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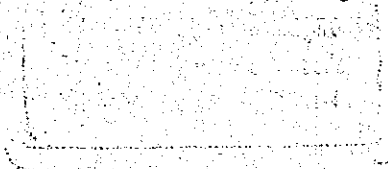
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Cabo Frio, 24/03/2011

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# Differential pressure hazards in diving

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for the Health and Safety Executive 2009

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## 2 Background

### 2.1 Differential pressure hazards in diving

Differential pressure, also known as 'Delta P', 'heavy water' or suction, occurs where water moves from an area of high pressure to one of low pressure. The flow may be the result of the movement of water under its own weight or an active process involving powered machinery (e.g. pumps or thrusters). When the flow is localised about a boundary between the high pressure and the low pressure areas, e.g. at an opening in a barrier between the two areas or the intake point of a pump, any diver encroaching on the flow from the high pressure (or upstream) side may be trapped or injured by it. Divers drawn into turning ducted thrusters or open propulsors inevitably suffer traumatic injuries.

The review did not include large scale mass movements of water such as in rivers or tidal currents. While these are undoubtedly due to a pressure differential their scale makes them a much more intuitive and observable hazard and thus not a priority for this review.

The review characterized four types of differential pressure hazard:

1. When water levels between adjoining areas vary (e.g. at dams and canals or tidal locks, see Figure 2.1);
2. When water is juxtaposed against gaseous voids at lower pressure than the water pressure (e.g. at submarine pipelines and other underwater structures with hollow components and also around ships, see Figure 2.2);
3. When water is mechanically drawn through intakes (e.g. at cooling water intakes for power stations or at sea chests on ships, see Figure 2.3).
4. When water is mechanically drawn towards propulsors, or other types of thrusters on ships (e.g. see Figure 2.3).

Incidents caused by open propulsors undoubtedly occur and are almost invariably fatal. However, the mechanism of injury is significantly different and does not involve being trapped or injured by the differential pressure *per se*, rather it is a traumatic mechanical injury caused directly by the propulsor. In addition, incidents of this type are frequently caused by a propulsor being activated when a diver is working on or close to it; in these cases differential pressure is not necessarily involved.

This review has included example open propulsor incidents, but due to the conceptually somewhat different character of this type of hazard, has not characterised them directly as differential pressure hazards. Nonetheless, the hazard is real and in need of robust control measures. The approach for risk assessing and controlling this hazard is, in principle, the same as for the other differential pressure hazards referred to.

Incidents that do occur are unlikely to be due to the hazard being unknown or its seriousness being underestimated; rather they will almost always be due to a failure of control measures.

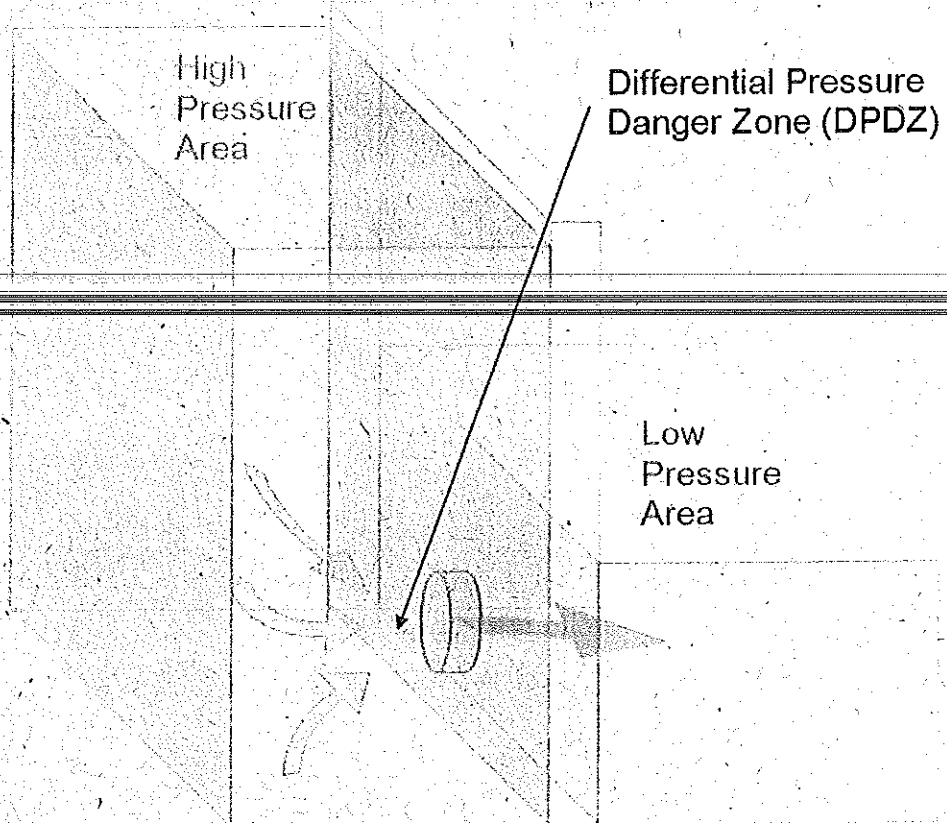


Figure 2.1: Simplified differential pressure hazard, type 1, open pipe between adjoining water levels.

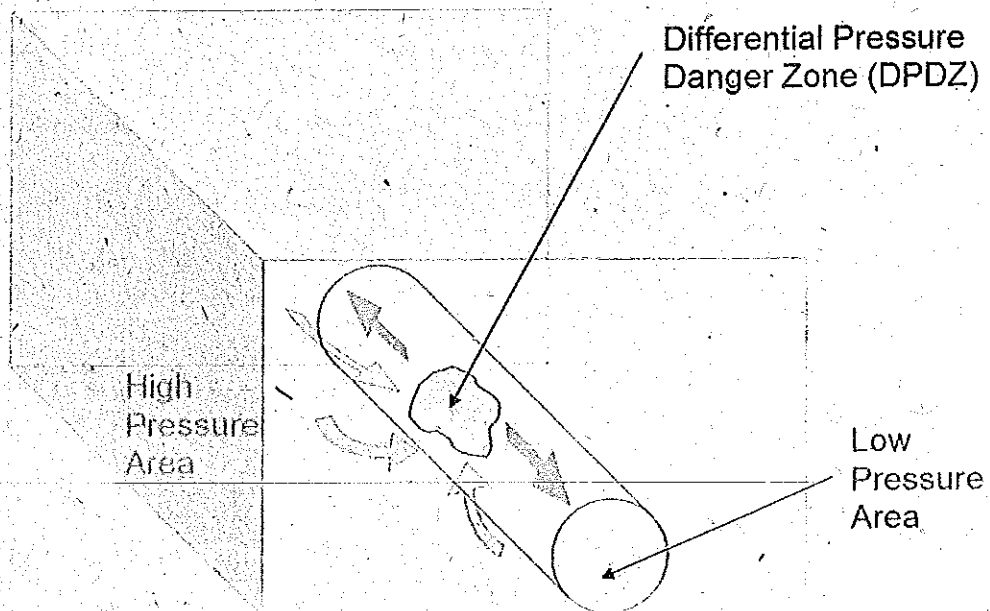


Figure 2.2: Simplified differential pressure hazard, type 2, damaged gaseous void (pipeline).

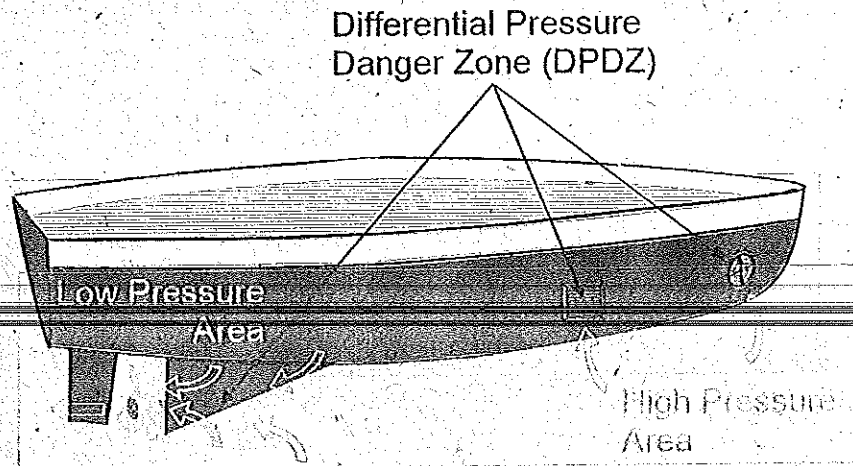


Figure 2.3: Simplified differential pressure hazard, types 3 (sea chest/intake), 4 (bow thruster) and open propulsor.

Differential pressure is a latent hazard i.e. it presents no risk when no water is flowing from the area of high pressure to the area of low pressure. But once initiated, the force generated by such a hazard can be considerable and easily sufficient to draw divers onto an opening, injuring them, damaging their equipment and holding them there indefinitely.

The forces can prevent rescuers from pulling the victim away from the opening and may also trap or injure those attempting to provide assistance.

Differential pressure flows can start instantaneously and are typically undetectable by the diver when at a safe distance.

They occur in a wide variety of structures, environments and water depths and thus represent an insidious and persistent threat to diver safety.

## 2.2 Rationale and aims of the review

In spite of a greater appreciation and emphasis on hazard identification and formal risk assessment, divers continue to be involved in incidents with differential pressure as a primary cause of injury and fatality. It was considered that a wide ranging survey throughout the diving industry may be able to identify common causes and contributory factors to differential pressure accidents, leading to improved advice and reductions in accidents.

The aims of this review were thus:

- to identify incidents of differential pressure hazards and injury in various diving communities (including recreational/sport, commercial/industrial, military and public service divers);
- to establish, where possible, root causes of incidents;
- to identify commonalities (if any) between incidents;
- to identify examples of best practice or technology in the management of differential pressure hazards and;
- to provide guidance for the diving industry on the reduction of risk and renewed emphasis and guidance on safe working practices, when diving close to localised pressure gradients.

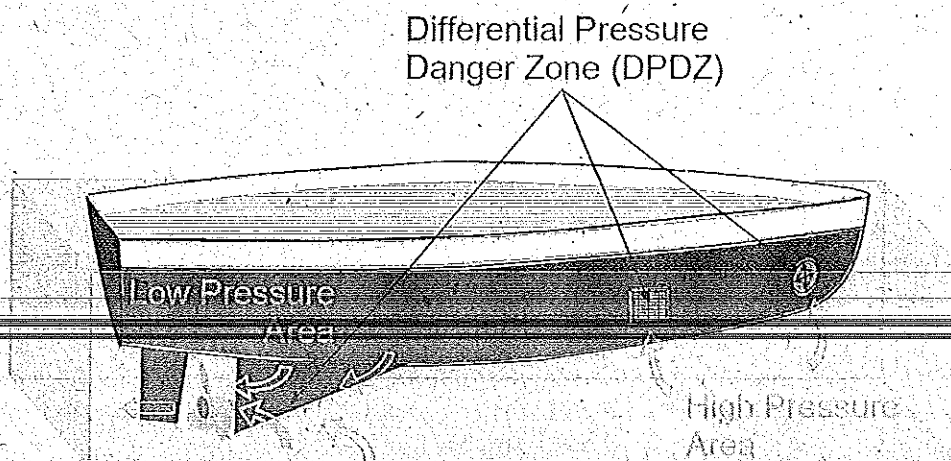


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### 3.3 Incident data analysis

In order to identify trends in differential pressure accidents, particular diving communities most at risk, high risk operations or procedures, incident data were categorised for analysis. The categories used, along with a brief explanation of each, are shown at Annex C. The potential for bias in the assigning of incidents to a category and assumptions made during the process are also discussed at Annex C.

The incident reports themselves are listed separately in Annex D.

The sources for the incident reports are referenced in Section 11. The same reference number is used to identify the incident reports in the Annex D tables and the reference list. This number is used throughout the main text where a particular incident highlights a specific point and is shown in the following format e.g. [1-78].

The numbers of incidents falling into particular categories e.g. geographical location, fatality/injury/near miss are shown graphically in Annex E. The main points that are highlighted by the graphical analysis and the incident descriptions are discussed in the subsequent section (Section 4).

As it was not possible to determine the overall amount of diving in the data collection areas the reports collated can in no way estimate the 'rate' of differential pressure injury within a collection group and the data are presented in a comparative only format.

### 3.4 Other information

The review examined over 20 sources of information and advice on differential pressure hazards. QinetiQ was also contacted by, and interviewed, several working divers from a variety of fields, to discuss their experiences of differential pressure hazards; examples of best practice and the successful management of hazards. Conversations are referenced by date; however, in accordance with the QinetiQ information request allowing anonymous submission of data, individuals are not identified.

When found, examples of extant advice and information available to the diving community were summarised and referenced in the report.

#### 4.2.3 Classification and structure

Of the four types of differential pressure hazard classified and shown in Section 2, incidents involved 'levels' (Type 1) in 41 % of cases, 'intakes' (Type 3) 29 %, 'voids' (Type 2) 22 %, and 'thrusters' (Type 4) in 5 % of cases (Figure E.2).

The classes of hazard roughly associate with the structures on which diving took place. Voids are associated with ships and pipelines, intakes with water extraction for various forms of plant, especially power generation, differences in water level are generated by a diverse group of structures but most typically dams. If a particular structure could be suggested as being especially dangerous, dams make up the largest single percentage of structures dived upon during differential pressure accidents (26 %) (Figure E.3). However, the term 'dam' embraces a huge variety of structures differing in size by several orders of magnitude and it would be unwarranted to identify it individually as an especially dangerous structure.

A more fundamental conclusion would be that the review has successfully gathered a wide variety of incidents representative of diverse diving environments and that differential pressure hazards can be found in all of them.

#### 4.2.4 The effect of increasing depth

Differential pressure forces are often proportional to depth (e.g. Types 1, 2 and 3). This has an effect upon injury mechanism (discussed below) and it might be expected for fatalities to increase with greater depth. Also, as (when recorded) the depths of inland diving incidents were predominantly no greater than 10 m, while offshore diving incidents predominantly occurred at depths greater than 10 m (Figure E.4), a similar association between offshore diving and increased fatalities might be anticipated.

However while the potential differential pressure forces generated during deeper diving (>10 m) are so much greater, the fact that the forces generated at relatively shallow depths are sufficient to result in fatalities explains why there is no association between depth and fatality and why no particular field of diving suffers disproportionately from fatalities during accidents involving differential pressure.

Examination of the limited number of incidents where the depth was recorded shows that fatalities have occurred in as little as 3 m of water [I-16], [I-36], [I-40]. Further reports record fatalities in very shallow structures such as ponds, swimming pools and water tanks (Figure E.5). Incidents involving energised pumps could occur at any depth of water, with the pump itself providing additional suction force. However in depths as shallow as 3.5 m, divers have been killed, suffering primary event trauma during incidents involving only the potential energy of the water [I-32].

#### 4.2.5 Injury mechanism

Primary event trauma (defined in Annex C) was the most common injury mechanism occurring in 49 % of the recorded incidents. This was followed by entrapment and drowning in 22 % of cases. 18 % of the incidents were near misses involving no injury to the diver, with the remaining 11 % of the incidents involving rescue trauma/hypothermia or unknown injuries (see Figure E-6). At depths greater than 10 m primary event trauma predominates as the mechanism of injury (Figure E.7). In these cases there would be no or very limited opportunities for rescuers to render assistance to the diver.

#### 4.2.7 Field of operation

The bulk of the reported incidents (59 %) were from the field of inland commercial diving, with smaller contributions from offshore (11 %), inshore (9 %) recreational (6 %) and search and rescue (6 %) fields of diving (Figure E.9). As it is not feasible to determine the overall amount of diving within each community it is not possible to suggest that inland diving is intrinsically more dangerous than other areas of diving, however, its repeated inclusion would indicate the inland diving community to be especially at risk from differential pressure hazards. Analysis of the field of operation during fatal incidents only (Figure E.10.) shows broadly the same distribution as that for all incidents, indicating that no field suffers disproportionately from fatalities during differential pressure accidents.

#### 4.2.8 Use of communications

In the majority of incidents the presence or absence of communication mechanisms with the surface was not explicitly stated in the report (Figure E.11).

In three reports the absence of audio communications was mentioned as a contributory factor in the incident, suggesting that had audio communication with the divers been available the outcome may have been different [I-05], [I-17], [I-26].

In a further three incidents, while it is unclear if the divers were using audio communications, there may have been an opportunity for the divers to communicate their predicament to the surface and initiate a rescue [I-15], [I-19], [I-38].

As the benefit of audio communications to the diver depends upon the ability of rescuers to respond to a call for assistance and rapidly equalize the differential pressure to release them, they are only likely to be useful during a small number of entrapment type incidents.

There are a limited number of entrapment incidents where this appears to have been an available course of action, although it is frequently very difficult to establish this from the reports.

Additionally, of the total number of 66 differential pressure incidents collected, the injury mechanism in 32 was classified as primary event trauma where no opportunity would have existed for rescuers to render assistance to the diver regardless of the presence or absence of audio communications.

While it is clear that should an incident occur, audio communication with the surface would be beneficial, the nature of differential pressure hazards is such that the opportunity or ability of rescuers at the surface to render assistance is often limited.

Audio communication with the diver should therefore be considered as 'best practice' but should not be considered or implemented as a direct control measure for differential pressure hazards.

As entrapment type incidents may result in the total immobilisation of the diver [I-55], communication with the surface should be able to be made without recourse to movement by the diver i.e. Voice Operated Transmission (VOX) rather than push-to-talk audio communications.

#### 4.2.9 Incident source

As a substantial number of incidents were gathered from open source press reporting (45 %) (Figure E.12), there was a concern that this might introduce a bias towards fatalities over injury and near miss reports, as it could be expected for open source recording to concentrate on the more 'sensational' incidents. However

which an incident occurred but does not indicate that it was the only failure in risk control to have occurred during the incident.

#### 4.3.2 Detection of differential pressure hazards by divers

Reports from divers and incidents indicate that at high differential pressures, flows are audible [2] or can be felt as vibrations through structures [3], and in good visibility a vortex may be seen [4]. The operation of pumps may also be associated with additional mechanical noise and vibration.

However, as much commercial diving occurs in noisy, black water environments and the localisation of sound sources by divers is poor, there is no indication that differential pressure hazards can reliably be detected by a diver.

Divers in the US reported using a mop [5] or a rag [6] held at arms length to provide an early warning device of differential pressure hazards, when searching for cracks in the face of a dam. Given the difficulty in equalizing the pressure differential in such environments, and that entrapment on such structures typically results in the diver's death, this approach seems unnecessarily reckless [I-13], [I-44], [I-46].

#### 4.3.3 Escape following entrapment

Analysis of the incidents provided, including near misses, indicates that typically once encountered it is virtually impossible for a diver to disentangle themselves from a differential pressure hazard.

From the incidents studied there were only three instances of escape following an encounter with a differential pressure hazard which had not been equalised:

- a minor soft tissue injury where the differential pressure hazard was of a very small area [I-50].
- a near miss where the diver required assistance from a standby diver to free himself from a hazard with a small area [I-58].
- a near miss where the diver required assistance from three colleagues to free himself from a pump inlet [I-54].

