Lost Bell Survival

Review:

Equipment, Procedures and Recovery Rev16

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The recommendations and conclusions of this report are the author's personal view. They do not necessarily reflect any specific company policy. In this complex area of health and safety, the issues raised are indicative rather than exhaustive. Readers will judge the relevance of recommendations to their particular situation.

Revision History		
Rev	**Date**	**Change**
1	28th January 2008	Issued
2	1st August 2008	Changed wording to more generic-less Technip / CSO Alliance and added authors note
4	April 2010	Revised new Sofnolime label. Regs changed from Corrosive to irritant
5	27th October 2010	Added about castellated door and pressuring over bottom depth –page 30
6	31st March 2012	Inclusion of FIIRSM to footer. Changed email address and added logos and reworded front cover
7	16 June 2012	Inclusion of NSRS AGA mask , 1.2kg 797 sorb containers and solid block of sorb 16.1 changed reference to Appendix 4
8	21st April 2013	Front cover layout, front cover OCM to Diving Safety Consultant, Various Typo's, Section numbering, added RSP to footer, added OGP requirements, added CoSHH fit test and added calories from various IMCA guidelines that were previously omitted;
9	10th August 2013	Added references to IMCA DESIGN 24 rev 1 March 2013; removal of seats and inclusion of 'restraints'; recommendations of isolations of buoyant ascent weights.
10	11th January 2015	Changed front cover for 4 Seas Safety website
11-12	April 2022	Major review; content and format update. Added recovery overview Removed contractor references Removed product names Peer review
13	May 2022	Re-issued
13.1	June 2022	Added some minor details Added bell cooling curve requirement
14	October 2022	Added paragraph from IMCA CPD Unit 3 BDS Module 11 in regard active heating deeper than 180msw
15	October 2023	Reviewed and amended to IMCA D77
16	July 2024	Annual review and check by Grammarly

Authors Note

The original version of this report was presented to a leading diving contractor's onshore and offshore management in January 2008. Very few, if any, of the identified issues were addressed or closed out at the time or since.

The report was originally vessel-specific. It was revised to reflect a more industry-wide overview. However, it is northern hemisphere, deep, and cold water-specific.

In the authors' 40 years of diving experience, all vessels and diving contractors have a similar attitude regarding a lost bell…' It doesn't happen anymore.' There is a real threat of complacency within the industry on this subject.

The Diving at Work Regulations 1997, supporting ACOP and IMCA guidance, require divers in a lost bell to survive at least 24 hours. IOGP requires recovery of a lost bell/stricken bell within 75% of the maximum accepted and proven life support capability endurance of that lost diving bell. That could be as little as 18 hours.

The diving contractors equip their bells with standard survival equipment, tick the boxes, and go to work; the lost bell scenario needs more thought.

This report isn't meant to be a safety manual; acts and Regulations are omitted from the text. However, the Corporate Manslaughter and Corporate Homicide Act may interest senior management. Under this act, if equipment and procedures are found to be insufficient, they are eligible to go to prison in the event of fatalities within a lost bell.

This report has been presented at an IMCA meeting. Therefore, senior and diving management have been made aware of it and potential omissions regarding a lost bell.

Fatalities have occurred before; therefore, there are lessons to be learned. Equipment is mainly old and ineffective. Procedures are generally inadequate. Risk assessments are and continue to be unsuitable and insufficient.

As stated on the front cover, this report and the information contained herein are the author's personal views based on years of experience in diving bells.

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1.0 Executive Summary

A lost diving bell is among the most dangerous scenarios that could occur offshore. It cannot realistically be drilled as part of a training and competency matrix.

Current guidance and some company policies are too vague to be 100% effective in the event of a lost bell. The occupants of a lost bell will have to carry out precise actions to aid their survival and rescue while suffering impaired mental and physical state due to a range of life-threatening conditions, including hypothermia, carbon dioxide poisoning, and possibly a depleted oxygen supply.

The diving industry should review the current equipment and formulate a precise set of procedures so the occupants can have a chance to survive the (UK) legally (IMO) required and IMCA recommended 24 hours and, where applicable, satisfy IOGP requirements. The current policies and equipment must be revised to ensure a successful rescue in the required time.

It is a common misconception, such as the Kürsk tragedy, that trapped personnel will die because they 'run out of oxygen'. Personnel in a small confined space succumb to carbon dioxide poisoning long before running out of oxygen, that's if they haven't already died of hypothermia.

With the thermal conductivity of helium being approximately six times that of air, with a typical water temperature in the North Sea of 5°C, it reckoned that the equivalent 'air' temperature within a stricken bell could be as low as -150°C once the bell has cooled to the ambient seawater temperature.

Previous experience from incidents and research trials has shown that survival time will be reduced if the equipment isn't used correctly in the correct order. The onset of hypothermia and carbon dioxide poisoning will increase, and the time to effect a successful rescue will be reduced.

Within the UK offshore sector of the North Sea, 25% of all recorded (non-medical) closed bell diving fatalities have been caused by a lost bell.

Catastrophic events like this are so rare that they appear impossible, and the circumstances and causes seem irrelevant.

If you get it wrong, there may be up to three fatalities.

A lost bell is a high consequence / low probability event.

Photograph 1

2.0 Background

One of the risks of saturation diving is the possibility that the bell and its occupants cannot be recovered from depth. This could be because the bell is trapped or fouled, or the lift wires and umbilical are severed. The term *'lost bell'* is used when the breathing gas and/or heating supplies are lost from the surface (Life support services).

Hypothermia, carbon dioxide poisoning, and oxygen depletion are the hazards to overcome. Thermal survival bags and carbon dioxide (CO_2) gas scrubbers with a built-in heat regenerator unit are provided within all bells (where a risk assessment shows a requirement), along with an onboard oxygen (O_2) supply.

Assuming that the survival equipment is undamaged and used effectively by the divers, survival predictions vary from 12 to 24 hours. These times depend on individual physiology, bell cooling rates, depth, the number of divers in the bell, and whether the divers are already cold from the onset of the emergency.

The rate of heat loss is the most important. It is a technical factor, i.e., dependent on the composition of breathing gas, the ambient sea temperature, and the thermal resistance between the divers and the sea (amount of bell insulation, if any). The rate of oxygen depletion and carbon dioxide production are human factors; if there are problems with the carbon dioxide absorbent, such as incorrect grade, not enough, or the survival bags are wet, survival time decreases dramatically, possibly to as little as six hours.

