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CONFINED SPACE WORKING SAFETY STUDY

BP INSTITUTE – CAMBRIDGE UNIVERSITY

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INTRODUCTION

The question of safety in confined spaces in our industry has been a topic of discussion for many years.

The industry operators, regulators and service industries are well aware that working in confined spaces and working at heights create potential risk of injuries or worse.

What is not commonly known is the quantum of risk.

Without this information it is difficult for stakeholders, particularly at senior levels, to give clear direction to their organisations on what to do to mitigate or eliminate this risk to a level that is ethically acceptable and that demonstrates duty of care to regulators.

As a director of EM&I and as Project Director of HITS and other safety focused JIPs, I was not sure that we had the requisite information to make good decisions in this context.

This being the case I sought on behalf of EM&I and HITS to sponsor an independent study which might provide the guidance needed.

The BP Institute (University of Cambridge) appeared to have the capability to do the required work under the supervision of Professor Andrew Woods and they were duly commissioned to carry out a study that would quantify risk and give guidance on how this might be mitigated.

The study has proved to give important insights on confined space risk, and we are happy to offer this information to HITS and other organisations that might use it to improve safety in our industry.

I hope you find it useful in improving safety in our industry.

Danny Constantinis

Professor Andy Woods
BP Institute
University of Cambridge

Safety in confined spaces with reference to Floating Production Storage and Offloading Units (FPSOs) and other marine vessels

Note: The analysis carried out in this report is of an experimental and developmental nature. No representation or warranty, express or implied, is provided by Professor Andrew Woods, Cambridge University Technical Services Limited noting that the report or the analysis herein will provide any particular result or outcome.
The analysis was commissioned by EM&I.

ABSTRACT
The offshore Oil & Gas (O&G) floating production industry has long been aware of the combined risks of death and serious injury presented by Confined Space Entry (CSE) and working at heights in those confined spaces. The commercial and financial impact of incidents leading to death or serious injury is high. Policy and practices have been developed to mitigate the risk, reducing probability and consequences of accidents.

This report describes and quantifies the safety risks, using historic data of confined space working in the context of both Trading and Floating Offshore vessels of similar structure, and summarises some of the regulations and laws regulating the safety procedures for confined space working.
Using historic reports of some fatal accidents in confined spaces, the contributing factors are discussed, leading to an assessment of the likelihood of a fatal accident, assuming similar industry wide application of safety protocols.

This paper provides guidance on how stakeholders such as owners, regulators, insurance, and classification societies can calculate the risks in their own sector and how much effort and cost should be expended to reduce the risk to a level as Low as Reasonably Practicable (ALARP).
Whilst Duty holders should set their own criteria for the acceptability and tolerability of total risk to individuals, the broadly acceptable level of risk of a fatality is 1 in 1,000,000 per person per year ($1x10^{-6}$).

Drawing on data available in the public domain, this report suggests that current risk of a fatality in a confined space on an FPSO is about 8.6×10^{-4} per person per year, and on a ship around 1.3×10^{-4} per person per year, clearly higher than the broadly acceptable risk level.

In 2020, HM Treasury in the United Kingdom assessed that the cost of an incident resulting in a fatality might be in the order of GBP 2 million (~US$2.75M).
The ALARP principle, and regulatory guidance suggests that reasonable expenditure to mitigate the risk should be in 'gross disproportion' to the cost of an incident. This paper suggests how stakeholders can calculate expenditure reasonably required to eliminate or mitigate the risk of fatalities. (The report does not consider risk or mitigation costs of avoiding injury or health issues).

Whereas improved procedural methodology is a useful way of mitigating these risks, it cannot eliminate them. Technology for eliminating such risks is becoming commercially available and may prove to be a step forward in removing or reducing exposure risk for confined space working.
Such technology can provide a means to comply with the ALARP principle of safety; compliance with which is described by various regulators and may be the focus of courts when assessing if adequate steps have been taken to avoid or mitigate the risk.

Footnote - The HITS JIP (Hull Inspection Techniques and Strategy Joint Industry Project) was established in 2013 by a group of operators, classification societies, service providers and academic organisations to improve the way hulls were inspected, including CSE, initially on FPSOs. The JIP encourages and supports development of methods to avoid or at least minimise CSE, thus demonstrating the desire within industry stakeholders to improve safety with respect to this known hazard.
Other organisations are also encouraging industry to take steps to reduce injuries and fatalities.

https://shipinsight.com/articles/initial-results-from-deaths-in-enclosed-spaces-research-released

https://www.imarest.org/themarineprofessional/interactions/6353-engineering-out-enclosed-space-deaths

Contents

1. Executive Summary

1.1 Background

Industry has long been aware of the dangers of confined space entry and of working at height within confined spaces.

Many guidance documents have been developed to reduce the risk of entry and working in such spaces.

The offshore hydrocarbons and marine industries have been particularly aware of such risks and have similarly adopted guidance and practices to reduce the probability and consequences of such events.

The consequences in terms of death, injury and commercial loss are high and evidence suggests that there are things that can be done to reduce, mitigate or eliminate such risks.