The amount of force a diver could generate and apply in attempting to get free from entrapment at a differential pressure hazard is highly variable, being dependent on the diver's bodily position and suitable surrounding structures to push against.

Under such circumstances attempting to predict a 'safe' differential pressure from which a diver could free themselves becomes essentially impossible.

#### 4.3.4 Assistance from standby/rescue divers

If the hazard has not been neutralised, standby divers and rescuers (even when forewarned that an incident has occurred) can be as vulnerable as the diver, and on several occasions have been injured or become trapped on the same hazard as the diver, leading to further fatalities [I-11], [I-14], [I-30], [I-36].

#### 4.3.5 Assistance from buddy divers

Similarly, three incidents involve multiple fatalities and give no indication that pairs of divers were able to offer assistance to each other during an incident [I-15], [I-26], [I-38].

Divers can be assisted in working safely by actively participating in the risk assessment process and by the provision of all necessary information and instructions prior to commencing the dive. However, these precautions will be irrelevant if divers and dive crews are not permitted to take heed of the hazards identified and allowed to work at a suitable and safe pace.

#### 4.4 Summary of results and analysis

The review identified 66 differential pressure incidents involving 74 individuals. To illustrate the hazard of open propulsors, a further 12 example propulsor incidents are included.

These were drawn from a diverse range of diving communities worldwide. They encompassed a period of over 100 years and continue to affect divers today.

The majority of the reports were from the US and UK and it was found that it is predominantly working divers who are affected by differential pressure hazards.

Inland diving was highly represented, although the study identified incidents throughout the commercial diving environment.

The review found that divers were typically unable to detect differential pressure hazards in the water and once encountered it was very difficult for divers to escape from them.

Encounters with differential pressure hazards were frequently fatal (even in shallow water) and there was often no opportunity for intervention by rescuers.

No effective technique, other than the equalization of the differential pressure, was identified for freeing a diver from a hazard. The involvement of buddy or standby divers or attempts by rescuers at the surface to use force to free a diver, prior to the equalisation of pressure, frequently resulted in further injuries or fatalities.

The review found contradictory evidence regarding the awareness of differential pressure hazards in diving communities and identified that in some cases divers were compelled to work in environments which they knew to be unsafe.

Audio communication was indicated as beneficial in some cases.

### 5.3.2 Principles of diving

This type of advice was most notable by its absence. Of all of the sources consulted, none covered differential pressure hazards in a general way as part of a section on diving principles, theory or hazards.

There was some discussion of a general nature in parts of the "Professional Diver's Handbook" [11], but these were contained within sub-sections on operational safety for specific environments.

Good advice of a 'general principles' type on differential pressure is contained within an educational video produced by the Association of Diving Contractors International (ADC-I) [33], but this is specific to the differential pressure hazard, rather than being part of an overall course on diving theory.

A more general educational discussion of differential pressure as an identified class of hazard may exist in training syllabuses that were not accessed for this report.

A general discussion of the principles and methods for quantifying differential pressure hazards is contained in the following Section 6.

### 5.3.3 Risk and hazard assessment

In the sources consulted, the most common occurrence of any mention of differential pressure hazards is in risk and hazard assessment sections, although they are not often grouped together as a single overall class of hazard.

Most recent manuals that contain sections on the principles of risk assessment, and almost all of the ACOPs, identify particular examples of differential pressure hazard as examples of hazards in general. The examples given depend, as expected, on the relevant field that the ACOP or manual covers.

For example, the HSE Scientific and Archaeological ACOP [19] does not list any differential pressure hazards in the sections on 'Clients and others' or 'Diving project plan and risk assessment', whereas the HSE Commercial diving projects inland/inshore ACOP [22] lists '*locks, weirs, water intakes or discharge points causing suction or turbulence, and ship propellers*' in paragraph 27 (d) on the responsibilities of clients and others and covers '*Water flow, intakes and discharges*', '*Underwater currents*', '*Diving near remotely operated vehicle (ROV) operations*' and '*Diving from vessels*' in paragraphs 49, 52, 53 and 59 of the section on Diving project plan and risk assessment.

Hazards of Type 1 '*Levels*', Type 3 '*Intakes*' and Type 4 '*Thrusters*' are reasonably well covered. However, Type 2 '*Gaseous voids*', is less well covered and the only code of practice which specifically addresses this type of hazard is the International Marine Contractors Association (IMCA) publication D 014 [25] in paragraph 7.3.27. There is also a brief mention of 'under pressure' in IMCA D 006 '*Diving operations in the vicinity of pipelines*' [34].

Some other specific hazards are covered in depth by some publications but not discussed in others for example the ADC-I Consensus Standards [28] contains a whole section on diving in potable water tanks, which is not covered elsewhere. Another example concerns air lifts. Whilst these are referred to in many instances and recognised as potentially hazardous due to their buoyancy, only the "Professional Diver's Handbook" [11] recognises the hazard due to the suction generated.

Of the ACOP/standards type of documents consulted, the 'Consensus Standards' produced by the ADC-I [28] is the only document that groups all of these hazards together as an identified class of 'Differential pressure'.

- Docks and harbours
- Weirs and locks
- Spillways, reservoirs and dams
- Outfalls
- Airlifts and dredges
- Unmanned submersibles

The UK Police diving manual [16] also has a comprehensive section on diving in reservoirs, locks and docks.

#### 5.3.6 Specific advice

General principles of 'best practice' risk assessment and hazard control as applied to differential pressure will be further discussed in section 7; however, instances of advice of a numerical or very specific nature from the documents consulted are listed below:

- DP vessels:
  - diver umbilical should be at least 5 m shorter than the distance to the nearest thruster (or other hazard such as intakes or propulsors) [11],[15]
  - the standby's umbilical should be 2 m longer than the diver's umbilical [15]
- Weirs and locks – diving should not be permitted when there is an opening at the bottom of a vertical lift gate greater than about 2 cm [11]
- Dams and reservoirs – never go head first into an opening less than 42 inches (1.06 m) in diameter [11]
- Air lifts and dredges – extra care must be taken at depths greater than 10 m [11]
- Operations should not be conducted in currents greater than 1 knot (0.5 m s<sup>-1</sup>) [28]
- Umbilicals and lifelines:
  - shall have a minimum break strength of the hose assembly, including terminating hardware of 1000 lbs (454 kg) [28]
  - breaking strain not less than 480 kg [16]
- Ships:
  - Diving within 50 ft (15.24 m) of an active sea suction (on the same side of the keel) maintaining a suction of 50 gpm (189 l min<sup>-1</sup>) or more is not authorised [14]
  - Divers are not to approach within 15 m of main inlets unless the main circulators are running at or below the safe speed laid down in the ship's book [15],[16]

#### 5.4 Summary

From the above examination of available advice it is clear that, in recent literature at least, the existence of most, if not all, differential pressure hazards are widely acknowledged and promulgated.

Relevant codes of practice generally indicate the likely presence of such hazards in their field of application, although without claiming to be fully comprehensive, hence slightly different lists of hazards are covered by, for example, HSE, IMCA and ADC-

## 6 Understanding and quantifying the hazard

### 6.1 General

This section contains some general discussion of the nature and scale of the differential pressure hazard and some methods for quantifying the hazard.

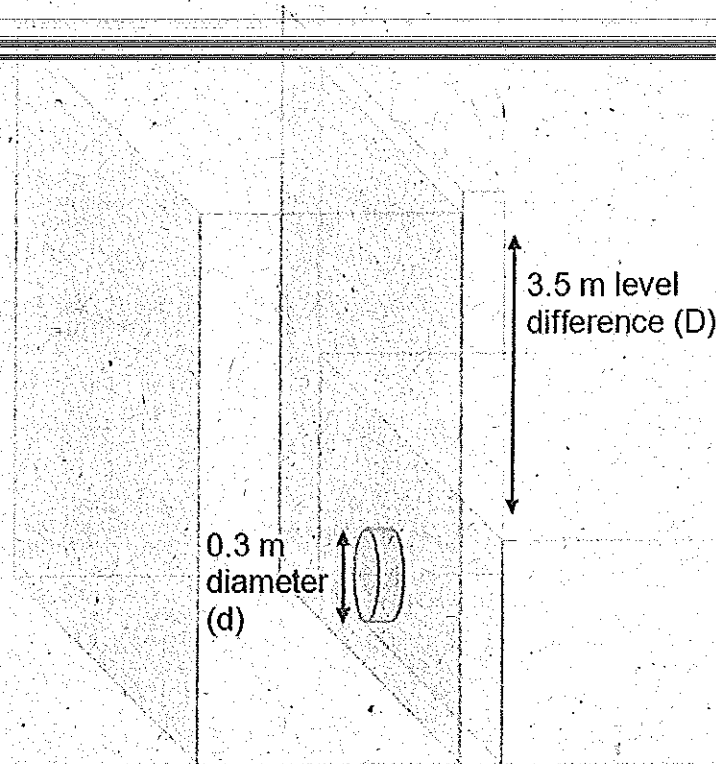
### 6.2 ~~The force generated by differential pressure~~

The force due to the differential pressure across a hazard can be calculated using the formula shown below in Figure 6.1.

### Basic formula

$$\text{Force} = \text{Pressure} \times \text{Area}$$

The example below calculates the force acting on an object blocking a 0.3 m diameter pipe connecting two bodies of water with a difference in level of 3.5 m.



$$F = D \times \text{density} \times A$$

Where:

- F = Force (kgf) (kgf is kilogramme force)
- D = Difference in level (m)
- density = 1025 kg · m<sup>-3</sup> for sea water  
or = 1000 kg · m<sup>-3</sup> for fresh water
- A = Area (m<sup>2</sup>) ( $\pi \times (d/2)^2$  (approx. 0.79 x d x d) where d is diameter in m)

$$\text{Force} = 3.5 \times 1025 \times \pi \times (0.3/2)^2 = 254 \text{ kgf}$$

Figure 6.1: Force due to differential pressure calculation

Note: To estimate the force due to differential pressure across an opening into a gaseous void substitute D with the depth of the void below the water surface. For a pump intake substitute D with the depth of the intake below the water surface. (Increase the depths further (up to 10 m) if the gas in the void is at a pressure below atmospheric pressure or the pump is capable of generating negative pressures below atmospheric pressure.

Look-up tables are provided in Annex F (Tables F.1 and F.2), showing the differential pressure force generated at a variety of depths of water over a range of areas derived from common pipe diameters and areas of openings mentioned in incident reports.

Examination of Tables F.1 and F.2 shows that even relatively modest depths of water can generate considerable forces. For example at a depth of as little as 0.5 m the differential pressure force generated over an area of  $\sim 700 \text{ cm}^2$  (the area of a 30 cm diameter pipe which the torso of an adult could cover) is over 35 kg.

As mentioned in 4.3.3 entrapment risks from even small forces may be compounded by factors such as the immobilisation of limbs and the application of even this much force to the torso may have the capacity to impair ventilation and disrupt blood flow. Current advice from the Home office [38] indicates that the application of any pressure to the chest, back or torso is to be avoided.

Likewise, at greater depths, the forces generated across even very small areas would be capable of causing injury [1-50], [2].

While a common sense approach would indicate that differential pressure hazards of very small area or in very shallow depths of water (which generate forces of no more than a few kilograms) have a limited capacity to injure or trap a diver, it becomes apparent that there is essentially no diving environment or depth of water in which divers can easily discount the risks of entrapment or injury posed by differential pressure. See also 4.2.4 and 4.2.5.

Further research, including experimental investigation into the physical effects of differential pressure may be warranted and provide a better understanding of the dangers posed by differential pressure hazards.

### 6.3

#### Increase in water velocity as a hazard is approached

The reasons why divers seem unable to detect and avoid differential pressure hazards can be explained by considering the way in which water enters a hazard. The velocity profile of a hazard is such that at the periphery the diver may approach without any perceptible increase in water flow velocity.

Figure 6.2 shows the water velocity at increasing distances from a hypothetical differential pressure hazard. A diver approaching the hazard moving from point *a* to point *b*, would be unlikely to perceive the small increase in flow velocity; moving an equal distance closer from point *b* to *c* the diver would experience a large increase in flow velocity and, as a result, likely to be drawn onto the hazard. It is thus very difficult for divers to perceive or approach active differential pressure hazards without becoming entangled with them.

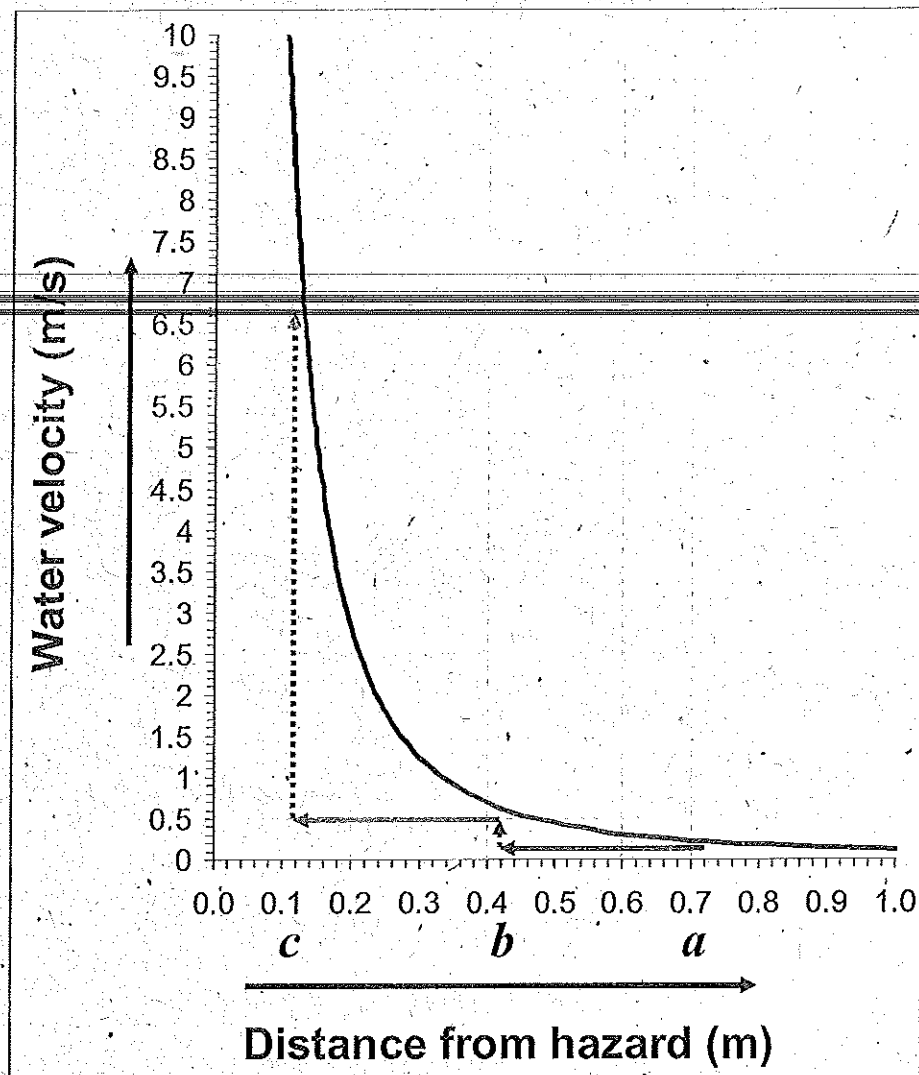


Figure 6.2: Hypothetical water velocity profile approaching a differential pressure hazard

Current industry guidelines suggest divers can safely operate in water currents up to  $0.5 \text{ m}\cdot\text{s}^{-1}$  [35],[37]. The area around a hazard where water is moving faster than  $0.5 \text{ m}\cdot\text{s}^{-1}$  should not be entered by the diver. Any minimum exclusion zone should seek to maintain the diver in water currents no faster than  $0.5 \text{ m}\cdot\text{s}^{-1}$  and the tendency for velocities to increase rapidly with movement towards a hazard warrants an extensive safety margin to this zone.

## 6.4 Estimation of the minimum DPDZ around a hazard

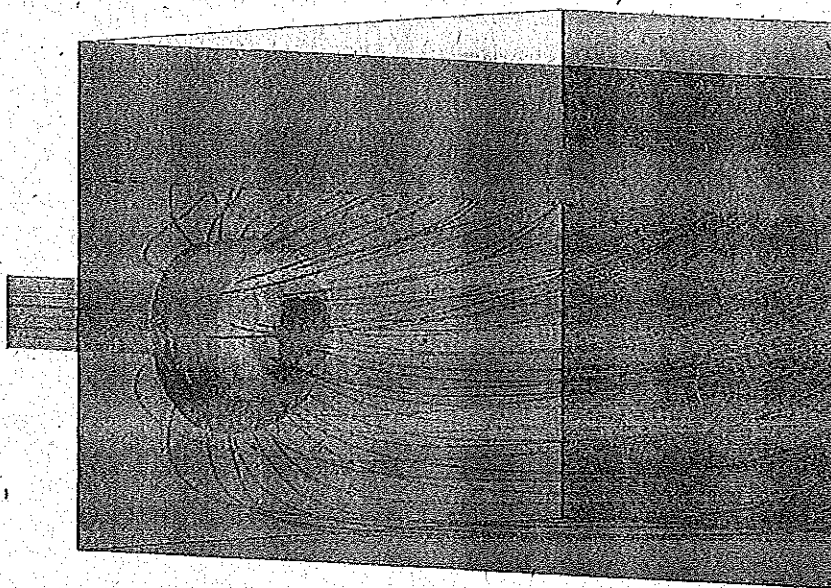
### 6.4.1 Computer modelling

The DPDZ about a known hazard can be calculated by a number of methods. An example of computer modelling (using the CFX5 software package produced by ANSYS Inc.) of simple intakes e.g. a pipe opening onto a flat wall is shown in Figure 6.3. It shows a roughly hemispherical area of water flow at a velocity of  $0.5 \text{ m}\cdot\text{s}^{-1}$  around a circular inlet (0.3 m diameter). Increasing distance from the back

wall is indicated by the transition from blue to red (0.0 to 1.5 m), with blue lines indicating the flow path of water at lower velocity.

Water velocity increases as it approaches the intake point with peak flows directly in front of the intake point. This 'capture area' (that is water moving at a velocity of  $0.5 \text{ m}\cdot\text{s}^{-1}$ ) thus forms a roughly hemispherical shape around the intake point.

A diver working outside of this area would experience flow velocities below  $0.5 \text{ m}\cdot\text{s}^{-1}$ . However, without attention to his position the diver would continue to drift towards the inlet. Some incidents indicate that in low visibility it may be impossible for a diver to be aware of movement towards a hazard [1-08], [1-23], [1-26], [1-38].



*Figure 6.3: Computer modelling (CFX5, ANSYS Inc.) of flow velocity around a circular intake*

Complex computer modelling of this type would obviously not be suitable as a technique for the estimation of a DPDZ. However, an acceptable estimation of the size of the hemisphere of water with a flow velocity of  $0.5 \text{ m}\cdot\text{s}^{-1}$  around an intake can be made once the flow of water is known.

#### 6.4.2 Calculation of water flow through an opening

The calculation of a DPDZ first requires an estimation of the water flow through the hazard. Flow will be dependent on the area of the boundary between high and low pressures, the depth (and density) of the water and friction effects during water transit.

