercial grain rescue tube was made by Carpenter and Bean (1992) who described a three-piece modular stainless steel and reported on the successful real-time use of the device manufactured by The Andersons grain company. A case study describing the successful employment of an improvised grain rescue tube also noted that a vacuum was used to remove the grain from around the entrapped casualty's body, quickly freeing him (Bahlmann et al., 2002).

Kingman, Muller, and Nelson (2007) describe the successful test of a PVC grain rescue tube modelled on the aforementioned Anderson's tube. A mock casualty entrapped in corn was able to be rescued (with the casualty's assistance) just ten minutes after the rescue was initiated, and without the benefits of an auger or vacuum to remove the grain in close proximity to the casualty. Commercial grain rescue tubes didn't become widely available in the US until 2006 (Riedel & Field, 2011; Roberts, Field, Maier, & Stroshine, 2012), and Roberts et al. (2011) noted a gradual increase in their application – often in combination with portable vacuum units. Insertion of a grain rescue tube to retrieve a casualty is not easy, and a later study of the force required to insert the tube noted that factors such as the type of grain, the grain compaction, and the moisture contact all had an impact on the ease of insertion (Roberts et al., 2012).

As previously identified, attempting to physically pull a casualty directly out of a free-flowing solid is difficult, and attempts to do so have resulted in physical injury or even death to the casualty in the past (Roberts et al., 2011). Unsurprisingly, the pull forces required to extricate a buried casualty increase with the depth the casualty is buried (Schwab, Ross, Piercy, & McKenzie, 1985), the point of attachment to the casualty (Roberts et al., 2015), and the angle of pull for the extraction (Issa & Field, 2017). Interestingly, Roberts et al. (2015) found the pull force required to be higher

[16] A cofferdam is a temporary structure usually used in a body of water to create an enclosure from which the water can be pumped out to create a dry environment for work to be carried out.

when attempting to pull a casualty from a shoulder attachment point than a waist attachment point. Most commercially available fall arrest harnesses (the type most commonly used) have a rear dorsal attachment point that will extend to shoulder level or above when retrieval is attempted. Only work positioning (also known as suspension or rope access) harnesses have a waist attachment point, and these are generally not suitable in full fall arrest applications. Trying to fit a harness to a casualty buried shoulder deep in grain is not feasible. As noted by Issa et al. (2018), there are barriers in the use of fall arrest equipment in grain production and storage.

As mentioned, Issa and Field (2017) undertook physical measurements on the forces required to extricate a casualty at various pull angles. They found the forces required were not significantly different in a general vertical pull, only increasing substantially when the pulling angle was 30^{o} or less off the horizontal. Of interest, the experiments conducted by Schwab et al. (1985) were undertaken with two different grain types: dry corn and dry wheat. It was expected that the pull forces would vary between the two due to their different shape and size; however the pull forces were found to be very similar. Issa and Field (2017) conducted their pull test experiments with two different grain types – dry corn and dry soy beans – the most common materials involved. Again it was found that the pull forces were similar except at 15^{o} off horizontal. While this is of note for rescue, there has been no study into the likelihood or propensity for entrapment or engulfment with different grain types – an experimental study worth being conducted.

The procedure for the extraction of a casualty who has been entrapped or engulfed is described and discussed in *Chapter 5 – Confined Space Rescue: A Proposed Procedure to Reduce the Risks* above; and while such a rescue should be conducted in accordance with that proposed procedure, the hazards of engulfment should be noted and training and rehearsal in the specific rescue techniques for engulfment rescue should be undertaken prior. The use of fall arrest equipment to prevent a casualty from full engulfment and to assist in retrieval or extrication has been found to have a number of challenges such as acceptance, training, and a lack of suitable anchor points in structures such as silos and grain bins (Issa et al., 2018); however the combination of rope or similar to prevent further sinking and an improvised or commercial grain rescue has proven to be successful.

So while prevention of entrapment and engulfment is preferred, methods to rescue engulfed casualties have been developed. When used in combination with incident prevention strategies, the incident, injury and fatality rate of confined space engulfment episodes should be reduced. This is especially important for higher risk industries such as grain production and storage. As noted above, the propensity for entrapment in various common grain types should be explored.

CHAPTER SEVEN –
FINAL DISCUSSION, FUTURE DIRECTIONS AND CONCLUSIONS

This chapter provides a summary of the research. There are common causal factors which increase the risks of confined space work, which can result in incidents with the potential for injury or death. These factors are most commonly related to poor identification of the hazards and control of the risks. The root cause of confined space incidents has been identified as poor employment of the risk management process. This chapter includes a review and discussion of those related causal factors which regularly lead to confined space incidents; future directions in technology; the potential for future research; and conclusions of the body of research completed.

7.1 DISCUSSION

Common procedural factors leading to confined space incidents were summarised by Selman et al. (2019 - Chapter 5 of this work) – most of which *ultimately* result from an inadequate risk assessment stemming from poor application of the risk management process. Common procedural factors include lack of identification of confined spaces, lack of or an inadequate risk assessment, lack of confined space knowledge and training, lack of safe confined space procedures, lack of atmospheric testing (and ventilation), lack of isolation (lockout/tagout) procedures, and inadequate rescue planning. There were also a number of violations identified including deliberate entry in contravention of confined space procedures and poorly-conceived attempted rescues. These key causal factors – which are also predominantly human factors – are discussed in detail below.

7.1.1 Knowledge, Training, and Experience

A number of studies have identified that the majority of workplace fatalities occur amongst workers undertaking non-technical or blue-collar tasks; work which, in many cases, does not requiring technical education or training (Driscoll et al., 2001). Young and inexperienced workers are also at a greater risk of injury and death, especially those in the higher risk industry groups of agriculture, forestry, and fishing; and transportation, postal, and warehousing (Ehsani, McNeilly, Ibrahim, & Ozanne-Smith, 2013; Rauscher & Myers, 2016). Confined space fatalities are no exception, with many incidents occurring amongst workers undertaking repair, maintenance, and cleaning tasks (Burlet-Vienney et al., 2015b; Manwaring & Conroy, 1990; Meyer, 2003; Sahli & Armstrong, 1992); and involving younger workers as previously identified by Selman et al. (2017 - Chapter 3 in this work), which attributed these fatalities to lack of experience, inadequate knowledge of the hazards, insufficient training, and immature personal risk assessment skills.

It has also been noted that developing countries do not have the same maturity in workplace health and safety regulations and systems – either government legislated and directed or industry standards – and workers are often unaware of the risks in their workplace (Liu & Hammitt, 1999). A study of confined space workers in South Sudan found that 80% of entrants had received no specific confined space training and that no risk assessment was conducted prior to entry (Abdalwhab & Yassin, 2015). Alarmingly, the same study found that atmospheric testing was not conducted at all for any confined space entry. The lack of education and training in workplace safety in developing countries carries through with immigrant workers, and several studies demonstrate that such workers have higher accident rates in developed countries than local or native-born workers (Reid et al., 2014; Ronda-Perez, Gosslin, Martinez, & Reid, 2019). Reasons include lack of baseline workplace health and safety knowledge, language difficulties, and reluctance to raise concerns with the potential to be seen as a 'trouble-maker' (Guldenmund, Cleal, & Mearns, 2013).

Workers from all three groups (low-skill or blue-collar, young, and migrants) are therefore less likely to have the knowledge, training and experience to safely conduct confined space tasks in the workplace. They require specific training and close observation by their supervisors in the workplace to ensure adherence to established confined space safety systems to reduce the potential for confined space incidents. All confined space regulations and standards however, do include a minimum requirement for training before entry which generally includes the hazards of confined spaces; the requirement to comply with the Permit to Work (PTW) system; the selection, fit, and use of PPE; and the actions to be undertaken in the event of an emergency (Commonwealth of Australia, 2016b; Government of Canada, 2017; Government of Singapore, 2009a; Government of the United Kingdom, 1997; OSHA, 2011c; Standards Australia, 2009). Singapore also requires that supervisors of confined space work undertake training specific to their role (Government of

Singapore, 2009a). In some jurisdictions, such as Australia, the UK, and Singapore, confined space entry training may only be delivered by government accredited training providers who follow a government or industry syllabus.

7.1.2 Safe Work Procedures

Confined space entry must take place under a PTW system in all legislation and / or standards of the various industrialised countries or jurisdictions referenced in this work (Government of Canada, 2017; Government of Singapore, 2009a; Government of the United Kingdom, 1997; OSHA, 2011c; Safe Work Australia, 2018). In the absence of jurisdictional legislation or where the span of work is across multiple jurisdictions, many multi-national companies such as BP (BP, 2018), Chevron (Chevron, 2013), and Anglo American (Anglo American, 2008), among others; or international trade associations such as the International Maritime Organisation (IMO) and the International Association of Oil and Gas Producers (IOGP) have instituted safety requirements (often known as life-saving rules) including PTW systems for confined space work (IMO, 2011; IOGP, 2018). Of note, the US confined space legislation is unique in that it divides confined spaces into confined spaces and *permit-required confined spaces* (PRCS). Regular confined space work is that which is conducted in a place which has limited or restricted means for entry or exit and is not designed for continuous employee occupancy; but which does *not* contain or has a potential to contain a hazardous atmospheres, a risk of engulfment, an internal configuration which may lead to entrapment, or any other serious potential hazard (OSHA, 2011c). Confined spaces with any of those hazards are permit-required confined spaces.

Typical safe work procedures for confined space entry and work include the requirement for a risk assessment; the control of atmospheric risks (through testing, ventilating the space and monitoring the conditions); the control of electrical, mechanical, radiological, and product ingress hazards (usually through lockout / tagout systems); the control of environmental risks (excessive heat or cold); and the control of the risks of engulfment. These safe work procedures cannot entirely remove the risk, but should control the risk so far as is reasonably practicable[17]. Workers must also comply with workplace safe work procedures and not take short-cuts or commit safety violations. In doing so they put themselves (and other workers and rescuers) at risk. Confined space entry in contravention of safety procedures or a PTW system can result in an incident leading to injury or fatality and is a constant theme in confined space incident case studies (ATSB, 2010; CSB, 2006; NIOSH, 2004; Worksafe BC, 2004); and thus having good safe work procedures and adherence to these procedures is critical.

7.1.3 Atmospheric Testing and Monitoring

As previously mentioned, common requirements of regulations and standards include the conduct of atmospheric testing[18] and/or monitoring[19], which will likely reveal the presence of atmospheric hazards (either an unsafe level of oxygen or toxic airborne contaminants) or flammable atmospheric hazards (flammable gases, vapours and dusts). If any of these atmospheric hazards are present, then they need to be controlled in accordance with the hierarchy of control[20] from elimination of the hazard through to administration and personal protective equipment.

Testing is conducted before entry, and in all but the most exceptional circumstances, entry should not take place if the testing indicates the atmosphere of a confined space is anything other than that specified by the appropriate regulations or standards. There are a number of exceptions including when the atmosphere is expected to be non-respirable, such as entry into a nitrogen-filled vessel, and this is only conducted with appropriate entry and rescue planning and appropriate PPE (breathing apparatus systems) worn by entrants. The atmosphere may also be unsafe when rescuers enter to save life, but they also may enter using appropriate control measures (such as

[17] *Reasonably practicable* means what is reasonably able to be done to ensure health and safety, taking into account and weighing up all relevant matters including what is known about a hazard, the likelihood of harm resulting from the hazard, the potential level of harm from the hazard, the means to eliminate or minimise the risk, and the cost associated with eliminating or minimising the risk – including whether the cost is grossly disproportionate to the risk.
[18] Atmospheric *testing* refers to a one-off or regular *non-continuous* scientific procedure to determine the atmospheric contents of the confined space.
[19] Atmospheric *monitoring* refers to the *continuous* scientific examination of the contents of the atmosphere of a confined space throughout the occupation of the space.
[20] The hierarchy of control refers to the system used to minimise the risks of hazards – in decreasing effectiveness: elimination, substitution, engineering, isolation, administration and personal protective equipment.

supplied air breathing apparatus) to reduce the risks of rescue. Typically, confined space regulations and standards refer to an oxygen content of not less than 19.5% by volume, toxic contaminant presence less than specified occupational exposure limits such as the Time Weighted Average (TWA)[21], and flammable concentrations less than 5% of the Lower Explosive Limit (LEL)[22]. These atmospheric requirements for entry are very similar for all jurisdictions, although differences do exist, particularly exposure limits for toxic airborne contaminants (Schenk, Hansson, Rudén, & Gilek, 2008). The lack of or inadequate testing for oxygen content, the presence of toxic airborne contaminants, and the presence of flammable airborne contaminants can have deadly consequences, and accounts for up to half of all confined space fatalities (Selman et al., 2018 - Chapter 4 of this work).