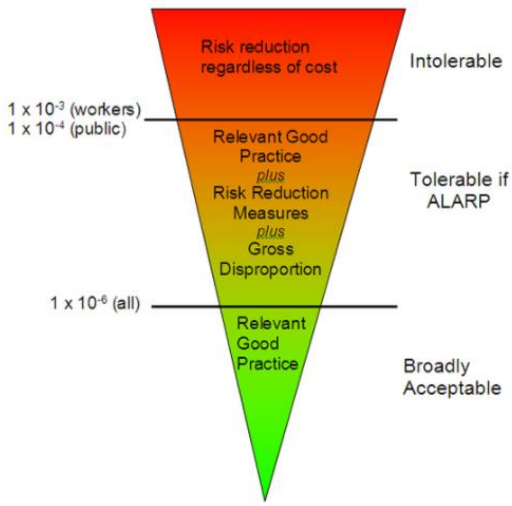
Around 8 years ago a group of operators, classification societies, service providers and academic organisations agreed to form HITS (Hull Inspection Techniques and Strategy), a Joint Industry Project (JIP) to improve the way hulls were inspected.

HITS and other groups, encouraged the offshore and shipping industry to develop ways of avoiding or minimising tank entry, thus demonstrating the desire within industry stakeholders to improve safety with respect to this known hazard.

This document focuses on the issue of working in confined spaces in the offshore oil and gas sector so that stakeholders at all levels can better understand and mitigate or eliminate such risks.

The document also provides guidance on how to calculate the risks and how much effort and cost should be expended to reduce the risk to a level as low as reasonably practicable.

Whilst Duty holders should set their own criteria for the acceptability and tolerability of total individual risk, it is common practice that the broadly acceptable level of individual risk is at least 1 in 1,000,000 per year.



The cost of mitigating or eliminating a risk of a fatality is connected to the risk level, with regulatory guidance suggesting that expenditure should be in ‘gross disproportion’ to the cost of an incident, which might be in the order of GBP 2 million (UK HM Treasury in 2020).

Thus, whilst different organisations may choose particular risk targets as being tolerable, in the event of death or injury the relevant courts may have to decide if the risk level and mitigation actions chosen were reasonable in the circumstances.

This report suggests that current risk of a fatality in a confined space on an FPSO is about 8.6 x 10^{-4} per person year and on a ship around 1.3 x 10^{-4} per person year.

These risk levels while in the tolerable range, if they are managed to be as low as reasonably practicable (ALARP), are nevertheless clearly far higher than what is the lower level of broadly acceptable.

Additional consequences should be considered by stakeholders, for example, loss of production, reputational loss, or loss of share value and thus industry stakeholders should be encouraged to reduce, mitigate, or eliminate the risks related to confined space entry and working at height within such spaces to a broadly acceptable level.

Examples are given later in the document for how stakeholders can calculate the risks and actions to reasonably mitigate or eliminate such risks.

It should be noted that such examples are very much subject to the data available and should be regularly reviewed so as to remain current.

1.2 The Risks

Risk is defined as the Probability of an event taking place multiplied by the Consequences of such an event.

This study seeks to identify and quantify the risk but notes that the number of events in the Oil/Gas sector is relatively small although the consequences are high.

By looking at similar industries with more data, for example shipping, probability information can reasonably be used to inform the likelihood of incidents in the Oil / Gas sector, particularly for floating assets such as floating production, storage and offtake vessels (FPSOs).

Consequences are also discussed, and the study draws on available data that describes certain consequences such as death or injury to the workforce, loss of assets and reduced production.

Other consequences, such as loss of reputation, are more difficult to quantify but may be significant, nevertheless.

Owners, operators, and regulators will no doubt be aware of the risks and one of the purposes of this document is to provide a greater understanding and quantification of these risks.

1.3 Regulatory Guidance

Regulators across many countries have provided guidance on confined space working and guidance for working at heights. In the oil / gas sector these activities often occur at the same time, for example rope access technicians working at height inside a cargo oil tank, thereby compounding the risks.

Regulatory guidance covers topics such as how to decide when a risk is As Low As Reasonably Practicable (ALARP) and how much effort and cost is reasonable to expend on reducing such risks from a human safety viewpoint.

The study explores this topic using the United Kingdom HSE as an example, noting that their approach is often mirrored with other Regulators.

1.4 Observations

A number of observations may be drawn from the study including that the current level of risk of a fatality is higher than industry guidelines would wish and that the consequences of these incidents although relatively rare are very substantial in terms of both the fatality and also collateral impacts of lost production and corporate reputation.

HSE guidelines suggest that the risk of a fatality for a worker of less than 1 in 1,000 per person per year is intolerable, whilst the risk of a fatality of more than 1 in 10,000 per person per year for the general public is intolerable.

Broadly acceptable risks, however, in contrast are 1 in 1,000,000 per person year.
The HSE introduced the concept of “tolerability”, and explained it as follows (HSE 1992):

“Tolerability” does not mean “acceptability”. It refers to a willingness to live with a risk so as to secure certain benefits and in the confidence that it is being properly controlled. To tolerate a risk means that we do not regard it as negligible or something we might ignore, but rather as something we need to keep under review and reduce further if and when we can. For a risk to be “acceptable” on the other hand means that for purposes of life or work, we are prepared to take it pretty well as it is.

The HSE criteria have been proposed for application to average individual risk on offshore installations as follows (Schofield 1993: A framework for offshore risk criteria in: Safety and Reliability, Taylor and Francis): the maximum tolerable risk for installations in general is 1 in 1,000 per person per year; the benchmark for new/modern installations is 1 in 10,000 per person year, and the risk which is broadly acceptable is 1 in 1,000,000 per person per year. However, the official assessment principles for offshore safety cases state (HSE 1998: “Assessment Principles for Offshore Safety Cases”, HS(G)181, Health & Safety Executive, HMSO).

Duty holders should set their own criteria for the acceptability and tolerability of total individual risk and may wish to follow the abovementioned industry guidelines.