However, an acceptable estimation of the flow rate through a non-powered differential pressure hazard can be calculated using the formula shown in Figure 6.4.

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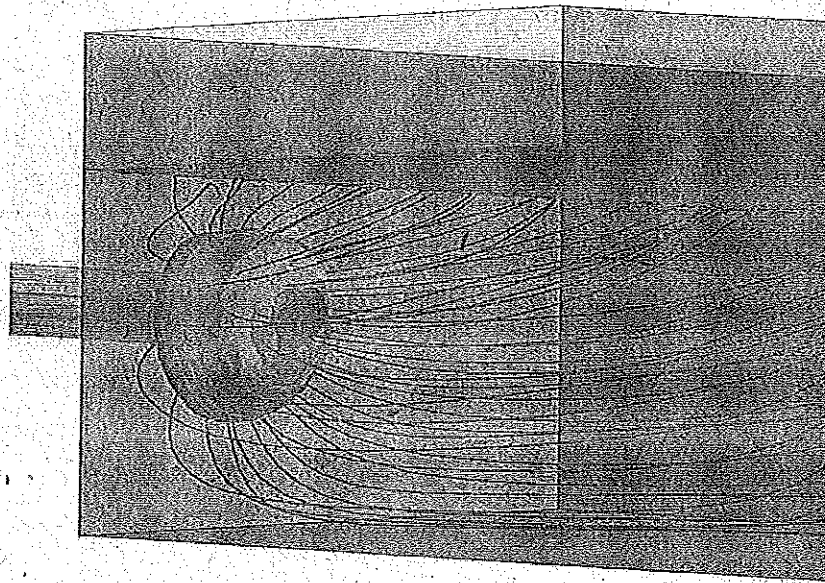


Figure 6.3: Computer modelling (CFX5, ANSYS Inc.) of flow velocity around a circular intake

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6.4.3

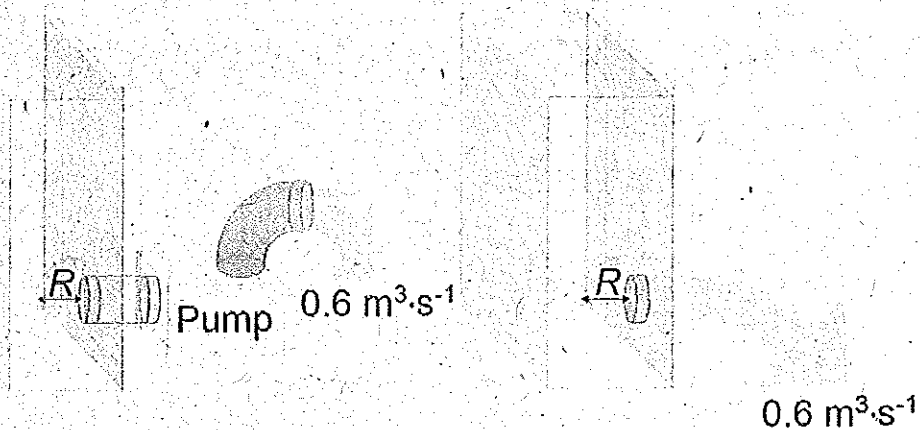
Calculation of the minimum distance from the hazard for a water velocity of  $0.5 \text{ m} \cdot \text{s}^{-1}$

Having calculated the flow through an opening using the formula in Figure 6.4, or using a known pump capacity, the stand-off distance or DPDZ can now be calculated using the approximate formula in Figure 6.5.

#### Basic formula

$$\text{Distance} = \sqrt{(\text{Flow rate} / \pi)}$$

The example below calculates the distance from an intake, of the hemisphere of water with a flow velocity of  $0.5 \text{ m} \cdot \text{s}^{-1}$ , for a flow rate of  $0.6 \text{ m}^3 \cdot \text{s}^{-1}$ .



*n.b.* Not to scale

$$R = \sqrt{(Q / \pi)}$$

Where:

R = Distance from intake (m)

Q = Flow rate (or pump capacity) ( $\text{m}^3 \cdot \text{s}^{-1}$ )

$$\text{Distance} \approx \sqrt{(0.6/3.14)} \approx 0.44 \text{ m}$$

Figure 6.5: Radius of a DPDZ around an intake with a water velocity of  $0.5 \text{ m} \cdot \text{s}^{-1}$

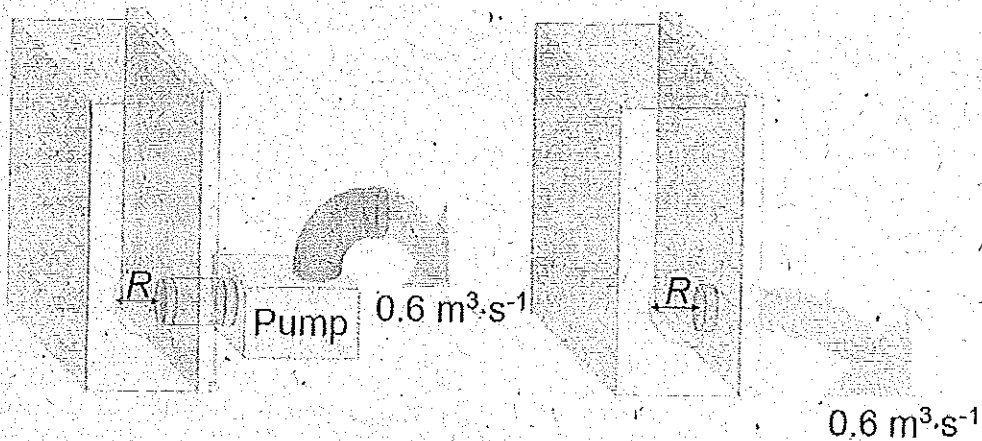
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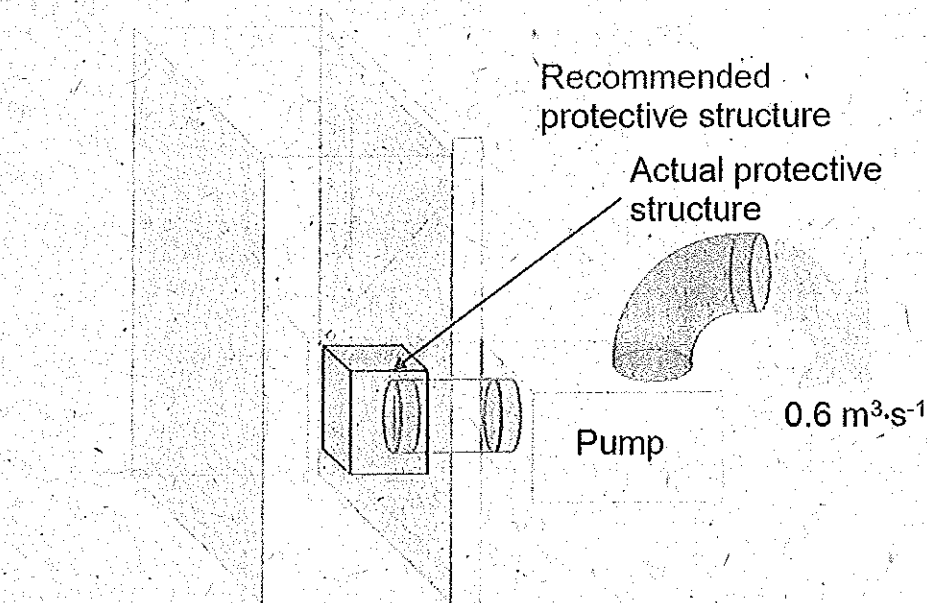
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Figure 6.5: Radius of a DPDZ around an intake with a water velocity of  $0.5 \text{ m}\cdot\text{s}^{-1}$

## Basic formula

$$\text{Flow rate}_{(\text{restricted})} = \text{Area} \times \text{Maximum water flow velocity}$$

The example shown considers a pump operating at  $0.6 \text{ m}^3 \cdot \text{s}^{-1}$ . Assessment by IMCA document AODC 055 [35] indicates the need for a protective structure with an area of  $3.3 \text{ m}^2$ , however site constraints mean the largest protective structure that can be built is  $2.7 \text{ m}^2$ .



*n.b.* Not to scale

$$F_{(r)} = (A - A_d + A_s) \times 0.5$$

Where:

$F_{(r)}$  = Restricted flow rate of the pump ( $\text{m}^3 \cdot \text{s}^{-1}$ )

$A$  = Total area of the protective structure ( $\text{m}^2$ )

$A_d$  = Area presented by 2 divers and their equipment (assumed to be  $2 \text{ m}^2$ )

$A_s$  = Area of the material forming the protective structure (for this illustration assumed to be  $0.1 \text{ m}^2$ )

$$\text{Restricted flow} = (2.7 - 2.0 - 0.1) \times 0.5 = 0.3 \text{ m}^3 \cdot \text{s}^{-1}$$

*i.e.* the pump must be run at half capacity.

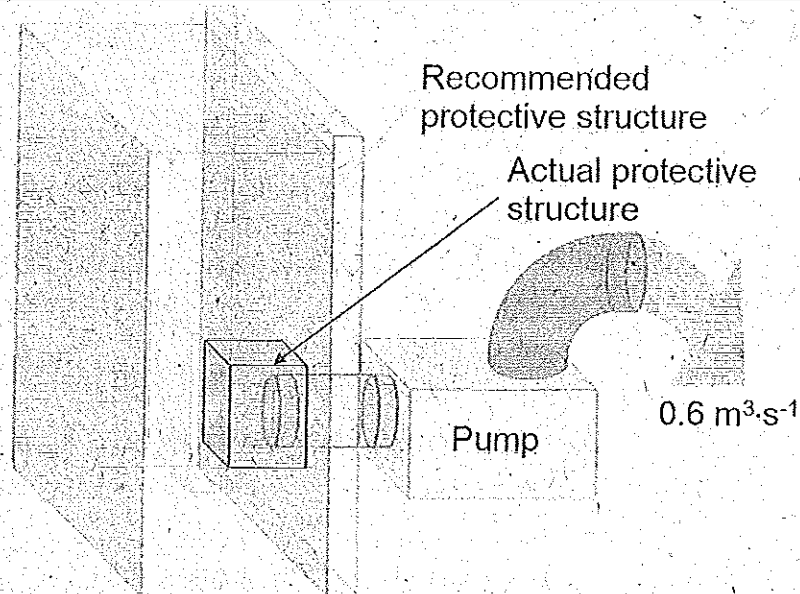
Figure 6.6: Modification of pump capacity with existing external guard

Note: Divers should not operate in the vicinity of protective structures presenting an area of less than  $2.0 \text{ m}^2$  plus the area of the material forming the protective structure due to the capacity for the divers to completely occlude the intake.

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$$F_{(r)} = (A - A_d - A_s) \times 0.5$$

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## 7.2 Management of differential pressure hazards and control hierarchy

### 7.2.1 Hierarchy of risk control

The preferred mechanism for the control of risk is in a hierarchical manner as shown in Figure 7.1.

Control measures should be implemented from the top down and only when a control measure has been found not to be practicable should measures from a lower level be considered.

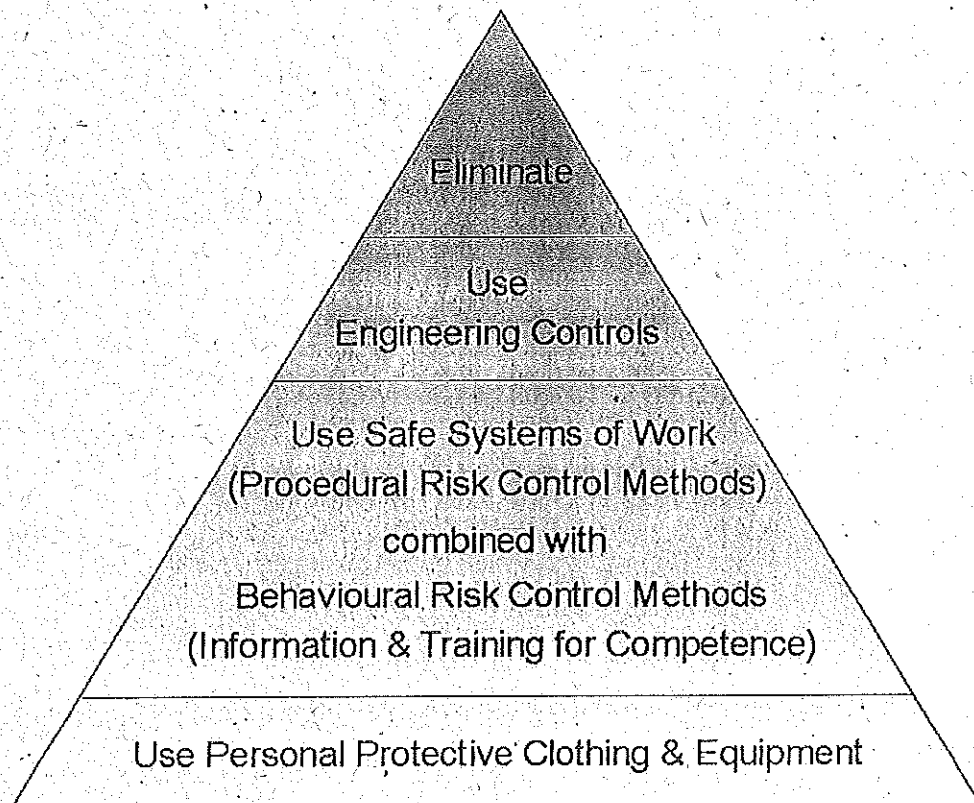


Figure 7.1: Hierarchical risk control principles

### 7.2.2 Elimination/avoidance of the differential pressure hazard

Given the difficulties divers face, detecting and escaping from differential pressure hazards, the default position should always be to avoid or eliminate the hazard prior to diving. This embraces best practice recommended by the ADC.

The approach should seek to neutralise the hazard. This may be achieved by techniques such as:

- diving on the downstream side of the hazard; or
- flooding to equalise water levels or fill any void.

Alternately the diver may be substituted by using:

- a remotely operated vehicle (ROV); or
- performing the operation remotely from the surface.

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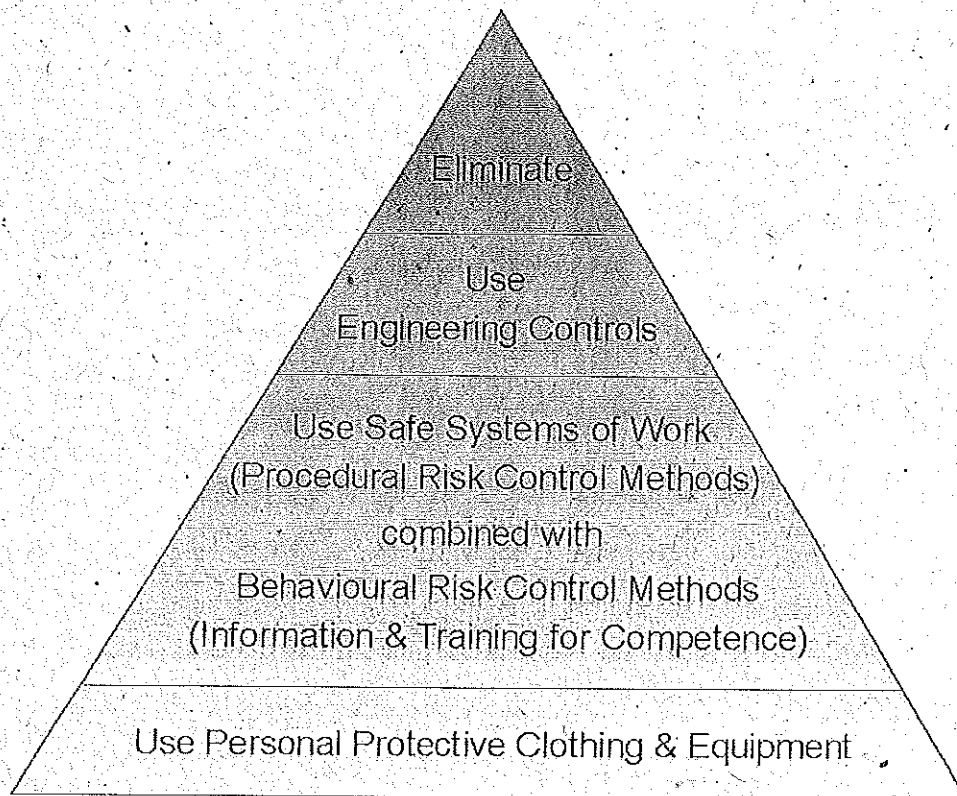


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- diving on the downstream side of the hazard; or
- flooding to equalise water levels or fill any void.

Alternately the diver may be substituted by using;

- a remotely operated vehicle (ROV); or
- performing the operation remotely from the surface.

- (3) Should it be necessary to dive for prolonged periods adjacent to or on the main inlets, the main circulators should, whenever possible, be stopped and the main inlet and discharge valves shut. "

Divers may be protected from hazards that cannot be neutralized by the provision of guards and screens. An assessment of the provision of screens and guards may be made in accordance with IMCA document AODC 055 [35], paying particular attention to the area and mesh size of any guard, an awareness of the effect of partial occlusion on flow velocity and the necessity of control of the umbilical, lanyards etc by the diver. Existing guards and screens on intakes may be present to keep debris out of pumps and may not be wholly suitable for the purpose of protecting the diver [I-26], [I-61].

Where there is an absolute necessity for divers to operate in the vicinity of guarded intakes and an assessment indicates that existing screens and guards allow the generation of water velocities above  $0.5 \text{ m}\cdot\text{s}^{-1}$  there is a potential to reduce the speed of the pump to reduce water velocity at the intake screen. However, this calculation should be used with caution, considering the uncertainties associated with it and that the potential consequences of miscalculating could be injury or entrapment of the diver [I-26], [I-52], [I-61]. See Figure 6.6 for calculation of the reduced pump speed.

#### 7.2.5 Preventing the formation of a DPDZ

As differential pressure is a latent hazard the DPDZ may be prevented from forming by the use of robust lock-off isolation procedures to isolate valves, pumps, intakes and propulsors.

Any lock-off isolation procedure should be implemented as part of a detailed (procedural) safe system of work. This may be incorporated into a formal permit-to-work/permit-to-dive system. Various incidents have been caused by failures of isolation procedures for valves and intakes [I-03], [I-15], [I-27], [I-34], [I-37], [I-42], [I-66].

At its simplest a lock-off isolation procedure should identify pertinent controls and valves with tags. Pictorial representation may be more effective than text, especially in working environments with multiple languages, but physical barriers to the operation of valves and intake controls are preferable. Techniques include the locking of valves and controls with padlocks, the keys to which are held by the dive supervisor or diver. The isolation of the power supply rather than controls can guard against the remote or automatic activation of pumps [I-42].

Police divers working in situations where intakes and valves may be opened deliberately in an attempt to sabotage operations reported using techniques such as posting a guard on the bridge or engine room, and confiscating fuses from control panels to prevent the operation of pumps and intakes.

As with procedures to equalise differential pressure the effectiveness of the control measure should be assessed prior to the diver entering the water. Where this procedure cannot be performed from the downstream or low pressure side of a hazard a pre-dive inspection by ROV may even be required [I-12], [I-19], [I-28].

When closed valves represent the main defence against exposure to a DPDZ, where possible, use more than one valve as a barrier to exposure (i.e. try to have multiple redundancy in your defensive system).