All regulations and standards require testing using suitable (Government of the United Kingdom, 2014) calibrated (OSHA, 2011c; Standards Singapore, 2005) scientific (Standards Australia, 2009) instruments, which usually means the use of an electronic portable gas detector – or when suitable electronic detectors are not available or not appropriate – the use of chemically reactive tests such as gas sampling tubes. Portable electronic gas detectors are available from a wide range of manufacturers and use a number of technologies to detect the presence of gases and vapours; such as catalytic bead sensors (used to measure concentrations of flammable gases – but which also require a certain concentration of oxygen to operate), infrared sensors (used to measure concentration of flammable hydrocarbon gases without the need for oxygen), electrochemical (used to measure concentrations of toxic gases and vapours through chemical reactions), Photo Ionisation Detector (PID) sensors (used to measure very low concentrations of flammable gases such as Volatile Organic Compounds – VOCs – which may be toxic before reaching a flammable concentration), and Flame Ionisation Detector (Keys, Fidanza, Karvonen, Kimura, & Taylor) sensors (used to measure high flammability organic compounds such as methane or ethane and continue to work efficiently in situations with high humidity).

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[21] The Time Weighted Average (TWA) is an exposure limit defined as an average workplace exposure to any hazardous contaminant or agent using the baseline of an 8 hour day or 40 hours per week work schedule. In general working conditions, the TWA should not be exceeded.
[22] The Lower Explosive Limit (LEL) refers to the lowest concentration (by percentage) of a gas or vapour in air that is capable of producing a flash of fire in presence of an ignition source.

Selecting the correct detector suite is critical for safety, and selection should be undertaken using a thorough risk assessment taking into account what contaminants may be or may have previously been inside the confined space, what contaminants may be inside the confined space as a result of chemical reactions or by-products, and what contaminants may be generated through the work being carried out – both directly and as by-products of the work. Multi-gas detectors with four or five sensors are commonly used for general confined space entries, and are most often fitted with oxygen, carbon monoxide, and hydrogen sulphide electrochemical sensors; and a catalytic LEL sensor commonly calibrated for methane. It is important to note that catalytic LEL sensors should be calibrated to the most likely or most flammable gas or vapour in the workplace rather than methane, as some flammable gases have lower LEL. For example, gasoline vapour is more than twice as explosive as methane gas, and a gas detector calibrated to methane may underestimate the atmospheric flammability. Furthermore, catalytic sensors are very poor at measuring diesel fuel vapours, and thus the gas detector suite employed in workplace which contain or are likely to contain flammable gases and vapours should be selected with rigour (Haag & Hintch, 2005; Levine & Thornton, 2004).

Five-gas detectors often include a PID sensor for VOCs or other toxic flammable gases or vapours. Electronic detectors are suitable for a wide range of situations, and many have interchangeable sensors, permitting users to exchange non-applicable sensors for others suitable for the workplace (for example removing the carbon monoxide sensor and replacing it with a chlorine sensor). Electrochemical sensors are available for approximately 25 of the most common industrial toxic contaminants including ammonia, sulphur dioxide, phosphine, hydrogen cyanide, nitrogen dioxide, chlorine, and chlorine dioxide; however this only represents a very small fraction of the tens of thousands of chemicals in use. A wider number (approximately 300) of gases and vapours can be tested using gas sampling tubes, but the range is still limited. While the use of gas sampling tubes is suitable for confined space testing, the results are not rapid enough for this system to be used for confined space atmospheric monitoring for safety (Reed, Pisaniello, Benke, & Burton, 2013).

As previously noted by Selman et al. (2019 - Chapter 5 of this work), lack of confined space training and lack of atmospheric testing were common factors in confined space fatalities; and training in the correct use of atmospheric testing equipment is essential for safe confined space entry and work. Electronic gas detection equipment is becoming easier to use, with manufacturers improving accuracy and response times (Piedrahita et al., 2014) and using remote detection and real-time tracking systems via internet of things (Smith et al.) technologies such as Wi-Fi, Radio-frequency identification (RFID), and other wireless systems (Achkar, Haidar, Makhoul, & Osseili, 2013; Botti et al., 2015; Riaz, Arslan, Kiani, & Azhar, 2014). While data logging for later download is an available option on many models of gas detector, models with real-time monitoring and sharing of atmospheric conditions to supervisor's workstations and portable electronic devices is also gaining acceptance. With the current explosion in wearable technology for health and fitness monitoring (Heikenfeld et al., 2018; Steinmetz & Jones, 2016), application development to provide real-time health and safety monitoring of confined space entrants via smart gas detectors and other wearable technologies also provides the opportunity for greater supervision and safety (Kiehl, Durkee, Halverson, Christensen, & Hellstern, 2019; Mardonova & Choi, 2018).

The requirement for safety training and the correct use of atmospheric testing equipment is not negated however, as the process still requires planning and knowledge of the basic principles in order for the testing to be effective. Appendix B to the US OSHA Regulation requires that testing is conducted first for oxygen, acknowledging that catalytic sensors are oxygen dependent for function (OSHA, 2011c), although most commercial multi-gas detectors conduct all readings simultaneously. Appendix B of the regulation also requires that testing be conducted in consideration of vertical stratification of atmospheric contaminants (lighter- and heavier-than-air gases and vapours), and recommends that calibration be conducted in accordance with manufacturer's instructions or a risk assessment; and that function testing (also known as 'bump testing') be conducted daily. Most electronic detector manufacturers also recommend regular functional testing against a known sample gas.

While commonly-available electronic portable gas detectors are suitable for detection of the most common atmospheric hazards (unsafe level of oxygens and toxic or flammable airborne contaminants including gases and vapours), different instruments are required to measure other potential hazards such as flammable dusts, harmful fibres or other products (such as asbestos or silica), and biological contaminants –

which once again demonstrates the requirement for a thorough risk assessment before any confined space entry or work is undertaken.

7.1.4 Ventilation and Purging

If atmospheric testing reveals the presence of atmospheric hazards at unacceptable levels (as specified by the appropriate regulations) such as oxygen below 19.5% by volume; or toxic contaminants greater than the occupational or permissible exposure limits such as the TWA or Short Term Exposure Limit (STEL)[23], then actions can be taken to reduce the hazards through ventilation or purging. Like atmospheric testing, ineffective or inadequate ventilation will not remove the hazard, and may even introduce a false sense of security among confined space entrants or rescuers.

To prevent the development of, or to clear hazardous atmospheres from confined spaces, natural airflow or ventilation is often required. In some cases, a safe atmosphere can be achieved through natural airflow. In more complex cases, forced ventilation may be required. Portable fans and ducting can be used to evacuate toxic or flammable atmospheres from confined spaces; however consideration must be made for the source of the air (and the exhaust location of the evacuated atmosphere), the complexities (including voids) of the confined space, and ventilation should be planned in consideration of the weight of the potential contaminants – which may be lighter or heavier than air. In some cases, typically confined spaces which normally hold hydrocarbons or other flammable gases or vapours, fresh air ventilation is not suitable (as an explosive air mixture may be formed) and thus purging with an inert gas is required. After any ventilation or purging, atmospheric testing should be undertaken again to test for a safe atmosphere before entry. If contaminants are still detected, then the ventilation or purging should continue until safe atmospheric conditions – as specified in legislation and standards – are achieved; and at regular intervals to ensure the atmospheric conditions remain safe for entry and work.

[23] The Short Term Exposure Limit (STEL) is an exposure limit defined as exposure over a short period of time, usually 15 minutes. Exposure up to the STEL is usually acceptable as long as the time-weighted average is not exceeded.

7.1.4 Confined Space Rescue

In 1986, NIOSH issued an alert which concluded that ‘More than 60% of confined space fatalities occur among would-be rescuers’ (NIOSH, 1986). The sample size used to produce this alert was very small and had no stated selection criteria. An analysis of a number of studies since by Selman et al. (2018 - Chapter 4 of this work) found that proportion of rescuer fatalities was much lower, and no more than 17% of all deaths. Few of the rescuer fatalities were ‘professional rescuers’ – members of professional emergency services or other personnel trained and appointed as rescuers – and in many cases there was the potential for many more rescuer injuries and deaths. Unlike confined space entrants – for whom the mechanism of injury was up to half from physical hazards – rescuers died almost exclusively as a result of atmospheric hazards, mostly the result of hasty and unplanned rescue attempts.

Unplanned or ad-hoc rescue attempts by untrained rescuers are a high risk endeavour with low rates of success. A study of many confined space incidents between 1974 and 1982 led McManus (1998) to calculate that rescue was only successful in 15% of attempts – and that nearly half of the would-be rescuers died in those attempts. It is a requirement of Australian Standard 2865 *Confined Spaces* (and similar in many others in other jurisdictions) that, ‘Appropriate emergency response and first aid procedures and provisions shall be identified, planned, established and rehearsed.’ (Standards Australia, 2009, p. 12). Relying on professional emergency services (such as through dialling 000 or 911) to conduct confined space rescue may be insufficient in a time-sensitive situation, and thus on-site or in-house rescue teams and personnel – with appropriate training – can react more quickly and can successfully retrieve or extricate a casualty from a confined space with little risk.

While professional rescue teams and emergency services are likely appropriately trained and resourced for confined space rescue, workplace rescue personnel are expectedly less experienced and less resourced and the hierarchy of rescue should be prioritised to self-rescue and non-entry rescue. In some circumstances, an entry rescue is required. A simplified rescue procedure, suitable for an on-site or in-house confined space rescue team, consisting of five steps using the acronym REALE (Reconnaissance, Eliminate the hazards, Access the casualty, Life-saving First Aid, and Extrication) was developed and presented in Chapter 5 – *Confined space rescue: A proposed procedure to reduce the risks*.

The decision to conduct an entry rescue should not be taken lightly, as it remains a dangerous undertaking with an historically low rate of success. Appropriate training, rehearsal, and rescue practice using such a procedure will greatly reduce the risk to rescuers should the need for a confined space entry rescue ever arise. In some circumstances a rescue should not be attempted at all; such as when the incident is clearly fatal to the original entrant, or when the danger to the rescuers is too high and the risk of further casualties or fatalities is likely. This is understandably a very difficult moral decision to make, and is not limited to confined spaces. Attempted rescues by would-be, under-trained, or under-equipped rescuers can have fatal consequences for the rescuers in a range of scenarios (Brander et al., 2019; McKie & Richardson, 2003; Pearn & Franklin, 2012).

7.1.5 Safety Culture

A good workplace safety culture[24] is essential to preventing individual accidents and large-scale (or societal) incidents. However, many incidents are caused by unsafe worker behaviours because workplace safety culture is poor. While safety culture is intangible and difficult to measure, personal behaviours which are indicative of the safety culture in a workplace can be observed (Borys, Else, & Leggett, 2009). It is human nature to take shortcuts, especially if safety procedures are believed to be too difficult or time-consuming (Caponecchia & Sheils, 2011; Hopkins, 2005). Confined space work is no exception, and it was observed by Beaver and Field (2007) that there was a level of risk acceptance amongst confined space entrants who assessed the benefits of completing a task to be greater than the potential costs and knowingly entered a confined space despite the risks. This may be more prevalent in confined space entry than other work, as the hazards (such as toxic atmospheres) may be invisible to workers, and this is especially so when an incident occurs as workers find it difficult not to intervene when a fellow worker's life is in danger. More research into the motivations and actions of deliberate safety violations concerning confined space work is recommended.

[24] Safety culture can be defined as the collaborative approach in which people work together to actively identify potential hazards and risks and control them before any loss occurs.

7.2 RESEARCH CONCLUSIONS

Although the dangers of confined spaces have been known since Roman times, it has only been since the structural change in society, from being based on agriculture to being based on industry, brought about by the mechanisation of the means of production, that exposure to confined spaces hazards in the workplace became an occupational concern for many workers. Occupational or workplace fatalities – both traumatic and chronic (resulting from exposures) – result in the injury and death of many workers annually, and considerable effort has taken place to reduce these incidents through the implementation of general workplace and confined space safety regulations and standards. While the exact definition of a confined space varies by jurisdiction, a confined space can be commonly defined as an enclosed or partially enclosed space, which is not intended or designed for occupation for work, and which has a risk of a hazardous atmosphere; or a risk of engulfment by a free-flowing solid or liquid. Confined spaces include vats, tanks, pits, pipes, ducts, silos, sewers, pressure vessels, interiors of machines or plant, and some shipboard spaces. Confined spaces generally do not include ceiling spaces, trenches or mines.

Physical hazards, atmospheric hazards (toxic, oxygen deficient, or flammable), and the dangers of engulfment result in risks to persons working in or in close proximity to confined spaces. There are additional risks to rescuers attempting to retrieve or rescue entrants after an incident, and in some cases, rescuers are killed.

While all WHS authorities or regulatory bodies in industrialised countries have specific regulations or codes of practice for confined space entry and work, the capture of data on confined space fatalities, injuries, and incidents is difficult as there are often no specific coded categories for confined space incidents. The reporting of workplace deaths is required in all industrialised countries, and a numeration of confined space fatalities can often be determined through other means such as coronial records, compensation data, or specific studies, but non-fatal incidents are generally indeterminate.

The original aim was to identify the number, rate, and aetiologies of work-related traumatic confined space fatalities in Australia. This body of work makes a number of conclusions to meet the objectives of this research.