A diving bell must be able to maintain the divers' life support requirements in the bell for a minimum of 24 hours, independently and in addition to the bell run time. The International Oil and Gas Producers (IOGP) recommends within the report, *Saturation Diving Emergency Hyperbaric Rescue Performance Requirements*, states "*A successful rescue of a lost bell shall be achievable within 75% of the maximum proven life support capability endurance of that lost bell".* That could mean a successful rescue, divers in an HRF, or back in the system within 18 hours, not just life within a stricken bell.

With the reduction in divers' excursion distances, it is likely that at some work sites, the bell will be below the height of subsea assets, which isn't immediately apparent when the Diving Supervisor or DPO looks at a navigation screen. A small DP excursion in the wrong direction could result in a lost bell.

Most previous lost bell incidents have proved fatal.

- The Wild Drake bell suffered a severed umbilical incident, and the divers died of hypothermia.
- The Star Canopus bell; two divers died from hypothermia following a severed umbilical.
- The Norjarl (Approximately two weeks before the Star Canopus incident) bell inverted at 550 fsw. The divers got a seal but were not recovered for over two hours. Both divers were incapable of self-rescue and had given up due to hypothermia.
- Divers in the Stena Seaspread bell recovered after 10 hours; they shivered uncontrollably before rescue.
- Wodeco V: The main lift wire parted on recovery when the bell was on the surface. The bell sank, and two divers died.
- The Seaway Falcon bell was lost for two hours, and the divers survived.

3.0 Scope

This is a brief review of the equipment and procedures for a lost bell. The findings will also be relevant for divers in a lost welding habitat. One or more points will apply to most closed-bell DSVs industry-wide (except possible vessels operating in Norwegian waters).

It is written for non-diving personnel and hopes to paint an interesting picture of a lost bell scenario and potential hazards faced at work by closed bell divers.

4.0 Aims

Open up a company/industry-wide correspondence on how to deal with a lost bell, disseminate information, prevent a lost bell scenario, and, if not preventable, allow the divers to recover and survive.

5.0 Positive Factors Affecting Duration of Diver Survival within a Lost Bell

5.1 Overview of Positive Factors Affecting Divers' Survival Time in a Lost Bell

5.1.1 Autonomous Survival Mode

Control of thermal balance within the bell

- SP1 contains a thermal suit/bag and towel
- SP2 thermal regenerator fitted to CO_2 absorbent
- SP2 contains high-energy foods to promote shivering

Control of carbon dioxide within the bell

- CO_2 analysis equipment in bell
- Personal CO_2 scrubber
- Bell emergency CO_2 scrubber with fresh absorbent
- A bell onboard battery operates the emergency bell CO_2 scrubber
- Reserve CO_2 absorbent for personal scrubber
- Bell onboard gas can be used initially to flush the bell atmosphere of CO_2
- Procedures and training

Control of oxygen partial pressure (ppO2) and volume within the bell

- External oxygen cylinder with O_2 adds system
- Minimum O_2 quantity requirement known
- Battery-operated O_2 analyser in bell
- Procedures

Bell location devices

- Bell is fitted with a strobe
- Bell is fitted with a transponder c/w independent battery
- Bell is fitted with Through Water Communications (TWC)
- Diver-operated interrogator/receiver (minimum range of 500m)
- Option of vessel ROV sonar
- Option of vessel transponder array interrogation

5.1.2 Surface Intervention Mode

- Procedures for ROV and Diver Intervention
- Bell emergency umbilical (Installed by ROV or diver)
- Procedures for Through Water Transfer (TWT)
- Procedures for bell recovery
- Tapping code posted inside and outside of the bel

5.2 Lost Bell Survival Equipment

Lost Bell Survival Packs (SP) :

- Towel, undersuit, survival bag c/w integrated harness, inflatable mattress.*
- CO_2 scrubber, thermal regenerator, rations, water, sanitary bags
- Reserve CO_2 absorbent for personal scrubbers

Bell emergency equipment

- Emergency communications
- Bell location devices
- Emergency surface umbilical (Optional)

Photograph 2

SP 1 (Suit) SP2 (Scrubber & thermal regenerator)

Photograph 3

Typical storage of SPs 1 & 2 within a bell

5.3 Control of Thermal Balance

5.3.1 Survival Suit & Thermal Regenerator

Survival Pack 1 contains a one-piece thermal body suit and a survival bag with a hood. Both are constructed of tri-layer insulation.
Survival pack 2 contains a personal scrubber complete with a thermal regenerator.

The scrubber/ regenerator works in three ways

- The scrubber/regenerator within the insulated bag reduces immediate contact with the cold bell gas.
- As the gas is scrubbed, the diver's exhaled gas within the canister creates heat as part of the chemical reaction, thereby heating the gas.
- The heat contained within the diver's exhaled gas, plus the heat gained from the chemical reaction, is transferred to the thermal regenerator (heat exchanger).

Note: IMCA D59 Diver Emergency Heating Report explains a diver's heat loss and Watt net loss during a lost bell.

*Not all bells have inflatable mattresses supplied; their use should be risk assessed.

The survival bag and thermal regenerator complement each other. Survival would be doubtful if the thermal regenerator were unserviceable.

As the body begins to cool, it mobilises its heat-generating and insulating resources to resist cold. This response is characterised by peripheral vasoconstriction and increased metabolic activity to prevent a drop in the body's core temperature.

Photograph 4

Diver in thermal survival bag

Photograph 5

SP2 Thermal regenerator

5.3.2 Survival Rations

If shivering is triggered by low skin temperature, it cannot be sustained indefinitely; fatigue will set in, followed by a further drop in temperature. Survival Pack 2 contains high-energy rations.

Photograph 6

Photograph 7

SP2 rations and water

High-glucose sweets are supplied within survival pack 2 to allow divers to shiver and produce heat for long periods without exercising.

Research reports conclude that emergency rations should provide 500g of carbohydrates daily to replace what is consumed by the increase in metabolism in the cold. This should help maintain blood sugar levels and metabolic heat production.

Metabolic heat production may have to be maintained for many hours to prevent deep body temperature from falling to dangerous levels; shivering represents the most critical effective response of the thermoregulatory system.

Shivering produces heat without external work by simultaneously contracting the flexor and extensor muscles. It can range in intensity from mild to levels where metabolic heat production is increased by five times that of rest.

Various trials suggest that after an initial fall in deep body temperature, many individuals will generate enough metabolic heat through shivering to ensure thermal balance and stabilise deep body temperature. Individuals will succumb to shivering at different times; this has to do with an individual's body fat content and the rate at which it utilises glucose.