An assessment of the condition of the structure on which diving is taking place is also required when implementing engineering controls. The likelihood of a failure of the structure leading to the formation of a DPDZ should be considered in assessing the suitability of this control mechanism [I-56].

## 7.2.8 Technology in the control of differential pressure hazards/rescue techniques

No specific technology or product for use when assisting in the rescue of a trapped diver was identified during the review. However, two novel techniques for equalising pressure differentials using compressed air were reported:

- Following damage to the external hull of a frigate the compartment of the damaged section was pressurised by placing several free flowing SCUBA into the compartment and sealing it. This action was performed primarily to displace water from the flooded compartment but also had the effect of allowing a diver to safely approach and inspect the exterior of the vessel.
- A maritime research organisation found reductions in differential pressure force could be achieved by injecting compressed air at the point of entrapment. The technique was most effective during entrapment on differential pressure hazards on vertical surfaces.

## 7.3 Summary of best practice

Differential pressure hazards must be assumed to be present where:

- water levels between adjoining areas vary;
- water is juxtaposed against gaseous voids;
- water is mechanically drawn through intakes and
- water is mechanically drawn towards propulsors, impellers, or other types of thrusters on ships.

A risk assessment should always be performed and differential pressure hazards cannot be dismissed as trivial or insignificant in any diving environment or at any depth of water.

The risk assessment should be completed in conjunction with staff fully familiar with the dive site and the assessment must encompass both actual and potential hazards, reflecting the latent nature of many differential pressure hazards. This may require an element of knowledge of the integrity of the structure in which the dive is taking place along with the likelihood and mode of potential structural failure.

Simple formulae are available to estimate force, flow and size of DPDZ.

The distances required to stay outside of the DPDZ can be relatively small but the nature of the hazard is such that a physical barrier between the diver and the DPDZ must be achieved.

The preferred mechanism of control/management of the differential pressure hazard is a hierarchical approach. Examples of failures in control of differential pressure hazards stress the necessity of assessing the effectiveness of control measures prior to the diver entering the water and the use of robust physical barriers to the operation of valves/intakes/other machinery and the separation of divers from the DPDZ.

Rigorous and proper application of Permit-to-Work systems incorporating appropriate lock-off isolation procedures is required for satisfactory control of many differential pressure risks at dive sites.

High quality, well-informed leadership and supervision backed up by the provision of adequate information, instruction and training for dive teams and other relevant personnel will reduce the likelihood of safe systems of work breakdown.

The use of surface supplied diving equipment and voice-activated communications is recommended.

## 8

## Conclusions

Differential pressure hazards have been present throughout the history of diving and remain a hazard to divers today.

Differential pressure hazards predominantly affect divers at work and are found throughout the commercial diving environment in virtually any depth of water.

Divers are typically unable to detect differential pressure hazards in the water.

Once encountered, it is very difficult for divers to escape from them and the equalization of the differential pressure is usually required before freeing a diver from a hazard.

Differential pressure hazards, once encountered, are frequently fatal with no opportunity for intervention from rescuers.

The involvement of buddy or standby divers or attempts by rescuers at the surface to use force to free a diver, prior to the equalisation of pressure, frequently result in further injuries or fatalities.

Evidence regarding the awareness of differential pressure hazards in diving communities is contradictory; although awareness seems to be widespread, underestimation of the seriousness of the hazard may underlie some incidents.

Divers may sometimes feel compelled to work in environments which they know to be unsafe.

Differential pressure hazards can be successfully controlled allowing divers to work safely in the vicinity of differential pressure hazards. The preferred mechanism of control/management of the differential pressure hazard is a hierarchical approach following adequate and informed risk assessment.

Simple calculations may be used to estimate the size of a DPDZ, although no differential pressure hazard can be deemed to be trivial or insignificant.

Examples of failures in control of differential pressure hazards stress the necessity of assessing the effectiveness of control measures prior to the diver entering the water and the use of robust physical barriers to the operation of valves/intakes/other machinery and the separation of divers from a DPDZ.

Rigorous and proper application of Permit-to-Work systems incorporating appropriate lock-off isolation procedures is required for satisfactory control of many differential pressure risks at dive sites.

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## A Information request

The information request used to elicit incident and other data is reproduced below in Figure A.1.



**Study of hazards and risks associated with localised differential pressure**

QinetiQ are conducting a study for the United Kingdom (UK) Health and Safety Executive (HSE), (a non-profit governmental organisation), on localised differential pressure hazards in the diving industry.

This project follows in the wake of a number of recent diving incidents where differential pressure (or Delta P) was identified as a causative agent or contributory factor.

Divers can encounter a localised pressure gradient when:

- Water levels between adjoining areas vary (e.g. at dams or locks);
- Water is juxtaposed against gaseous voids at different pressure to the water pressure (e.g. at submarine pipelines);
- Water is mechanically drawn through intakes (e.g. at cooling water intakes for power stations or at sea chests on ships) and ducted propellers, impellers, or other types of thrusters are operated in the vicinity of diving operations (e.g. on shipping).

Examples of incidents where divers encountered differential pressure hazards include:

- A diver working in the vicinity of a partially open sluice gate was trapped when the tide changed lowering the water level downstream of the gate.
- Divers operating in 30 m of water damaged a valve on a pipeline containing gas at atmospheric pressure. The sudden inrush of water into the pipe pulled the arm of one of the divers into the resulting hole.
- Inadequate lockout procedures allowed the activation of a bow thruster, while a diver performed a hull inspection. The diver was drawn into the propeller.

As a first stage of this project QinetiQ are collecting information from the diving community. It is expected that the outcome of the project will allow the HSE to formulate industry guidance, which will be of benefit to the diving community as a whole.

This information could take the form of:

- accident or near miss reports where pressure gradients have been cited as a primary or contributory factor;
- anticipated differential pressure risk scenarios;
- examples of successful procedures or technology in the management of differential pressure hazards.

Reports and data will be treated in the strictest confidence and individuals or organisations will not be identified in the final document. A confidentiality agreement can be made if required.

If you feel you could assist with this study I would be most grateful if you could contact me or forward any relevant information (details at the foot of the page) at your earliest convenience. Any assistance you can provide with this project would be gratefully received.

Figure A.1: Information request

## C Data categorisation

### C.1 Classification of incident data

#### C.1.1 General

The incident reports were categorised according to the categories listed in the left hand column of Table C.1. The type of values available for each category are listed in the middle column, with more detail in the right hand column.

| Category                                     | Value                           | Description                                                                                                                                                                                                          |
|----------------------------------------------|---------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| QinetiQ Reference Number                     |                                 | Incidents were allocated a unique number to identify them. Incidents are referred to in the text by this reference.                                                                                                  |
| Incident Type                                | Fatality                        | Any incident where the diver was killed during or shortly after and as a direct result of the incident.                                                                                                              |
|                                              | Injury                          | Any incident where the diver was injured but survived.                                                                                                                                                               |
|                                              | Near miss                       | Any incident where the diver was uninjured or the injury was trivial.                                                                                                                                                |
| QinetiQ Differential Pressure Classification | Levels                          | Where water levels between adjoining areas vary.                                                                                                                                                                     |
|                                              | Voids                           | Where water is juxtaposed against gaseous voids.                                                                                                                                                                     |
|                                              | Intakes                         | Where water is mechanically drawn through an intake.                                                                                                                                                                 |
|                                              | Thrusters                       | Where water is mechanically drawn through an intake in conjunction with the propulsion of a ship or boat.                                                                                                            |
|                                              | Open Propulsors                 | Where water and/or equipment is mechanically drawn into an open propulsor.                                                                                                                                           |
| Structure                                    |                                 | When mentioned in reports the structure on which the dive was taking place is recorded.                                                                                                                              |
| Depth                                        | m                               | Depth was quoted as that at which the diver was operating unless the report states the differential depth e.g. A diver working in 4 m of water upstream of a water level of 1 m would be listed as operating at 3 m. |
| Differential Pressure                        | kg of force                     | Where sufficient data was present the differential pressure involved during the incident was calculated.                                                                                                             |
| Opening                                      | m <sup>2</sup>                  | The area of the hole or opening involved.                                                                                                                                                                            |
| Opening                                      | m                               | The dimensions of the hole or opening involved.                                                                                                                                                                      |
| Flow                                         | m <sup>3</sup> ·s <sup>-1</sup> | When mentioned in reports the flow at pumps and intakes.                                                                                                                                                             |
| Injury Mechanism                             | Primary event trauma            | Injuries sustained by the diver as an immediate consequence of exposure to differential pressure e.g. Acute crushing or laceration injury or interruption of gas supply.                                             |

|                      |      |                                                                                                                        |
|----------------------|------|------------------------------------------------------------------------------------------------------------------------|
| Date                 | Year | When known, incidents are ordered by the year in which the incident occurred. No limit was made on the age of reports. |
| Incident description |      | A brief description of the incident.                                                                                   |

Table C.1: Incident data categorisation

#### C.1.2 Differential pressure classification

The category of **Thrusters** has been selected to include incidents involving ducted propellers and intakes which generate a focussed negative pressure region capable of drawing a diver towards it and potentially trapping them at an inlet point. It does not include standard propellers or other propulsors, as although these undoubtedly generate a negative pressure gradient capable of drawing any diver or diver's equipment in the vicinity towards it, they have no capacity to trap and hold a diver at an inlet point; these have been classified separately as **Open propulsors**. It may be that differential pressure incidents involving open propulsors may be under-reported through the omission of any suitable 'keywords' such as ducts, nozzles, thrusters *etc* in descriptions of the incidents. Such incidents could be reported as simple collisions and propeller entanglements.

Some reports mention divers being drawn into an 'intake' or 'inlet', however details in the reports indicate that the system was passive and not powered by a pump thus these reports are classified under **Levels**.

#### C.1.3 Diver qualifications and diving field

The category of **Recreational diving** is essentially redundant before the 1950's. Prior to this, unless otherwise stated, it is assumed that all diving is 'commercial' in nature and thus all diving qualifications are similarly commercial (however this makes no assumption that any such qualification is comparable with modern commercial diving qualifications). See also section 4.1.2 Relevancy.

Police, fire service and military divers have been assigned **Professional** qualifications to indicate they have had some form of official training, and this qualifies them to work in the fields of 'Military' and 'Search and rescue/recovery' diving.

#### C.1.4 Injury mechanism

Frequently reports contain only partial details of the injury suffered by the diver. The following logic has been applied in the categorisation of diver injuries.

**Primary event trauma** has been allocated when reports explicitly list:

- acute injuries suffered by the diver;
- an immediate loss of gas supply; or
- fail to mention any period of entrapment.

Primary event trauma encompasses events such as the severing of an umbilical or loss of a demand regulator (even when the cause of death is drowning). This classifies together incidents in which, due to their immediate onset, there is very limited or no opportunity for rescuers to render assistance to the diver.

**Entrapment, drowning** has been allocated when reports explicitly list:

## D Incident record tables

### D.1 Table layout

Each of the tables in this annex contains details of a single incident. Incidents have been sorted into three types: Fatalities (section D.2), Injuries (section D.3) and Near miss incidents (section D.4). Each incident has been given a unique reference identifier which is shown in the first row of the table, this matches the incident reference in the main body of the report (Section 11 - Incident References)

All figures are quoted in S.I. units; imperial equivalents are also shown, where appropriate. Where no information was located for a particular field, the respective line in the record table is not shown.

The full list of possible fields within each record table is shown in Table D.1.

| <b>INCIDENT NUMBER</b>                   |  |
|------------------------------------------|--|
| Type:                                    |  |
| Differential pressure classification:    |  |
| Structure:                               |  |
| Depth (m):                               |  |
| Differential pressure (kg):              |  |
| Opening (area m <sup>2</sup> ):          |  |
| Opening (diameter/dimension (m)):        |  |
| Flow (m <sup>3</sup> .s <sup>-1</sup> ): |  |
| Injury mechanism:                        |  |
| Qualifications:                          |  |
| Field:                                   |  |
| Communications:                          |  |
| Source:                                  |  |
| Jurisdiction (country):                  |  |
| Year:                                    |  |
| Incident description:                    |  |

Table D.1:<sup>4</sup> Showing all of the fields possible in an incident record with full information

| <b>INCIDENT 03</b>                                                                                                                                                                                                                                                   |                     |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                         | Fatality            |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                         | Levels              |
| <b>Structure:</b>                                                                                                                                                                                                                                                    | Sluice              |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                             | Rescue trauma       |
| <b>Qualifications:</b>                                                                                                                                                                                                                                               | Commercial          |
| <b>Field:</b>                                                                                                                                                                                                                                                        | Commercial - Inland |
| <b>Communications:</b>                                                                                                                                                                                                                                               | Unknown             |
| <b>Source:</b>                                                                                                                                                                                                                                                       | Open source press   |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                       | UK                  |
| <b>Year:</b>                                                                                                                                                                                                                                                         | 1900                |
| <b>Incident description:</b><br>When a sluice valve was opened in the vicinity of a diver his left arm was drawn into the hole and his umbilical severed. In desperation the sluice was closed severing the divers left arm. The diver was recovered but died later. |                     |

| <b>INCIDENT 04</b>                                                                                                                                                                           |                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| <b>Type:</b>                                                                                                                                                                                 | Fatality                  |
| <b>Differential pressure classification:</b>                                                                                                                                                 | Void                      |
| <b>Structure:</b>                                                                                                                                                                            | Unknown                   |
| <b>Depth (m):</b>                                                                                                                                                                            | 18.3 (60 ft)              |
| <b>Injury mechanism:</b>                                                                                                                                                                     | Primary event trauma      |
| <b>Qualifications:</b>                                                                                                                                                                       | Commercial                |
| <b>Field:</b>                                                                                                                                                                                | Commercial - unknown      |
| <b>Communications:</b>                                                                                                                                                                       | Unknown                   |
| <b>Source:</b>                                                                                                                                                                               | Industry safety reporting |
| <b>Jurisdiction (country):</b>                                                                                                                                                               | USA                       |
| <b>Year:</b>                                                                                                                                                                                 | 1901                      |
| <b>Incident description:</b><br>A diver wearing standard gear was recovered bleeding heavily from eyes and nose, a ruptured air hose with failure/absence of non-return valve was suspected. |                           |

| <b>INCIDENT 07</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                      |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Fatality             |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Void                 |
| <b>Structure:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Fixed plant - power  |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Primary event trauma |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Commercial           |
| <b>Field:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Commercial - Inland  |
| <b>Communications:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Unknown              |
| <b>Source:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | HSE report           |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | UK                   |
| <b>Year:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 1970                 |
| <b>Incident description:</b><br>Prior to an operation to permanently seal a water intake tunnel with concrete, two divers were clearing a blockage from the bell mouth opening of the tunnel, in tidal waters. The tunnel was linked to a well chamber but was thought to be isolated from it by a valve gate. However the valve had been prevented from closing properly by accumulated debris and when the well chamber was pumped dry to allow repairs to take place, the tunnel was also inadvertently pumped dry, creating a void behind the blockage in the bell mouth. During the final stages of the clearing operation the blockage suddenly collapsed and the divers were drawn into the intake tunnel, severing their air and lifelines. |                      |

| <b>INCIDENT 09</b>                                                                                                                                                                                                                                                                                                                                                                                                               |                              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                                                                                                                                                                                     | Fatality                     |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                                                                                                                                                                                     | Levels                       |
| <b>Structure:</b>                                                                                                                                                                                                                                                                                                                                                                                                                | Dam                          |
| <b>Depth (m):</b>                                                                                                                                                                                                                                                                                                                                                                                                                | 4.6 (15 ft)                  |
| <b>Opening (area m<sup>2</sup>):</b>                                                                                                                                                                                                                                                                                                                                                                                             | 5.20 (8064 in <sup>2</sup> ) |
| <b>Opening (diameter/dimension (m)):</b>                                                                                                                                                                                                                                                                                                                                                                                         | 2.44 x 2.13 (96 x 84 in)     |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                                                                                                                                                                                         | Primary event trauma         |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                                                                                                                                                                           | Commercial                   |
| <b>Field:</b>                                                                                                                                                                                                                                                                                                                                                                                                                    | Commercial - Inland          |
| <b>Communications:</b>                                                                                                                                                                                                                                                                                                                                                                                                           | Unknown                      |
| <b>Source:</b>                                                                                                                                                                                                                                                                                                                                                                                                                   | HSE report                   |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                                                                                                                                                                                   | UK                           |
| <b>Year:</b>                                                                                                                                                                                                                                                                                                                                                                                                                     | 1971                         |
| <b>Incident description:</b><br>A faulty valve allowed water to drain, through a culvert, from behind a dam. While attempting to position a temporary wooden dam a diver entered the culvert and closed the entrance behind him. This allowed a differential pressure to develop causing the temporary wooden dam to crush the diver's umbilical. The standby diver was unable to prise the dam off the air line with a crowbar. |                              |

| <b>INCIDENT 11</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                              |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|
| Type:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Fatality                     |
| Differential pressure classification:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Void                         |
| Structure:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Pipeline                     |
| Depth (m):                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 39.6 (130 ft)                |
| Differential pressure (kg):                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 26518                        |
| Opening (area m <sup>2</sup> ):                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 0.66 (1018 in <sup>2</sup> ) |
| Opening (diameter/dimension (m)):                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 0.91 (36 in)                 |
| Injury mechanism:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Primary event trauma         |
| Qualifications:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Commercial                   |
| Field:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Commercial - Offshore        |
| Communications:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Audio                        |
| Source:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Industry safety reporting    |
| Jurisdiction (country):                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | UK                           |
| Year:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1975                         |
| <b>Incident description:</b><br>Following repair work to a gate valve at the end of a pipeline a diver was asked to observe the operation of the valve. When the valve was opened the diver was sucked onto grating and his breathing apparatus pulled off. When communication with the diver was lost a standby diver who went to his aid and was sucked into the pipe. A third diver narrowly escaped injury when he too was drawn into the pipe, however he was able to exit the pipe as the pressure differential had equalised. |                              |

| <b>INCIDENT 12</b>                                                                                                                                                                                |                           |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Type:                                                                                                                                                                                             | Fatality                  |
| Differential pressure classification:                                                                                                                                                             | Intake                    |
| Structure:                                                                                                                                                                                        | Fixed plant - power       |
| Depth (m):                                                                                                                                                                                        | 10 (32.8 ft)              |
| Injury mechanism:                                                                                                                                                                                 | Primary event trauma      |
| Qualifications:                                                                                                                                                                                   | Commercial                |
| Field:                                                                                                                                                                                            | Commercial - Inland       |
| Communications:                                                                                                                                                                                   | Unknown                   |
| Source:                                                                                                                                                                                           | Industry safety reporting |
| Jurisdiction (country):                                                                                                                                                                           | France                    |
| Year:                                                                                                                                                                                             | 1979                      |
| <b>Incident description:</b><br>While inspecting a power plant cooling system a diver was sucked into an intake. The valve had been key locked by the client, unfortunately in the open position. |                           |

| <b>INCIDENT 14</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                            |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| Type:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Fatality                   |
| Differential pressure classification:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Levels                     |
| Structure:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Dam                        |
| Depth (m):                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 15.2 (50 ft)               |
| Differential pressure (kg):                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 314                        |
| Opening (area m <sup>2</sup> ):                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.02 (32 in <sup>2</sup> ) |
| Opening (diameter/dimension (m)):                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.1 x 0.2 (4 x 8 in)       |
| Injury mechanism:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Rescue trauma, hypothermia |
| Qualifications:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Commercial                 |
| Field:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Commercial - Inland        |
| Communications:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Audio, rope                |
| Source:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Court reporting            |
| Jurisdiction (country):                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | USA                        |
| Year:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 1989                       |
| <b>Incident description:</b><br>Following maintenance work on a "Deep gate" (a gate installed to regulate flow in a tunnel passing through a dam) a maintenance gate installed up stream of the deep gate was due to be removed. The equalization valve on the maintenance gate failed to operate correctly and a diver cut rectangular holes in the maintenance gate to allow water levels to equalise. The divers legs became trapped in the holes he had just created. A second diver entered the water and he too became trapped. A third diver attached a chain hoist to the trapped diver's harnesses. Diver one's harness broke and he expired underwater, his body being recovered the following morning. The second divers lower leg was ripped from his body during the recovery and he was pronounced dead upon arrival at hospital. |                            |