7.2.1 Rate of Traumatic Confined Space Fatalities

There were 59 work-related confined space deaths in Australia over the period 2000 – 2012; 6 work-related confined space deaths in New Zealand over the period 2007 – 2012; and 18 work-related confined space deaths in Singapore over the period 2004 – 2014. The rate of confined space deaths in similar industrialised countries can be estimated to lie between 0.05 and 0.08 fatalities per 100,000 workers, with rates of 0.05 per 100,000 workers in Australia, 0.05 in New Zealand, 0.07 in the US, 0.08 in Singapore, 0.07 in the Canadian province of Quebec, and a claimed rate of 0.05 in the UK. This is a fraction of the rate of overall workplace deaths.

While the rates of confined space fatalities were found to be similar in the industrialised countries included in this research, there remain variations between the countries in industry mix which can have considerable influence on the confined space fatality rate. Workers in some industry groups – notably construction, manufacturing, agriculture, transportation, and utility services – are likely to have a much greater likelihood of exposure to confined space work and thus higher risk. Comparison between countries or jurisdictions is difficult due to differences in industry classification. Both Australia and NZ use the ANZSIC system, Singapore uses the Singapore Standard Industrial Classification (SIC), and the US and Canada use the North American Industry Classification System (NAICS) (Australian Bureau of Statistics, 2013; Standards Singapore, 2005; US Census Bureau, 2017), between all of which there are categorical differences.

Industry groups which are shown to have higher general workplace fatality rates such as the agriculture, forestry and fishing group; the electricity, gas, water, and waste water services group; the construction group; and the transportation, postal, and warehousing group (Safe Work Australia, 2017; Wiatrowski & Janocha, 2014) also had high comparative rates of confined space fatalities across all jurisdictions. One exception was Singapore, which is under-represented by employment in agriculture, forestry and fishing (Government of Singapore, 2017). The manufacturing industry group has a general workplace fatality rate much lower than the other high risk industry sectors but has been found to have a high rate of confined space deaths – most likely due to the exposure to confined space work in particular. While it can be concluded that the risk of a confined space fatality is higher in those industries already regarded as high risk, the risk of a confined space deaths is the manufacturing industry group is also high, and thus countries with a higher proportion of the labour force in those industry groups are likely to have a higher rate of confined space fatalities.

Work-related fatalities remain a significant issue worldwide. While the raw numbers of traumatic confined space fatalities are a fraction of all workplace deaths, and the rate is lower than general workplace deaths, any loss of life has financial impacts and affects family, friends, and workplace colleagues terribly. The identification of the numbers and rate of traumatic confined space fatalities is of benefit to businesses, industry associations, and unions, who will be better informed of the potential for a confined space incident; and to government WHS authorities and regulators, who may use this information to conduct specific-to-confined-spaces safety information campaigns, inspections, and audits.

7.2.2 Confined Space Hazards

Across all similar industrialised countries it was found that up to half of all confined space deaths were due to atmospheric hazards while the remainder were due to physical hazards, including electrocution, entrapment in machinery, falls from height, and engulfment. Engulfment – particularly in grain and other agricultural products is a significant hazard in the agricultural industry.

Up to 17% of the confined space fatalities were found to be those undertaking rescue (lower than the previously published and often-referenced figure of 60%), which were found to be overwhelmingly as a result of hazardous atmospheres.

The underlying root cause for most confined space fatalities was found to be inadequate assessment of the risks to enter or perform work in a confined space and inadequate application of the risk management process. To reduce confined space fatalities, recommendations include improved worker training, knowledge, and supervision; compliance with safe work procedures (including the risk management system and legislation, codes of practice and standards); and the conduct of thorough atmospheric testing and monitoring, ventilation, and purging as required. The organisation must also have safe work procedures for confined space entry and work and safety leadership to instil a good safety culture around confined space work.

The benefits of these findings are to inform businesses, industry associations, unions, government WHS authorities, regulators and legislators of the hazards that may be present and the risks that may arise from working in and around confined spaces. Businesses and workplaces (at all levels) may use this information for the conduct of better hazard awareness and identification, and better conduct of the risk management process in respect to confined space work. Industry associations, unions, and WHS authorities and regulators may also use this information to conduct specific-to-confined-spaces safety information campaigns.

A simplified rescue procedure suitable for in-house or on-site rescue teams was developed based on the standard procedures used by professional rescuers and emergency services which was in regards to the hierarchy of rescue (self-rescue, non-entry rescue, and entry rescue – with an increasing level of difficulty and danger); including specific rescue procedures for confined space engulfment. Businesses and workplaces can use this proposed procedure to prevent fatalities among entrants and rescuers occurring from confined space incidents (by implementing the hierarchy of rescue) and can critically examine the need for an in-house or on-site rescue team and their training needs.

Finally, future and emerging technologies such as smart multi-gas monitors and other wearable technologies are being implemented in various industries, and can provide real-time environmental and worker information to supervisors and managers, enhancing worker safety and reducing confined space incidents. Businesses and workplaces can implement these technologies as available.

7.3 Further Directions in Research

This body of work has identified that the available information on confined space incidents is incomplete. There are a number of areas of study which could be pursued to provide greater clarity on confined space incidents including the identification of incidents which do not result in a fatality; research into the properties of various grains and other agricultural products which lead to confined space incidents; and research into the psychosocial factors of confined space incidents – including the unauthorised entry for rescue.

7.3.1 Identification of Confined Space Incidents

There are difficulties in identifying both fatal and non-fatal confined space incidents. Firstly, while there are a number of coding systems used internationally for the categorisation of accidents and incidents, none have specific coding for confined space incidents with the exception of the system used in the US – the Occupational Injury and Illness Classification System (OIICS) (US Bureau of Labor Statistics, 2012) – although with the caveat that under OIICS, confined spaces would typically only be selected as the *secondary source* (after the *source* – which is essentially the mechanism of injury such as heat, grain engulfment, etc.).

WHS authorities and regulators in Australia use the Type Of Occurrence Classification System (TOOCS) (ASCC, 2008), as described in Chapter 3 – *Work-Related Traumatic Fatal Injuries Involving Confined Spaces in Australia, 2000-2012*, above; while the NCIS uses the International Classification of External Causes of Injury (ICECI) system produced by the World Health Organisation (WHO, 2004). In Europe, the European Statistics on Accidents at Work (ESAW) Methodology is used to classify workplace incidents (European Union, 2012), while the UK uses the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) classification system (Government of the United Kingdom, 2013). As noted, none of these systems have specific coding for confined space incidents although Selman et al. (2017 - Chapter 3 of this work) made recommendations as to how the Australian TOOCS coding could be amended to include confined space incidents.

The second difficulty is in the identification of confined space incidents which result in less-than-fatal injuries or even no injuries (such as near-misses); and incidents which result in chronic injuries and illnesses which may have fatal consequences long after the incident. WHS authorities and jurisdictions often have set criteria for the reporting of workplace injuries and incidents (such as near misses or dangerous incidents), often defined by the type of injury or incident (usually a set number of categories), or the resultant time away from work as the result of an injury. Even so, many incidents, even those which result in injury or which meet the reporting threshold, go unreported and many studies have identified that up to half of all WHS incidents are not reported (de Castro, 2003; Lindquist et al., 2014; Probst & Graso, 2013). There is a substantial research opportunity to attempt to identify an accurate rate of non-fatal confined space incidents.

7.3.2 Confined Space Agricultural Engulfment Incidents

Confined space-related engulfment fatalities occur when workers are entrapped or engulfed in free flowing solids or liquids. Within the agricultural industry, engulfment in agricultural products, particularly grain, has been a recognised issue for many years. Typically, engulfment incidents occur when workers sink into a mass of grain while a silo or other storage facility is being unloaded, when workers are covered by an avalanche of vertical grain, or when workers fall into a hidden void (Issa et al., 2016; Riedel & Field, 2013), as previously described in Chapter 6 – *Confined Space Engulfment*. Incidents also occur in or around agricultural transport vehicles of various kinds – particularly when workers are inside the vehicle or performing vehicle unloading (Cheng, Nour, et al., 2018).

While a range of agricultural products have been identified as the agent of engulfment, food products are the most common. These include grains such as corn, soybeans, canola, wheat, sorghum, barley, and rice; and other food products such as sugar, sunflower seeds and peanuts. Testing has been conducted to determine if there is any difference in the force required to extract a worker trapped in different materials, with the tests revealing the extraction forces in all but extreme angles were similar for corn, soy beans, and wheat (Issa & Field, 2017; Roberts et al., 2011; Roberts et al., 2015). Although it is generally safe (but poor practice) to walk on stationery grains in storage of all types, there has been no study into the likelihood or propensity for entrapment or engulfment with different grain or food product types. This is an area for future experimental research.

7.3.3 Safety Culture

It has been identified at several points in this research that although workers (and supervisors) are aware of the potential dangers of confined space work, safe work procedures are sometimes undertaken poorly or even ignored. This is particular to confined space rescue attempts, as although all confined space regulations and standards emphasise the dangers in unplanned or ad-hoc rescue attempts, up to 17% of all confined space fatalities occurred to those undertaking rescue (Selman et al., 2018 - Chapter 4 of this work); with many of those attempts undertaken by workers despite an understanding of the dangers in doing so. This is an area of possible future qualitative research, in which the motivations to undertake confined space entry and rescue despite non-compliance with the recognised regulations and standards.

References

Abdalwhab, S. M., & Yassin, K. E. E. (2015). Hazards Arising from Working in Confined Spaces - Case Study: Khartoum North Industrial Area, Sudan. *Uni Khartoum Eng J, 5*(1).

Achkar, R., Haidar, C. A., Makhoul, N., & Osseili, H. (2013, 17-20 Nov 2013). *Gas ascertainment via smartphone.* Paper presented at the 2013 7th IEEE GCC Conference and Exhibition, Doha, Qatar.

Agricola, G. (translated 1912). *De Re Metallica (On the Nature of Minerals)* (H. C. Hoover & L. H. Hoover, Trans.). London, England: The Mining Magazine, London.

Anglo American. (2008). The Anglo American safety golden rules. In (pp. 7). London, UK: Anglo American, plc.

ANSI. (1977). Safety Requirements for Working in Tanks and Other Confined Spaces In (Vol. Z117.1). Washington, D.C., United States: American National Standards Institute.

ASCC. (2008). *Type of Occurrence Classification System*. Canberra, ACT: Commonwealth of Australia

ATSB. (2010). *Safety Report: Fatality on board the chemical tanker Bow De Jin at sea off New South Wales* (MO-2009-010). Canberra, ACT: Australian Transport Safety Bureau, Commonwealth of Australia Retrieved from https://www.atsb.gov.au/media/2096584/mo2009010.pdf

Australian Bureau of Statistics. (2013). Australian and New Zealand Standard Industrial Classification 2006 (Revision 2). In (pp. 513). Canberra, ACT: Australian Bureau of Statistics, Commonwealth of Australia.

Australian Bureau of Statistics. (2014). *Report 6202.0, Labour Force, Australia*. (No. 6202.0). Canberra, Australia: Commonwealth of Australia

Bahlmann, L., Klaus, S., Heringlake, M., Baumeier, W., Schmucker, P., & Wagner, K. F. (2002). Case Report: Rescue of a patient out of a grain container: the quicksand effect of grain. *Resusc, 53*(2002), 101-104. doi:10.1016/S0300-9572(02)00009-6

Beaver, R., & Field, W. (2007). Summary of Documented Fatalities in Livestock Manure Storage and Handling Facilities - 1975-2004. *J Agromedicine, 12*(2), 3-23. doi:10.1300/J096v12n02_02

Bluff, E., & Johnstone, R. (2005). The Relationship Between 'Reasonably Practicable' and Risk Management Regulation. *Australian Journal of Labour Law, 18*(3), 197-239.

Borys, D., Else, D., & Leggett, S. (2009). The fifth age of safety: The adaptive age. *J Health Saf Res Pract, 1*(1), 19-27. Retrieved from https://www.aihs.org.au/sites/default/files/JHSRP%20Vol%201%20Issue%201.pdf

Botti, L., Duraccio, V., Gnoni, M. G., & Mora, C. (2015). *A framework for preventing and managing risks in confined spaces through IOT technologies.* Paper presented at the Safety and Reliability of Complex Engineered Systems: ESREL 2015, Zurich, Switzerland.

Botti, L., Duraccio, V., Gnoni, M. G., & Mora, C. (2018). An integrated holistic approach to health and safety in confined spaces. *J Loss Prev Process Ind, 55*(2018), 25-35. doi:10.1016/j.jlp.2018.05.013

BP. (2018). PRO-4.5-0001-1-04 Confined Space Entry In (pp. 11). London, UK: British Petroleum, plc.

