Local Service **Global** Support

EM&I

Delivering Integrity

A REPORT ON FATALITIES IN COMMERCIAL DIVING

Institute of Energy and Environmental Flows
UNIVERSITY OF CAMBRIDGE

www.emialliance.com

Professor Andy Woods
Institute of Energy and Environmental Flows
University of Cambridge

EXECUTIVE SUMMARY

We discuss some of the historical data concerning fatalities and serious injuries during commercial diving operations. The risk of death as a commercial diver is extremely high, being one of the most dangerous professions, even though there are very comprehensive safety protocols from both national and international organisations.

We assess the risk of a fatality in commercial diving in the context of UK HSE guidelines including the level of investment required to prevent fatalities, injuries, and long-term illness at work.

We also observe that some of the reports summarising fatal events in commercial diving suggest a more rigorous implementation of safety protocols or minimising diving exposure would reduce the risks significantly.

There is a role for technology to help reduce the risks for work where diving has been traditionally considered as the preferred option.

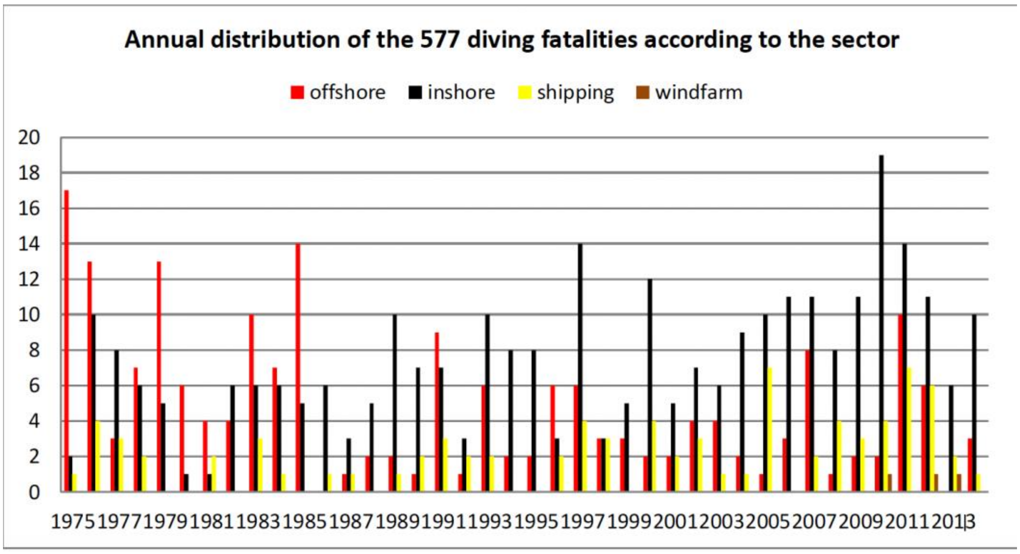
CONTENTS

1. **Introduction and Safety Guidelines**

Accidents and fatalities in the offshore industry represent a major challenge, and some of the activities, including diving are especially hazardous. This report outlines some of the issues concerning commercial diving in terms of the nature of the hazards, their impact on divers, and we provide some historical accounts of accidents. This leads to the conclusion that, although the data is sparse and poorly reported, there is considerable scope for improvements in the safety of commercial diving and perhaps a role for technology in mitigating some of the hazards by carrying out the work using diverless methods.

In compiling this report, a number of detailed reports have been analysed to provide data and information about historical incidents and to help learn from the past. However, to date we have not found any compilations or databases of recent incidents, although this would be of great value for shared learning and improved safety going forward. There are national protocols for safe commercial diving, and an extensive series of training programmes and some international organisations to help improve safety; nonetheless, the data suggests that accidents do continue to occur.

The data available are somewhat dispersed through different publications and websites, but in addition to the national government websites and international organisations, one notable source are law firms who specialise in maritime incidents and who have some detailed information on their websites about accidents in commercial diving, suggesting that this is an important challenge for the industry. There are a range of numbers which have been quoted. Values from 1998 in the US on a study of 3000 commercial divers suggest that the fatality rate was about 18.1 deaths per 10,000 divers per year in the US (Deaths Associated with Occupational Diving -- Alaska, 1990-1997 http://www.cdc.gov/mmwr/preview/mmwrhtml/00053331.htm).