Calories

One calorie is the energy required to raise the temperature of 1g of water by 1ºC. As this is a minimal amount of power, a larger unit, the kilocalorie (kcal), is used. A kilocalorie is the energy required to raise the temperature of 1kg of water by 1ºC. This is equal to 1000 calories.

The energy value of food is measured in kcal. However, it often needs to be correctly stated as calories.

Metabolism

Metabolism is the total of the entire chemical and physical processes by which the body converts food eaten into energy.

The metabolic rate is how the body burns calories for energy.

The basal metabolic rate (BMR) is the rate at which the body burns calories to perform essential body functions, such as breathing, blood circulation, and maintaining a constant body temperature. It accounts for most of the calories burned daily.

BMR also depends on the percentage of lean muscle tissue. Muscle cells are up to eight times more metabolically active than fat cells. The more muscle, the higher the metabolic rate.

As a rule of thumb, the Basel Metabolic Rate uses 12 calories per half-kilo of body weight (Male). Therefore, a 90kg man would require 2160 calories to maintain body function. Then, multiply that figure by their activity level. If the person is more muscular than average, add another 150 kcals.

5.4 Control of Carbon Dioxide in the Bell during Survival Mode

5.4.1 Analysation of Bell Atmosphere for CO_2

Diving bells are equipped with hand-operated bellows and colorimetric tubes, commonly called 'Dräger' tubes, to detect the level of CO_2 within the bell.

The bellman usually undertakes hourly CO_2 analyser readings during normal operations and reports the results to the diving supervisor. The maximum allowable CO_2 is five mbar/5000ppm (Surface Equivalent). If this is reached, the bellman will be instructed to carry out one or a combination of the following:

- Flush the bell
- Check the bell scrubber is seated correctly
- Switch on the emergency scrubber
- Re-analyse

5.4.2 CO_2 Absorbent

CO_2 absorbent is used to remove CO_2 form breathable gases. It is a mixture of calcium carbonate and sodium hydroxides. The CO_2 absorbent is contained in the both the bell scrubbers and personal.

The gases are passed through the scrubber either mechanically, via electrically powered motor (bell scrubber) or manually (personal scrubber) and the CO_2 is removed, scrubbed, by a base catalysed chemical reaction, converting the CO_2 to calcium carbonate which is retained within the scrubber. The reaction produces water and heat.

Photograph 8

Bell scrubber canister and drum of CO_2 absorbent

Each granule is' used up' when the passing gas molecules have attached themselves to the CO_2-absorbent granules, and the chemical reaction occurs.

The granules are stacked one behind the other in the scrubber. The first to make contact with the CO_2 are the first to become affected and no longer active. The following molecules of CO_2 pass the inactive granules and form the chemical reaction with the following active scrubber molecules. As the reaction takes place, it moves further through the scrubber until all the granules are depleted. Once a breakthrough has occurred, the CO_2 level exiting the gas stream will increase.

Industry guidance for the duration of CO_2 absorbent:

- 1kg lasts one man 4 hours or 6 kilograms per day irrespective of depth.
- Production of CO_2 to O_2 consumption as a ratio of 1:1

Within the diving industry, two sizes of CO_2 absorbent are used for different applications. They are different sizes and different shapes:

- CD grade: irregularly shaped granule sized 2.5 – 5.0mm
- 797 grade; spherical granules, size 1.0 – 2.5mm

797 particles are smaller than CD grade and are used in personal scrubbers. Due to their smaller particle size, they react quickly, which results in a smaller reaction zone volume. The smaller the reaction zone volume, the greater the scrubber's efficiency.

The smaller particle size ensures that each particle can be used entirely due to the smaller distance to the centre of the particle. A bigger particle size, such as a CD grade, will have a greater distance to the centre; therefore, the material at the centre remains unreacted.

The advantage of a smaller granule tends to be a greater volumetric flow rate through the scrubber, as this is when the smaller reaction zone volume takes effect. 797 is used in personal scrubbers and recommended by the manufacturer.

If a scrubber is inadequately packed and channelling settlement occurs, some CO_2 can pass through the stack without contacting any active CO_2 absorbent particles.

The position of inactive to active particles within the scrubber is crucially important. If, for example, a partially used bell scrubber is used to fill a personnel scrubber, the CO_2 absorbent granules would not be in the same order as active granules behind inactive. Routes would form that would allow poisonous CO_2 to pass through the scrubber. This is why scrubbers must be packed tightly so granules maintain their position relative to each other.

A recharged scrubber should not rattle when shaken. Repacking it with used material could be fatal. When repacking a scrubber, it should be full, fresh and of the correct grade.

5.4.3 Bell Emergency CO_2 Scrubber

Diving bells usually have two internal CO_2 scrubbers. It is best working practice to change the CO_2 absorbent prior to each bell run.

Usual routine is that one scrubber is operating for the duration of the bell run and the other, usually covered by a plastic bag to prevent activation of the absorbent, is for emergency use. If needed it is acceptable to use the emergency scrubber for short periods if CO_2 is high. This can happen if the divers remain within the bell for extended periods.

In an emergency the scrubber will draw power from the bell battery.

Photograph 9

Bell CO_2 scrubbers

5.4.4 Personal CO_2 Scrubber

It is a misconception that people trapped in a confined space, such as the Kursk tragedy, or a lost bell, will "run out of oxygen and die", they would have succumbed to CO_2 poisoning long before the oxygen is depleted below levels that support life (if not already succumbed to hypothermia).

Without CO_2 scrubbers, carbon dioxide will reach fatal levels about four times faster than the lack of oxygen.

Diving bells are usually equipped with two bell scrubbers, one for standard operations and one for emergency use along with the bell survival packs (SP2) contain an emergency personal CO_2 scrubber for each bell occupant.

Photograph 10

SP2 Personal scrubber and thermal regenerator

The bell battery supplies power to the emergency scrubber unit. A power schematic and power draw-down calculation including length of time the bell scrubber /bell electrics should be used should be available.

The SP2 contains the passive lung-powered CO_2 scrubber unit and thermal regeneration system. Exhaled gases are passed through the CO_2 scrubber to the thermal regenerator fitted into the survival bag wall. Fresh gas is taken from the bell through the thermal regenerator to the oral nasal.

The scrubber contains a 2.5kg charge of 797 grade CO_2 absorbent in a clear Perspex canister.

The carbon dioxide scrubber should be donned immediately during the emergency. In practice, this will be once the divers have followed company procedures and donned their survival suits. While preparing themselves, they will be breathing a bell atmosphere, which the emergency bell scrubber will scrub.

5.4.5 Reserve CO_2 Absorbent for Personal Scrubber

Reserve CO_2 absorbent for the personal scrubbers should be carried in the bell for a charge to allow survival to the proven life support capability endurance of that lost diving bell.