Brander, R. W., Warton, N., Franklin, R. C., Shaw, W. S., Rijksen, E. J. T., & Daw, S. (2019). Characteristics of aquatic rescues undertaken by bystanders in Australia. *PLoS One, 14*(2), e0212349. doi:10.1371/journal.pone.0212349

Bugeja, L., Ibrahim, J. E., & Brodie, L. (2010). Occupational death investigation and prevention model for coroners and medical examiners. *Inj Prev, 16*(1), 2-6. doi:10.1136/ip.2009.021808

Burlet-Vienney, D., Chinniah, Y., & Bahloul, A. (2014). The Need for a Comprehensive Approach to Managing Confined Space Entry: Summary of the Literature and Recommendations for Next Steps. *J Occup Environ Hyg, 11*(8), 485-498. doi:10.1080/15459624.2013.877589

Burlet-Vienney, D., Chinniah, Y., Bahloul, A., & Roberge, B. (2015a). Design and application of a 5 step risk assessment tool for confined space entries. *Saf Sci, 80*(2015), 144-155. doi:10.1016/j.ssci.2015.07.022

Burlet-Vienney, D., Chinniah, Y., Bahloul, A., & Roberge, B. (2015b). Occupational safety during interventions in confined spaces. *Saf Sci, 79*(2015), 19-28. doi:10.1016/j.ssci.2015.05.003

Burlet-Vienney, D., Chinniah, Y., Bahloul, A., & Roberge, B. (2016). Risk analysis for confined space entries: Critical analysis of four tools applied to three risk scenarios. *J Occup Env Hyg, 13*(6), D99-D108. doi:10.1080/15459624.2016.1143949

CAIRS. (2011). *Agricultural Fatalities in Canada 1990-2008*. Retrieved from Edmonton, Alberta: https://www.cair-sbac.ca/wp-content/uploads/2012/03/National-Report-1990-2008-FULL-REPORT-FINAL-EN.pdf

Campbell, C. (1990). All About Confined Spaces. *Prof Saf, 35*(2), 33-35.

Caponecchia, C., & Sheils, I. (2011). Perceptions of personal vulnerability to workplace hazards in the Australian construction industry. *J Saf Res, 42*(4), 253-258. doi:10.1016/j.jsr.2011.06.006

Carpenter, T., & Bean, T. (1992). A portable modular grain rescue tube. In *ASAE Paper No. 92-4010*. St Joseph, Michigan: ASAE.

Cassells, V. (2000). *The capital ships: their battles and their badges*. East Roseville, Sydney: Simon & Schuster.

CDC. (1996). *Morbidity and Mortality Weekly Report - Suffocations in Grain Bins - Minnesota, 1992–1995*. Morgantown, West Virginia, United States: Centers for Disease Control, United States Government

Chan, A. P. C., Wong, F. K. W., Hon, C. K. H., Lyu, S., & Javed, A. A. (2017). Investigating ethnic minorities' perceptions of safety climate in the construction industry. *J Saf Res, 63*, 9-19. doi:10.1016/j.jsr.2017.08.006

Cheng, A., Field, W., Issa, S., Kelley, K., Heber, M., & Turner, R. (2018). Summary of U.S. Injuries and Fatalities Involving Entrapment and Suffocation in Grain Transport Vehicles. *J Agric Saf Health, 24*(2), 73-88. doi:10.13031/jash.12479

Cheng, Y., Nour, M., & Field, W. (2018). *2017 Summary of U.S. Agricultural Confined Space-Related Injuries and Fatalities*. West Lafayette, Illinois: Purdue University Retrieved from https://web.nicc.edu/marketing/necas/nfshw/2018/Purdue-Space_Confined_Summary_2017.pdf

Chevron. (2013). JOSOP 403 - Confined Space Entry Standard. In (pp. 26). San Ramon, US: Chevron.

CMC Rescue. (2012). *Confined Space Entry and Rescue Manual*. Goleta, California, US: FSP Books and Videos.

Commonwealth of Australia. (2016a). Model Work Health and Safety Act. In. ACT, Australia: Safe Work Australia, Commonwealth of Australia.

Commonwealth of Australia. (2016b). Model Work Health and Safety Regulations. In. Canberra, ACT: Safe Work Australia, Commonwealth of Australia.

CSB. (2006). *Case Report: Confined Space Entry - Worker and Would-be Rescuer Asphyxiated*. (2006-02-I-DE). Washington, DC, United States: US Government Retrieved from https://www.csb.gov/valero-refinery-asphyxiation-incident/

Day, L., Voaklander, D., Sim, M., Wolfe, R., Langley, J., Dosman, J., . . . Ozanne-Smith, J. (2009). Risk factors for work related injury among male farmers. *Occup Env Med, 66*(5), 312-318. doi:10.1136/oem.2008.040808

de Castro, A. B. (2003). Health & Safety: Barriers to Reporting a Workplace Injury. *Am J Nurs, 103*(8), 112.

Doh, D. S. Q. (2012). Can We Reduce Workplace Fatalities by Half? *Saf Health Work, 3*(2), 104-109. doi:10.5491/SHAW.2012.3.2.104

Dong, X. S., Fujimoto, A., Ringen, K., Stafford, E., Platner, J. W., Gittleman, J. L., & Wang, X. (2011). Injury underreporting among small establishments in the construction industry. *Am J Ind Med, 54*(5), 339-349. doi:10.1002/ajim.20928

Doolan, K. (2007). *HMAS Tobruk: Warship for every crisis*. Queanbeyan, New South Wales: Grinkle Press.

Dorevitch, S., Forst, L., Conroy, L., & Levy, P. (2002). Toxic Inhalation Fatalities of US Construction Workers, 1990 to 1999. *J Occup Environ Med, 44*(7), 657-662.

Driscoll, T., Mitchell, R., Mandryk, J., Healey, S., Hendrie, L., & Hull, B. (2001). Work-related fatalities in Australia, 1989 to 1992: an overview. *J Occup Health Saf: Aust NZ, 17*(1), 45-66.

Driscoll, T., Mitchell, R., Mandryk, J., Healey, S., Hendrie, L., & Hull, B. (2003). Coverage of work related fatalities in Australia by compensation and occupational health and safety agencies. *Occup Env Med, 60*, 195-200.

Ehsani, J. P., McNeilly, B., Ibrahim, J. E., & Ozanne-Smith, J. (2013). Work-related fatal injury among young persons in Australia, July 2000–June 2007. *Saf Sci, 57*(2013), 14-18.

European Union. (1989). On the introduction of measures to encourage improvements in the safety and health of workers at work. In (Vol. 89/391/EEC). Bilbao, Spain: European Agency for Safety and Health at Work.

European Union. (2012). *European Statistics on Accidents at Work (ESAW) - Summary methodology*. Luxemburg, Belgium: European Commission, European Union Retrieved from 1977-0375

European Union. (2018). *Fatal accidents at work, 2015 (incidence rates per 100 000 persons employed)*. Luxembourg: eurostat, European Union Retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php/Accidents_at_work_statistics

Feyer, A.-M., Williamson, A. M., Stout, N., Driscoll, Usher, T. H., & Langley, J. D. (2001). Comparison of work related fatal injuries in the United States, Australia, and New Zealand: method and overall findings. *Inj Prev 7*(1), 22-28. doi:10.1136/ip.7.1.22

Field, B. (1980). The Dangers of Flowing Grain. In (Vol. Publication S-77). West Layfayette, Indiannapolis: Purdue University.

Fishwick, T. (2007). Safe working practices in trenches and shallow ditches. *Loss Prevent Bull, Jun 2007*(195), 12-14.

Freeman, S., Kelley, K., Maier, D., & Field, W. (1998). Review of Entrapments in Bulk Agricultural Materials at Commercial Grain Facilities. *J Saf Res, 29*(2), 123-134. doi:10.1016/S0022-4375(98)00008-5

Fuller, D. C., & Suruda, A. J. (2000). Occupationally related hydrogen sulphide deaths in the United States from 1984 to 1994. *J Occup Env Med, 42*(9), 939-942.

Government of Alberta. (2009). Occupational Health and Safety Code. In (Vol. Alberta Regulation 87/2009). Edmonton, Alberta: Government of Alberta.

Government of British Columbia. (1997). Occupational Health and Safety Regulation. In (Vol. 296/97). Victoria, British Columbia: Queen's Printer, British Columbia.

Government of Canada. (1985). Canada Labour Code. In *RSC 1985 c.L-2*. Ottowa, Canada: Government of Canada.

Government of Canada. (2017). Canadian Occupational Health and Safety Regulations (SOR/86-304). In *Part XI - Confined Spaces*. Ottowa, Canada: Department of Justice, Government of Canada.

Government of Hong Kong. (1999). Factories and Industrial Undertakings (Confined Space) Regulation. In (Vol. Chapter 59AE). Hong Kong: Hong Kong Special Administrative Region, Government of China.

Government of Ireland. (2001). Safety, Health and Welfare at Work (Confined Spaces) Regulations. In (Vol. 218/2001). Dublin: Office of the Attorney General, Government of Ireland.

Government of Malaysia. (2010). Industry Code of Practice for Safe Working in a Confined Space. In (Vol. JKKP DP(S) 127/379/3-1). Putrajaya, Malaysia: Ministry of Human Resources, Government of Malaysia.

Government of Manitoba. (2006). The Workplace Safety and Health Regulations. In (Vol. W210 - 217/2006). Winnipeg, Manitoba: Government of Manitoba.

Government of New Brunswick. (1991). Occupational Health and Safety Act - Regulation. In (Vol. 91-191). Fredericton, New Brunswick: Queen's Printer, Government of New Brunswick.

Government of New South Wales. (1962). Factories, Shops and Industries Act. In (Vol. 43). Sydney, New South Wales: Government of New South Wales.

Government of New South Wales. (2017). *Work Health and Safety Regulation*. Sydney, New South Wales, Australia: Government of New South Wales Retrieved from https://www.legislation.nsw.gov.au/#/view/regulation/2017/404

Government of New Zealand. (2015). Health and Safety at Work Act. In. Wellington, New Zealand: Government of New Zealand.

Government of New Zealand. (2016). *Health and Safety at Work (Mining Operations and Quarrying Operations) Regulations 2016*. Wellington, New Zealand: Government of New Zealand Retrieved from http://www.legislation.govt.nz/regulation/public/2016/0017/latest/DLM6732829.html

Government of Newfoundland and Labrador. (2012). Occupational Health and Safety Regulations. In (Vol. 5/12). St John's, Newfoundland: Queen's Printer, Government of Newfoundland and Labrador.

Government of Northwest Territories. (2015). Occupational Health and Safety Regulations. In (Vol. R-039-2015). Yellowknife, Northwest Territories: Territorial Printer, Government of Northwest Territories.

Government of Nova Scotia. (2013). Occupational Safety General Regulations. In. Halifax, Nova Scotia: Queen's Printer, Government of Nova Scotia.

Government of Nunavut. (2016). Occupational Health and Safety Regulations. In (Vol. R-003-2016). Iqaluit, Nunavut: Territorial Printer, Government of Nunavut.

Government of Ontario. (2017). Ontario Regulations 632/05 - Confined Spaces. In (Vol. Ontario Regulations 632/05). Toronto, Ontario: Queen's Printer for Ontario, Government of Ontario.

Government of Prince Edward Island. (2013). Occupational Health and Safety Act - General Regulations. In. Charlottetown, Prince Edward Island: Queen's Printer, Government of Prince Edward Island.

Government of Quebec. (2017). Regulation respecting occupational health and safety. In *chapter S-2.1, r.13*. Quebec, Quebec: Publications Quebec, Government of Quebec.

Government of Queensland. (1999). *Mining and Quarrying Safety and Health Act*. Brisbane, Queensland, Australia: Government of Queensland Retrieved from https://www.legislation.qld.gov.au/view/html/inforce/current/act-1999-040

Government of Queensland. (2011). *Work Health and Safety Regulation*. Brisbane, Queensland, Australia: Government of Queensland Retrieved from https://www.worksafe.qld.gov.au/laws-and-compliance/workplace-health-and-safety-laws/laws-and-legislation/work-health-and-safety-regulation-2011

Government of Sasketchewan. (1996). The Occupational Health and Safety Regulations, 1996. In (Vol. O-1.1 REG 1). Regina, Saskatchewan: Government of Saskatchewan.

Government of Singapore. (2008a). *Workplace Safety & Health, 2008, National Statistics*. Singapore: Ministry of Manpower, Government of Singapore

Government of Singapore. (2008b). Workplace Safety and Health (Ship Building and Ship Repairing) Regulations 2008. In. Singapore: Ministry of Manpower, Government of Singapore.

Government of Singapore. (2009a). Workplace Safety and Health (Confined Spaces) Regulations 2009. In. Singapore: Ministry of Manpower, Government of Singapore.

Government of Singapore. (2009b). Workplace Safety and Health (Workplace Safety and Health Officers) Regulations 2007. In. Singapore: Ministry of Manpower, Government of Singapore.

Government of Singapore. (2009c). Workplace Safety and Health Act. In *Chapter 354A*. Singapore: Government of Singapore.

Government of Singapore. (2015). *Singapore Yearbook of Manpower Statistics 2015*. Singapore: Ministry of Manpower, Government of Singapore

Government of Singapore. (2017). *Singapore Yearbook of Manpower Statistics 2017*. Singapore: Ministry of Manpower, Government of Singapore

Government of South Africa. (1986). General Safety Regulations, 1986. In (Vol. R: 1031). Pretoria, South Africa: Department of Labour.

Government of South Australia. (1910). Factories Act Amendment Act. In (Vol. 1020). Adelaide, South Australia: Government of South Australia.