In the UK figures published by the HSE in 2010 suggest 2-4 fatalities per 10,000 divers per year, while in France, data collected since 1991 suggest 11.2 fatalities per 10,000 divers per year (http://docplayer.fr/14768667-Etude-sur-1692-plongeurs-mention-a-surveilles-au centremedical-subaquatique-depuis-1991.html). It is not clear why there is such a difference in these quoted safety rates, but the different fatality rates may correspond to data from different periods of time. The chart below illustrates the distribution of commercial diving fatalities up to 2014 in different industrial sectors where there is significant commercial diving activity, and this highlights the large number of deaths in the offshore sector (Hermans 2016).

Some of the more recent data on deaths during commercial diving are included in the commercial diving directory which is presented on the website www.longstreath.com This directory reports a series of commercial diving fatalities. In particular, for the past 5-6 years, the directory mentions a series of diving fatality events as summarised in the Table below at a series of sites worldwide.

Table 1 - Commercial diving fatality events (from www.longstreath.com)

2021	10
2020	5
2019	2
2018	7
2017	15
2016	26
2015	10

Some of these events were associated with divers becoming entangled in nets, or divers becoming trapped underwater when they were near inflow pipes or openings with lower pressures and were unable to free themselves from the suction pressure. However, there are a range of causes of fatality in commercial diving and we summarise these later in the report.

In assessing the data above, it is helpful to refer to the health and safety guidelines for risks of a fatality at work (UK HSE). These identify certain thresholds for the risk of fatalities at work and we use these to help inform the data herein. In particular, the HSE suggests that if the risk of a fatality is 1 in 1000 per year for a worker, then that is an intolerable risk for the workplace. In contrast, if the risk of a fatality to a member of the general public is 1 in 10,000 per year per person, then that is an intolerable risk. At the other end of the risk spectrum, if the risk of a fatality per year is 1 in 1,000,000 to the general public, then the HSE deems that this is broadly acceptable. According to the data, commercial diving is one of the most dangerous professions, and the data presented above from historical incidents suggest the risk levels have in the past been close to the intolerable threshold of 1 in 1000.

In comparison to other workers, in the US, the government agency OSHA suggested (in 1998) that the risk of fatality in commercial diving was about 40 times that in other sectors, while in the UK, the HSE has published data suggesting that the risk of a fatality in commercial diving is about 12-24 times that of the construction sector, an industry with a known high record of accidents and incidents, while in France the risk is 8-10 times that of their construction sector.

2. HEALTH AND SAFETY PRINCIPLES

Health and safety guidelines in the UK for significant risks, such as a death at work, use a principle of ALARP in the management of such risks. The UK HSE website includes a useful discussion of ALARP, and we summarise some of this below:

“ALARP is short for "as low as reasonably practicable". The concept of reasonably practicable involves weighing a risk against the trouble, time and money needed to control it. Thus, ALARP describes the level to which the HSE expects to see workplace risks controlled. Using the reasonably practicable approach allows the HSE to set goals for duty-holders, rather than being prescriptive. For high hazards, complex or novel situations, safety builds on good practice, using more formal decision-making techniques, including cost-benefit analysis, to inform judgement.

A formal or legal definition of ‘reasonably practical’ was set out by the Court of Appeal (in its judgment in Edwards v. National Coal Board, [1949] 1 All ER 743) is:

"'Reasonably practicable' is a narrower term than 'physically possible' … 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."

In essence, making sure a risk has been reduced to ALARP is about weighing the risk against the sacrifice needed to further reduce it. The decision is weighted in favour of health and safety because the presumption is that the duty-holder should implement the risk reduction measure. To avoid having to make this sacrifice, the duty-holder must be able to show that it would be grossly disproportionate to the benefits of risk reduction that would be achieved. Thus, the process is not one of balancing the costs and benefits of measures but, rather, of adopting measures except where they are ruled out because they involve grossly disproportionate sacrifices. Extreme examples might be:

- To spend £1 million to prevent five staff suffering bruised knees is obviously grossly disproportionate: but
- To spend £1 million to prevent a major explosion capable of killing 150 people is obviously proportionate.

In reality, many decisions about risk and the controls that achieve ALARP are not so obvious. Factors come into play such as ongoing costs set against remote chances of one-off events. It requires judgment. There is no simple formula for computing what investment will achieve ALARP, and it is ultimately a matter for the courts.

2.1 INTERPRETATION IN THE CONTEXT OF THIS REPORT

Although there is no formula, in the context of the risk of death at work, which is especially relevant for commercial diving, the ALARP principle of risk management may be interpreted in terms of the level of investment (for example in people, process or equipment) made by an employer to mitigate the risk of a fatality compared to the cost of a fatality. Although it is difficult to put a value on a fatality, there are a number of sources which suggest a value to use in a calculation; here we use £2 million, which has been used by the UK Treasury in 2020.