The cost of mitigating or eliminating a risk of a fatality is connected to the risk level, with the guidance suggesting that the mitigating cost should higher in gross disproportion to the value of preventing the fatality (Reducing Risks, Protecting People: HSE's Decision Making Process, 2001). In the document HSE (1999), "Reducing Risks, Protecting People", Discussion Document, Health & Safety Executive, there is some clarification of the meaning of gross disproportion.

"The test of 'gross disproportion' when weighing risks against costs implies that, at least, there is a need to err on the side of safety in the computation of safety costs and benefits. In short, case law requires that there should be a transparent bias on the side of health and safety. The acceptance of this bias is fundamental to conformity with the law. Moreover, the extent of the bias (i.e., the relationship between action and risk) has to be argued in the light of all the circumstances applying to the case and the precautionary approach that these circumstances warrant. Our general approach is that as a rule, whenever possible, standards should be improved or at least maintained".

Thus, whilst different organisations may choose particular risk targets as being tolerable, in the event of death or injury the relevant courts may have to decide if the risk level and mitigation actions chosen were reasonable in the circumstances.

Additional consequences of an event are another key factor in assessing the level of risk for stakeholders, for example, loss of production, reputational loss, or loss of share value, may play a significant part in assessing what an organisation is willing to pay to mitigate the risk.

All sectors of the industry should be encouraged to reduce, mitigate, or eliminate the risks related to confined space entry and working at height within such spaces.

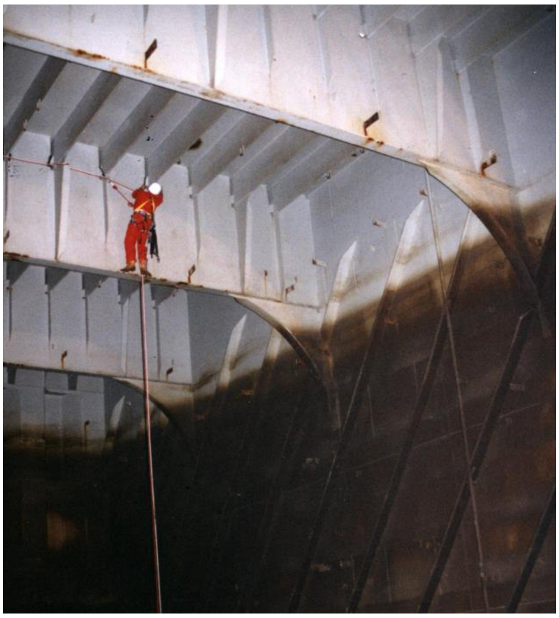
Regulations and industry guidelines on operating in these environments safely have had a positive effect in reducing these risks over the years, albeit the risk levels remain close to the limit of 'tolerable risk'.

Incidents still occur and it may be that technology that reduces the need to work in confined spaces may assist in bringing the risk levels down to a more acceptable level.

Guidance on what are considered as reasonable costs and effort for risk reduction are also discussed in this report and this guidance can be a useful tool for stakeholders to give direction to their organisations on risk reduction actions.

It is important to recognise that human entry into confined spaces also requires considerable time and planning to ensure the safety protocols are followed.
Activities such as tank cleaning and inspection by people working inside the confined space incurs considerable exposure to risk and, potentially impacting production. Indeed, in the context of FPSOs and similar oil and gas producing vessels with flow rates of 50-100 thousand barrels a day, and oil prices of USD 50 - 100 a barrel, the value of production in 24 hours may represent USD 2.5-10 million.

Although the cost models are different, technology to reduce the time involved and remove or reduce the need for people to enter confined spaces may then also have a benefit for the ongoing operation of trading vessels.



1.5 Outline of the report

In this report we describe the dangers of confined spaces in the context of marine vessels, including FPSOs used in the oil and gas industry, and more generally marine cargo vessels. We also summarise some of the regulations and laws regulating the safety procedures for preventing accidents in confined spaces.

Some historic reports of fatal accidents in confined spaces are then presented, including a discussion of some of the factors leading to these incidents. Based on the historical record of accidents which have been reported in a variety of publications, we assess the likelihood of a fatal accident, assuming similar industry wide application of safety protocols, and we assess the cost and other implications of such an accident.

Detailed assessments of other short and long-term risks of confined space incidents, such as injury, exposure to toxic substances, and consequent health issues, are not within the scope of this report but should not be ignored in the overall risk considerations.

We also note the predicted increase in the number of Floating Units worldwide and thus the increasing numbers of potential accidents in confined spaces for the oil / gas sector.

Technology which removes the need for human entry into confined spaces or reduces the amount of time required within the confined space, especially on FPSOs or other maritime vessels has a significant potential to mitigate the risks of fatalities, injury, and long-term health issues due to exposure to toxic substances associated with confined spaces.

It should be noted that the risks of injury and health issues have not been considered in this report, even though they may be considerable. This omission is not an oversight but a recognition that considerable effort is needed to source, analyse and compile the information.

Such technology can provide a means to comply with the As Low As Reasonably Practicable (ALARP) principle of safety, compliance with which is described by various regulators and may be the focus of courts when assessing if adequate steps have been taken to avoid or mitigate the risk.