Government of the United Kingdom. (1980). Entry into Confined Spaces In (Vol. Guidance Note GS5). Sudbury, Suffolk, England: Health and Safety Executive, Government of the United Kingdom.

Government of the United Kingdom. (1997). The Confined Spaces Regulations. In. London, England: Health and Safety Executive, Government of the United Kingdom.

Government of the United Kingdom. (2013). The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations. In. London, England: Health and Safety Executive, Government of the United Kingdom.

Government of the United Kingdom. (2014). Safe work in confined spaces - Approved code of practice and guidance. In. London, England: Health and Safety Executive, Government of the United Kingdom.

Government of the United Kingdom. (2017). *European Comparisons - Summary of UK Performance*. London, England: Health and Safety Executive, Government of the United Kingdom Retrieved from http://www.hse.gov.uk/statistics/european/european-comparisons.pdf

Government of the United Kingdom. (2018). *Workplace fatal injuries in Great Britain 2018*. London, England: Health and Safety Executive, Government of the United Kingdom Retrieved from http://www.hse.gov.uk/statistics/pdf/fatalinjuries.pdf

Government of Victoria. (2017). *Occupational Health and Safety Regulations 2017*. Melbourne, Victoria, Australia: Government of Victoria

Government of Victoria. (2018). Confined spaces. In. Melbourne, Australia: Work Safe Victoria, Victoria State Government.

Government of Western Australia. (1904). An Act Relating to Factories. In (Vol. 22 of 1904). Perth, Western Australia: Government of Western Australia.

Government of Western Australia. (1996). *Occupational Safety and Health Regulations*. Perth, Western Australia, Australia: Government of Western Australia

Government of Western Australia. (2019). *Work Health and Safety Bill 2019* Perth, Western Australia: Government of Western Australia

Government of Yukon. (2006). Occupational Health and Safety Regulations. In *Part 2 - Confined Spaces*. Whitehorse, Yukon: Territorial Printer, Government of Yukon.

Grandjean, C., McMullen, P., Miller, K., Howie, W., Ryan, K., Myers, A., & Dutton, R. (2006). Severe occupational injuries among older workers: Demographic factors, time of injury, place and mechanism of injury, length of stay, and cost data. *Nurs Health Sci, 8*, 103-107. doi:10.1111/j.1442-2018.2006.00260.x

Grant, T. (2017, 29 Oct 2017). 'We're not seeing the truth': Inside the hidden dangers of the Canadian workplace. *The Globe and Mail*. Retrieved from https://www.theglobeandmail.com/news/national/canadian-workplace-hidden-dangers/article36763608/

Guldenmund, F., Cleal, B., & Mearns, K. (2013). An exploratory study of migrant workers and safety in three European countries. *Saf Sci, 52*, 92-99. doi:10.1016/j.ssci.2012.05.004

Gunby, P. (2011). How bad is the state of occupational fatalities in New Zealand? *N Z J Employ Relat, 36*(1), 31-51.

Haag, W. R., & Hintch, B. (2005). Know Your Application for Gas Detection. *Compliance Magazine, 12*(3), 17-19, 25.

Hämäläinen, P., Takala, J., & Kiat, T. B. (2017). Global estimates of occupational accidents and work-related illnesses, 2017. In. Singapore: Ministry of Manpower, Government of Singapore.

Harrison, C. (1912). *Report of the Departmental Committee on Deep Excavations*. London: Her Majesty's Stationery Office, Government of the United Kingdom

Heikenfeld, J., Jajack, A., Rogers, J., Gutruf, P., Tian, L., Pan, T., . . . Kim, J. (2018). Wearable sensors: modalities, challenges, and prospects. *Lab Chip, 18*(2), 217-248. doi:10.1039/c7lc00914c

Higgins, D. N., Casini, V. J., Bost, P., Johnson, W., & Rautiainen, R. (2001). The Fatality Assessment and Control Evaluation program's role in the prevention of occupational fatalities. *Inj Prev, 7*((Suppl 1)), 27-33. doi:10.1136/ip.7.suppl_1.i27

Hofmann, D. A., Burke, M. J., & Zohar, D. (2017). 100 Years of Occupational Safety Research: From Basic Protections and Work Analysis to a Multilevel View of Workplace Safety and Risk. *J App Psych, 102*(3), 375-388. doi:10.1037/apl0000114

Hopkins, A. (2005). *Safety, culture and risk : The organisational causes of disasters*. Sydney, Australia: CCH Australia.

Hutchins, B. L., & Harrison, A. (1911). *A History of Factory Legislation* (2 ed.). Westminster: P.S King & Son.

IMO. (2011). *Revised Recommendations for Entering Enclosed Spaces Aboard ShipsA.1050(27)* (pp. 13). Retrieved from http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Documents/A%20-%20Assembly/1050(27).pdf

IOGP. (2018). *IOGP Life-Saving Rules* [3]*Report 549* (pp. 22). Retrieved from https://www.iogp.org/bookstore/product/life-saving-rules/

Issa, F., Nour, M., & Field, W. (2018). Utilization and Effectiveness of Harnesses and Lifelines in Grain Entrapment Incidents: Preliminary Analysis. *J Agric Saf Health, 24*(2), 59-72. doi:10.13031/jash.12170

Issa, S., Cheng, Y., & Field, W. (2016). Summary of Agricultural Confined-Space Related Cases: 1964-2013. *J Agric Saf Health, 22*(1), 33-45.

Issa, S., & Field, W. (2017). Determining the Pull-Forces Required to Extricate a Victim Entrapped at Various Angles in a Grain Mass. *Safety, 3*(1), 11-19. doi:10.3390/safety3010011

Issa, S., Field, W., Schwab, C., Issa, F., & Nauman, E. (2017). Contributing Causes of Injury or Death in Grain Entrapment, Engulfment, and Extrication. *J Agromedicine, 22*(2), 159-169. doi:10.1080/1059924X.2017.1283277

Issa, S., Schwab, C., & Field, W. (2015). *A review on the environmental impact and physiological conditions on the human body during an engulfment, entrapment and extrication.* Paper presented at the 2015 ASABE Annual International Meeting, New Orleans, Louisiana, United States.

Johnstone, R. (1999). Improving worker safety: Reflections on the legal regulation of OHS in the 20th century. *J Occup Health Saf Aust NZ, 15*(6), 521-526.

Jones, C., Routley, V., Trytell, G., Ibrahim, J., & Ozanne-Smith, J. (2012). A descriptive analysis of work-related fatal injury in older workers in Australia 2000–2009. *Int J Inj Contr Saf Promot, 21*(1), 85-90. doi:10.1080/17457300.2012.679001

Keys, A., Fidanza, F., Karvonen, M. J., Kimura, N., & Taylor, H. L. (1972). Indicies of relative weight and obesity. *Int J Epidemiol, 43*(3), 655-665. doi:10.1093/ije/dyu058

Kiehl, Z. A., Durkee, K. T., Halverson, K. C., Christensen, J. C., & Hellstern, G. F. (2019). Transforming work through human sensing: a confined space monitoring application. *Struct Health Monit, 2019*, 1-16. doi:10.1177/1475921719840994

Kingman, D. (2005). Using Fault Tree Analysis to Identify Contributing Factors to Engulfment in Flowing Grain in On-Farm Grain Bins. *J Agric Saf Health, 11*(4), 395-405. doi:10.13031/2013.19718

Kingman, D., Deboy, G., & Field, W. (2003). Contributing Factors to Engulfments in On-Farm Grain Storage Bins: 1980 Through 2001. *J Agromed, 9*(1), 39-63. doi:10.1300/J096v09n01_06

Kingman, D., Muller, J., & Nelson, K. (2007). Evaluation of Plastic Grain Engulfment Rescue Device. *J Agric Technol Manag Educ, 22*(2007), 727-741.

Koehoorn, M., Tamburic, L., Xu, F., Alamgir, H., Demers, P. A., & Mcleod, C. B. (2015). Characteristics of work-related fatal and hospitalised injuries not captured in workers' compensation data. *Occup Environ Med, 72*, 413-420. doi:10.1136/oemed-2014-102543

Leigh, J., Du, P., & McCurdy, S. (2014). An estimate of the U.S. government's undercount of nonfatal occupational injuries and illnesses in agriculture. *Ann Epidemiol, 24*(4), 254-259. doi:10.1016/j.annepidem.2014.01.006

Levine, S. P., & Thornton, J. R. (2004). LEL Monitoring During Hazard Surveys for Issuance of Hot Work Permits. *Prof Saf, 49*(2), 31-39.

Leyerle, B. (2009). Refuse, Filth, and Excrement in the Homilies of John Chrysostom. *J Late Antiqu, 2*(2), 337-356.

Lilley, R., Samaranayaka, A., & Weiss, H. (2013). *International comparison of International Labour Organisation published occupational fatal injury rates: How does New Zealand compare internationally?* . Retrieved from Dunedin, New Zealand:

Lindquist, S. L., Yardley, A. J., & Champion de Crespigny, F. E. (2014). Estimating the true number of work-related fatalities due to injury: The traumatic injury fatalities dataset. *J Health Saf, Res Pract, 6*(6), 8-14.

Liu, J., & Hammitt, J. K. (1999). Perceived risk and value of workplace safety in a developing country. *J Risk Res, 2*(3), 263-275. doi:10.1080/136698799376835

Lower, T., Rolfe, M., & Monaghan, N. (2017). Non-intentional farm injury fatalities in NSW, Australia, 2001–2015. *Public Health Res Pract, 27*(5). doi:10.17061/phrp2751746

MacCarron, C. (2006). *Confined Space Fatalities*. (PhD). Edith Cowan, Perth, Western Australia,

MacDonald, W., Driscoll, T., Stuckey, R., & Oakman, J. (2012). Occupational Health and Safety in Australia. *Industrial Health, 50*(3), 172-179. doi:https://doi.org/10.2486/indhealth.MS1374

Madison, H. N., & Wilson, M. P. (2008). *Protecting Workers in Industrial Confined Spaces: California's emergency response requirements are ambiguous and less protective than the federal standard*. Berkely, California: School of Public Health, University of California

Manwaring, J. C., & Conroy, C. (1990). Occupational Confined Space-Related Fatalities: Surveillance and Prevention. *J Safety Res, 21*(4), 157-164. doi:10.1016/0022-4375(90)90023-5

Mardonova, M., & Choi, Y. (2018). Review of Wearable Device Technology and Its Applications to the Mining Industry. *Energies, 11*(3). doi:10.3390/en11030547

Matthews, L. R., Johnstone, R., Quinlan, M., Rawlings-Way, O., & Bohle, P. (2019). Work fatalities, bereaved families and the enforcement of OHS legislation. *J Ind Relat, 61*(5), 637-656. doi:10.1177/0022185619829181

McCann, M., & Zaleski, N. (2006). *Deaths and Injuries Involving Elevators and Escalators*. Retrieved from Silver Spring, Maryland, US:

McCurdy, S., Farrar, J., Beaumont, J., Samuels, S., Green, R., Scott, L., & Schenker, M. (2004). Nonfatal Occupational Injury Among California Farm Operators. *J Agric Saf Health, 10*(2). doi:10.13031/2013.16070

McKenzie, K., Mitchell, R., Scott, D. A., Harrison, J. E., & McClure, R. J. (2009). The reliability of information on work-related injuries available from hospitalisation data in Australia. *Aust NZ J Public Health, 33*(4), 332-338.

McKie, J., & Richardson, J. (2003). The Rule of Rescue. *Soc Sci & Med, 56*(2003), 2407–2419.

McManus, N. (1998). *Safety and Health in Confined Spaces*. Boca Raton, Florida, United States: CRC Press.

Meyer, S. (2003). Fatal occupational injuries involving confined spaces, 1997-2001. *Occup Health Saf, 72*(11), 58-64.

Midson, D. W. (2011). The lessons learnt from hydrogen sulphide incidents in the Royal Australian Navy. *Naval Hist Rev*(March 2011).

Moore, K., & Jones, C. (2017). Grain Entrapment Pressure on the Torso: Can You Breathe while Buried in Grain? *J Agric Saf Health, 23*(2), 99-107. doi:10.13031/jash.11648

NFPA 350. (2019). Guide for Safe Confined Space Entry and Work In (Vol. 350). Quincy, Massachusetts, US: National Fire Protection Association (NFPA).

NIOSH. (1979). Criteria for a Recommended Standard - Working in Confined Spaces. In *80-106*. Cincinnati, Ohio, United States: National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government.