In order to assess whether a risk mitigation measure is proportionate in a quantitative sense we go through a series of steps:

I. First, we estimate the risk of a fatality per diver involved in commercial diving activities per year.

II. Second, we multiply this by the number of divers engaged in the activity.

III. Third, we multiply this by the value (£2 million) as above. This leads to an estimate of the expected value associated with the risk of fatalities in an organisation.

Measures to mitigate the risk should have a cost which exceeds this, so that the organisation can establish it is investing in a proportionate way and weighted towards safety systems designed to mitigate the risks. However, it should be noted that, irrespective of these general principles, in the context of commercial diving, which is an especially hazardous activity, the organisation will need to invest in the basic processes of good health and safety, and its management, as well as all the regulatory training for the divers and the support crew.

In terms of commercial diving risks if, as an example, we assume that there is a specific risk leading to a fatality of 5 in 10,000 per year, then this would imply a value for this fatality risk of £1000 per employee involved in diving per year. To mitigate this risk, the organisation should be investing in specific risk mitigation processes/technology in excess of this amount. Over the working life of say 30 years of one employee involved in diving, the value of this risk is about £30,000 and this provides a reference for investment in measures to mitigate this risk, through technology, safety management processes or equipment, noting that the ALARP principle recognises the time, trouble and financial investment needed to mitigate risks to employees. If there are several divers in the organisation, then the investment should increase in proportion to the number of divers. In this context, it should be emphasized that the HSE regulations require an organisation to follow the safety protocols associated with commercial diving, including pre-dive planning, hazard assessment and risk mitigation, provision of a properly equipped and trained surface support team, provision of appropriate diving equipment, and provision of appropriate training for all those involved in the activity - this forms a part of the cost, time and trouble in managing risks while delivering commercial diving services, and likely represents a substantial financial cost.

In compiling the data about historical accidents, one recurring message relates to the lack of appropriate implementation of safety processes and that this led to incidents which could have been avoided. Examples include inadequate pre-dive hazard assessments; inadequate planning; inadequate provision of appropriately trained and alert surface support teams. In some cases these emerge from a lack of an appropriate safety culture or poor management leadership regarding safety.

2.2 SAFETY PROTOCOLS

In addition to the above safety principles, there are strict operational guidelines for diving as mentioned above with the US agency OSHA (Occupational Safety and Health Administration) having several commercial diving focussed documents including the following:

- Keep Workers Alive During Diving Operations. OSHA Alert (Publication 4141), (2021). NEW
- 29 CFR Part 1910, Subpart T – Commercial Diving Operations. OSHA Directive CPL 02-00-151, (June 13, 2011). Provides guidelines for the occupational safety and health standards for commercial diving operations, 29 CFR Part 1910, Subpart T.

Figure 1 - Examples of Diving Focussed Documents from the OSHA

In the UK, the UK Health and Safety Executive (HSE) also has a series of protocols for safe diving practice These are described in their guide, the 'Diving at work regulations (1997) – Approved Code of Practice and Guidance'. This outlines the safe practice for commercial diving, and the HSE also has a series of more recent documents which include details of good practice in commercial diving. In addition, the UK HSE guidelines refer to the IMCA (International Marine Contractors Association) guidelines on safe practice for commercial diving. These international guidelines provide an important reference which should result in reductions in fatalities in commercial diving globally, especially given the variability of the safety guidelines for commercial diving in different countries.

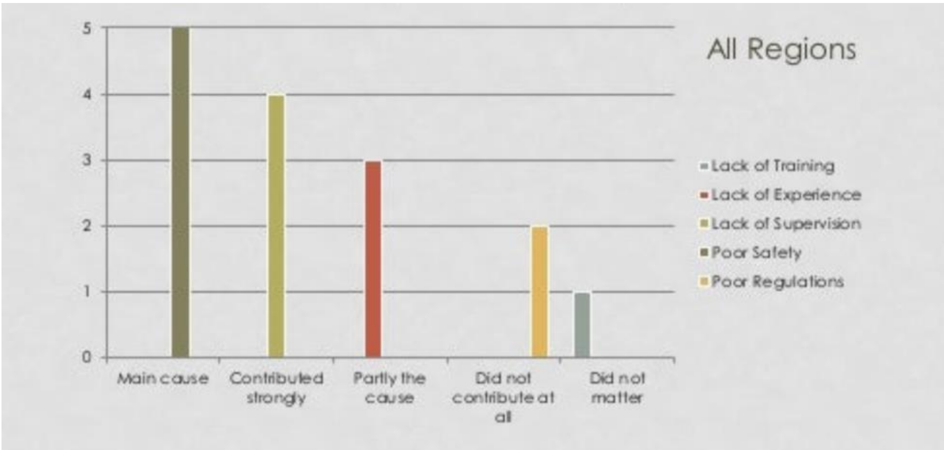
Indeed, the IMCA is one of several independent organisations which has established safe working practices and organise training. These also include the Divers Association and the ADCI (Association of Diving Contractors International) which have a mission of developing safe working practices for divers, following an international code of practice to ensure diving operations are safe worldwide. The Maritime Injury Guide (maritimeinjurtguide.com) also have some information which they publish concerning diving fatalities.