2. Hazards in Confined Spaces

2.1 Hazards

The UK Health and Safety Executive (HSE) defines confined spaces as tanks, pits etc. which, by virtue of their enclosed nature, create conditions which gives rise to likelihood of an accident, harm, or injury of such a nature as to require emergency action due to the presence or reasonably foreseeable presence of:

- Flammable or explosive atmospheres
- Harmful gas fume or vapour
- Free flowing solid or ever-increasing level of liquid
- Excess of oxygen
- Excessive temperature
- Working at Height

The nature of the hazards in these confined spaces depend on the situation but include:

- A toxic atmosphere from previous cargo / fire or flames / disturbance of sludge
- Oxygen deficiency through displacement by other gas, chemical or biological reactions which consume the oxygen, absorption onto surfaces
- Oxygen enrichment, which may lead to spontaneous generation of fire
- Flammable or Explosive Atmospheres
- Liquid (or flowing solids) which can cause drowning, suffocation, burns
- Excessive heat which can cause heat stroke or heat stress induced collapse

Owing to these hazards there are many rules and regulations pertaining to confined spaces. For example, the UK HSE Confined Spaces Regulations 1997 states (Link: https://www.legislation.gov.uk/uksi/1997/1713/regulation/4/made)

(1) No person at work shall enter a confined space to carry out work for any purpose unless it is not reasonably practicable to achieve that purpose without such entry.

(2) Without prejudice to paragraph (1) above, so far as is reasonably practicable, no person at work shall enter or carry out any work in or (other than as a result of an emergency) leave a confined space otherwise than in accordance with a system of work which, in relation to any relevant specified risks, renders that work safe and without risks to health.

Also, for comparison, the Safety Health and Welfare at Work Regulations (2001) from the Irish HAS includes Regulation 5 (https://www.hsa.ie/eng/Topics/Confined_Spaces/) which require that:

(i) A person shall not carry out work in a confined space if it is reasonably practical that it could be avoided
(ii) If the work must be carried out, Hazard Identification and Risk Assessment must be carried out prior to the work
(iii) A person shall not enter a confined space unless there is a system of work that has been planned, organised, performed, and maintained so as to render the work safe and without risk to health
(iv) Anyone entering a confined space must be provided with appropriate information, training, and instruction appropriate to the particular characteristics of the proposed work activities

This regulation is very exacting and provides a strong steer away from entering confined spaces if possible, and for establishing rigorous protocols and procedures to try to ensure safety if people enter a confined space. Nonetheless, in spite of the regulations, there continue to be confined space accidents resulting in fatalities.

In many instances, entry into a confined space requires compliance with a detailed work permit system, as well as the use of appropriate personal protection equipment and/or breathing apparatus. Personnel involved in access to confined spaces, for example in maritime occupations, require training and practice of safety protocols. Typically for confined spaces there is a permit system.

The details of the permit system may vary, but a typical system is described by the US Occupational Safety and Health Administration (OSHA). In this regime, the permit system is a written procedure for preparing and issuing permits for entry to and for returning the permit space to its normal use of a confined following termination of the entry. There is typically a rescue service which details the personnel designated to rescue personnel from the permit space and a retrieval system, meaning the equipment, to be used for non-entry retrieval of the personnel from the permit space. Typically, there is a specified protocol of testing the permit space to identify and evaluate the hazards which may confront the entrants to the permit space. Similar rules have been developed in other countries.

For comparison, the Brazilian regulations, which are documented in the Brazilian Health, Safety and Environment document NR33 – Working in Confined Spaces (August 29 2012) details a series of protocols, which overlap some of the HSE regulations, including the need for a permit system controlled by an entry supervisor, training of the risks and protocols for working in the confined space, and appointment of a designated watchman, who remains outside the confined space and remains in contact with the workers within the confined space. There is also a need to have a set of emergency and rescue procedures. The objective of the regulations is to permanently ensure the safety and health of the workers who interact directly or indirectly with these spaces.

There is also the ISGOTT (International Safety Guide for Oil Tankers and Terminals) which provides a detailed set of guidelines for safety on oil tankers. Chapter 10 is dedicated to the risks of confined spaces. This includes a description of the hazards in confined spaces and some of the control measures for entry to such spaces. There is also a section about emergency procedures for evacuation and rescue as well as a description of the use of breathing apparatus and safe working practices. (Link: https://slcprdwordpressstorage.blob.core.windows.net/wordpressdata/2018/12/MOTEMS-2019-referece-8.2-10.20.pdf)

In addition, the organisation Safety of Life at Sea (SOLAS) introduced a new regulation X1-1/7 in 2016 the "Atmosphere testing instruments for enclosed spaces" in the International Convention for Safety of Life at Sea, which requires ships to carry appropriate portable atmosphere testing instrument or instruments, capable, as a minimum, of measuring concentrations of oxygen, flammable gases or vapours, hydrogen sulphide and carbon monoxide, prior to entry into enclosed spaces.

The Standard Club has issued a comprehensive course guide for access to enclosed spaces on ships, and this can be found at https://www.iims.org.uk/wp-content/uploads/2014/03/A-Masters-Guide-to-Enclosed-Space-Entry.pdf

This provides much more information and anecdotes about the dangers of confined spaces and protocols to minimise the risks of entering such a space.

2.2 Hazard Assessment and ALARP

In assessing the hazard of confined spaces, as with other hazards of employment, the UK HSE has a principal of ALARP (As Low As Reasonably Practicable) whereby in assessing risks and factors introduced to mitigate the risks, the ALARP principle is core. The ALARP principle provides a valuable reference point for assessing the measures in place to mitigate the risks of fatalities in confined spaces on FPSOs and maritime vessels in general. While the ALARP principle of risk management does not have a formulaic prescription to determine what is reasonably practical, the HSE provides some important guidance, and the key elements of this are explained below.