NIOSH. (1985). *Alert 85-110 - Preventing Deaths and Injuries From Excavation Cave-Ins*. Morgantown, West Virginia, United States: National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government Retrieved from https://www.cdc.gov/niosh/docs/85-110/default.html

NIOSH. (1986). *Alert 86-110 - Preventing Occupational Fatalities in Confined Spaces*. Morgantown, West Virginia, United States: National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government

NIOSH. (1987a). *Alert 88-102 - Preventing Entrapment and Suffocation Caused by the Unstable Surfaces of Stored Grain and Other Materials*. Morgantown, West Virginia, United States: National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government Retrieved from https://www.cdc.gov/niosh/docs/88-102/

NIOSH. (1987b). *A Guide to Safety in Confined Spaces*. Washington, DC, United States: National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government

NIOSH. (1993). *Publication 93-116 - NIOSH Warns Farmers of Deadly Risk of Grain Suffocation*. (93-116). Morgantown, West Virginia, United States: National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government

NIOSH. (1994). *Worker Deaths in Confined Spaces - A Summary of NIOSH Surveillance and Investigative Findings*. Cincinnati, Ohio, United States: National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government

NIOSH. (2004). *Case Report: Mechanic Dies from Lack of Oxygen in Transport Tank*. (04-OR-002-01). Portland, Oregon: National Institute for Occupational Safety and Health, Centers for Disease Control, United States Government Retrieved from https://www.cdc.gov/niosh/face/stateface/or/04or002.html

OECD. (1990). Occupational Accidents in OECD Countries. In. In *Employment Outlook 1990* (pp. 133-159). Paris, France: Organisation for Economic Co-operation and Development.

OSHA. (1989). Excavations. In (Vol. Code of Federal Regulations Title 29, Part 1926, Subpart P). Washington, D.C., United States: Occupational Safety and Health Administration, Department of Labor.

OSHA. (1993). Permit-required confined spaces. In (Vol. Code of Federal Regulations Title 29, Part 1910.146). Washington, D.C., United States: Occupational Safety and Health Administration, Department of Labor.

OSHA. (2011a). Grain handling facilities. In (Vol. Code of Federal Regulations Title 29, Part 1910.272). Washington, D.C., United States: Occupational Safety and Health Administration, Department of Labor.

OSHA. (2011b). Occupational Safety and Health Standards for Agriculture. In (Vol. Code of Federal Regulations Title 29, Part 1928). Washington, D.C., United States: Occupational Safety and Health Administration, Department of Labor.

OSHA. (2011c). Permit-required confined spaces. In (Vol. Code of Federal Regulations Title 29, Part 1910.146). Washington, D.C., United States: Occupational Safety and Health Administration, Department of Labor.

OSHA. (2016). Confined Spaces in Construction. In (Vol. Code of Federal Regulations Title 29, Part 1926, Subpart AA). Washington, D.C., United States: Occupational Safety and Health Administration, Department of Labor.

Pate, M., & Dai, X. (2014). Estimating the Effect of Selected Predictors on Agricultural Confined-Space Hazard Perceptions of Utah Farm Owner/Operators. *J Agric Saf Health, 20*(2), 109-125. doi:10.13031/jash.20.10386

Pawlak, H., & Nowakowicz-Dębek, B. (2015). Agriculture: Accident-prone Working Environment. *Agric Agric Sci Procedia, 7*, 209-214. doi:10.1016/j.aaspro.2015.12.019

Pearn, J. H., & Franklin, R. C. (2012). "The Impulse to Rescue": Rescue Altruism and the Challenge of Saving the Rescuer. *Int J Aquat Res Educ, 6*(4), 325-335. doi:10.25035/ijare.06.04.07

Pettit, T. A., Braddee, R. W., Suruda, A. J., Castillo, D. N., & Helmkamp, J. C. (1996). Worker deaths in confined spaces. *Prof Saf, 41*(11), 22-25.

Piedrahita, R., Xiang, Y., Masson, N., Ortega, J., Collier, A., Jiang, Y., . . . Shang, L. (2014). The next generation of low-cost personal air quality sensors for quantitative exposure monitoring. *Atmos Meas Tech, 7*(10), 3325-3336. doi:10.5194/amt-7-3325-2014

Probst, T. M., & Graso, M. (2013). Pressure to produce = pressure to reduce accident reporting? *Accid Anal Prev, 59*, 580-587.

Rauscher, K. J., & Myers, D. J. (2016). Occupational fatalities among young workers in the United States: 2001–2012. *Am J Ind Med, 59*(6), 445-452. doi:10.1002/ajim.22581

Reed, D. (2004). The risky business of production agriculture: health and safety for farm workers. *AAOHN J, 52*(9), 401-411.

Reed, S., Pisaniello, D., Benke, G., & Burton, K. (Eds.). (2013). *Principles of Occupational Health and Hygiene* (2nd ed.). Sydney, NSW, Australia: Allen and Unwin.

Reid, A., Lenguerrand, E., Santos, I., Read, U., LaMontagne, A. D., Fritschi, L., & Harding, S. (2014). Taking risks and survival jobs: Foreign-born workers and work-related injuries in Australia. *Saf Sci, 70*, 378-386. Retrieved from http://www.sciencedirect.com/science/article/pii/S0925753514001611

Rekus, J. (2018). *Complete Confined Spaces Handbook* (2 ed.). Boca Raton, Florida: CRC Press.

Rhodes, P. (2003). *Technical Rope Systems, and Confined Space Rescue: Urban Technical Rescue, Volume 1* (3rd ed. Vol. 1): Premium Source Publishing.

Riaz, Z., Arslan, M., Kiani, A. K., & Azhar, S. (2014). CoSMoS: A BIM and wireless sensor based integrated solution for worker safety in confined spaces. *Automat Constr*, *45*(2014), 96-106. doi:10.1016/j.autcon.2014.05.010

Riedel, S., & Field, W. (2011). *2010 Summary of Grain Entrapments in the United States*. West Lafayette, Illinois: Purdue University

Riedel, S., & Field, W. (2013). Summation of the Frequency, Severity, and Primary Causative Factors Associated with Injuries and Fatalities Involving Confined Spaces in Agriculture. *J Agric Saf Health*, *19*(2), 83-100.

Robens, A. L. (1972). *Report of the committee on safety and health at work, 1970-1972*. London: Her Majesty's Stationery Office

Roberts, M., Deboy, G., Field, W., & Maier, D. (2011). Summary of Prior Grain Entrapment Rescue Strategies. *J Agric Saf Health*, *17*(4), 303-325. doi:10.13031/2013.39804

Roberts, M., Field, B., Maier, D., & Stroshine, R. (2012). Determination of Effort Required to Insert a Rescue Tube into Various Grain Types. *J Agric Saf Health*, *18*(4), 293-308.

Roberts, M., Field, W., Maier, D., & Stroshine, R. (2015). Determination of Entrapment Victim Extrication Forces with and without Use of a Grain Rescue Tube. *J Agric Saf Health*, *21*(2), 71-83. doi:10.13031/jash.21.10150

Ronda-Perez, E., Gosslin, A., Martinez, J., & Reid, A. (2019). Injury vulnerability in Spain. Examination of risk among migrant and native workers. *Saf Sci*, *115*, 36-41. doi:https://doi.org/10.1016/j.ssci.2019.01.026

Roop, M., Vines, T., & Wright, R. (1998). *Confined Space and Structural Rope Rescue*. St Louis, Missouri, US: Mosby-Year Book.

Ross, P. (2007). Confined Space Entry - Mitigating Risk in General Industry. *AAOHN J*, *55*(6), 245-249.

Royal Australian Air Force. (2001). *Report of the F111 Deseal/Reseal Board of Inquiry* Canberra, ACT: Royal Australian Air Force, Department of Defence

Royal Australian Navy. (1998). *Report of the Board of Inquiry into the fire in HMAS Westralia on 5 May 1998* Canberra, ACT: Royal Australian Navy, Department of Defence

Russell, D. (2015). Grain engulfment 2015 - case study. Retrieved from http://news-cfa-stage.data-solutions.com.au/news/grain-engulfment-2015-case-study.html

Safe Work Australia. (2015). *Explanatory notes for Safe Work Australia datasets* Canberra, ACT: Commonwealth of Australia Retrieved from https://www.safeworkaustralia.gov.au/system/files/documents/1911/explanatory-notes-datasets.pdf

Safe Work Australia. (2016). *Code of Practice: Confined Spaces*. Canberra, ACT: Commonwealth of Australia

Safe Work Australia. (2017). *Work-related Traumatic Injury Fatalities, Australia 2016*. Canberra, ACT: Commonwealth of Australia Retrieved from https://www.safeworkaustralia.gov.au/system/files/documents/1710/work-related-traumatic-injury-fatalities-report-2016.pdf

Safe Work Australia. (2018). *Code of Practice: Confined Spaces*. Canberra, ACT: Commonwealth of Australia Retrieved from https://www.safeworkaustralia.gov.au/system/files/documents/1810/model-cop-confined_spaces.pdf

Sahli, B., & Armstrong, C. (1992). Confined Space Fatalities in Virginia. *J Occup Med, 39*(9), 910-917. doi:10.1016/0022-4375(93)90011-B

Sargent, C. (2000). *Confined Space Rescue* (J. Bacon, J., Ed.). Saddlebrook, New Jersey, US: Fire Engineering Books and Videos.

Schenk, L., Hansson, S. O., Rudén, C., & Gilek, M. (2008). Occupational exposure limits: A comparative study. *Regul Toxicol Pharmacol, 50*(2), 261-270.

Schwab, C., Ross, U., Piercy, L., & McKenzie, B. (1985). Vertical pull and immersion velocity of mannequins trapped in enveloping grain flow. *Trans ASABE, 28*(6), 1997-2002. doi:10.13031/2013.32555

Selman, J., Spickett, J., Jansz, J., & Mullins, B. (2017). Work-related traumatic fatal injuries involving confined spaces in Australia, 2000-2012. *J Health Saf Env, 33*(2), 197-215.

Selman, J., Spickett, J., Jansz, J., & Mullins, B. (2018). An investigation into the rate and mechanism of incident of work-related confined space fatalities. *Saf Sci, 109*(Nov 2018), 333-343. doi:10.1016/j.ssci.2018.06.014

Selman, J., Spickett, J., Jansz, J., & Mullins, B. (2019). Confined space rescue: A proposed procedure to reduce the risks. *Saf Sci, 113*(2019), 78-90. doi:10.1016/j.ssci.2018.11.017

Smith, T. D., Herron, R., Le, A., Wilson, J. K., Marion, J., & Vicenzi, D. A. (2018). Assessment of confined space entry and rescue training for aircraft rescue and fire fighting (ARFF) members in the United States. *J Saf Res, 67*, 77-82. doi:10.1016/j.jsr.2018.09.014

Smith, T. J., Marriott, B. P., Dotson, L., Bathalon, G. P., Funderburk, L., White, A., . . . Young, A. J. (2012). Overweight and Obesity in Military Personnel: Sociodemographic Predictors. *Obesity*, 1534-1538.

Sprigge, S. S. (1921). Motor Exhaust Gas in Confined Spaces. *Lancet* (Nov. 12), 1017-1018.

Sprince, N., Zwerling, C., Lynch, C., Whitten, P., Thu, K., Logsden-Sackett, N., . . . Alavanja, M. (2003). Risk Factors for Agricultural Injury: A Case-Control Analysis of Iowa Farmers in the Agricultural Health Study. *J Agric Saf Health, 9*(1), 5. doi:10.13031/2013.12346

Standards Australia. (1995). Safe Working in a Confined Space. In (Vol. 2865). Sydney, Australia: SAI Global.

Standards Australia. (2009). Confined Spaces. In (Vol. 2865). Sydney, Australia: SAI Global.

Standards Singapore. (2005). Entry into and safe working in confined spaces. In (Vol. CP 84:2000). Singapore: SPRING Singapore.

Statistics New Zealand. (2016). *Household Labour Force Survey (series)*. Wellington, New Zealand: Government of New Zealand

Statistics New Zealand. (2017). *Work-related injury targets at a glance: 2008–16*. Wellington, New Zealand: Government of New Zealand

Steinmetz, L. M., & Jones, A. (2016). Sensing a revolution. *Mol Syst Bio, 12*(4). doi:10.15252/msb.20166873

Stennett, A. (2018, 5 Aug 18). Engineer's Angle: Dangers In Confined Work Space. *The Gleaner*. Retrieved from http://jamaica-gleaner.com/article/news/20180805/engineer-angle-dangers-confined-work-space

Suruda, A. (1992). Work-related deaths in construction painting. *Scand J Work Environ Health, 18*(1), 30-33.

Suruda, A., & Agnew, J. (1989). Deaths from asphyxiation and poisoning at work in the United States 1984-86. *Br J Ind Med*(46), 541-546.

Suruda, A., Pettit, T., Noonan, G., & Ronk, R. (1994). Deadly rescue: The confined space hazard. *J Hazard Mater, 36*(1), 45-53. doi:10.1016/0304-3894(93)E0051-3

Suruda, A., Smith, G., & Baker, S. P. (1988). Deaths from trench cave-in in the construction industry. *J Occup Med, 30*(7), 552-555.

Suruda, A., Whitaker, B., Bloswick, D., Philips, P., & Sesek, R. (2002). Impact of the OSHA Trench and Excavation Standard on Fatal Injury in the Construction Industry. *J Occup Env Med, 44*(10), 902-905.

Takala, J. (1999). Global Estimates of Fatal Occupational Accidents. *Epidemiology, 10*(5), 640-646.

Thackrah, C. T. (1832). *The Effects of the Principal Arts, Trades, and Professions on Health and Longevity* (2nd ed.). London, England: Longman, Rees, Orme, Brown, Green, & Longman.