3. Cause of Fatalities in Commercial Diving

Although there are many commercial diving fatalities, these have not been collated in a systematic way over recent years. Learning from previous incidents becomes more difficult without such data but this is extremely important for learning. There is a very valuable report by Francis Hermans dating from 2016 which describes many of the accidents in the preceding 30 years. This report highlights the very significant risks of fatality in commercial diving. It is useful to understand the range of causes of death in providing some detail about the numbers.

3.1 UNDERLYING CAUSES

Notwithstanding the safety protocols described above, Francis Hermans has reviewed the cause of many commercial diving fatalities and finds that poor safety culture and poor supervision are important factors contributing to the fatalities.



Kyra Richter, a retired diver has a LinkedIn page in which she has reviewed some of the data on fatalities in commercial diving on behalf of the Divers Association. She reported 392 fatalities from 2002-2014, of which 251 had reported diver ages. The mean age of these fatalities was 37 years, with 80% of the fatalities being likely to be in the age range 35-40. This provides some support for the hypothesis that fatalities arise to experienced as well as inexperienced divers, and that some of the challenge associated with preventing accidents arises from the diligence with to which safety protocols are adhered. Indeed, Kyra Richter states

“These numbers could clearly demonstrate that the issue is not the diver’s lack of training or experience, nor is it the state of his health, but that companies are getting away with poor safety measures and investigations need some serious revision if they really mean to improve conditions for employees and not protect the interests of the company,” Kyra Richter

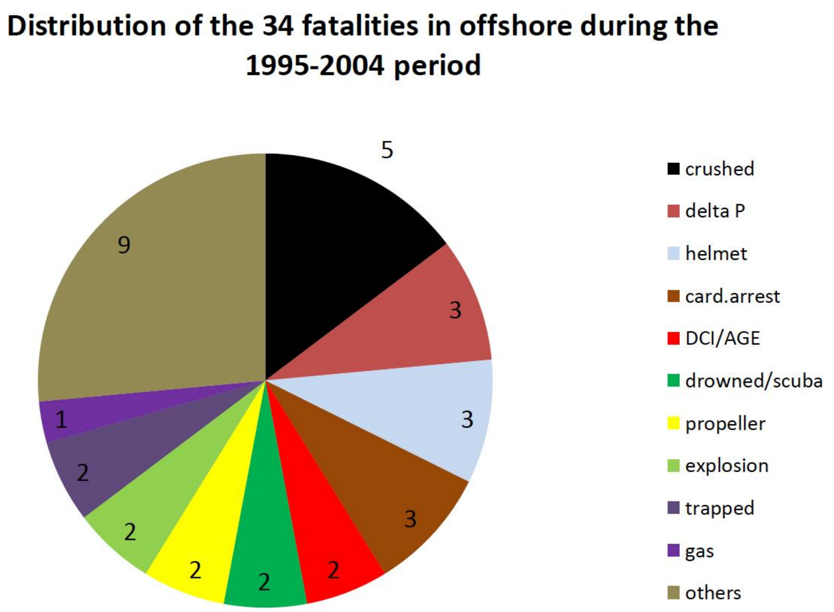
3.2 SPECIFIC CAUSES OF FATALITIES

There are many types of incidents which can lead to death in commercial diving and this is a reflection of the very dangerous circumstances. Particular problems include:

I. issues with the gas supply,
II. entrapment below water often associated with differential pressures, for example across inflow of outflow pipes,
III. a diver may become entangled or hooked onto wire, netting or other objects and is unable to escape
IV. equipment trouble, including masks, air supply or umbilical air line
V. propellor cuts to the diver or the umbilical air-line.
VI. impacts with the dive boat,
VII. crushing or burial from falling objects
VIII. underwater welding, causing burns or explosions
IX. injuries from improper decompression tables, sometimes causing arterial gas embolisms
X. cardiac arrests also occur during diving, sometimes induced if the divers have high blood pressure, or are overweight.