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                             |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| Type:                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Fatality                    |
| Differential pressure classification:                                                                                                                                                                                                                                                                                                                                                                                                                                | Levels                      |
| Structure:                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Sluice                      |
| Depth (m):                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 4.3 (14 ft)                 |
| Differential pressure (kg):                                                                                                                                                                                                                                                                                                                                                                                                                                          | 799                         |
| Opening (area m <sup>2</sup> ):                                                                                                                                                                                                                                                                                                                                                                                                                                      | 0.19 (288 in <sup>2</sup> ) |
| Opening (diameter/dimension (m)):                                                                                                                                                                                                                                                                                                                                                                                                                                    | 0.15 x 1.22 (6 x 48 in)     |
| Injury mechanism:                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Entrapment, drowning        |
| Qualifications:                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Professional                |
| Field:                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Commercial - Inland         |
| Communications:                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Rope                        |
| Source:                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Open source press           |
| Jurisdiction (country):                                                                                                                                                                                                                                                                                                                                                                                                                                              | USA                         |
| Year:                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1991                        |
| <b>Incident description:</b><br>An off duty fire-fighter was attempting to remove an obstruction from a submerged river water gate. Following uncertain rope signals attempts were made to pull the diver from the water including tying his lifeline to the bumper of a vehicle, resulting in injuries to his legs. Only when this was unsuccessful was a secondary gate opened to relieve water pressure and a second diver able to recover the body of the first. |                             |

| <b>INCIDENT 18</b>                                                                                                      |                      |
|-------------------------------------------------------------------------------------------------------------------------|----------------------|
| Type:                                                                                                                   | Fatality             |
| Differential pressure classification:                                                                                   | Intake               |
| Structure:                                                                                                              | Lake                 |
| Injury mechanism:                                                                                                       | Entrapment, drowning |
| Qualifications:                                                                                                         | Professional         |
| Field:                                                                                                                  | Commercial - Inland  |
| Communications:                                                                                                         | Unknown              |
| Source:                                                                                                                 | Open source press    |
| Jurisdiction (country):                                                                                                 | USA                  |
| Year:                                                                                                                   | 1993                 |
| <b>Incident description:</b><br>A diver drowned while he and two other divers were cleaning an intake screen in a lake. |                      |

| <b>INCIDENT 21</b>                                                                                                                              |                             |
|-------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| Type:                                                                                                                                           | Fatality                    |
| Differential pressure classification:                                                                                                           | Levels                      |
| Structure:                                                                                                                                      | Dam                         |
| Depth (m):                                                                                                                                      | 9 (29.53 ft)                |
| Differential pressure (kg):                                                                                                                     | 799                         |
| Opening (area m <sup>2</sup> ):                                                                                                                 | 0.19 (288 in <sup>2</sup> ) |
| Opening (diameter/dimension (m)):                                                                                                               | 0.15 x 1.22 (6 x 48 in)     |
| Injury mechanism:                                                                                                                               | Primary event trauma        |
| Qualifications:                                                                                                                                 | Recreational                |
| Field:                                                                                                                                          | Commercial - Inland         |
| Communications:                                                                                                                                 | Unknown                     |
| Source:                                                                                                                                         | Industry safety reporting   |
| Jurisdiction (country):                                                                                                                         | France                      |
| Year:                                                                                                                                           | 1997                        |
| <b>Incident description:</b><br>While inspecting the upstream side of a leaking valve a recreational diver was drawn into the valve and killed. |                             |

| <b>INCIDENT 22</b>                                                                                                                                                                                                                                                                                                                                                                       |                              |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|
| Type:                                                                                                                                                                                                                                                                                                                                                                                    | Fatality                     |
| Differential pressure classification:                                                                                                                                                                                                                                                                                                                                                    | Levels                       |
| Structure:                                                                                                                                                                                                                                                                                                                                                                               | Dam                          |
| Injury mechanism:                                                                                                                                                                                                                                                                                                                                                                        | Entrapment, drowning         |
| Qualifications:                                                                                                                                                                                                                                                                                                                                                                          | Professional                 |
| Field:                                                                                                                                                                                                                                                                                                                                                                                   | Search and rescue / recovery |
| Communications:                                                                                                                                                                                                                                                                                                                                                                          | Rope                         |
| Source:                                                                                                                                                                                                                                                                                                                                                                                  | Open source press            |
| Jurisdiction (country):                                                                                                                                                                                                                                                                                                                                                                  | USA                          |
| Year:                                                                                                                                                                                                                                                                                                                                                                                    | 1998                         |
| <b>Incident description:</b><br>During an operation to recover the body of a drowned child a police diver was trapped in a sluice near the base of a dam. The diver's safety line was snapped during attempts by fellow officers and passers-by to pull the diver to the surface with it. The bodies were recovered, only when the water levels at the sluice were lowered sufficiently. |                              |

| <b>INCIDENT 25</b>                                                                                                                                                                                                                                                    |                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                          | Fatality                    |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                          | Void                        |
| <b>Structure:</b>                                                                                                                                                                                                                                                     | Pipeline                    |
| <b>Depth (m):</b>                                                                                                                                                                                                                                                     | 22.9 (75 ft)                |
| <b>Differential pressure (kg):</b>                                                                                                                                                                                                                                    | 3834                        |
| <b>Opening (area m<sup>2</sup>):</b>                                                                                                                                                                                                                                  | 0.16 (254 in <sup>2</sup> ) |
| <b>Opening (diameter/dimension (m)):</b>                                                                                                                                                                                                                              | 0.46 (18 in)                |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                              | Primary event trauma        |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                | Commercial                  |
| <b>Field:</b>                                                                                                                                                                                                                                                         | Commercial - Offshore       |
| <b>Communications:</b>                                                                                                                                                                                                                                                | Audio                       |
| <b>Source:</b>                                                                                                                                                                                                                                                        | Industry safety reporting   |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                        | USA                         |
| <b>Year:</b>                                                                                                                                                                                                                                                          | 2000                        |
| <b>Incident description:</b><br>A diver was removing a mud plug from a pipeline which had been severed by a mudslide. Workers on the surface had failed to flood the pipe. When the diver cleared the plug he was sucked into the pipe which was at surface pressure. |                             |

| <b>INCIDENT 27</b>                                                                                                                              |                      |
|-------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| Type:                                                                                                                                           | Fatality             |
| Differential pressure classification:                                                                                                           | Intake               |
| Structure:                                                                                                                                      | Dam                  |
| Injury mechanism:                                                                                                                               | Primary event trauma |
| Qualifications:                                                                                                                                 | Commercial           |
| Field:                                                                                                                                          | Commercial - Inland  |
| Communications:                                                                                                                                 | Unknown              |
| Source:                                                                                                                                         | Court reporting      |
| Jurisdiction (country):                                                                                                                         | USA                  |
| Year:                                                                                                                                           | 2002                 |
| <b>Incident description:</b><br>A diver was sucked into an intake pipe which had been opened without his knowledge before he entered the water. |                      |

| <b>INCIDENT 28</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Type:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Fatality                  |
| Differential pressure classification:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Levels                    |
| Structure:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Dam                       |
| Injury mechanism:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Primary event trauma      |
| Qualifications:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Professional              |
| Field:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Commercial - Inland       |
| Communications:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Unknown                   |
| Source:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Industry safety reporting |
| Jurisdiction (country):                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | USA                       |
| Year:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 2002                      |
| <b>Incident description:</b><br>While conducting maintenance operations on a dam a diver was drawn into an intake port located on a dam pier. An intake shutter placed over the port had failed to seat properly leaving a gap at the lower edge of the port. The task of inspecting the intake port was not part of the divers original dive plan and originated from an individual other than the one supervising the dive. The diver's body could not be recovered until the pressure differential was equalized. |                           |

| <b>INCIDENT 30</b>                                                                                                                                                                                                                                                                                              |                           |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                                                                    | Fatality                  |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                                                                    | Intake                    |
| <b>Structure:</b>                                                                                                                                                                                                                                                                                               | Fixed plant - power       |
| <b>Depth (m):</b>                                                                                                                                                                                                                                                                                               | 10 (32.8 ft)              |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                                                                        | Entrapment, drowning      |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                                                          | Commercial                |
| <b>Field:</b>                                                                                                                                                                                                                                                                                                   | Commercial - Inland       |
| <b>Communications:</b>                                                                                                                                                                                                                                                                                          | Unknown                   |
| <b>Source:</b>                                                                                                                                                                                                                                                                                                  | Industry safety reporting |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                                                                  | Italy                     |
| <b>Year:</b>                                                                                                                                                                                                                                                                                                    | 2003                      |
| <b>Incident description:</b><br>A diver was attempting to clear a partially blocked power plant water intake. He became trapped by differential pressure. In the absence of a standby diver the fire brigade was asked to attend. The fire brigade diver drowned while the first diver managed to free himself. |                           |

| <b>INCIDENT 31</b>                                                                                                                                                                                                                                                                                |                             |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                                                      | Fatality                    |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                                                      | Levels                      |
| <b>Structure:</b>                                                                                                                                                                                                                                                                                 | Pond                        |
| <b>Opening (area m<sup>2</sup>):</b>                                                                                                                                                                                                                                                              | 0.16 (254 in <sup>2</sup> ) |
| <b>Opening (diameter/dimension (m)):</b>                                                                                                                                                                                                                                                          | 0.46 (18 in)                |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                                                          | Entrapment, drowning        |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                                            | Professional                |
| <b>Field:</b>                                                                                                                                                                                                                                                                                     | Commercial - Inland         |
| <b>Communications:</b>                                                                                                                                                                                                                                                                            | Unknown                     |
| <b>Source:</b>                                                                                                                                                                                                                                                                                    | Open source press           |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                                                    | USA                         |
| <b>Year:</b>                                                                                                                                                                                                                                                                                      | 2004                        |
| <b>Incident description:</b><br>A diver was attempting to remove obstructions from the blocked drain of a privately owned pond which had overflowed. After failing to surface the alarm was raised by the divers wife. Authorities believe part of his body was sucked into the 18 in drain pipe. |                             |

| <b>INCIDENT 34</b>                                                                                                                                                                                                            |                      |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| <b>Type:</b>                                                                                                                                                                                                                  | Fatality             |
| <b>Differential pressure classification:</b>                                                                                                                                                                                  | Thruster             |
| <b>Structure:</b>                                                                                                                                                                                                             | Ship                 |
| <b>Injury mechanism:</b>                                                                                                                                                                                                      | Primary event trauma |
| <b>Qualifications:</b>                                                                                                                                                                                                        | Commercial           |
| <b>Field:</b>                                                                                                                                                                                                                 | Commercial - Inland  |
| <b>Communications:</b>                                                                                                                                                                                                        | Audio, video         |
| <b>Source:</b>                                                                                                                                                                                                                | Open source press    |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                | Malta                |
| <b>Year:</b>                                                                                                                                                                                                                  | 2004                 |
| <b>Incident description:</b><br>A diver was conducting a video inspection of the hull of a container ship. A bow thruster was activated while the diver was in the water. The diver was drawn into the propellers and killed. |                      |

| <b>INCIDENT 35</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                           |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Fatality                  |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Levels                    |
| <b>Structure:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Dam                       |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Primary event trauma      |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Commercial                |
| <b>Field:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Commercial - Inland       |
| <b>Communications:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Rope                      |
| <b>Source:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Industry safety reporting |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | USA                       |
| <b>Year:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 2005                      |
| <b>Incident description:</b><br>During a routine inspection of the head gates at a hydro-electric power station a diver was drawn into a gate valve opening. Attempts to retrieve the diver by pulling on his lifeline were unsuccessful. After water levels were lowered to recover the diver's body, he was found to have suffered from compression asphyxia. Power station staff stated they had informed the diver that the valve would be open but other members of the dive team had not been briefed. |                           |

| <b>INCIDENT 38</b>                                                                                                                                                                                                                                                                                                                                                                                                                                  |                      |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                        | Fatality             |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                                                                                                                                                                                                        | Intake               |
| <b>Structure:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                   | Fixed plant - power  |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                                                                                                                                                                                                            | Entrapment, drowning |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                                                                                                                                                                                              | Recreational         |
| <b>Field:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                       | Recreational         |
| <b>Communications:</b>                                                                                                                                                                                                                                                                                                                                                                                                                              | Unknown              |
| <b>Source:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                      | Open source press    |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                                                                                                                                                                                                      | USA                  |
| <b>Year:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                        | 2007                 |
| <b>Incident description:</b><br>A party of five recreational divers entered a river intending to drift into an adjacent tributary. In poor visibility the party became separated. Three of the divers were able to exit the water. The two remaining divers were found five days later near the intake of a hydro-electric power plant. Maintenance work by the power generation company may have temporarily altered the normal flow of the river. |                      |

| <b>INCIDENT 39</b>                                                                                                                                             |                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| <b>Type:</b>                                                                                                                                                   | Fatality                  |
| <b>Differential pressure classification:</b>                                                                                                                   | Levels                    |
| <b>Structure:</b>                                                                                                                                              | Dam                       |
| <b>Depth (m):</b>                                                                                                                                              | 5.5 (18 ft)               |
| <b>Injury mechanism:</b>                                                                                                                                       | Entrapment, drowning      |
| <b>Qualifications:</b>                                                                                                                                         | Commercial                |
| <b>Field:</b>                                                                                                                                                  | Commercial - Inland       |
| <b>Communications:</b>                                                                                                                                         | Unknown                   |
| <b>Source:</b>                                                                                                                                                 | Industry safety reporting |
| <b>Jurisdiction (country):</b>                                                                                                                                 | USA                       |
| <b>Year:</b>                                                                                                                                                   | 2007                      |
| <b>Incident description:</b><br>A diver was drowned while attempting to remove a temporary dam between the main body of water and a newly constructed channel. |                           |

| <b>INCIDENT 42</b>                                                                                                                                                                                                                              |                          |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| <b>Type:</b>                                                                                                                                                                                                                                    | Fatality                 |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                    | Intake                   |
| <b>Structure:</b>                                                                                                                                                                                                                               | Fixed plant - water tank |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                        | Primary event trauma     |
| <b>Qualifications:</b>                                                                                                                                                                                                                          | Commercial               |
| <b>Field:</b>                                                                                                                                                                                                                                   | Commercial - Inland      |
| <b>Communications:</b>                                                                                                                                                                                                                          | Unknown                  |
| <b>Source:</b>                                                                                                                                                                                                                                  | Open source press        |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                  | USA                      |
| <b>Year:</b>                                                                                                                                                                                                                                    | 2008                     |
| <b>Incident description:</b><br>A commercial diver's umbilical was sucked into a pump and severed while he was diving in a water storage tank. The pumps were off when the diver entered the water but activated automatically during the dive. |                          |

| <b>INCIDENT 43</b>                                                                                                                                                                         |                            |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| <b>Type:</b>                                                                                                                                                                               | Fatality                   |
| <b>Differential pressure classification:</b>                                                                                                                                               | Intake                     |
| <b>Structure:</b>                                                                                                                                                                          | Fixed plant - desalination |
| <b>Injury mechanism:</b>                                                                                                                                                                   | Primary event trauma       |
| <b>Qualifications:</b>                                                                                                                                                                     | Recreational               |
| <b>Field:</b>                                                                                                                                                                              | Commercial - Inland        |
| <b>Communications:</b>                                                                                                                                                                     | Unknown                    |
| <b>Source:</b>                                                                                                                                                                             | Open source press          |
| <b>Jurisdiction (country):</b>                                                                                                                                                             | United Arab Emirates       |
| <b>Year:</b>                                                                                                                                                                               | 2008                       |
| <b>Incident description:</b><br>While employed to carry out commercial underwater repair work a sport/recreational qualified diver was sucked into an intake pipe at a desalination plant. |                            |

| <b>INCIDENT 46</b>                                                                                                                        |                      |
|-------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| Type:                                                                                                                                     | Fatality             |
| Differential pressure classification:                                                                                                     | Levels               |
| Structure:                                                                                                                                | Dam                  |
| Injury mechanism:                                                                                                                         | Primary event trauma |
| Qualifications:                                                                                                                           | Commercial           |
| Field:                                                                                                                                    | Commercial - Inland  |
| Communications:                                                                                                                           | Unknown              |
| Source:                                                                                                                                   | 3rd person report    |
| Jurisdiction (country):                                                                                                                   | Australia            |
| Year:                                                                                                                                     | Unknown              |
| <b>Incident description:</b><br>While searching for a leak in a dam face a diver became stuck in the crack he was seeking and was killed. |                      |

| <b>INCIDENT 47</b>                                                                                                                                                                                                                                                                                                                                                               |                              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|
| Type:                                                                                                                                                                                                                                                                                                                                                                            | Fatality                     |
| Differential pressure classification:                                                                                                                                                                                                                                                                                                                                            | Levels                       |
| Structure:                                                                                                                                                                                                                                                                                                                                                                       | Dam                          |
| Injury mechanism:                                                                                                                                                                                                                                                                                                                                                                | Primary event trauma         |
| Qualifications:                                                                                                                                                                                                                                                                                                                                                                  | Professional                 |
| Field:                                                                                                                                                                                                                                                                                                                                                                           | Search and rescue / recovery |
| Communications:                                                                                                                                                                                                                                                                                                                                                                  | Unknown                      |
| Source:                                                                                                                                                                                                                                                                                                                                                                          | Industry safety reporting    |
| Jurisdiction (country):                                                                                                                                                                                                                                                                                                                                                          | USA                          |
| Year:                                                                                                                                                                                                                                                                                                                                                                            | Unknown                      |
| <b>Incident description:</b><br>While searching for lost tools during a training dive, a fire-fighter discovered a plate covering an intake in the face of a dam was missing. While attempting to replace the plate the diver's legs became trapped in the intake opening. The diver was pulled free by a crane, the autopsy stated that he died of "hyperventilation syndrome". |                              |

|                                                                                       |                       |
|---------------------------------------------------------------------------------------|-----------------------|
| Type:                                                                                 | Injury                |
| Differential pressure classification:                                                 | Void                  |
| Structure:                                                                            | Pipeline              |
| Injury mechanism:                                                                     | Primary event trauma  |
| Qualifications:                                                                       | Commercial            |
| Field:                                                                                | Commercial - Offshore |
| Communications:                                                                       | Unknown               |
| Source:                                                                               | 1st person report     |
| Jurisdiction (country):                                                               | USA                   |
| Year:                                                                                 | 2000                  |
| Incident description:<br>A diver suffered a weal after backing onto a split pipeline. |                       |

|                                                                                                                                                                                                                                                                                                                              |                            |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| <b>INCIDENT 51</b>                                                                                                                                                                                                                                                                                                           |                            |
| Type:                                                                                                                                                                                                                                                                                                                        | Injury                     |
| Differential pressure classification:                                                                                                                                                                                                                                                                                        | Void                       |
| Structure:                                                                                                                                                                                                                                                                                                                   | Pipeline                   |
| Depth (m):                                                                                                                                                                                                                                                                                                                   | 140                        |
| Differential pressure (kg):                                                                                                                                                                                                                                                                                                  | 1157                       |
| Opening (area m <sup>2</sup> ):                                                                                                                                                                                                                                                                                              | 0.01 (13 in <sup>2</sup> ) |
| Opening (diameter/dimension (m)):                                                                                                                                                                                                                                                                                            | 0.1 (4 in)                 |
| Injury mechanism:                                                                                                                                                                                                                                                                                                            | Primary event trauma       |
| Qualifications:                                                                                                                                                                                                                                                                                                              | Commercial                 |
| Field:                                                                                                                                                                                                                                                                                                                       | Commercial - Offshore      |
| Communications:                                                                                                                                                                                                                                                                                                              | Unknown                    |
| Source:                                                                                                                                                                                                                                                                                                                      | Industry safety reporting  |
| Jurisdiction (country):                                                                                                                                                                                                                                                                                                      | Unknown                    |
| Year:                                                                                                                                                                                                                                                                                                                        | 2001                       |
| Incident description:<br>Wooden flange protectors had been fitted to a spool piece (a small joining pipe). These had not been vented and a negative pressure developed at depth. When the diver succeeded in prying these off with his knife his arm was sucked into the pipe resulting in a dislocated thumb and fractures. |                            |