This depends on the type of scrubber used. There needs to be enough CO_2 absorbent, of the correct grade, to ensure maximum accepted and proven life support capability endurance of that lost diving bell.

Consideration needs to be given to allowing for spillage etc and carrying spare absorbent. In case it has become wet.

Photograph 11

CO_2 absorbent inside a bell (Juice containers)

5.5 Control of Oxygen Partial Pressure and Volume

The bell will have at least one oxygen cylinder mounted externally. The cylinder is usually 50 litres. Or thereabouts. Industry guidance requires calculations for endurance and minimum reserves to be known and readily available. A dive should only commence if gas supplies are within the known minimum; this includes the bell oxygen and mixed OBG.

As the bell occupants breathe in the bell atmosphere, they not only exhale CO2 but also metabolically deplete the oxygen within the bell.

To overcome this metabolic consumption rate of 30 litres an hour per diver, a manual oxygen injection system (known as the O_2 adds system) is fitted.

In a lost bell situation with three divers, the bellman (or whoever is closest to it) would have to add O_2 every 20 minutes to maintain the recommended ppO_2. During normal operations, it is common for the bellman to add O_2 when instructed.

Emergency procedures allow the bellman to increase the ppO_2 to 900mb at the start of the emergency. This raised level will be breathed down but should not fall dangerously low within the 24 hours required in a lost bell situation.

The 900mb of O_2 is also below the threshold for chronic lung damage.

5.6 Procedures: Recovery of a Lost Bell

The potential for recovery measures within the diving industry is well documented. Every contractor who carries out closed bell diving should have suitable procedures (usually approved by the client).

Lost bell procedures should be contractor, vessel and site/region specific.

The following is an overview of industry high-level lost bell requirements. Most of the rules are aligned across the industry. Class societies also have their own rules. However, they are generally aligned to the following:

International Marine Organisation

Diving Systems Code of Safety for Diving Systems 1995 requires:

- 2.3.1 A diving bell should be fitted with a manifold at a suitable point close to the primary lifting attachment and should include connections for the following services

  ¾ inch NPD (female)-for hot water

  ½ inch (female) for breathing mixture

  The manifold should be marked and suitably protected
- 2.6.3 Diving bell should be designed with a self-contained breathing gas system capable of maintaining a satisfactory concentration of breathing gas for the occupant for at least 24 hours at its maximum operating depth
- 2.6.8 There should be a means to maintain the divers within the diving bell in thermal balance in an emergency for at least 24 hours. Such requirements may be satisfied by the use of passive means carried in the bell
- 2.7.6 In the event of a single component failure of the main handling system, alternative means should be provided whereby the bell can be returned to the surface compression chamber. In addition, provision should be made for emergency retrieval of the bell if the main and alternative means fail. If this involves buoyant ascent, the bell should have suitable stability to maintain a substantially upright position and means should be provided to prevent accidental release of the ballast
- 2.10.4 Each surface compression chamber and diving bell should have adequate means of routine and emergency lighting to allow an occupant to read gauges and operate the system within each compartment
- 2.12.2 Alternative means of communication with divers in the surface compression chamber and diving Bell should be available in emergency
- 2.12.4 A self-contained through-water communication system should be provided for emergency communication with diving bells operating underwater
- 2.12.5 A diving Bell should have an emergency locating device with a frequency of 37.5 KHZ designed to assist personnel on the surface in establishing and maintaining contact with the submerged diving bell if the umbilical to the surface is severed
- 2.12.6 in addition to the communication systems referred to above, a standard bell emergency communication tapping code should be adopted

National Legislation

There might be national legislative requirements regarding recovering a lost bell (Personnel within the lost bell). Example:

Commercial diving projects offshore Diving at Work Regulations 1997 Approved Code of Practice L103

- 67 A contingency plan should exist to relocate and recover a lost closed bell. This plan should identify the role of the diving contractor and other personnel and provide specific equipment, such as locators.
- 80 Excessive heat and cold can affect the health, safety and efficiency of divers and the dive team. Appropriate personal protective equipment and procedures should be provided to maintain thermal balance.
- 105 All bell diving operations must have the capability of deploying a surface standby diver in an emergency unless effective alternative means are available to ensure that assistance can be rapidly provided at all depths within the working range of a surface diver.
- 139 Plant and procedures should be provided to enable the diving bell to be rescued if the bell is accidentally severed from its lifting wires and supply umbilical.
- 140 The bell should be equipped with a relocation device using the frequency recognised by the International Maritime Organisation (IMO) agreement to enable rapid location if it is lost.
- 141 The bell should be capable of sustaining the lives of trapped divers for at least 24 hours.
- 142 The bell will require an alternative method for returning to the surface if the main lifting gear fails. If weight-shedding is employed, the weights should be designed so the divers inside the bell can shed them. This design should ensure that the weights cannot be shed accidentally

International Oil & Gas Producers

IOGP 478 Performance of saturation diving emergency hyperbaric evacuation and recovery requires:

- Successful recovery of divers from a lost and stricken bell should be achievable within 75% of the maximum accepted and proven life support capability endurance of that lost diving bell.
- a plan for the support, recovery and transfer of the occupants of a lost diving bell or abandoned habitat
- the specification of the on-board life support equipment, its capacity and the limit duration for the occupants of a lost diving bell(s), habitat or hyperbaric evacuation system
- suggests that a dual entry (side-mating) bell should be used as it allows evacuation of bell occupants in the event of a blocked door (unconscious or parlayed divers)

IOGP 411 Recommended Practices for Diving Operations requires:

- The remoteness of the worksite and access to suitable emergency rescue support
- Hyperbaric evacuation of all chamber and bell occupants to a safe refuge and decompression to the surface as specified in IOGP 478
- The diving contractor must be satisfied that sufficient plant, suitable for the use of which it will be put, is provided for the diving project and that sufficient plant is available, whenever needed, which is suitable to carry out safely any action which may need to be taken in a reasonably foreseeable emergency

IOGP 468 Diving system assurance recommended practice requires:

- Satisfactory bell thermal balance trials witnessed by the class
- Check on location devices for climatic and sea temperatures
- Hypothermic and hyperthermic testing of Bell’s internal

International Marine Contractors Association

The International Code of Practice for Offshore Diving, IMCA D14, requires the Diving Project Plan to have the following stated:

- Suitable emergency and contingency plans for the location/country where the work is going to be carried out, which will be agreed upon by all relevant parties, including:
  - Rescue of divers from a habitat
  - Lost bell recovery
- Diving crew familiarisation plan and sign-off sheets
- Diving/operating/maintenance procedures
- Equipment audit reports and certification
- Lift plans
- How divers are to be kept in thermal balance