These factors can lead to drowning, hypothermia, gas narcosis, decompression illness which occurs when, owing to rapid decompression, nitrogen dissolved in the blood at high pressure is exsolved and forms bubbles; these can then travel through arteries and block blood vessels, barometric pressure injuries and gas poisoning. Also, divers can experience dysbaric osteonecrosis (which is a type of avascular necrosis of the bone most commonly found in undersea divers and workers breathing compressed air or gas). This condition can lead to increased risk of fracture depending on the location and size of the bony defect.

The pie chart below illustrates the large range of incidents which lead to fatalities, and shows that, other than being trapped, the risks for each cause are similar (Hermans 2016).



Another former diver, Steve Donavon, has drawn together a report on the risks of fatality from pressure differentials, and based on an incident in 2015 in Annapolis, Nova Scotia where a diver lost his life, he has called for much improved safety protocols and planning, and for the use of technology to detect hazards prior to divers entering the water. The death in 2015 caused by pressure differential could have been avoided by changing the time of the maintenance work relative to the level of the tide, thereby removing much of the pressure difference. He reports that pressure differentials account for about ¼ of commercial diving incidents (CBC news).

3.3 INJURIES

There can also be some long-term impacts on health through injury, even if there is no fatality and there are a large number of injuries which arise from commercial diving: data from the US Bureau of Labour shows that there were 460 non-fatal injuries compared to the 39 fatal injuries associated with commercial diving from 2011-2017. Some of the underlying causes of such accidents include inexperience and lack of training, not following safety protocols, defective equipment, poor maintenance and dangerous environmental conditions. In the US the Jones act provides divers with the right to seek compensation if the accident was caused by negligence by the vessel's owner, crew or the manufacturer of equipment.

In terms of the details, many injuries arise from the decompression of gas at too high a speed. Barotrauma occurs from the uncontrolled expansion of gas within gas-filled body compartments and decompression sickness arises from too rapid a return to atmospheric pressure after breathing air under increased pressures. Areas in the body affected in this way include the middle ear, the eustachian tubes, the sinuses, the thorax, and the gastrointestinal tract. A review of these injuries has been described by Alan Spira : " Diving and Marine Medicine Review: part II - Diving Diseases" , as summarised below:

I. If the eustachian tubes are blocked, then pressure equilibration across the ear drum cannot be achieved, and the ear drum (the tympanic membrane) may burst. This can lead to vertigo, nausea and vomiting and underwater can be fatal; in the longer term it can lead to hearing loss or tinnitus.
II. Thoracic squeeze can occur if the lungs are compressed to a volume smaller than the residual volume; diffuse alveolar haemorrhage may occur.
III. Barodontalgia (tooth squeeze) occurs if there are defective crowns caps or cavities, which trap gas; on descent the tooth may implode and on ascent it may explode.
IV. Pulmonary over-pressurisation syndrome occurs from pulmonary barotrauma, sometimes known as burst lung, which arises from gas expansion during ascent, rupturing the alveolar tissue. It occurs when air is breathed in at depth, and this air expands on ascent, increasing the lung volume beyond the original surface volume.
V. Arterial Gas Embolism occurs when bubbles of expanding gas rupture from overdistended alveoli into the blood stream and become emboli, which lodge in arterioles or capillaries, producing damage. If they lodge in the brain, they may lead to vertigo, unconsciousness, convulsions paralysis, seizures or even death; in the heart they can cause myocardial infarction, and in the spinal cord they lead to paralysis or numbness. Underwater, such embolisms are often fatal

VI. Pneumothorax occurs when the expanding gas ruptures alveoli and fills the pleural spaces causing collapse of the lung.

VII. Decompression sickness occurs because at depth the amount of nitrogen absorbed into tissues increases, and when the pressure is released, nitrogen comes out of solution and can form bubbles in the tissues. Often this is known as the bends. The bends occurs if a diver spends too much time at depth so that the nitrogen supersaturates tissues, or it may occur if the diver ascends too quickly and the nitrogen is produced faster than the body can remove this gas. Since there are a variety of gas dissolution rates in the body, the bends can occur even if one follows the diving depth-time tables designed for safe diving. Data suggest the risk of the bends is 1-2 divers per 10,000. Flying after diving can induce the bends owing to the greater change in pressure.