Tucker, S., & Keefe, A. (2018). *2018 Report on Work Fatality and Injury Rates in Canada*. Regina, Saskatchewan: University of Regina Retrieved from https://www.uregina.ca/business/faculty-staff/faculty/file_download/2018-Report-on-Workplace-Fatalities-and-Injuries.pdf

US Bureau of Labor Statistics. (2012). *Occupational Injury and Illness Classification Manual* Washington, D.C., United States: Bureau of Labor Statistics, Department of Labor Retrieved from https://www.bls.gov/iif/oiics_manual_2010.pdf

US Bureau of Labor Statistics. (2017). *National Census of Fatal Occupational Injuries in 2016*. (USDL-17-1667). Washington, D.C., United States: Bureau of Labor Statistics, Department of Labor Retrieved from https://www.bls.gov/news.release/pdf/cfoi.pdf

US Bureau of Labor Statistics. (2018). *All Employees, Total non-farm, Seasonally Adjusted, Time series CES0000000001*. (CES0000000001). Washington, D.C., United States: Bureau of Labor Statistics, Department of Labor Retrieved from https://data.bls.gov/timeseries/CES0000000001

US Census Bureau. (2017). North American Industry Classification System 1997. In (pp. 513). Washington, D.C., United States: US Census Bureau, Department of Commerce.

Occupational Safety and Health Act of 1970, (1970).

Veasey, D. A., McCormick, L. C., Hilyer, B. M., Oldfield, K. W., Hansen, S., & Krayer, T. H. (2005). *Confined Space Entry and Emergency Response*. Hoboken, New Jersey, US: J. Wiley & Sons.

Vivona, B. D., & Ty, R. (2011). Traumatic Death in the Workplace: Why Should Human Resource Development Care? *Adv Dev Hum Resour, 13*(1), 647-666. doi:10.1177/1523422311410654

Walsh, M. (2000). Farm accidents: Their causes and the development of a nurse led accident prevention strategy. *Emerg Nurs, 8*(7), 24-31.

WHO. (2004). *International Classification of External Causes of Injuries*. Amsterdam, The Netherlands: World Health Organisation Retrieved from https://www.whofic.nl/sites/default/files/2018-05/ICECI%20in%20English.pdf

Wiatrowski, W. J., & Janocha, J. A. (2014). Comparing fatal work injuries in the United States and the European Union. *Mon Labor Rev, 6*, 1-6. doi:10.21916/mlr.2014.23

Wilson, D. J., Takahashi, K., Sakuragi, S., Yoshino, M., Hoshuyama, T., Imai, T., & Takala, J. (2007). The ratification status of ILO conventions related to occupational safety and health and its relationship with reported occupational fatality rates. *J Occup Health, 49*, 72-79.

Wilson, M., Madison, H., & Healy, S. (2012). Confined Space Emergency Response: Assessing Employer and Fire Department Practices. *J Occup Env Hyg, 9*(2), 120-128. doi:10.1080/15459624.2011.646644

Winder, C. (2009). The development of OHS legislation in Australia. *J Occup Health Saf Aust NZ, 25*(4), 277-287.

Windholz, E. (2013). The long and winding road to OHS harmonisation. *Labour History*(104), 169-188.

Windholz, E. (2016). Work health and safety laws and professional sport: New Zealand and Australia compared *Australian and New Zealand Sports Law Journal, 11*(1), 1-25.

Woolford, M. H., Bugeja, L., Driscoll, T., & Ibrahim, J. E. (2017). Missed Opportunities to Prevent Workplace Injuries and Fatalities. *New Solut, 27*(1), 16-27. doi:10.1177/1048291117693389

Workplace Safety and Health Council. (2011). *Workplace Safety and Health, 2011, National Statistics*. Singapore: Ministry of Manpower, Singapore Government

Worksafe BC. (2004). *Accident Alert: Four Workers Die in Confined Space* (AA-03-1). Richmond, British Columbia, Canada: Workers' Compensation Board of British Columbia, Government of British Columbia

Yoshimura, A., Kako, Y., & Satoh, F. (2007). A Study on Requirements for Confined Space Rescue and Confined Space Medicine Training Facilities in Japan *J Soc Saf Sci, 9,* 311-320.

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ETHICS APPROVAL –
CURTIN UNIVERSITY

Curtin University

Memorandum

To	Associate Professor Ben Mullins, School of Public Health/Department of Health, Safety and Environment
From	Professor Stephan Millett, Chair, Human Research Ethics Committee
Subject	Protocol Approval **HR 18/2013**
Date	1 February 2013
Copy	Mr. Jason Selman School of Public Health Professor Jeff Spickett School of Public Health

Office of Research and Development
Human Research Ethics Committee

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for providing the additional information for the project titled "*Work-related traumatic fatal injuries involving confined spaces in Australia*". The information you have provided has satisfactorily addressed the queries raised by the Committee. Your application is now **approved**.

- You have ethics clearance to undertake the research as stated in your proposal.
- The approval number for your project is **HR 18/2013.** *Please quote this number in any future correspondence.*
- Approval of this project is for a period of twelve months **29-01-2013** to **29-01-2014**. To renew this approval a completed Form B (attached) must be submitted before the expiry date **29-01-2014**.
- It is your responsibility, as the researcher, to meet the conditions outlined above and to retain the necessary records demonstrating that these have been completed.

Applicants should note the following:

It is the policy of the HREC to conduct random audits on a percentage of approved projects. These audits may be conducted at any time after the project starts. In cases where the HREC considers that there may be a risk of adverse events, or where participants may be especially vulnerable, the HREC may request the chief investigator to provide an outcomes report, including information on follow-up of participants.

The attached **FORM B** should be completed and returned to the Secretary, HREC, C/- Office of Research & Development:
When the project has finished, or

- If at any time during the twelve months changes/amendments occur, or
- If a serious or unexpected adverse event occurs, or
- 14 days prior to the expiry date if renewal is required.
- An application for renewal may be made with a Form B three years running, after which a new application form (Form A), providing comprehensive details, must be submitted.

Yours sincerely

Professor Stephan Millett
Chair Human Research Ethics Committee

ETHICS APPROVAL –

JUSTICE HUMAN RESEARCH ETHICS COMMITTEE

(FOR ACCESS TO THE NATIONAL CORONIAL INFORMATION SYSTEM)

Department of Justice

Justice Human Research Ethics Committee

Planning Performance and Projects
Level 21
121 Exhibition Street
Melbourne, Victoria 3000
GPO Box 123A
Melbourne, Victoria 3001
Telephone: (03) 8684 1514
Facsimile: (03) 8684 1525
DX 210077

3 May 2013

Reference: CF/13/6856

Dr Ben Mullins
Curtin University

Re: Work Related Traumatic Fatal Injuries Involving Confined Spaces in Australia

Dear Ben,

The Department of Justice Human Research Ethics Committee (JHREC) considered your application in relation to the project *Work Related Traumatic Fatal Injuries Involving Confined Spaces in Australia* at its meeting on 1 May 2013 and granted **full approval** for the duration of the investigation. The Department of Justice reference number for this project is CF/13/6856. Please note the following requirements:

- To confirm JHREC approval sign the Undertaking form attached and provide both an electronic and hardcopy version within ten business days.
- The JHREC is to be notified immediately of any matter that arises that may affect the conduct or continuation of the approved project.
- You are required to provide an Annual Report every 12 months (if applicable) and to provide a completion report at the end of the project (see the Department of Justice Website for the forms).
- Note that for long term/ongoing projects approval is only granted for three years, after which time a completion report is to be submitted and the project renewed with a new application.
- The Department of Justice would also appreciate receiving copies of any relevant publications, papers, theses, conferences presentations or audiovisual materials that result from this research.
- All future correspondence regarding this project must be sent electronically to ethics@justice.vic.gov.au and include the reference number and the project title. Hard copies of signed documents or original correspondence are to be sent to The Secretary, Justice Human Research Ethics Committee, PO Box 4356, Melbourne, Victoria, 3001.

If you have any queries regarding this application you are welcome to contact me on (03) 8684 1514 or email: ethics@justice.vic.gov.au.

Yours sincerely,

Ms Nicole Wilson, Secretary,
Department of Justice Human Research Ethics Committee

ETHICS APPROVAL –
CORONER'S COURT OF WESTERN AUSTRALIA
(FOR ACCESS TO WA DATA IN THE NATIONAL CORONIAL INFORMATION SYSTEM)

CORONER'S COURT OF WESTERN AUSTRALIA

OUR REF: **EC13/13**

Jason Selman
7 Bendigo Court
ANNANDALE QLD 4817

By e-mail: ***jason.selman@curtin.edu.au***

22 April 2014

Dear Mr Selman

Application for access to WA Coronial Data via NCIS

I refer to your letter to the Coronial Ethics Committee dated 13 February 2014. Your letter was considered at the Committee meeting on 8 April 2014.

The State Coroner, at the recommendation of the Committee, has approved your application subject to the following conditions:

i. access be for a period of three years, until **7 April 2017**;

ii. that only the named applicants be 'authorised persons' for the purposes of access (and the Committee be notified of any changes in writing); and

iii. at the end of the three year period, the Committee will require notification about whether the needs and applications for the data have changed, so as to assess whether any changes in the form of the original application are required (although an entirely new application will not necessarily be required); and

iv. the applicant is to provide the Committee with an **annual report** or update on the progress of the research. Your first update report is due **6 April 2015**.

I can advise you that items such as full police reports and post mortem reports from Western Australia will not be able to be accessed on the NCIS. If this information is essential, a further application may be required in order for arrangements to be made for an approved person to attend the Court and view files. This will require the submission, to the Ethics Committee, of a curriculum vitae, and current police criminal record check, for each person being nominated to view the files.

Please also note that great care ought to be taken to ensure that identifiable information is protected. All identifiable information must be accessed and stored on a suitably secure computer, and that computer should preferably be one that can only be accessed via a secure room at the Curtin University.

Should you have any questions, please do not hesitate to contact me on (08) 9425 2900.
Yours faithfully,

Kate Ellson
Secretary - Coronial Ethics Committee

cc **Joanna Cotsonis**
NCIS Access Liaison Officer
VIFM
57-83 Kavanagh Street
SOUTHBANK VICTORIA 3006
E-mail: joannac@ncis.org

CENTRAL LAW COURTS, LEVEL 10, 501 HAY STREET, PERTH WA 6000
telephone: (08) 9425 2900 | **fax:** (08) 9425 2901 | **country callers:** 1800 671 994
general email: dave.dent@justice.wa.gov.au | **web:** www.coronerscourt.wa.gov.au

PUBLICATION STATEMENT
(ALL PUBLICATIONS FROM THESIS, CHAPTERS 3, 4, 5)

I, Jason Stuart Selman, provided the following contribution to the three journal papers:

- Work-related traumatic fatal injuries involving confined spaces in Australia, 2000-2012. Selman J, Spickett J, Jansz J, Mullins B. *Journal of Health, Safety and Environment*, 2017; 33(2): 197-215.
- An investigation into the rate and mechanism of incident of work-related confined space fatalities. Selman J, Spickett J, Jansz J, Mullins, B. *Safety Science*, 2018; 109 (2018): 333-343.
- Confined space rescue: A proposed procedure to reduce the risks. Selman J, Spickett J, Jansz J, Mullins, B. *Safety Science*, 2019; 113 (2019): 78-90.

- conception and design of the research

- data collection and cleaning

- statistical design / method selection and analysis

- interpretation and discussion

- final approval and submission

Jason Selman ____________________________

I, as a co-author, endorse that this level of contribution by the candidate indicated above is appropriate and consistent with the candidate being named as first author.

My contributions to this consisted of advising on study design, ethical issues, data analysis approach, content advice, editing, and proof-reading the paper prior to submission.

Jeffrey Spickett ____________________________

Janis Jansz ____________________________

Ben Mullins ____________________________

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Tue 22/01, 7:35 AM
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Dear Jason

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THE DEFINITION OF A CONFINED SPACE

The table below is a consolidated list of the definition of a confined space as per the legislation and / or standards of various countries or jurisdictions referenced in this work.

Table 3. The definition of a confined space by various jurisdiction.