IMCA also requires: (not definitive)

- The diving bell is fitted with suitable protective devices that will prevent uncontrolled loss of the atmosphere inside the diving bell if any or all of the components in the main umbilical are ruptured.
- The bell has a relocation device that uses the internationally recognised frequency to enable rapid location if lost.
- Bell fitted with the internationally agreed standard manifold block for attachment of an emergency umbilical.
- The bell to sustain the lives of trapped divers for at least 24 hours.
- Bell fitted with through water communications.
- Each diving bell needs an alternative recovery method to the surface if the main lifting gear fails. This is usually done using the guide wires and their lifting equipment. If release weights are employed, they must be designed so the divers inside the bell can shed them. This design must ensure that the weights cannot be released accidentally. The bell must be fitted with a stand-off arrangement so the divers can freely exit and re-enter the bell.
- During closed diving bell operations, an appropriate recovery method must be provided for the divers in the case of a stricken or fouled closed diving bell. This might be done by a surface standby diver or another robust alternative method.
- A risk assessment of recovery methods is needed to establish the most suitable method, equipment, and resources.
- When a surface standby diver is planned to be used, the diver must be available with equipment suitable to assist in an emergency within the applicable working depth range. An entire surface diving system doesn’t need to be provided, but the equipment which is provided should meet the relevant sections on minimum requirements for surface diving equipment as laid out in IMCA D 023
- The alternative assistance plan should be robust (proven through exercises) and developed to ensure rapid assistance can be given to a stricken or fouled bell at all depths, including the period. In contrast, the bell is close to or in a moonpool.
- In line with IMCA D77, a transponder operating on 37.5 kHz must be fitted to the bell to aid in location in an emergency
- A strobe light with a minimum operating duration of 24 hours must be fitted to the bell to assist in location in an emergency.

6.0 Negative Factors Affecting Duration of Diver Survival within a Lost Bell

6.1 Overview of Negative Factors Affecting Divers' Survival Time in a Lost Bell

Each of these factors can lead to life-threatening situations.

6.1.1 Autonomous Survival Mode

Loss of thermal balance

- Divers locked out have no active heating (Hot water supply)
- Time against divers as 1st stage drop weights require deploying to allow access to the buoyant bell
- Bellman will be chilled due to bell flooding on the descent and unable to rewarm as there is no active heating
- Cooling of the bell to ambient water temperature
- SP2 thermal regenerator fitted to CO2 absorbent relies on dry CO2 absorbent
- SP1 (survival suits) need to be stored above the up zone so they remain dry
- Emergency rations may not be suitable
- Heliox conducts heat 6x faster than in an air atmosphere
- Water conducts heat 26x faster than being dry
- No industry standard bell internal active heating system (Deeper than 180msw)

Carbon dioxide (CO_2) build-up

- CO_2 absorbent must be dry (within manufacturer parameters)
- SP2s need to be stored above flood up zone
- CO_2 absorbent needs to be stored above flood up zone
- CO_2 absorbent needs to be the correct grade for the intended purpose
- CO_2 absorbent needs to be of adequate quantity for the intended purpose
- CO_2 absorbent needs to be kept in a suitable container
- Potential that external battery is damaged or removed during impact with asset

Lack of oxygen partial pressure (ppO2) and volume

- Potential that external oxygen cylinder damaged or removed during impact with asset
- The potential that external oxygen pipework is damaged or removed during impact with asset

Lost bell location & communication devices

- The transponder and battery may have been damaged or removed during impact with the asset
- Through Water Communications (TWC) damaged or removed during impact with asset
- It is difficult for the bellman to communicate via TWC whilst wearing an oral nasal

6.1.2 Surface Intervention Mode

- Procedures for ROV and diver intervention should be more specific to be of value.
- Bell emergency umbilical (Installed by ROV or diver) rarely, if ever, deployed, mated and tested
- Procedures for Through Water Transfer (TWT) or bell recovery usually must be improved.
- TWT rarely drilled with 2nd bell; never drilled with 2nd vessel
- Buoyant ascent never drilled; no lessons learnt

6.2 Loss of Thermal Balance

Heat loss is the most critical factor in a lost bell situation.

With the average water temperature of the North Sea at approximately 5ºC, trials have shown that within a heliox-filled and insulated bell, the bell could cool to ambient water temperature within 4-6 hours.

Although diving bells are externally insulated with synaptic foam, they do not effectively store heat. The consequent increase in buoyancy limits the thickness of the insulation.

IMCA states, "..it is essential to ensure that all diving bells are insulated as effectively as possible".(IMCA D77).

Trials have also shown that a heliox-filled bell in 5ºC ambient seawater would have the equivalent (theoretical) air temperature of -150ºC. (The lowest recorded temperature on earth is Antarctica at -89ºC.)

Equally important is that the internal gas temperature took only 30 minutes to fall below the recommended minimum. A diver in a heliox environment will lose 24% of their total body heat via lung evaporation and 30-40% heat loss via the head.

- Water conducts heat 26 times faster than air at the same temperature
- Helium conducts heat six times faster than air

Within a living chamber of a saturation system at approximately 100 msw, the temperature will be around 30ºC. If the temperature decreases by 1ºC, the chamber occupants will feel this decrease. (IMCA D22 recommends that the living chamber be kept between 25-33ºC)

Sometimes, chamber heating fails, or an overzealous LST reduces the temperature by 3 or 4ºC. The chamber occupants will become very cold and request that the emergency heating be activated.

Being inside a diving bell at 5ºC when wet and exhausted confirms to the author that the theoretical, minus 150ºC equivalent air temperature is, unfortunately, very believable.

If the thermal balance is lost in the bell and the diver's core temperature reaches 35ºC, the diver will experience mental confusion and impaired rational thought.

Below 35ºC the diver will suffer memory loss, poor articulation, sensory and motor degradation and amnesia.

Divers in this condition cannot be relied on to carry out basic tasks (or self-rescue).

6.2.1 Bellman Loss of Thermal Balance

For the bell to be 'lost', the most likely cause will be a catastrophic event resulting in the bell and guide wires along with the bell umbilical being severed and the bell, complete with at least the bellman, descending to the seabed (or fouled/lodged in a subsea asset).

When the bell descends, it will flood due to its increased depth. The amount of flooding will depend on the depth increase and internal volume of the bell.

The bellman can increase the bell's internal pressure using the bell's onboard gas supply and expel the excess water; however, it is unlikely the bellman will have the presence of mind or time to do so at the start of the emergency (catastrophic event, disorientation, falling bell, power loss, etc.).