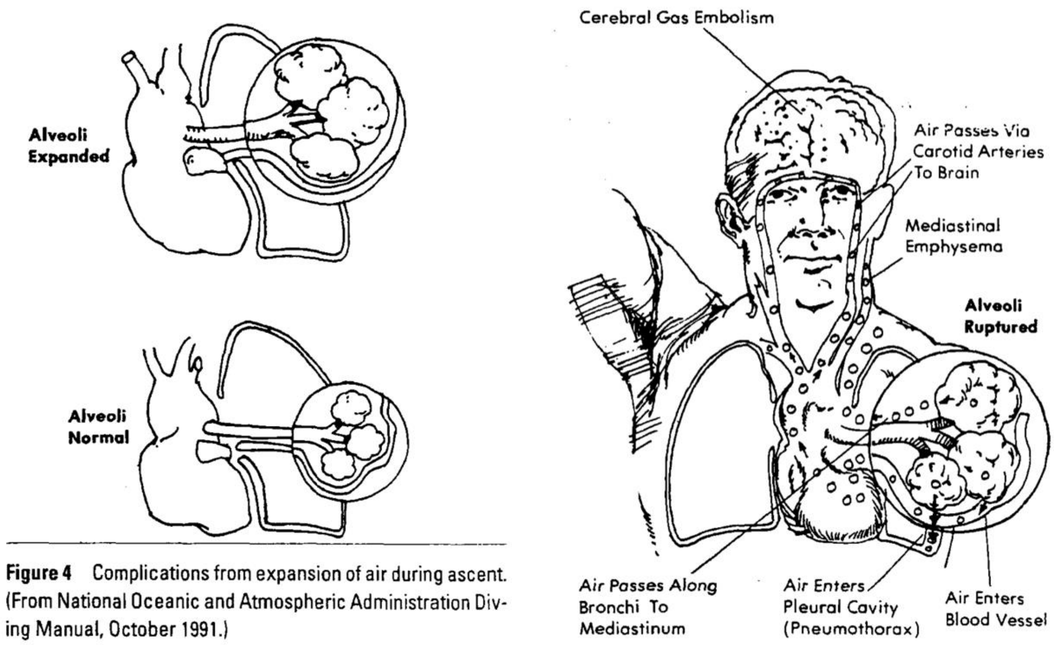


Figure 2 - Illustration of damage to the alveoli – image from NOAA Diving Manual.

4. Examples of Accidents

It is useful to list some of the accidents reported to gain insight into the hazards. Although some of these are associated with onshore diving fatalities, some of the hazards also arise offshore. Owing to the lack of a database listing the different types of accident, and also owing to the common nature of some of the causes of fatality, we have listed a range of incidents.

1. On July 5 2022, a diver died while performing an adapter mating test on the Petronas Bunga Kertas FPSO in Malaysian waters. The adapter lost its buoyancy and sank, taking the diver to 55 metres. Although he was put in a decompression chamber, he died (energy voice.com)

2. A diver was killed during a hull cleaning operation on a supertanker, in which, owing to poor management and planning, a diver was drowned in a failed attempt to rescue him. The diver suffered some problems with the air supply and so surfaced and removed his helmet. However, the umbilical was then drawn back up to the surface, dragging the diver under the ship and he perished. The incident, in the Gulf of Mexico has been described by Delise and Hall, the attorneys who represented the family of the deceased in court (divelawyer.com)

3. There are some historical accounts of diving accidents in diving bells, including the Venture One accident in 1977 in which there was an accident with a diving bell used to install a BOP, and the Waage Drill II in which an error occurred with the pressure gauges when two divers were being decompressed, so that they were recompressed with helium gas, leading to their death. In 1974, the Drill Master diving bell lost its dead weight and rose rapidly to the surface, dragging two divers upwards. They died of the rapid decompression and drowning. In 1979, an accident occurred on the Wildrake in which the diving bell became separated from the main lift wire at a depth of 180m. The two divers in the bell died of hypothermia.

4. In a report published in January 2013 by the IMCA, a near fatal accident was reported in which the umbilical of one diver was broken at a depth of 90 m; he became unconscious, but through team-work was rescued by the other diver and the ground crew working together. He regained consciousness and recovered, but the incident highlighted the dangers of diving and the need for careful training and safety protocols in the event of an incident (Serious DP diving incident – IMCA (imca-int.com)

Kyra Richter also reported a number of commercial diving fatalities, and we include these below (although these are not all offshore, they provide some useful context)

- 42-year-old, just North of the Hood Canal Bridge, using a drill underwater to install buoy anchors, entangled, apparently drowned Saturday when the hydraulic drill he was using tore away his air-line and entangled him 50 feet under water. Reported in the Spokesman review and Moscow Pullman Daily News.