The HSE documentation states that there is relatively little legal guidance about the definition of whether an employer is following the ALARP approach. However, the key legal case for reference is the historic legal case Edwards v. The National Coal Board[1]. In that case, the Court of Appeal considered whether or not it was reasonably practicable to make the roof and sides of a road in a mine secure. The Court of Appeal held that:

"... in every case, it is the risk that has to be weighed against the measures necessary to eliminate the risk. The greater the risk, no doubt, the less will be the weight to be given to the factor of cost".

and

" 'Reasonably practicable' is a narrower term than 'physically possible' and seems to me to imply that a computation must be made by the owner in which the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other, and that, if it be shown that there is a gross disproportion between them - the risk being insignificant in relation to the sacrifice - the defendants discharge the onus on them".

While this ruling is not a quantitative prescription, it implies that to comply with the principle of ALARP, the investment costs in mitigation systems should exceed, by a gross disproportion, the cost of the risk, which represents the costs incurred in the event of the hazard occurring multiplied by the likelihood of the hazard.

However, there is also an expectation that the risk of a fatality in carrying out a worker's duties at work is not excessive. As mentioned in the introduction, the tolerability limit for workers in hazardous industry is 1 in a thousand per annum (UK HSE), while the threshold for a broadly acceptable risk is 1 in a million.

Ideally measures should be put in place to reduce the risk of a fatality to a value well below the tolerable level (1 in a thousand per person per year) and much closer to the broadly acceptable level (1 in a million per person per year , especially since there may be societal implications of the acceptability of personnel being exposed to such high level of risk by their employer in carrying out their work.

It is also relevant to note that the HSE states that where the benefit (of measures introduced) is the prevention of death, a cost benefit analysis adopts a benchmark value of GBP 2 million (UK HM Treasury in 2020) for the Value of Preventing a Fatality (VFP). The HSE are clear that this does not mean that this is the value of a person's life or the value of the compensation appropriate to the loss of life: the value of preventing a fatality (GBP 2million) can be understood as a figure representing the value to an individual of avoiding death.

Once a mitigation approach has been determined to mitigate the risk, the cost of the mitigation measures can be assessed by deriving a 'Cost of Preventing a Fatality' (CPF) which represents the total final cost of the mitigation measures, divided by the putative total fatalities prevented. The CPF may well be different from the VPF, and this may be used in assessing whether the employer is operating in a way consistent with the ALARP principle.

3. Record of Incidents

There have been many fatal accidents in marine shipping in general and FPSOs in particular associated with people entering confined spaces. There is also a long history of attempts to upgrade safety protocols and practice, but there continue to be accidents and fatalities. As well as there being accidents when people enter confined spaces for inspection or maintenance checks, a considerable number of the fatalities arise when an incident occurs in a confined space, and responders, who in the time-pressured situation of responding to an incident do not follow the HSE protocols and perish. Although extensive training and education programmes, as well as very stringent safety protocols have been developed, the data on fatalities, even in 2021, suggests that HSE on FPSOs or other maritime vessels is not always applied effectively during actual entry to confined spaces, as illustrated in the reports below.

In researching this report, it was noted that reports and publicity about fatal incidents do reach the trade literature, but there is less information and publicity in the trade literature about injuries, near-miss incidents and longer-term health issues, from which further lessons may be learnt. The history of accidents in general suggests that there are many more near miss situations than the incidents involving a fatality and making such data more readily available would be of great potential benefit for sharing experience and learning.

We now summarise some of the recent incidents on FPSOs and then turn to a more general review of recent fatal incidents involving enclosed spaces in the more general maritime industry, since there is considerable overlap in the nature of the incidents, the number of incidents in FPSOs is small owing to the small number of these vessels, and technology available for FPSOs might also be deployed more generally to mitigate the risks of the hazards of confined spaces in ships.

3.1 Fatal Incidents on FPSOs Involving Confined Spaces

The Safety4Sea web site, as well as several of the trade magazines including Offshore Technology, Offshore Engineering, and Maritime Executive report many of the FPSO fatalities and incidents, and much of the data herein has been drawn from reports in these publications or their websites.

A market report on FPSOs was published on Feb 16, 2021, in Offshore Engineer (https://www.oedigital.com/news/485300-market-report-fpsos-charting-the-path-ahead). According to this report, there are presently over 175 FPSOs globally in operation with about 20 on order and 25 available.

The 20 FPSOs on order are being built with a projected capital expenditure of about USD 11.2 billion per year estimated over the next 5 years. About 60% of the world’s FPSO fleet are operated by either oil and gas production companies or FPSO design, manufacture, and lease companies, in particular SBM, BW Offshore and MODEC who operate about 22% of the world’s FPSO fleet, while Petrobras have 49, CNOOC 13, ExxonMobil 12, Total 9 and Shell 8, so there is a variety of organisations all operating FPSOs. Although the design of FPSOs varies, they all contain large tanks for storing oil or gas and also have tanks for diesel, methanol and slops.

FPSOs are challenging environments on which to work, being offshore, and the tanks require periodic cleaning and inspection, which can involve the risks of entering confined spaces coupled with the risks of working at height in the confined space, using ropes or scaffolding. Over the past 7 years, the following serious safety events have occurred:

Date	Company/FPSO	Fatalities	Event Detail	Source
Jan 31 2021	MODEC Cidade de Mangaratiba (Petrobras)	1 fatality	Technician fell from rope in platform tank in FPSO	Bahamas Maritime Authority and MODEC
Jan 21 2021	Espoir Ivoirien BW Offshore	2 fatalities	Gas leak in a tank	Offshore Technology
Jun 19 2019	SUNCOR Terra Nova	Near fatality	H_2S and Benzene released from a Slop Tank	Offshore Engineering
Feb 15 2015	BW Offshore Cidade de São Mateus	9 fatalities	Explosion in a pump room from a gas leak	Maritime Executive

These events all involved entry to confined spaces for inspection or maintenance; in the most recent case, on a MODEC operated FPSO for Petrobras (Cidade de Mangaratiba), a worker fell 18 metres to the base of a tank as his rope access harness was improperly attached to the tank according to a report from the Bahamas Maritime Authority. This incident points to the very large size of the tanks on FPSOs and the need to erect scaffolding and/or use rope access when personnel enter the tanks. Thus, working in confined tanks in FPSOs also introduces risks associated with working at height, as well as from the interior environment of the confined space. While the individual who fell was a qualified Industrial Rope Access Trade Association (IRATA) rope access technician, the safety protocol of a backup safety rope was not in use, leading to the incident.