The table below indicates the percentage of 'reduction of the gas bubble' within the bell as it descends. Without active heating, the bell occupants will get wet and chill rapidly.

Table 1

PERCENTAGE REDUCTION IN "BUBBLE" VOLUME IF DROP BELL

Bell internal depth msw \ BOTTOM DEPTH msw	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225	230	235	240
50		8	14	20	25	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60			0	7	13	18	22	26	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
65				0	6	12	17	21	25	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
70					0	6	11	16	20	24	27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75						0	6	11	15	19	23	26	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
80							0	5	10	14	18	22	25	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
85								0	5	10	14	17	21	24	27	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90									0	5	9	13	17	20	23	26	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
95										0	5	9	13	16	19	22	25	28	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
100											0	4	8	12	15	19	21	24	27	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
105												0	4	8	12	15	18	21	23	26	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
110													0	4	8	11	14	17	20	23	25	27	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
115														0	4	7	11	14	17	19	22	24	26	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
120															0	4	7	10	13	16	19	21	24	26	28	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
125																0	4	7	10	13	16	18	21	23	25	27	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
130																	0	3	7	10	13	15	18	20	22	24	26	28	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
135																		0	3	6	9	12	15	17	19	22	24	26	28	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
140																			0	3	6	9	12	14	17	19	21	23	25	27	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
145																				0	3	6	9	11	14	16	18	21	23	24	26	28	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150																					0	3	6	9	11	14	16	18	20	22	24	26	27	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
155																						0	3	6	8	11	13	15	18	20	21	23	25	27	28	30	[illegible]	[illegible]	[illegible]
160																							0	3	6	8	11	13	15	17	19	21	23	24	26	28	29	[illegible]	[illegible]
165																								0	3	5	8	10	13	15	17	19	20	22	24	26	27	29	30
170																									0	3	5	8	10	12	14	16	18	20	22	23	25	27	28
175																										0	3	5	8	10	12	14	16	18	20	21	23	24	26
180																											0	3	5	7	10	12	14	16	17	19	21	22	24
185																												0	3	5	7	9	11	13	15	17	19	20	22
190																													0	2	5	7	9	11	13	15	17	18	20
195																														0	2	5	7	9	11	13	15	16	18
200																															0	2	5	7	9	11	13	14	16
205																																0	2	4	7	9	10	12	14
210																																	0	2	4	6	8	10	12

Locally developed matrix indicating approximate flooding of bell on descent with open bottom door

6.2.2 Diver(s) Loss of Thermal Balance

The definition of a lost bell is a bell that has lost its surface-supplied life support capability. All surface-supplied life support gets to the bell via the bell umbilical.

In the worst-case scenario, two working divers could be locked out of the bell. Their hot water supply will have stopped flowing, and they will be rapidly chilling, most likely to the point that they are incapable of self-rescue. The divers need to re-enter the bell as soon as possible.

When a diver loses their hot water supply, the diver notices within seconds.

Considerations for lost bell risk assessment:

- Divers and the bellman should wear a close-fitting neoprene undersuit. Although this is passive heating it will give some thermal protection when the hotwater supply stops.
- A 'woolly bear' or coverals worn as thermal protection under a hotwater suit is inadequate to maintain passive thermal balance when wet.
- Hot water suits are meant to be loose fitting to allow circulation of hotwater, when the hotwater supply stops cold seawater circulates with every move the diver makes.

6.2.3 Hypothermia Risk: Diver(s) Access to a Bell (without Active Heating) on the Seabed

If the bell has had its umbilical and wires severed, it should land on the seabed (possibly that the bell is fouled in a structure or suspended by a wire/umbilical fouled in a structure).

It is generally assumed that a bell will descend to the seabed and sit upright. This wholly depends on how the bell and stand-off frame is configured, the bell's centre of gravity, and what the bell lands on. It is conceivable that the bell may land on its side.

There are two types of bell design; 'sinkers' and 'floaters'.

A **negative buoyant bell** (sinker) is designed to sink. The emergency response by the mothership to recover the divers is usually by either a second bell on the vessel (twin bell vessel) or a system purposely designed for recovery by vessel crane and ROV intervention (and use of surface standby diver within the air range)

A negatively buoyant bell usually has a fixed stand-off frame below the bell; this allows clear egress and access during routine diving operations. However, access may become restricted if the bell lands on a soft seabed. The centre of gravity of the bell and stand-off frame is essential; with the fixed stand-off, the combined bell and stage have a high centre of gravity and, therefore, have a higher probability that the bell might not land upright on the seabed, significantly if impacted a subsea asset or above a pipeline.

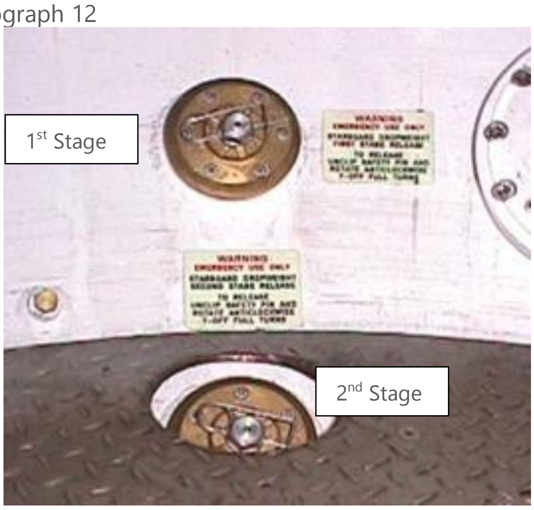
If a negative buoyant bell lands upright on a firm seabed, divers should be able to access it reasonably quickly.

A **positive buoyant bell** (floater) is designed to float and has a system purposely designed that allows ballast weights to be shed by the bell occupants for a buoyant ascent. The system is a two-part procedure; the first stage is deploying the weights from the bell on chains, allowing the weights to land on the seabed, the bell floating and restrained by the weights and chains, thus creating an access space for the divers to access the bell. (See Photograph 1-Buoyant Bell with separate stage)

The ballast weights are low on the bell, creating a low centre of gravity and a better chance that the bell will land upright. (Additional factors, such as the weight of the wires and umbilical, might change the centre of gravity.)

The bellman will have to act promptly to release each first-stage release to allow the divers access to the bell, remembering that the bell would have descended and flooded, the bellman would be chilled, and the bellman would have to find the appropriate procedures and tools for their release (this is usually by spanner, socket, or Enerpac with valve configuration. This might have to be carried out by torchlight).