#### D.4 Near miss incidents

| <b>INCIDENT 54</b>                                                                                                                                                                   |                     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| <b>Type:</b>                                                                                                                                                                         | Near miss           |
| <b>Differential pressure classification:</b>                                                                                                                                         | Intake              |
| <b>Structure:</b>                                                                                                                                                                    | Tunnel              |
| <b>Injury mechanism:</b>                                                                                                                                                             | None                |
| <b>Qualifications:</b>                                                                                                                                                               | Commercial          |
| <b>Field:</b>                                                                                                                                                                        | Commercial - Inland |
| <b>Communications:</b>                                                                                                                                                               | Unknown             |
| <b>Source:</b>                                                                                                                                                                       | Open source press   |
| <b>Jurisdiction (country):</b>                                                                                                                                                       | UK                  |
| <b>Year:</b>                                                                                                                                                                         | 1879                |
| <b>Incident description:</b><br>During operations to pump dry a flooded tunnel a diver was sucked against the inlet of a pump. He was freed with the assistance of three colleagues. |                     |

| <b>INCIDENT 55</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                      |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Near miss            |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                            | Void                 |
| <b>Structure:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Ship                 |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                | None                 |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Commercial           |
| <b>Field:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Commercial - Inshore |
| <b>Communications:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Rope                 |
| <b>Source:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Open source press    |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                          | UK                   |
| <b>Year:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 1892                 |
| <b>Incident description:</b><br>While attempting to fit a plate over a hole in the hull of a ship, a diver disturbed the cotton waste plug which had been used as a temporary repair. The divers arm was sucked into the hole. Without audio communications the diver was unable to reach his life line to signal to the surface, however the divers entrapment was noticed and a second diver was able to bring the first to the surface once the pressure differential was equalised. |                      |

| <b>INCIDENT 57</b>                                                                                                                                                                                                                                                                                                                                                                       |                     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                                                                                                                                             | Near miss           |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                                                                                                                                             | Levels              |
| <b>Structure:</b>                                                                                                                                                                                                                                                                                                                                                                        | Cylinder Foundation |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                                                                                                                                                 | None                |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                                                                                                                                   | Commercial          |
| <b>Field:</b>                                                                                                                                                                                                                                                                                                                                                                            | Commercial - Inland |
| <b>Communications:</b>                                                                                                                                                                                                                                                                                                                                                                   | Rope                |
| <b>Source:</b>                                                                                                                                                                                                                                                                                                                                                                           | Open source press   |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                                                                                                                                           | UK                  |
| <b>Year:</b>                                                                                                                                                                                                                                                                                                                                                                             | 1931                |
| <b>Incident description:</b><br>A diver was working inside a flooded cylinder which had been driven into the muddy bed of a river. When the tide fell the water level inside the cylinder was left higher than that outside. The diver was sucked under the rim of the cylinder and buried in the muddy bed of the river. The diver was eventually rescued, unharmed, after seven hours. |                     |

| <b>INCIDENT 58</b>                                                                                                                                                                             |                      |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| <b>Type:</b>                                                                                                                                                                                   | Near miss            |
| <b>Differential pressure classification:</b>                                                                                                                                                   | Void                 |
| <b>Structure:</b>                                                                                                                                                                              | Ship                 |
| <b>Injury mechanism:</b>                                                                                                                                                                       | None                 |
| <b>Qualifications:</b>                                                                                                                                                                         | Commercial           |
| <b>Field:</b>                                                                                                                                                                                  | Commercial - Inshore |
| <b>Communications:</b>                                                                                                                                                                         | Unknown              |
| <b>Source:</b>                                                                                                                                                                                 | Open source press    |
| <b>Jurisdiction (country):</b>                                                                                                                                                                 | UK                   |
| <b>Year:</b>                                                                                                                                                                                   | 1933                 |
| <b>Incident description:</b><br>A diver became temporarily stuck on the hole in the hull of a ship he was diving to investigate. Assistance from a standby diver was required to free himself. |                      |

| <b>INCIDENT 60</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Near miss                   |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Levels                      |
| <b>Structure:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Weir                        |
| <b>Depth (m):</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 2.3 (7.55 ft)               |
| <b>Differential pressure (kg):</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 1008                        |
| <b>Opening (area m<sup>2</sup>):</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 0.46 (720 ft <sup>2</sup> ) |
| <b>Opening (diameter/dimension (m)):</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 0.38 x 1.22 (15 x 48)       |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | None                        |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Commercial                  |
| <b>Field:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Commercial - Inland         |
| <b>Communications:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Rope                        |
| <b>Source:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 1st person report           |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | UK                          |
| <b>Year:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 1997                        |
| <b>Incident description:</b><br>During preparations to dive on a set of weir gates a third party intervened to isolate power to the gate motors to prevent their automatic opening in response to water level changes. However power was isolated before all the gates on which the dive was due to take place had fully closed. During the dive the diver encountered a partially open gate. The diver was temporary trapped at the base of the gate where the flow of water began to dislodge his mask and regulator. However the diver was forced through the gate and was able to regain the surface. |                             |

| <b>INCIDENT 63</b>                                                                                                                                                                                                                                                                                                                   |                                            |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                                                                                         | Near miss                                  |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                                                                                         | Intake                                     |
| <b>Structure:</b>                                                                                                                                                                                                                                                                                                                    | Fixed plant - power                        |
| <b>Depth (m):</b>                                                                                                                                                                                                                                                                                                                    | 12.2 (40 ft)                               |
| <b>Opening (area m<sup>2</sup>):</b>                                                                                                                                                                                                                                                                                                 | 0.89 (1385 in <sup>2</sup> )               |
| <b>Opening (diameter/dimension (m)):</b>                                                                                                                                                                                                                                                                                             | 1.07 (42 in)                               |
| <b>Flow (m<sup>3</sup>.s<sup>-1</sup>):</b>                                                                                                                                                                                                                                                                                          | 0.17 (6 ft <sup>3</sup> .s <sup>-1</sup> ) |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                                                                                             | None                                       |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                                                                               | Recreational                               |
| <b>Field:</b>                                                                                                                                                                                                                                                                                                                        | Recreational                               |
| <b>Communications:</b>                                                                                                                                                                                                                                                                                                               | Unknown                                    |
| <b>Source:</b>                                                                                                                                                                                                                                                                                                                       | Open source press.                         |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                                                                                       | USA                                        |
| <b>Year:</b>                                                                                                                                                                                                                                                                                                                         | 2008                                       |
| <b>Incident description:</b><br>During a recreational dive a diver was sucked into a 42 in hole in a damaged section of 8 ft diameter intake pipe. The diver was drawn into a larger (18 ft) diameter pipe travelling for 4,000 ft at 6 ft/s before being discharged into an open intake canal where she was able to exit the water. |                                            |

| <b>INCIDENT 64</b>                                                                                                                                                                                                                                                                                                       |                     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                                                                             | Near miss           |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                                                                             | Levels              |
| <b>Structure:</b>                                                                                                                                                                                                                                                                                                        | Lock                |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                                                                                 | None                |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                                                                   | Commercial          |
| <b>Field:</b>                                                                                                                                                                                                                                                                                                            | Commercial - Inland |
| <b>Communications:</b>                                                                                                                                                                                                                                                                                                   | Unknown             |
| <b>Source:</b>                                                                                                                                                                                                                                                                                                           | Open source press   |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                                                                           | UK                  |
| <b>Year:</b>                                                                                                                                                                                                                                                                                                             | Unknown             |
| <b>Incident description:</b><br>A diver was sucked into an upper sluice culvert where he became lodged by his equipment. As the sluice could not be closed as the divers legs had passed through it, he could only be rescued when a second sluice was opened filling the lock and equalizing the pressure differential. |                     |

## D.5

## Example open propulsor incidents

| <b>INCIDENT NUMBER 67</b>                                                                                                                                                                                                                                                                                                                                                                                                                                |                      |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| Type:                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Injury               |
| Differential pressure classification:                                                                                                                                                                                                                                                                                                                                                                                                                    | Open propulsor       |
| Structure:                                                                                                                                                                                                                                                                                                                                                                                                                                               | Ship                 |
| Injury mechanism:                                                                                                                                                                                                                                                                                                                                                                                                                                        | Primary event trauma |
| Qualifications:                                                                                                                                                                                                                                                                                                                                                                                                                                          | Commercial           |
| Field:                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Commercial - Inshore |
| Communications:                                                                                                                                                                                                                                                                                                                                                                                                                                          | Unknown              |
| Source:                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Open source press    |
| Jurisdiction (country):                                                                                                                                                                                                                                                                                                                                                                                                                                  | USA                  |
| Year:                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 2009                 |
| <b>Incident description:</b><br>A diver was working beneath a vessel cleaning the hull. The captain of the vessel started the boat's engines but did not put them into gear. Shortly after the diver was seen floating at the surface unconscious. It was known that the propeller still turned slowly in neutral and it was speculated that the diver received head and other injuries when his air and tending line became entangled in the propeller. |                      |

| <b>INCIDENT NUMBER 68</b>                                                                                                                                 |                           |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Type:                                                                                                                                                     | Fatality                  |
| Differential pressure classification:                                                                                                                     | Open propulsor            |
| Structure:                                                                                                                                                | Ship                      |
| Injury mechanism:                                                                                                                                         | Primary event trauma      |
| Qualifications:                                                                                                                                           | Commercial                |
| Field:                                                                                                                                                    | Commercial – Offshore     |
| Communications:                                                                                                                                           | Video                     |
| Source:                                                                                                                                                   | Industry safety reporting |
| Jurisdiction (country):                                                                                                                                   | UK                        |
| Year:                                                                                                                                                     | 1995                      |
| <b>Incident description:</b><br>A diver was killed during a cable laying operation when a support ships propeller was operated while he was in the water. |                           |

| <b>INCIDENT NUMBER 71</b>                                                                                                        |                           |
|----------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| <b>Type:</b>                                                                                                                     | Fatality                  |
| <b>Differential pressure classification:</b>                                                                                     | Open propulsor            |
| <b>Structure:</b>                                                                                                                | Ship                      |
| <b>Injury mechanism:</b>                                                                                                         | Primary event trauma      |
| <b>Qualifications:</b>                                                                                                           | Commercial                |
| <b>Field:</b>                                                                                                                    | Commercial – Inshore      |
| <b>Communications:</b>                                                                                                           | Unknown                   |
| <b>Source:</b>                                                                                                                   | Industry safety reporting |
| <b>Jurisdiction (country):</b>                                                                                                   | USA                       |
| <b>Year:</b>                                                                                                                     | 2005                      |
| <b>Incident description:</b><br>A diver's umbilical became entangled in a boat's spinning propeller drawing him into the blades. |                           |

| <b>INCIDENT NUMBER 72</b>                                                                                                                                                                                                                                                                                                         |                           |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| <b>Type:</b>                                                                                                                                                                                                                                                                                                                      | Near miss                 |
| <b>Differential pressure classification:</b>                                                                                                                                                                                                                                                                                      | Open propulsor            |
| <b>Structure:</b>                                                                                                                                                                                                                                                                                                                 | Ship                      |
| <b>Injury mechanism:</b>                                                                                                                                                                                                                                                                                                          | None                      |
| <b>Qualifications:</b>                                                                                                                                                                                                                                                                                                            | Commercial                |
| <b>Field:</b>                                                                                                                                                                                                                                                                                                                     | Commercial - Offshore     |
| <b>Communications:</b>                                                                                                                                                                                                                                                                                                            | Unknown                   |
| <b>Source:</b>                                                                                                                                                                                                                                                                                                                    | Industry safety reporting |
| <b>Jurisdiction (country):</b>                                                                                                                                                                                                                                                                                                    | Canada                    |
| <b>Year:</b>                                                                                                                                                                                                                                                                                                                      | 2008                      |
| <b>Incident description:</b><br>During a diving operation the captain of a vessel told a dive tender he needed to manoeuvre the boat. The tender made no adjustment to the diver's umbilical and excessive umbilical was severed in the propeller when the engines were started. The diver was able to ascend safely on bail out. |                           |

| <b>INCIDENT NUMBER 75</b>                                                                                                                                                                    |                      |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| <b>Type:</b>                                                                                                                                                                                 | Fatality             |
| <b>Differential pressure classification:</b>                                                                                                                                                 | Open propulsor       |
| <b>Structure:</b>                                                                                                                                                                            | Ship                 |
| <b>Injury mechanism:</b>                                                                                                                                                                     | Primary event trauma |
| <b>Qualifications:</b>                                                                                                                                                                       | Commercial           |
| <b>Field:</b>                                                                                                                                                                                | Commercial – Inshore |
| <b>Communications:</b>                                                                                                                                                                       | Unknown              |
| <b>Source:</b>                                                                                                                                                                               | Open source press    |
| <b>Jurisdiction (country):</b>                                                                                                                                                               | United Arab Emirates |
| <b>Year:</b>                                                                                                                                                                                 | 2008                 |
| <b>Incident description:</b><br>An engineer, unaware a diver was working below his ship started the engines. The diver, working near the propeller was caught between the blades and killed. |                      |

| <b>INCIDENT NUMBER 76</b>                                                                                                                                         |                           |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| <b>Type:</b>                                                                                                                                                      | Injury                    |
| <b>Differential pressure classification:</b>                                                                                                                      | Open propulsor            |
| <b>Structure:</b>                                                                                                                                                 | Ship                      |
| <b>Injury mechanism:</b>                                                                                                                                          | Primary event trauma      |
| <b>Qualifications:</b>                                                                                                                                            | Commercial                |
| <b>Field:</b>                                                                                                                                                     | Commercial – Inshore      |
| <b>Communications:</b>                                                                                                                                            | Unknown                   |
| <b>Source:</b>                                                                                                                                                    | Industry safety reporting |
| <b>Jurisdiction (country):</b>                                                                                                                                    | Singapore                 |
| <b>Year:</b>                                                                                                                                                      | 2008                      |
| <b>Incident description:</b><br>Three divers were cleaning the seven meter propeller of an oil tanker, when it began to rotate. One diver was critically injured. |                           |