The incident on the BW Offshore FPSO Espoir Ivoirien involved a gas leak into a confined tank which led to the death of two workers who entered the tank, while there was a near miss on the Suncor FPSO Terra Nova when a slop tank was opened leading to the release of hydrogen sulphide and benzene which affected the individual inspecting the tank and was deemed a near-miss of a potentially fatal incident.

The 2015 incident on the BW Offshore FPSO Cidade de São Mateus lead to the death of 9 people. This incident resulted from the fitting of on incorrect manifold on a vessel which failed and led to the release of gas in a pump room. Once the alarm was triggered more people were sent to the pump room. The gas exploded and led to 9 deaths and 26 other people were injured. In addition, the Cidade de São Mateus required extensive repair work and to date has not gone back in to service.
(https://www.oedigital.com/news/477096-brazil-fpso-charter-ends-5-years-after-deadly-explosion)

The data from these FPSOs is limited in terms of the number of events and the number of fatalities but do show that incidents continue to occur in confined spaces even in 2021. There have been 12 fatalities over the 7-year period 2015-2021 and proportionally more in the marine world.

This document uses this data to infer the risk of a fatality over the world's FPSO vessel fleet (comprising ~200 such vessels) over a 7-year period, assuming there are no other such incidents not included in this analysis and uses this data to calculate the probability and consequence of a fatal event and from that to infer how much effort and cost should be expended to avoid a fatality based on the ALARP guidelines.

The world's fleet of FPSOs is also becoming progressively older, with 55 FPSOs reaching their design life in the next 5 years (The Maritime Executive, August 15 2021), and this may lead to new safety challenges related to corrosion and cracking and consequent increases in the need for confined space entry and hence greater risk exposure of personnel.

It is also important to note that the above calculation is somewhat limited by the small number of events. To complement this analysis, one can also assess the incidents on tanker vessels for comparison given that there are some similarities between the two types of vessel. Spouge (2017, Hazards, IChemE) has estimated that the risk of an explosion in a tank on an FPSO is 3.9×10^{-4} per year based on data from tankers (from 1980-2013) of which there is a larger data set with about 2,000 tankers, although the risks have progressively dropped over time. Spouge also notes that several of the historic explosions occurred during inspection of the tanks. The risk given by Spouge is of the same order of magnitude as the risk we have estimated from the FPSO data.

3.2 Fatalities in More General Maritime Activity

The total fleet of cargo vessels is much larger, and so there is considerably more data on incidents involving confined spaces and fatalities. It is also likely that technology used in FPSO vessels to mitigate the risks will have application for most of the activities in cargo ships.

One very valuable source of information of incidents in cargo ships is the Marine Accident Investigators International Forum (MAIIF) which records and publishes accidents on ships. The UN International Maritime Organization (IMO) is presently working on ways to reduce fatalities in confined spaces on ships. The chair of the group leading this work, John Lloyd, Chief Executive of the Nautical Institute is quoted in the magazine Ship Insight (July 15 2021) as stating,

"*Every year the shipping industry suffers appalling loss of life in enclosed spaces. We need a massive effort to address these shocking deaths; deaths that can and should be avoided. Better design, more effective time management, alternative options to space entry and proper training are all ways that can help improve safety in these spaces. The HEIG regards this as the single most important area for seafarer safety and we welcome every initiative that can help raise awareness, improve safety and save lives*"

The International Marine Contractors Association (IMCA) is an international organisation representing 156 countries. It publishes a record of incidents on their fleet of registered ships, and this includes the following reports of fatalities, or near miss fatalities, from confined spaces for the period 2011-2021. These have largely been extracted from a search through the IMCA database over the past 11 years (imca-int.com Safety Flashes).

We have listed some of the incidents in terms of the number of casualties and nature of the incident but believe that these do not represent the full extent of incidents in confined spaces.

2011 3 people died entering a water tank on an onshore oil well; the water tank contained water with nitrogen

2012 On a Norwegian cargo ship, a crewman died entering cargo tank to retrieve a cargo sampling device; the atmosphere had >90% nitrogen and < 7% oxygen

2012 A worker was reading a meter in confined space where there was <6% oxygen in the atmosphere. The worker was unconscious for 15 minutes; this was a near miss incident.

2013 A crewman was injured opening ballast tanks owing to the high pressure in the tank which caused door to open rapidly

2014 Workers cleaning a sewage tank were exposed to hydrogen sulphide released from tank. Two workers became unconscious but were rescued and recovered.

2014 Two workers entered confined space after welding; they were exposed to a poor atmosphere and one of the workers died and one was rescued

2014 A riser tube filled with argon was inspected in Singapore by a worker who entered the tube. He died of asphyxiation / cardio-respiratory failure.

2014 A worker leaving a water ballast tank 11 m deep had his gas detector around his neck. The gas detector became stuck on the ladder, and he fell 10m. He received serious injuries and later died in hospital.