Photograph 12



1st & 2nd stage release with divers umbilical removed

Note: Different bell designs have different layouts

Photograph 13

1st and 2nd stage releases obscured by divers umbilical

Considerations for lost bell risk assessment:

- If a positive buoyant bell lands upright on a firm seabed the divers should be able to access the bell after the bellman has carried out the required procedures. This will not be a quick procedure and there is a high probability that the divers will be incapable of self-rescue due to lose of thermal balance. The bellman cannot lock out as he has no active heating.
    - The procedure should be that the bellman pulls the divers to the bell by their umbilical and recovers them into the bell on the man-hoist.
    - Procedures for 1st stage release should be posted in the bell adjacent to the release
    - Any tools needed for releasing the 1st stage should be included in bell checks and be readily available
    - The 1st stage and second stage release should be easily identified
- The releasing of the 1st stage (or 2nd stage) drop weights should be part of the drill/familiarisation matrix. The dive techs should dry release the weights on the surface every 12 months as part of the PMS, however, divers don’t get to practice the release.
    - Consider videoing the release as part of the divers familiarisation/competency and if possible get divers to do the release.
    - When bell umbilical requires ‘cut back’ have divers use hydraulic cutter in bell and get video of umbilical being cut for familiarisation and competency

6.2.4 Hypothermia Risk: Divers in the Bell During Survival Mode

Hypothermia may be mild, moderate or severe. The presentation ranges from shivering and piloerection (Goosebumps) to profound confusion, irreversible coma and death.

The average body temperature is approximately 37ºC. With a core temperature of 35ºC or below, you are considered hypothermic. If the core temperature cools to about 34ºC, the diver will become semi-conscious, confused, unable to coordinate motor function, and lethargic. He will need to be more capable of responding effectively to the situation or assisting in his rescue.

The body's temperature decreases as it is robbed of heat by its surroundings. Normal body functions slow down with reduced heart, respiratory, and metabolic rates.

Furthermore, peripheral vasoconstriction affects the body's extremities. The hands and feet cool quickly, resulting in reduced finger dexterity. Thinking is impaired, and speech becomes confused. Reflexes are slowed, and muscles become stiff and unusable. Then, life-threatening heart rhythms develop.

The active movement of the body tissues generates heat and CO_2. The most apparent metabolic activity is shivering thermogenesis as the body cools. Thermogenesis is simply the generation of heat.

The downside of uncontrolled shivering is oxygen consumption, two to five times the normal consumption. If the PPO_2 level drops, shivering will decrease. If shivering is limited or stops, the core temperature will decline, and the diver will become hypothermic. It must be remembered that the survival suits are passive, and if the diver cools, he enters a downward spiral.

The cessation of shivering can be regarded as disadvantageous in this scenario.

Survival time and effectiveness of the survival suit depend on Survival Pack 1 (SP1 survival suit/bag) remaining dry. When descended, SP1 must be kept out of the bell design flood-up zone and potential bell flood-up area (or whichever is greater). If the survival suit/bag is wet, survival time is reduced, possibly to as little as six hours.

Considerations for lost bell risk assessment:

A survival bag/suit is PPE and should be treated as such; risk assessed, capable of fitting the wearer, takes account of ergonomic requirements, appropriate for the risks involved, the conditions at the place of exposure, and period it is to be worn.

- Using the hierarchy of control, PPE is the least desirable control measure.
- Personnel should be trained in the use of PPE

Survival suits and survival bags are 'one size fits all'. During a diver familiarization an SP1 was unpacked, the volunteer (6' 14 $^1/_2$ stone, size 10 feet) who donned the suit had various problems such as;

- Sliding feet in to the suit legs
- Booty part of suit too small (Not in proportion to length of suit)
- Under suit tight all over and especially at the knees when sitting
- Shoulder harness was too small in body length and marginal on waist length
- Shoulder harness external tie straps would be better if fitted with hooks/clips
- Survival bag was snug fitting
- Removal of the arms out of the sleeve(as recommended) couldn't be achieved

Note: This was one specific brand of SP1 and doesn't reflect all SP1 equipment on the market

A discussion followed the familiarisation and concluded that the largest size of the person to don the survival PPE would be approximately 5′ 10″, 12-14 stones, size 9 feet. These anthropometric dimensions comprised only a tiny part of the dive team at that time and across the industry.

These suits may have been sized up and based on young divers from 30 years ago. Human anthropometric dimensions have changed. Also, when the SP1s are returned for inspection and repacking, they may get washed, dried, or dry cleaned, all of which have shrunk the suits/bags over time.

Further considerations for lost bell risk assessment:

- It is impossible to guarantee that the SP1 has not been affected by damp due to the high humidity within the diving bell. If damp, survival time will be reduced (by as much as 40%)
- Stowage can be difficult in some diving bells due to the confined space.
- Donning the system can be extremely difficult inside the confines of a diving bell and requires agility. It may be impossible if the diver is injured or unconscious.
- The insulating properties of the suit are reduced after periods of being compressed in the packaging, there is inadequate space to 'air' the suit/bag prior to donning.
- High heat loss occurs if, once the bag has been donned, it is opened to carry out functions within the bell such as:
    - CO_2 recharge
    - Eating/drinking
    - Urinating
    - Removing arms from bag to carry out bell functions such as PTT, analysing and adding O_2

Note: IMCA (in conjunction with the HSE) states: "Passive survival systems are of an acceptable standard properly, inspected and maintained, kept undamaged, and used correctly by the divers. Verification dives, and unmanned simulations show that survival time in a lost bell shallower than 180 m should exceed a minimum of 24 hours without active heating."

"For diving depths deeper than 180msw, using passive survival systems alone may be insufficient to ensure survival for 24 hours. These systems are coupled with passive individual installation systems and have heating wires forming an integral part of the thermal insulation suit/bag. Power for this type of system is supplied from the bell emergency batteries" (Ref IMCA D77)

6.2.5 Emergency Rations: Suitability

Industry guidance recommends that emergency rations provide 500g of carbohydrates daily to replace that consumed by the increase in metabolism in the cold. This should help maintain blood sugar levels and metabolic heat production. This amount is also stated in the HSE's report *'Estimation of diver survival time in a lost bell'.*

DMAC 08 (and IMCA D77) recommends 2000 calories for each diver. IMCA recommend one 21g bar per hour.

The contents of the ration pack looks, at first glance to be adequate, however, further examination indicates that, salted peanuts, boiled sweets aren't suitable and 'build up' drink that requires mixing with milk isn't practical nor suitable.