## E Graphical representation of categorised data

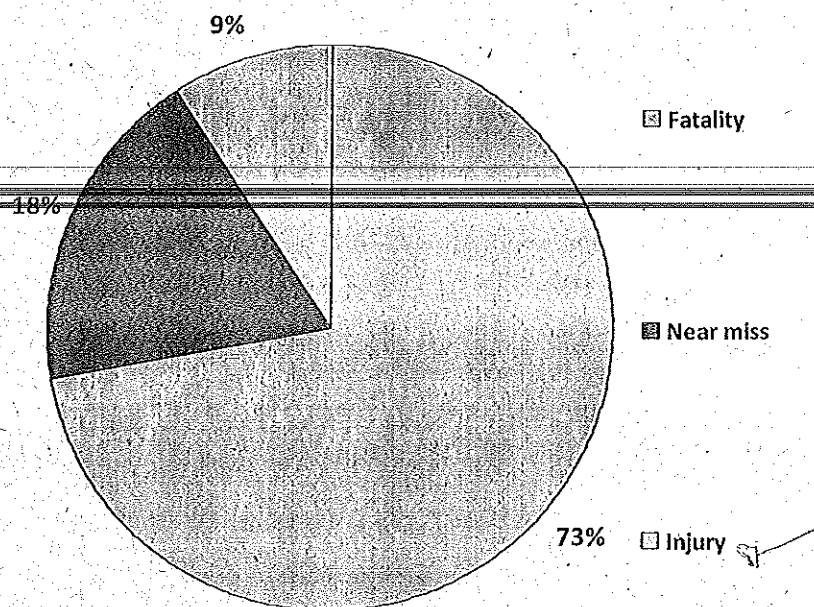


Figure E.1: Percentage analysis of incident type

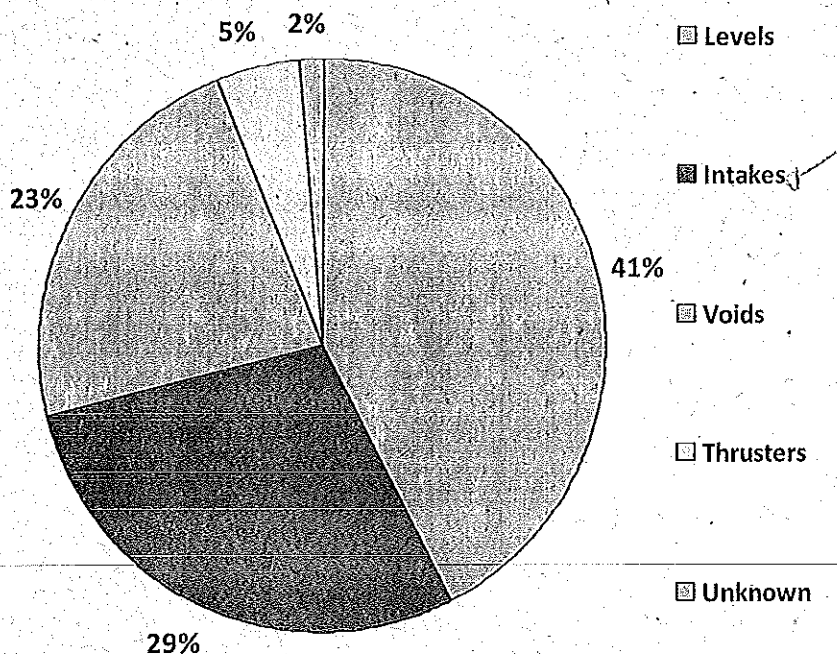


Figure E.2: Percentage analysis of differential pressure classification

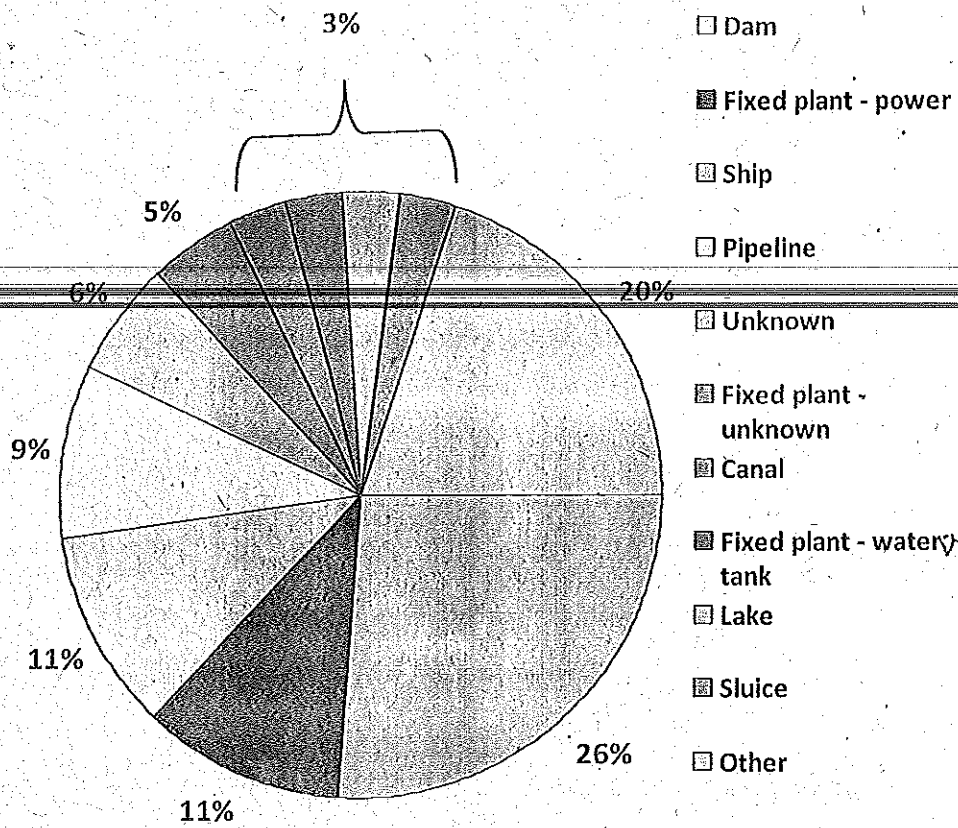


Figure E.3: Percentage analysis of structures dived upon

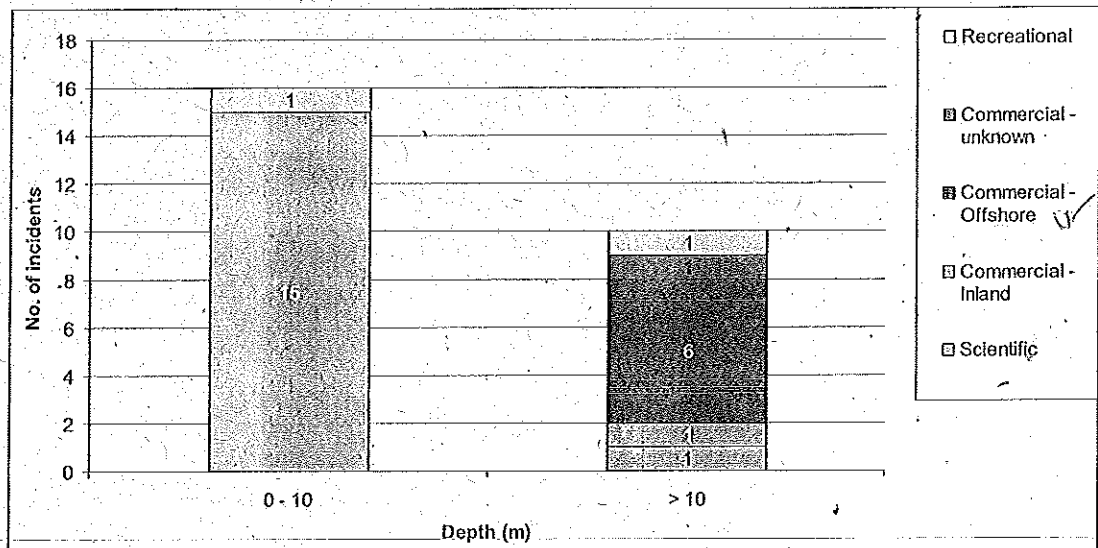


Figure E.4: Analysis of field of operation by depth (where known)

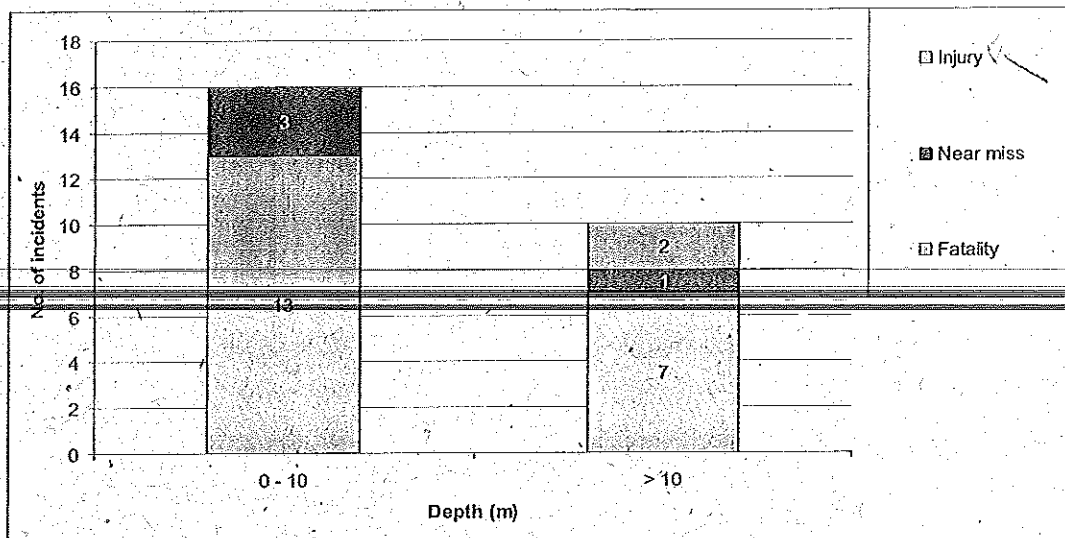


Figure E.5: Analysis of incident type by depth (where known)

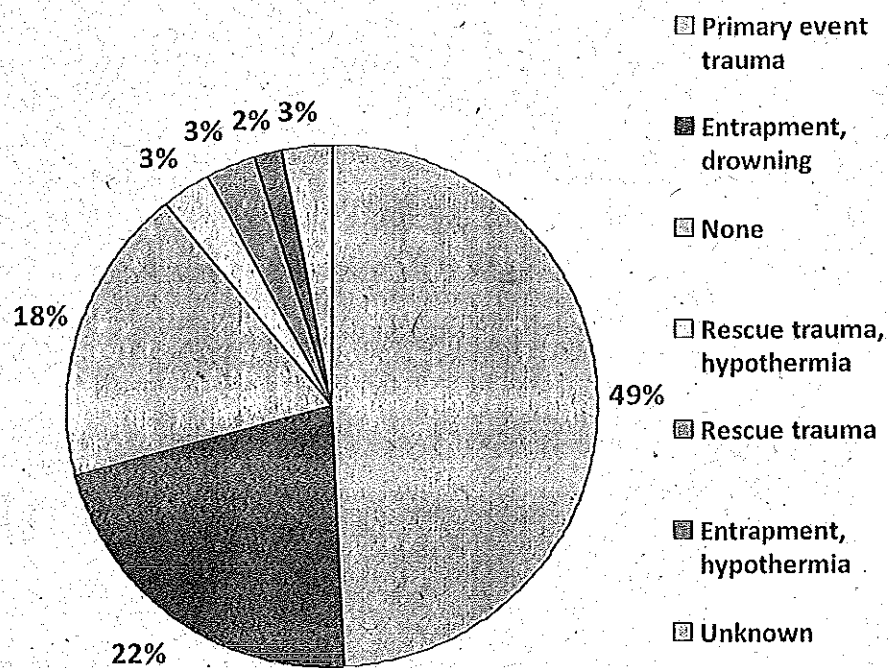


Figure E.6: Percentage analysis of injury mechanism

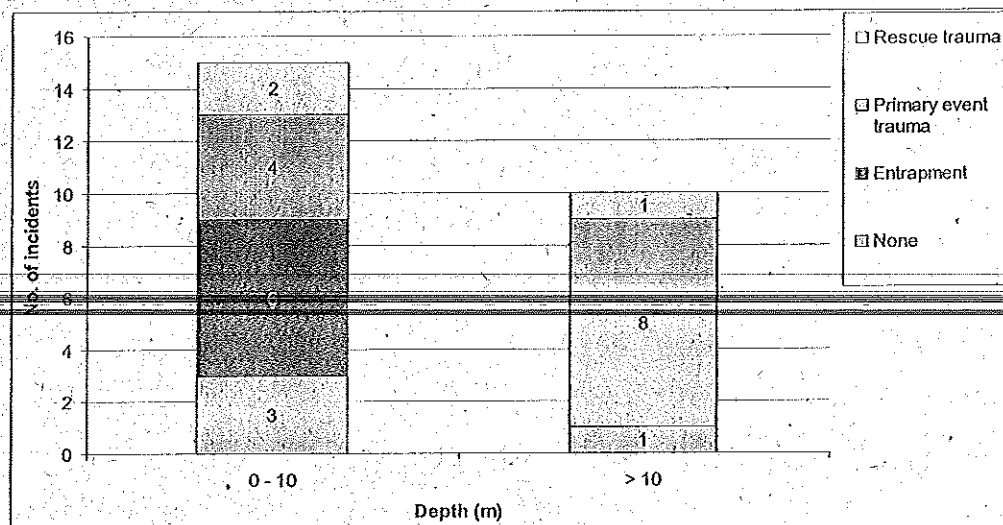


Figure E.7: Analysis of injury mechanism by depth (where known)

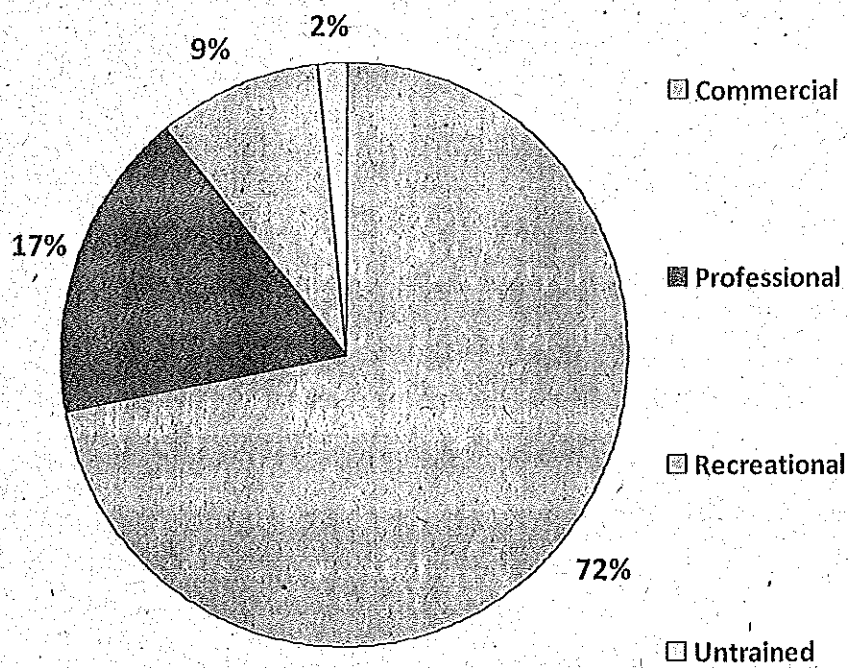


Figure E.8: Percentage analysis of diver qualification

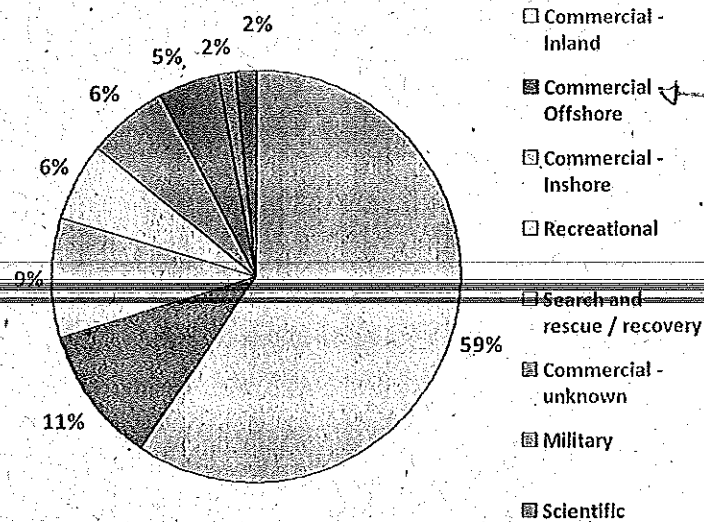


Figure E.9: Percentage analysis of field of operation (all incidents)

Percentage of fatalities only by field

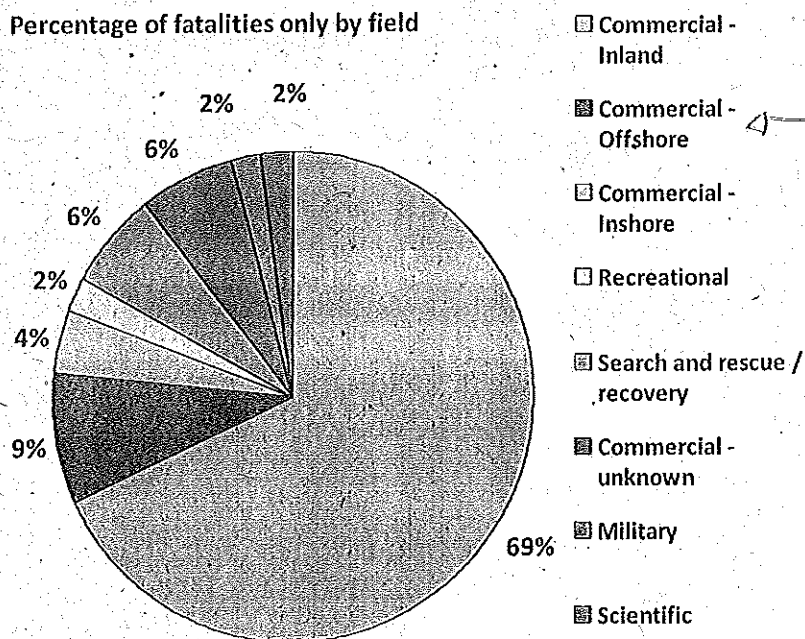


Figure E.10: Percentage analysis of field of operation (fatal incidents only)

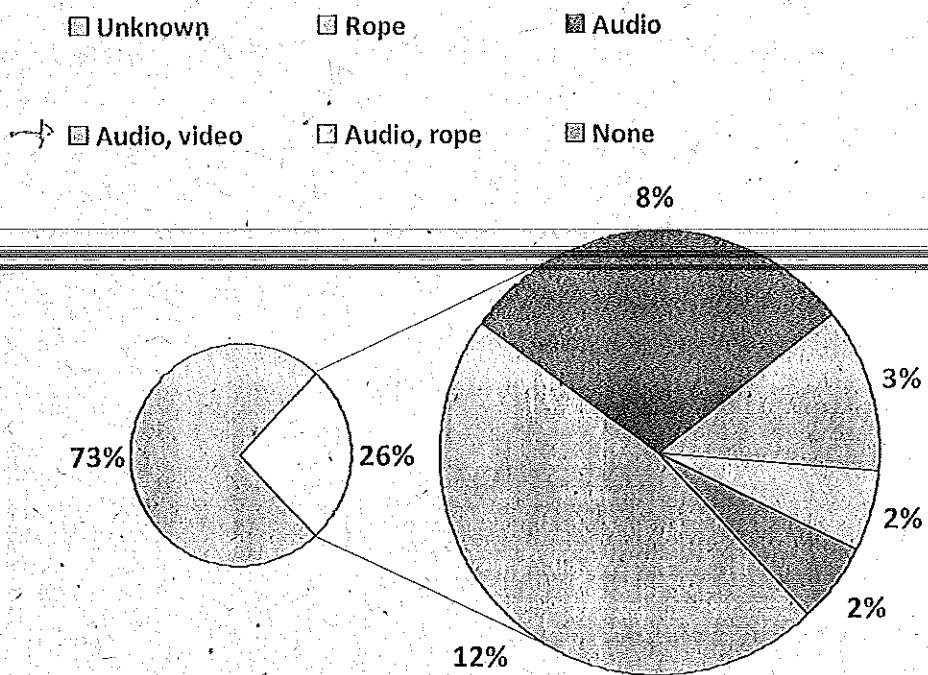


Figure E.11: Percentage analysis of communication mechanisms

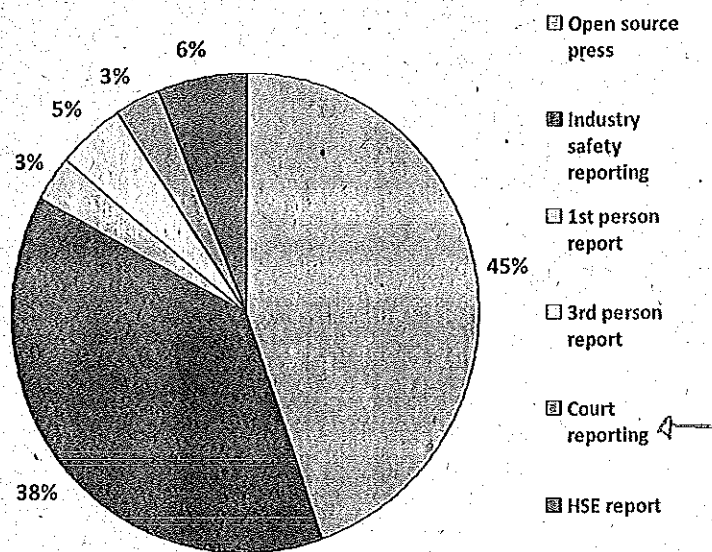


Figure E.12: Percentage analysis of report source.