2014 Three crewman died on the wood cargo ship Suntis while inspecting the cargo hold. The access compartment was a confined space and had a poor atmosphere and the crewman became unconscious and died.

2015 Three workers died on the MV Hi RAM, offshore Malaysia, in a confined space on the vessel and two others were injured

2015 Three dockworkers were killed while cleaning an enclosed space on a coal ship the MV Saga Frontier Captain in Antwerp.

2015 Five people died in a confined space in a pontoon after entering a tank 5 meters deep and became unconscious owing to poor air quality.

2015 11 incidents of near misses were reported by one member of the IMCA.

2016 Two crew entered an oil tank on the crude tanker Sharp Lady to retrieve equipment. They were using breathing equipment but were overcome by fumes. One escaped and the master tried to rescue the other. The master died and the other was rescued eventually.

2016 A crewman suffered scalding during tank cleaning.

2017 The door of a pressure proof enclosure burst open and killed a worker, owing to pressure build up in the enclosure. There was no pressure relief system for the enclosure.

2017 A painter entered a tank on a ship in port to inspect the tank. The other painter closed the entrance, and the painter was trapped inside for 3 hours but survived. This was a near miss.

2018 The 2nd engineer entered a refrigerated saltwater tank in a fishing vessel and became unconscious and died. Two people entered the confined space but failed to rescue him but they were recovered safely. The atmosphere in the tank had some freon R22 and <6% oxygen.

2018 Three crewman died in the hold of the Apollo Kita, a wood cargo ship.

2018 Workers in Singapore were cleaning and dismantling valves in a pump room on a marine vessel and smelt fumes. One worker became unconscious and died, but the others escaped.

2018 A worker felt dizzy cleaning a mud tank. He was rescued but this was a potential confined space incident

2019 A commissioning engineer was found unconscious in a gas valve unit (confined space). He recovered after Cardiopulmonary Resuscitation (CPR); this was a near miss.

2019 Three workers died in a Mobile Offshore Drilling Unit (MODU) in the US after entering a leg of the unit during dewatering. They became unconscious in this confined space and died. Two other workers were rescued and airlifted to hospital

2019 Hydrogen sulphide was released from a sewage tank being inspected for a faulty sensor and the crewman involved fell unconscious. This was a near miss.

2019 The C/O and bosun entered an unventilated cargo hold. The C/O died from the lack of oxygen.

2019 The Republic of the Marshall Islands (RMI) reported six deaths on two ships resulting from enclosed space entry.

2020 An explosion killed a worker spray painting the interior of a water tank in the steering gear room.

2020 A crewman fainted removing rust from a water ballast tank owing to the presence of hydrogen sulphide in the confined space.

2021 A worker inspecting sludge accumulation in a freshwater tank became unconscious and suffered severe brain damage. He will not be able to work again.

In total this list identifies 39 deaths associated with entry into confined spaces on a variety of marine vessels (other than FPSOs), with the fatalities largely resulting from noxious gases or lack of oxygen in the unventilated confined space (as reported by the IMCA). There are other incidents as well, for example, some individual incidents are reported in the following references:

https://mfame.guru/2-die-after-falling-in-ships-tank-1-survives/
https://safety4sea.com/lessons-learned-crew-fatality-during-tank-cleaning/?__cf_chl_jschl_tk__=pmd_gEWeu0IK6qcRw5BluKNG0057u9z9DJiT6tOU3.3Q1sY-1629649197-0-gqNtZGzNAhCjcnBszQiR
https://www.mardep.gov.hk/en/msnote/pdf/msin1544.pdf
https://wwwcdn.imo.org/localresources/en/OurWork/IIIS/Documents/Lesson%20learned%20per%20type%20of%20incident/Consolidated%20version%20Fatality%20-%20Injuries.pdf

A report from the International Transport Workers Federation (ITF) has quoted that there have been 145 deaths of seafarers and dockers owing to confined space accidents, including asphyxiation and explosions, or from falls after passing out due to bad air, over the past 20 years. This number is higher than the list from the IMCA database and suggests an average of about 7.2 deaths per year which is significantly higher than the deaths recorded on FPSOs which appear to average 1.7 per year.

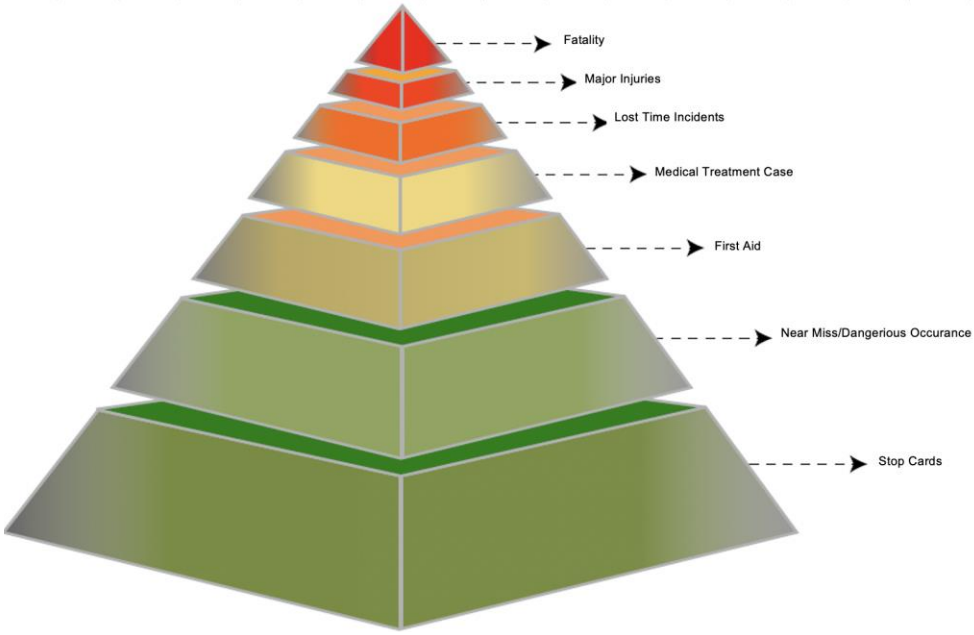
Example of a risk assessment calculation