Country / Jurisdiction and Regulation / Standard	Definition of Confined Space	Comments
Australia Code of Practice (Safe Work Australia, 2018)	An enclosed or partially enclosed space that: (a) is not designed or intended primarily to be occupied by a person; and (b) is, or is designed or intended to be, at normal atmospheric pressure while any person is in the space; and (c) is or is likely to be a risk to health and safety from: (i) an atmosphere that does not have a safe oxygen level; or (ii) contaminants, including airborne gases, vapours and dusts, that may cause injury from fire or explosion; or (iii) harmful concentrations of any airborne contaminants; or (Hämäläinen et al.) engulfment, but does not include a mine shaft or the workings of a mine.	Applies to all Australian States and Territories except Victoria and Western Australia
State of Victoria, Australia Regulation (Government of Victoria, 2017)	A space in any vat, tank, pit, pipe, duct, flue, oven, chimney, silo, reaction vessel, container, receptacle, underground sewer or well, or any shaft, trench or tunnel or other similar enclosed or partially enclosed structure, if the space —	

	(a) is, or is intended to be, or is likely to be, entered by any person; and (b) has a limited or restricted means for entry or exit that makes it physically difficult for a person to enter or exit the space; and (c) is, or is intended to be, at normal atmospheric pressure while any person is in the space; and (d) contains, or is intended to contain, or is likely to contain — (i) an atmosphere that has a harmful level of any contaminant; or (ii) an atmosphere that does not have a safe oxygen level; or (iii) any stored substance, except liquids, that could cause engulfment — but does not include a shaft, trench or tunnel that is a mine or is part of the workings of mine.	
State of Western Australia, Australia Regulation (Government of Western Australia, 1996)	An enclosed or partially enclosed space which — (a) is not intended or designed primarily as a workplace; and (b) is at atmospheric pressure during occupancy; and (c) has restricted means for entry and exit, and which either — (d) has an atmosphere containing or likely to contain potentially harmful levels of contaminant; or (e) has or is likely to have an unsafe oxygen level; or (f) is of a nature or is likely to be of a nature that could contribute to a person in the space being overwhelmed by an unsafe atmosphere or a contaminant.	

New Zealand Australian / New Zealand Standard 2865 (Standards Australia, 2009)	An enclosed or partially enclosed space that is not intended or designed primarily for human occupancy, within which there is a risk of one or more of the following: (a) An oxygen concentration outside the safe oxygen range. (b) A concentration of airborne contaminant that may cause impairment, loss of consciousness or asphyxiation. (c) A concentration of flammable airborne contaminant that may cause injury from fire or explosion. (d) Engulfment in a stored free-flowing solid or a rising level of liquid that may cause suffocation or drowning.	An approved Code of Practice under New Zealand legislation
Canada Regulation (Government of Canada, 2017)	An enclosed or partially enclosed space that (a) is not designed or intended for human occupancy except for the purpose of performing work, (b) has restricted means of access and egress, and (c) may become hazardous to any person entering it owing to (i) its design, construction, location or atmosphere, (ii) the materials or substances in it, or (iii) any other conditions relating to it.	National legislation. Applies to employees of companies or sectors that operate across provincial or international borders – approximately 6% of the Canadian workforce.
Province of Ontario, Canada Regulation (Government of Ontario, 2017)	An enclosed or partially enclosed space that: (i) is not primarily designed or intended for human occupancy, except for the purpose of performing work; and	

	(ii) has restricted means of entrance and exit; A ***hazardous confined space*** means a confined space that is or may become hazardous to a worker entering the confined space due to: (i) the design, construction or atmosphere of the confined space; (ii) the materials or substances in the confined space; (iii) the work activities or processes used in the confined space; or any other conditions relating to the confined space.	
Province of Quebec, Canada Regulation (Government of Quebec, 2017)	Any area that is completely or partially enclosed, especially a reservoir, a silo, a vat, a hopper, a chamber, a vault, a tank, a sewer including a ditch and a temporary manure storage ditch, a pipe, a chimney, an access shaft, a truck or freight car tank, which has the following inherent conditions: (1) is not designed for human occupation, nor intended to be, but may occasionally be occupied for the performance of work; (2) access to which can only be had by a restricted entrance/exit; (NFPA 350) can represent a risk for the health and safety of anyone who enters, owing to any one of the following factors: (a) its design, construction or location, except for the entrance/exit provided for in paragraph 2; (b) its atmosphere or insufficiency of natural or mechanical ventilation; (c) the materials or substances that it contains; (d) or other related hazards.	Known as an 'enclosed area' in Quebec

Province of Nova Scotia, Canada Regulation (Government of Nova Scotia, 2013)	An enclosed or partially enclosed space (a) not designed or intended for regular human occupancy; (b) with restricted access or exit; and (c) that is or may become hazardous to a person entering it because of its design, construction, location, atmosphere or the materials or substances in it or other conditions. When assessing whether a space is or may become hazardous to a person entering it because of its atmosphere under clause (1)(c), a person must not take into account the protection afforded to a person through the use of personal protective equipment or ventilation.	
Province of New Brunswick, Canada Regulation (Government of New Brunswick, 1991)	An enclosed or partially enclosed space not designed or intended for continuous human occupancy with restricted access or egress and which is or may become hazardous to a person entering it because of its design, construction, location, atmosphere or the materials or substances in it or other conditions, but does not include a development heading in an underground mine.	
Province of Manitoba, Canada Regulation (Government of Manitoba, 2006)	An enclosed or partially enclosed space that (a) except for the purpose of performing work, is not primarily designed or intended for human occupancy; and (b) has restricted means of access or egress.	

Province of British Columbia, Canada Regulation (Government of British Columbia, 1997)	An area, other than an underground working, that (a) is enclosed or partially enclosed, (b) is not designed or intended for continuous human occupancy, (c) has limited or restricted means for entry or exit that may complicate the provision of first aid, evacuation, rescue or other emergency response service, and (d) is large enough and so configured that a worker could enter to perform assigned work.	
Province of Prince Edward Island, Canada Regulation (Government of Prince Edward Island, 2013)	An enclosed or partially enclosed space (a) not designed or intended for human occupancy; (b) with restricted access or exit; and (c) that is or may become hazardous to a person entering it because of its design, construction, location, atmosphere or the materials or substances in it or other conditions, and includes any bin, tank, tanker, tunnel, silo, sewer, vault, chamber, pipeline, pit, vessel, vat and flue.	
Province of Saskatchewan, Canada Regulation (Government of Sasketchewan, 1996)	An enclosed or partially enclosed space that: (i) is not primarily designed or intended for human occupancy, except for the purpose of performing work; and (ii) has restricted means of entrance and exit; A hazardous confined space means a confined space that is or may become hazardous to a worker entering the confined space due to: (i) the design, construction or atmosphere of the confined space;	

	(ii) the materials or substances in the confined space; (iii) the work activities or processes used in the confined space; or (Hämäläinen et al.) any other conditions relating to the confined space.	
Province of Alberta, Canada Regulation (Government of Alberta, 2009)	A restricted space which may become hazardous to a worker entering it because of (a) an atmosphere that is or may be injurious by reason of oxygen deficiency or enrichment, flammability, explosivity or toxicity, (b) a condition or changing set of circumstances within the space that presents a potential for injury or illness, or (c) the potential or inherent characteristics of an activity which can produce adverse or harmful consequences within the space.	

Province of Newfoundland and Labrador, Canada Regulation (Government of Newfoundland and Labrador, 2012)	An enclosed or partially enclosed space that (a) is not designed or intended for human occupancy except for the purpose of performing work; (b) has restricted means of access and egress; and (c) may become hazardous to a person entering it as a result of (i) its design, construction, location or atmosphere, (ii) the materials or substances in it, or (iii) any other conditions relating to it. A worker shall not work in a confined space after January 1, 2013 unless he or she has completed a confined space entry program prescribed by the commission.	
Northwest Territories, Canada Regulation (Government of Northwest Territories, 2015)	An enclosed or partially enclosed space, that is not designed or intended for continuous human occupancy, with a restricted means of entry or exit. A *hazardous confined space* means a confined space that endangers or could endanger a worker entering into or already in the confined space due to: (i) the design, construction or atmosphere of the space; (ii) the materials or substances in the space; (iii) the work activities or processes used in the space; or (Hämäläinen et al.) any other conditions relating to the space.	

Territory of Nunavut, Canada Regulation (Government of Nunavut, 2016)	An enclosed or partially enclosed space, that is not designed or intended for continuous human occupancy, with a restricted means of entry or exit. A *hazardous confined space* means a confined space that endangers or could endanger a worker entering into or already in the confined space due to: (i) the design, construction or atmosphere of the space, (ii) the materials or substances in the space, (iii) the work activities or processes used in the space, or (iv) any other conditions relating to the space.	
Territory of Yukon, Canada Regulation (Government of Yukon, 2006)	An area, other than an underground mine, that (a) is enclosed or partially enclosed, (b) is not designed or intended for human occupancy, (c) has limited or restricted means for entry or exit that may complicate the provision of first aid, evacuation, rescue or other emergency response services, and (d) is large enough and so configured that a worker could enter to perform assigned work	
Singapore Regulation (Government of Singapore, 2009a)	Any chamber, tank, manhole, vat, silo, pit, pipe, flue or other enclosed space, in which — (a) dangerous gases, vapours or fumes are liable to be present to such an extent as to involve a risk of fire or explosion, or persons being overcome thereby; (b) the supply of air is inadequate, or is likely to be reduced to be inadequate, for sustaining life; or (c) there is a risk of engulfment by material;	

Singapore Standard (Standards Singapore, 2005)	Any chamber, tank, vat, pit, pipe, flue including any other similar space, in which: (a) dangerous airborne substances are liable to be present to such an extent as to involve risk of fire or explosion occurring; or (b) dangerous airborne substances are liable to be present to such an extent as to involve risk of persons being overcome by such substances; or (c) there is a risk of persons being asphyxiated due to inadequate supply of air.	Not mandatory – recommendation only.
United Kingdom Regulation (Government of the United Kingdom, 1997)	Any place, including any chamber, tank, vat, silo, pit, trench, pipe, sewer, flue, well or other similar space in which, by virtue of its enclosed nature, there arises a reasonably foreseeable ***specified risk***. A ***specified risk*** means a risk of — (a) serious injury to any person at work arising from a fire or explosion; (b) without prejudice to paragraph (a) — (i) the loss of consciousness of any person at work arising from an increase in body temperature; (ii) the loss of consciousness or asphyxiation of any person at work arising from gas, fume, vapour or the lack of oxygen; (c) the drowning of any person at work arising from an increase in the level of liquid; or (d) the asphyxiation of any person at work arising from a free flowing solid or the inability to reach a respirable environment due to entrapment by a free flowing solid.	

United States Regulation (general) – PRCS (OSHA, 2011c) Regulation (construction industry) (OSHA, 2016)	A ***confined space*** is a space that: (1) Is large enough and so configured that an employee can bodily enter and perform assigned work; and (2) Has limited or restricted means for entry or exit (for example, tanks, vessels, silos, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry.); and (NFPA 350) Is not designed for continuous employee occupancy. In addition, a ***permit required confined space (PRCS)*** 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; (NFPA 350) 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.	
United States NFPA Standard 350 (National Fire Protection Association – NFPA) – (NFPA 350, 2019)	A ***confined space*** is a space that (1) is large enough and so configured that a person can bodily enter and perform assigned work, (2) has limited or restricted means for entry or exit, and (NFPA 350) is not designed for continuous occupancy. A ***permit required confined space (permit-space)*** is a ***confined space*** that has one or more of the following characteristics:	NFPA standards are not mandatory but are recommendations only. NFPA standards are used extensively by professional emergency services in North America.

	(1) contains or has the potential to contain a hazardous atmosphere; (2) contains a material that has the potential for engulfing an entrant; (NFPA 350) 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.	
South Africa Regulation (Government of South Africa, 1986)	An enclosed, restricted, or limited space in which, because of its construction, location or contents, or any work activity carried on therein, a hazardous substance may accumulate or an oxygen-deficient atmosphere may occur, and includes any chamber, tunnel, pipe, pit, sewer, container, valve, pump, sump, or similar construction, equipment, machinery or object in which a dangerous liquid or dangerous concentration of gas, vapour, dust or fumes may be present.	
Republic of Ireland Regulation (Government of Ireland, 2001)	Any place which, by virtue of its enclosed nature creates conditions which give rise to a likelihood of accident, harm or injury of such a nature as to require emergency action due to — (a) the presence or the reasonably foreseeable presence of (i) flammable or explosive atmospheres, (ii) harmful gas, fume, or vapour, (iii) free flowing solid or an increasing level of liquid, (Hämäläinen et al.) excess of oxygen, or (v) excessively high temperature. (b) lack or reasonably foreseeable lack of oxygen.	

Hong Kong, China Regulation (Government of Hong Kong, 1999)	Any place in which, by virtue of its enclosed nature, there arises a reasonably foreseeable ***specified risk***, and without limiting the generality of the foregoing, includes any chamber, tank, vat, pit, well, sewer, tunnel, pipe, flue, boiler, pressure receiver, hatch, caisson, shaft or silo in which such risk arises. A ***specified risk*** means a risk of — (a) serious injury to any person at work arising from a fire or explosion; (b) the loss of consciousness of any person at work arising from an increase in body temperature; (c) the loss of consciousness or asphyxiation of any person at work arising from gas, fume, vapour or the lack of oxygen; (d) the drowning of any person at work arising from an increase in the level of liquid; or (e) the asphyxiation of any person at work arising from a free flowing solid or the inability to reach a respirable environment due to entrapment by a free flowing solid.	
Malaysia Industry Code of Practice (Government of Malaysia, 2010)	An enclosed or partially enclosed space that is at atmospheric pressure during occupancy and is not intended or designed primarily as a place of work, and – (a) is liable at any time to – (i) have an atmosphere which contains potentially harmful levels of contaminants; (ii) have an oxygen deficiency or excess; or (iii) cause engulfment; and (b) could have restricted means for entry and exit.	