### Incident type - open source press only

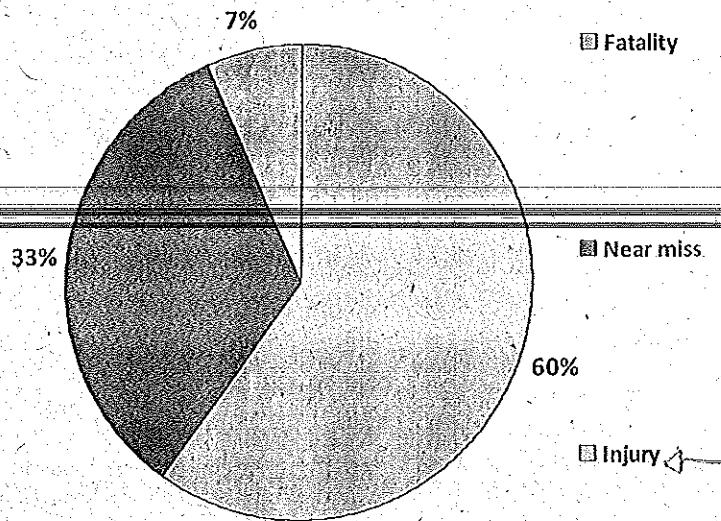


Figure E.13: Percentage analysis of incident type (open source press reports only)

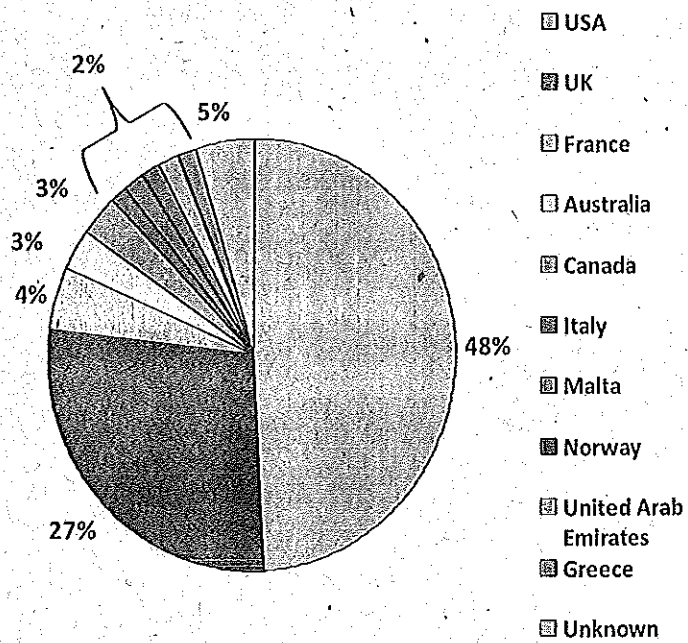


Figure E.14: Percentage analysis of jurisdiction in which incidents occurred

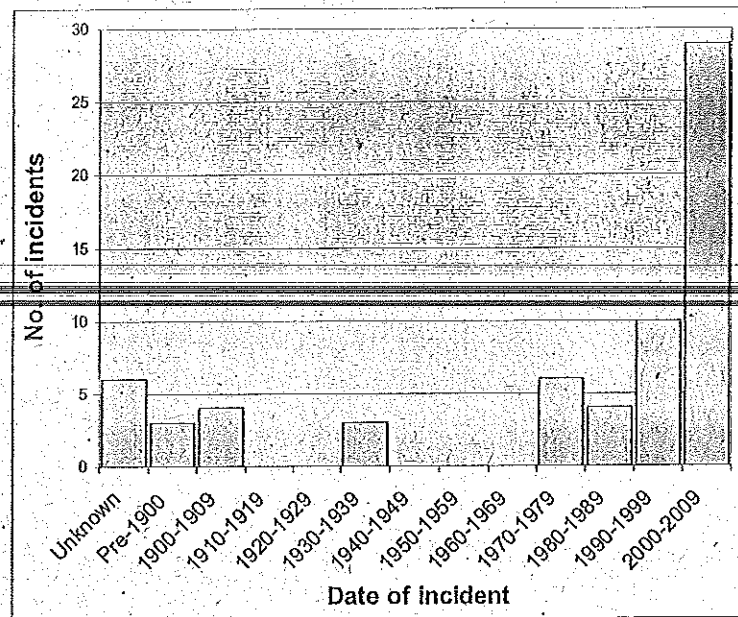


Figure E.15: Number of reported incidents arranged by year

## F Differential pressure – look-up tables

In the following tables, diameters given in inches are approximate equivalents of the diameter given in centimetres and metres. Depths are linear distances in metres rather than 'metres of seawater'.

### F.1 Force due to differential Pressure (kgf)

|                        |                           |       |       |       |       |       |       |       |       |       |       |
|------------------------|---------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Pipe diameter (m)      |                           | 0.08  | 0.10  | 0.15  | 0.20  | 0.30  | 0.45  | 0.60  | 0.75  | 1.00  | 1.25  |
| Pipe diameter (cm)     |                           | 8     | 10    | 15    | 20    | 30    | 45    | 60    | 75    | 100   | 125   |
| Pipe diameter (in)     |                           | 3.1   | 3.9   | 5.9   | 7.9   | 11.8  | 17.7  | 23.6  | 29.5  | 39.4  | 49.2  |
| Area (m <sup>2</sup> ) |                           | 0.005 | 0.008 | 0.018 | 0.031 | 0.071 | 0.159 | 0.283 | 0.442 | 0.785 | 1.227 |
| Depth (m)              | 0.5                       | 3     | 4     | 9     | 16    | 36    | 82    | 145   | 226   | 403   | 629   |
|                        | 1.0                       | 5     | 8     | 18    | 32    | 72    | 163   | 290   | 453   | 805   | 1258  |
|                        | 1.5                       | 8     | 12    | 27    | 48    | 109   | 245   | 435   | 679   | 1208  | 1887  |
|                        | 2.0                       | 10    | 16    | 36    | 64    | 145   | 326   | 580   | 906   | 1610  | 2516  |
|                        | 3.0                       | 15    | 24    | 54    | 97    | 217   | 489   | 869   | 1358  | 2415  | 3774  |
|                        | 5.0                       | 26    | 40    | 91    | 161   | 362   | 815   | 1449  | 2264  | 4025  | 6289  |
|                        | 10                        | 52    | 81    | 181   | 322   | 725   | 1630  | 2898  | 4528  | 8050  | 12579 |
|                        | 15                        | 77    | 121   | 272   | 483   | 1087  | 2445  | 4347  | 6792  | 12075 | 18868 |
|                        | 25                        | 129   | 201   | 453   | 805   | 1811  | 4075  | 7245  | 11321 | 20126 | 31447 |
|                        | 30                        | 155   | 242   | 543   | 966   | 2174  | 4891  | 8694  | 13585 | 24151 | 37736 |
|                        | 40                        | 206   | 322   | 725   | 1288  | 2898  | 6521  | 11592 | 18113 | 32201 | 50315 |
| 50                     | 258                       | 403   | 906   | 1610  | 3623  | 8151  | 14491 | 22642 | 40252 | 62893 |       |
|                        | Force < 50 kgf            |       |       |       |       |       |       |       |       |       |       |
|                        | Force ≥ 50 kgf < 200 kgf  |       |       |       |       |       |       |       |       |       |       |
|                        | Force ≥ 200 kgf < 350 kgf |       |       |       |       |       |       |       |       |       |       |
|                        | Force ≥ 350 kgf           |       |       |       |       |       |       |       |       |       |       |

Figure F.1: Force due to differential pressure - calculation matrix (sea water)

## F.2 Force due to differential Pressure (kgf)

| Pipe diameter (m)      | 0.08                      | 0.10  | 0.15  | 0.20  | 0.30  | 0.45  | 0.60  | 0.75  | 1.00  | 1.25  |
|------------------------|---------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Pipe diameter (cm)     | 8                         | 10    | 15    | 20    | 30    | 45    | 60    | 75    | 100   | 125   |
| Pipe diameter (in)     | 3.1                       | 3.9   | 5.9   | 7.9   | 11.8  | 17.7  | 23.6  | 29.5  | 39.4  | 49.2  |
| Area (m <sup>2</sup> ) | 0.005                     | 0.008 | 0.018 | 0.031 | 0.071 | 0.159 | 0.283 | 0.442 | 0.785 | 1.227 |
| Depth (m)              | 3                         | 4     | 9     | 16    | 35    | 80    | 141   | 221   | 393   | 614   |
|                        | 1.0                       | 5     | 8     | 18    | 31    | 71    | 159   | 283   | 442   | 785   |
|                        | 1.5                       | 8     | 12    | 27    | 47    | 106   | 239   | 424   | 663   | 1178  |
|                        | 2.0                       | 10    | 16    | 35    | 63    | 141   | 318   | 565   | 884   | 1571  |
|                        | 3.0                       | 15    | 24    | 53    | 94    | 212   | 477   | 848   | 1325  | 2356  |
|                        | 5.0                       | 25    | 39    | 88    | 157   | 353   | 795   | 1414  | 2209  | 3927  |
|                        | 10                        | 50    | 79    | 177   | 314   | 707   | 1590  | 2827  | 4418  | 7854  |
|                        | 15                        | 75    | 118   | 265   | 471   | 1060  | 2386  | 4241  | 6627  | 11781 |
|                        | 25                        | 126   | 196   | 442   | 785   | 1767  | 3976  | 7069  | 11045 | 19635 |
|                        | 30                        | 151   | 236   | 530   | 942   | 2121  | 4771  | 8482  | 13254 | 23562 |
|                        | 40                        | 201   | 314   | 707   | 1257  | 2827  | 6362  | 11310 | 17671 | 31416 |
|                        | 50                        | 251   | 393   | 884   | 1571  | 3534  | 7952  | 14137 | 22089 | 39270 |
|                        | Force < 50 kgf            |       |       |       |       |       |       |       |       |       |
|                        | Force ≥ 50 kgf < 200 kgf  |       |       |       |       |       |       |       |       |       |
|                        | Force ≥ 200 kgf < 350 kgf |       |       |       |       |       |       |       |       |       |
|                        | Force ≥ 350 kgf           |       |       |       |       |       |       |       |       |       |

Figure F.2: Force due to differential pressure - calculation matrix (fresh water)

F.3

Water flow through a hazard ( $\text{m}^3 \cdot \text{s}^{-1}$ )

| Pipe diameter (m)                                        | 0.08  | 0.10  | 0.15  | 0.20  | 0.30  | 0.45  | 0.60  | 0.75  | 1.00  | 1.25  |
|----------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Pipe diameter (cm)                                       | 8     | 10    | 15    | 20    | 30    | 45    | 60    | 75    | 100   | 125   |
| Pipe diameter (in)                                       | 3.1   | 3.9   | 5.9   | 7.9   | 11.8  | 17.7  | 23.6  | 29.5  | 39.4  | 49.2  |
| Area ( $\text{m}^2$ )                                    | 0.005 | 0.008 | 0.018 | 0.031 | 0.071 | 0.159 | 0.283 | 0.442 | 0.785 | 1.227 |
| Depth (m)                                                | 0.5   | 0.02  | 0.02  | 0.06  | 0.10  | 0.22  | 0.50  | 0.89  | 1.38  | 2.46  |
|                                                          | 1.0   | 0.02  | 0.03  | 0.08  | 0.14  | 0.31  | 0.70  | 1.25  | 1.96  | 3.48  |
|                                                          | 1.5   | 0.03  | 0.04  | 0.10  | 0.17  | 0.38  | 0.86  | 1.53  | 2.40  | 4.26  |
|                                                          | 2.0   | 0.03  | 0.05  | 0.11  | 0.20  | 0.44  | 1.00  | 1.77  | 2.77  | 4.92  |
|                                                          | 3.0   | 0.04  | 0.06  | 0.14  | 0.24  | 0.54  | 1.22  | 2.17  | 3.39  | 6.03  |
|                                                          | 5.0   | 0.05  | 0.08  | 0.18  | 0.31  | 0.70  | 1.58  | 2.80  | 4.38  | 7.78  |
|                                                          | 10    | 0.07  | 0.11  | 0.25  | 0.44  | 0.99  | 2.23  | 3.96  | 6.19  | 11.00 |
|                                                          | 15    | 0.09  | 0.13  | 0.30  | 0.54  | 1.21  | 2.73  | 4.85  | 7.58  | 13.48 |
|                                                          | 25    | 0.11  | 0.17  | 0.39  | 0.70  | 1.57  | 3.52  | 6.26  | 9.79  | 17.40 |
|                                                          | 30    | 0.12  | 0.19  | 0.43  | 0.76  | 1.72  | 3.86  | 6.86  | 10.72 | 19.06 |
|                                                          | 40    | 0.14  | 0.22  | 0.50  | 0.88  | 1.98  | 4.46  | 7.92  | 12.38 | 22.01 |
|                                                          | 50    | 0.16  | 0.25  | 0.55  | 0.98  | 2.21  | 4.98  | 8.86  | 13.84 | 24.60 |
| Flow < $0.85 \text{ m}^3 \cdot \text{s}^{-1}$            |       |       |       |       |       |       |       |       |       |       |
| Flow $\geq 0.85 < 3.35 \text{ m}^3 \cdot \text{s}^{-1}$  |       |       |       |       |       |       |       |       |       |       |
| Flow $\geq 3.35 < 13.45 \text{ m}^3 \cdot \text{s}^{-1}$ |       |       |       |       |       |       |       |       |       |       |
| Flow $\geq 13.45 < 29.0 \text{ m}^3 \cdot \text{s}^{-1}$ |       |       |       |       |       |       |       |       |       |       |
| Flow $\geq 29.0 \text{ m}^3 \cdot \text{s}^{-1}$         |       |       |       |       |       |       |       |       |       |       |

Figure F.3: Estimation of water flow through a hazard

F.4

## Minimum size of DPDZ (m)

| Flow ( $\text{m}^3 \cdot \text{s}^{-1}$ )                | Differential pressure Danger Zone (m) |
|----------------------------------------------------------|---------------------------------------|
| Flow < $0.85 \text{ m}^3 \cdot \text{s}^{-1}$            | 0.5                                   |
| Flow $\geq 0.85 < 3.35 \text{ m}^3 \cdot \text{s}^{-1}$  | 1                                     |
| Flow $\geq 3.35 < 13.45 \text{ m}^3 \cdot \text{s}^{-1}$ | 2                                     |
| Flow $\geq 13.45 < 29.0 \text{ m}^3 \cdot \text{s}^{-1}$ | 3                                     |
| Flow $\geq 29.0 \text{ m}^3 \cdot \text{s}^{-1}$         | > 3.0                                 |

Figure F.4: Estimation of minimum DPDZ for a known flow

## F.5 Comparison of pipe diameters

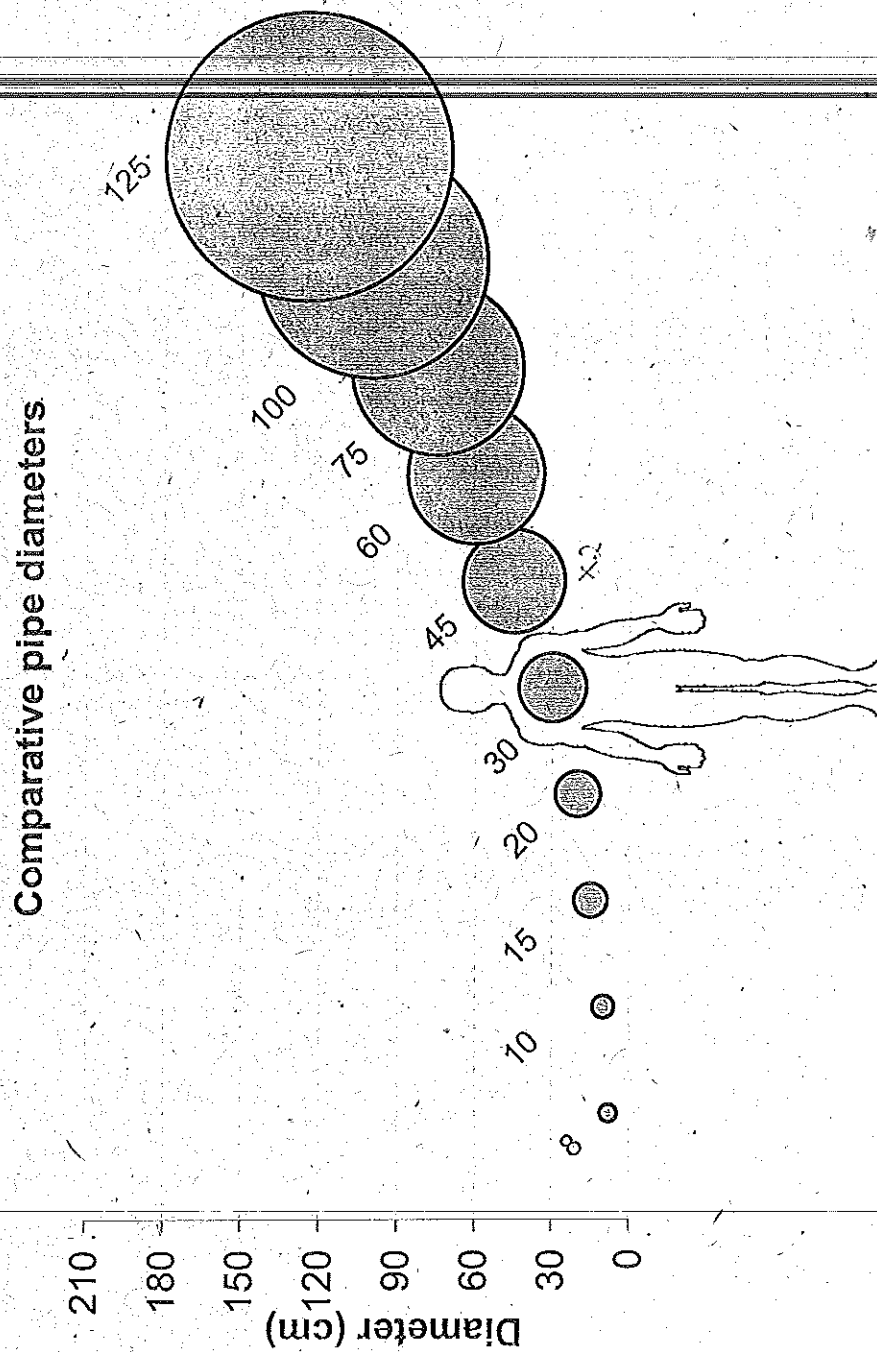


Figure F.5: Comparison of pipe areas to a human body



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Anexo 1 – Volume 2

Data Autuação: 10/06/2010

Procurador: Isabela Maul Miranda de Mendonça

Denunciante - MAURÍCIO PESSANHA DA SILVA

Investigado - SERVIÇOS MARÍTIMOS CONTINENTAL S.A

Investigado - PETRÓLEO BRASILEIRO S.A. PETROBRAS

Tema 1:

Nível : 1

...01. CODEMAT (Coordenadoria Nacional de Defesa do Meio Ambiente do Trabalho)

Nível : 2

.....01.29. Acidente de Trabalho

Tema 2:

Nível : 1

...01. CODEMAT (Coordenadoria Nacional de Defesa do Meio Ambiente do Trabalho)

Nível : 2

.....01.29. Acidente de Trabalho

Nível : 3

.....01.29.01. Sem morte

Tema 3:

Nível : 1

...01. CODEMAT (Coordenadoria Nacional de Defesa do Meio Ambiente do Trabalho)

Nível : 2

.....01.29. Acidente de Trabalho

Nível : 3

.....01.29.03. CAT - Comunicação de Acidente de Trabalho