- Aged 41, Contract diver working for the St Paul Regional Water Services, in Vadnais Lake, cleaning water plant intake filter, at end of dive he and his partner left the job site but he failed to surface, apparently got caught in some weeds and cables. His body was recovered about three hours later. No explanation. Reported in Star Tribune (MN)

- Drowned in a drainage pipe, no lifeline or standby diver, scuba gear minus straps, he was holding or dragging his air tank along the 36-inch-wide drainage pipe when he drowned.

- Employee of the State water dept., part of a volunteer team of approximately 12 divers who inspect/maintain the water system, died in an aqueduct, Dos Amigos pumping station, 5 mph current, tethered together, reported as not sucked onto the inlet grating, but no explanation, double fatality (Crawford) fined $16,120 for the two deaths.

- Aged 34, Trapped for about 15 minutes by water flow through a cofferdam, lost air supply, initially thought to be recovering, died 4 days later “the diver got stuck when flowing water forced him into a void between the cofferdam and the gate, which was open and releasing water. A partner working with him was able to tie a rope to the trapped diver's equipment but was not able to pull him free. When the diver was eventually pulled up, the air hose he was using to breathe had been knocked from his mouth. Officials were uncertain how long he had been without air”.

- 46-year-old from Conklin, New York, diving contractor out of New York, drowned Tuesday in Panguitch Lake, Utah. Failed to surface at about 1 p.m. He was removing a temporary dam his team had installed to allow water to be pumped out of a channel that crews were trying to dig deeper, Garfield County sheriff's deputies wrote in a statement. Other divers on the team found the diver under 18 feet of water.

- Aged 45, specialist lake and pond clearing contractor working at the Baxter health Care campus where there is a string of retention ponds. Diver got into difficulty; a second diver went in to aid him (he was hospitalized with hypothermia) but unable to pull him out. Recovered from the pond bottom 45 minutes later by fire department rescue divers, helicopter to hospital but pronounced dead. "Air hose had broken".

- Paraphrased from press reports:- “A 28-year-old diver from Arlington died at about 09:45 this morning while working inside a nearly full City of Richmond municipal above ground water storage tank in Richmond this morning. The diver worked for a contractor who was performing routine (two yearly silt removal) maintenance on the 500,000-gallon tank, which is about 50 feet tall and was three-quarters filled with water. The diver descended into the tank in SCUBA gear (09:15) and went to the bottom (09:18) was vacuuming the bottom of it to clean it. His partner who was outside the tank on the top noticed the diver's tether line became slack (09:28). He then also put on SCUBA gear and went into the tank to find what was wrong. He found the man unresponsive with his mask off but started having regulator problems and surfaced. The Richmond fire Department responded and recovered the diver’s body (10:50)". Declared dead. Houston Chronicle.

- American, aged 30, off duty fireman, working for "Pioneer Hydro" of Ware, Massachusetts, down a tunnel inspecting a turbine, got trapped underwater, tugged on his lifeline, but ran out of air.

- Hired by the US Army Corps of engineers to inspect a 130' deep shaft at the Hills Creek Reservoir dam. Two divers went to 90' in basket, Second diver then went to 130' to inspect the bulkhead, returned to 90' basket and both ascended to 10' and then second diver climbed onto the wall to remove his gear. Diver one’s lifeline went slack and was pulled up; no diver was on the line. Second diver got a fresh cylinder plus spare and went back into the water, down to 90'. After he had been there about 5 minutes, surface team reported that his bubbles suddenly got larger and then stopped. Basket recovered but second diver was dead. Diver one’s body was recovered from 130' by two SCUBA divers, Commercial divers who completed the inspection work the following day.