If there are ~54,000 ships in the global merchant fleet (number of ships over 1,000 Gross Tonnes (GT); (http://infomaritime.eu/index.php/2021/07/15/top-15-shipowning-countries/), then this represents a likelihood of:

$L = 7.2 / 54{,}000 = 1.33 \times 10^{-4}$ of a fatality per year on a merchant ship associated with confined spaces.

Whilst this should be regarded as an estimate, the data on the IMCA database of specific incidents, as listed above, suggests about 3.9 fatalities per annum over the last 10 years, which is consistent within a factor of 2.

In addition to the fatalities, there are many injuries and near misses, some involving injuries. The above list records some of the serious near miss incidents reports on the database, but there is likely a much larger number of such incidents not reported in the database. Typically, for every fatal incident there will be a much larger number of injuries and near miss events, some involving injuries, as suggested in the safety pyramid diagram below.



In summary, ships and FPSOs are host to a large number of confined spaces, including cargo tanks, fuel tanks, ballast tanks and slop tanks. These tanks are often hard to reach and enter, requiring scaffold, industrial rope access techniques and internal ladder systems. Also, they tend to be unventilated and may be deficient in oxygen or filled with noxious gases and often require gas freeing and ventilation. These hazards can lead to death of personnel unless they have certain breathing apparatus. There is also enormous time pressure to rescue people in the event of a problem in such confined spaces owing to the short time of survival, of the order of just several minutes, before individuals may die.

Developing an approach to avoid human entry to such confined spaces as far as is practically reasonable would therefore have much merit in reducing the risk of these hazards being manifest.

4 Value of Preventing a Fatality

The value of preventing a fatality has been set at GBP 2 million by the UK Treasury in terms of a quantitative risk assessment.

Here we can use the estimates of the likelihood of a hazard being realised to assess the cost of avoiding a fatality.

(a). The risk or likelihood of a fatality occurring is difficult to estimate owing to the small number of FPSOs, but the data from the last 7 years led to a value of

L = 0.0086 per FPSO per year

If for example, we assume that there are 10 people working on an FPSO who may be involved in confined space activities this implies a risk of about 8.6×10^{-4} per person per year.

(b) Data from the fleet of merchant ships, estimated at #54,000 combined with the IMCA database, and assuming a similar number of people working in confined spaces, implies a risk of about 13×10^{-4} per person per year.

If we take the range of estimated risk as representative, this still represents a very high likelihood and significantly above the 1 in 10^{-6} generally considered as 'broadly acceptable'.

While there may be some acceptance that working in an offshore environment is risky, there could be negative consequences to organisations whose employees, contractors and sub-contractors are involved in activities which have this risk of death, especially if there are available means to remove those risks through technology.

(It is noted that the calculated risk spans a very wide range based on the two estimates. The caveat on the FPSO data is the small number of such vessels and hence incidents so that estimating the probability is difficult to assess, and the caveat on the general merchant ship fleet relates to the different safety cultures in different parts of the industry, which may lead to different approaches to the implementation of safety protocols).

The UK HSE ALARP approach requires that the expenditure on a system to remove or mitigate the risk should be grossly disproportionate to the benefit of removing the risk, as estimated above.

The HSE do not prescribe what constitutes 'grossly disproportionate expenditure', but it might be argued that investing an amount of order a multiple of 10 of the benefit is consistent with this approach. In that case, and using the historical data from the FPSOs, as the most conservative estimate of the benefit, an expenditure of order GBP 20 million per annum, factored by the risk, might be a useful basis for stakeholders to assess expenditure for an ALARP approach.

5. Summary

This report discusses the dangers of confined spaces, especially in a Maritime context, focussing on FPSOs in particular. Historical data on fatalities for FPSOs and for the Maritime fleet in general lead to a risk assessment of a fatality on a vessel per year, using a mixture of data from trade publications and reports from official organisations including the MAIIF, the IMCA and the ITF.

Using a value of GBP 2 million for the value of avoiding a fatality (UK treasury 2020), and the need to spend a disproportionate amount (say a factor of 10 times) and the estimate that the risk of a fatality on an FPSO may be as high as 8.6×10^{-4} per annum based on the last 7 years of data, the cost and benefit of removing this risk can be calculated in terms of meeting the ALARP approach to risk management.

We note that these numbers are estimates but are consistent with the available historical record of fatal incidents on FPSOs.

We also note that this study has not attempted to quantify the risk and cost associated with injury and long-term illness due to exposure to certain hazardous contents in the confined spaces nor reputational damage caused to organisations involved in placing persons at risk.

It is important to recognise that human entry into confined spaces also requires considerable time and planning to ensure the safety protocols are followed, and activities such as tank cleaning, inspection and repairs can then incur a considerable time of several days or in some cases weeks, where multiple persons are exposed to safety risk.

Safe and efficient operations inside confined spaces may have the multiple benefit of improving safety and profitability; surely powerful drivers to find ways of developing and implementing methods to reduce or eliminate these risks.