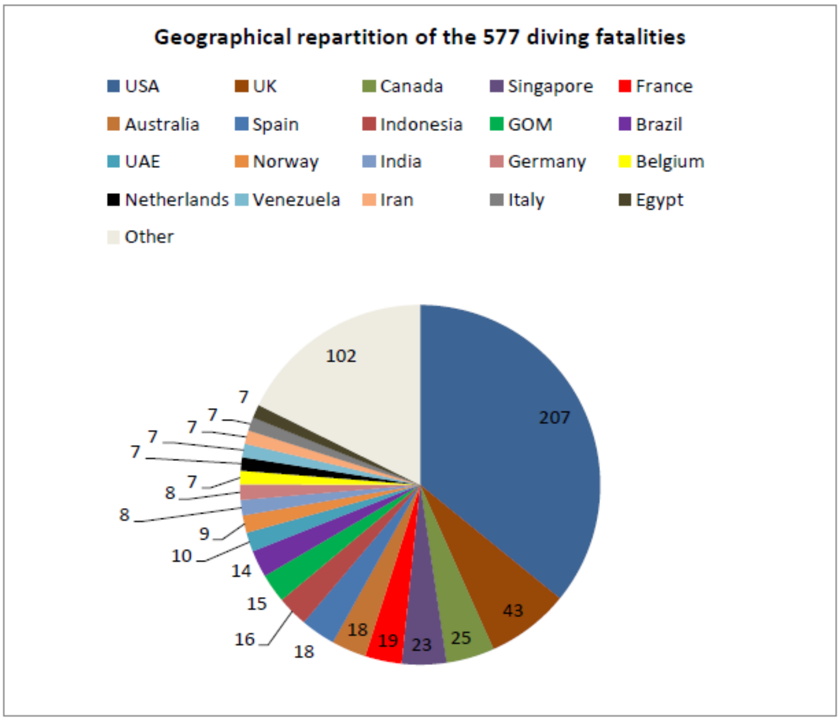
- American, aged 33, employed to remove cars from 2210 feet long, 13-foot diameter irrigation canal tunnel "syphon", trapped by flowing water, ran out of air, drowned. Two-man team, no stand-by divers/equipment. Two firemen died trying to rescue them, quadruple fatality.

- Brazilian, Canoa Quebrada hydroelectric plant at Lucas do Rio Verde, arm sucked up an 8” diameter pipe; three dive team members could not free him. A week later officials were still discussing whether to lower the water level in the lake in order to free the body.

4.1 GEOGRAPHICAL DISTRIBUTION

The geographical distribution of diving fatalities is shown below and suggests that commercial diving accidents occur worldwide. Although most of the information readily available relates to offshore accidents in the USA and the UK, there are also reports from Norway and indeed many other nations involved in the offshore industry as shown in the chart below from Hermans.

Chart n° 45:



5. Summary

Commercial diving involves considerable risks and has a very high incidence of fatality which historically has been related to some of the following factors: poor supervision; poor planning and safety management; equipment failure and dangerous environments. Although many of these factors can be addressed and there is considerable training available and national and international safety protocols to help mitigate their impact, the activity remains intrinsically dangerous.

Although data documenting all the fatalities over the past few years is not readily available, which, in itself would be very valuable for learning evolving safety processes, there are studies from pre 2015 which identify that the risks of fatality involved in commercial diving are at the level of about 3-10 per 10,000 over a year, which is extremely high and makes commercial diving one of the most hazardous occupations. Recent estimates of the risks are lower but still suggest a very high level of risk.

Some of the risks associated with diving could be mitigated through more use of technology, for example accidents involved pressure differentials are very common, but these might be detected remotely prior to divers entering the water.

Robotic and diverless systems are replacing divers for many tasks and there may be roles for carrying out some of the activity of divers, for example inspection and maintenance activities and hull cleaning their capabilities are expanding notably.

Where diving is the only practicable solution investment in mitigating the dangers through continual training, application of the strictest safety protocols and pre-dive planning and contingency planning may also help in mitigating some of the hazards. The cost of mitigating or eliminating a risk of a fatality is connected to the risk level. Although there is not a large pool of recent data, the risk of a fatality in commercial diving averaged over the USA and the UK based on the data from Hermans (2016) suggest a value in the range 3-10 fatalities per 10,000 divers per year. The ALARP principle of risk management suggests that, as well as ensuring investment in systems to mitigate the risks should be in excess of the risk-based value of a fatality occurring, which based on the above figures is in the range £600-2000 per annum per commercial diver although without access to a comprehensive set of data on recent diving fatalities, this number draws from older sets of data.

There can also be some long-term impacts on health through accidents or injury, as tabulated earlier in the report, even if there is no fatality and there are a large number of injuries which arise from commercial diving: data from the US Bureau of Labour shows that there were 460 injuries compared to the 39 fatal injuries associated with commercial diving from 2011-2017. Some of the causes of such accidents include inexperience and lack of training, not following safety protocols, defective equipment, poor maintenance and dangerous environmental conditions. In the US the Jones act provides divers with the right to seek compensation if the accident was caused by negligence by the vessel's owner, crew or the manufacturer of equipment. It is also relevant to note the reputational impact of providing a safe and well organised risk management process for commercial diving.