Chewing gum might help keep the mouth moist, as rebreathers dry the mouth, however a chewing will break the oral nasal seal. It is also a choking hazard and could block breathing equipment.

Photograph 14

24 hour survival rations for one diver

Although this is termed a 24-hour ration pack, the divers probably had a light snack an hour or two before diving, and the bell emergency could have occurred at the end of an eight-hour bell run. Therefore, the 24-hour ration pack could be the only food for up to 34 hours.

The total number of Kcals available in the ration pack is 2586. This is below the recommended level for an inactive (90kg male)* person. Technically, the bell occupants will be inactive; however, the heat and shivering have to be sustained for hours.

Thermal suits are passive. The diver still has to produce heat.

Table 2

Activity Level	% (of BMR) x BMR	Total Kcal's required per day
Inactive/Sedentary	20% x 2160 (BMR)	2592 Kcal's
Fairly	30% x 2160 (BMR)	2808 Kcal's
Moderately	40% x 2160 (BMR)	3024 Kcal's
Active	50% x 2160 (BMR)	3240 Kcal's
Very Active	70% x 2160 (BMR)	3672 Kcal's

Basal metabolic rate (BMR) calorie requirements for work load

Some of the items in the ration pack are either dangerous to eat or impossible to eat in a lost bell.

Taking a standard 58g Mars bar as a 'survival ration' benchmark. One Mars bar contains approximately;

- 260 calories, or 13% of the average daily calorific value [based on 2000 calories]
- 40g of carbohydrates, 34.6g of which are sugar.
- 9.9g of fat

IMCA D017 'Lost Bell Survival' recommends eating *One carbohydrate bar (21g) every hour. Dehydration may be prevented by taking 250ml of a carbonated drink instead of a solid bar every six hours or by drinking other fluids provided, such as water.'*

*Note: BMR is a complex subject that relies on many individual factors. Due to stringent diver medical requirements, divers are probably more muscular with less body fat than the average population.

Using the Mars bar as the benchmark and IMCA recommendations, the survival ration pack should contain enough 'solid bars' and fluids to eat/drink every hour. Therefore, taking half of a standard Mars bar every hour (20g of carbohydrates) for 5 hours, then a drink of water (no carbohydrate drink is supplied), the survival pack should contain 10 x 58g Mars bars and 750ml of water/carb drink. Half a Mars bar per hour for 5 hours, then a drink.
The carbohydrates in a Mars bar (or any 'candy bar') are laden with sugar that provides a sudden rush of energy but then leads to a 'crash'. The best sources of carbohydrates are whole grains, vegetables and fruit, which provide lasting energy.

Considerations for lost bell risk assessment:

- The lost bell procedures should state what and when the rations are consumed for maximum benefit
- Consider carb drinks complete with straw
- Involve the Diving Medical Advisor in the contents of and procedures for eating rations
- Avoid items that can easily become a choking hazard or that could block breathing equipment
- Avoid items that require excessive chewing, as chewing breaks the oral nasal seal
- Avoid items that are known to set off allergic reactions
- Ensure packaging is easy to open (divers could be hypothermic)
- Consider the time needed to eat it while the oral nasal is removed (heat loss v calories in)
- Consider contents that don't promote thirst (such as salted nuts etc.)
- Consider contents that give slow release of energy and not a spike
- Consider each diver being assessed for calorific requirements based on individual BMR requirements and developing individual ration pack.

6.3 Carbon Dioxide in the Bell during Survival Mode

It is a misconception that people trapped in a confined space, i.e. the Kursk tragedy, will "run out of oxygen and die", they would have succumbed to CO_2 poisoning long before that.

It is imperative that the carbon dioxide level within the bell (enclosed space) is monitored and controlled

Carbon dioxide will kill about four times faster than the lack of oxygen
Performance of any tight fitting face pieces are likely to be compromised if the equipment isn't matched to the wearer. Although there is a legal requirement in many countries to ensure this aspect, fit testing of personal scrubber RPE is neglected .
The passive personnel scrubber is a negative pressure ½ mask. It supplies bell environment gas only when the wearer inhales.

Photograph 15

SP2 –Negative pressure ½ mask

Photograph 16

BIBS full face mask with built in communications.

This particular type of oral nasal had hose connections to the oral nasal that were very flimsy and easily became accidently disconnected. They are difficult to reconnect it would be extremely difficult to achieve reconnection during a lost bell scenario.

If a diver's oral nasal became detached whilst sleeping it could prove fatal. It would be unlikely that other team members would notice due to the hoses being internal to the survival bag. He would be exposed to CO_2 and lose deep body heat via the lungs.

There are BIBS full face masks available (Photograph 16). They are available with built in communications. The one shown is fitted to a closed loop emergency BIBS system.

Considerations for lost bell risk assessment:

- Unless the oral nasal fits the face correctly it potentially expose the diver to:
    - Toxic levels of carbon dioxide
    - Respiratory heat loss, resulting in deep core cooling
    - Body heat loss due to exhaled gas not going through the thermal regenerator
    - Exposure to CO_2 absorbent dust during scrubber refills
- It is not enough to provide a face piece and maintain it in working order. It has to be suitable for the job, the working environment, the exposure level and of course fit the wearer.
    - Facial profiles are far too diverse for one size fits all.
    - Facial hair will negate a seal.

6.3.1 Signs and Symptoms of CO_2 Poisoning (Hypercapnia)

Symptoms of CO_2 poisoning usually start with a headache followed by sweating and increased respiration, usually accompanied by feelings of apprehension.

Breathing becomes rapid and shallow, leading to the lungs and dead space within breathing equipment not being adequately flushed. Therefore, the levels of CO_2 in the lungs increase, increasing the carbolic acid levels in the blood. This, in turn, stimulates more breathing. Breathing becomes faster and shallower, therefore caught in a dangerous cycle with the CO_2 in the body rapidly reaching toxic levels. Collapse can follow quickly without any other symptoms.

CO_2 in atmospheric air is about 380 PPM

Table 4

Parts per Million ppm	Millibar mb	Symptoms
20,000	20	No symptoms of poisoning
20,000-40,000	20-40	Onset of symptoms
150,000	150	Unconsciousness followed by death

Diving contractors' maximum allowable CO_2 limit in the bell is usually 5mb (20mb IMCA). Guidelines do not differentiate between normal diving operations and emergencies.

Flushing the bell with onboard gas is impractical, as only a limited amount is available. The divers returning to the bell, blowing the water out of it, and obtaining a seal could already seriously deplete this supply.

This leaves scrubbers as the primary method of controlling CO_2 buildup and colorimetric tubes as the primary method of analysing the bell atmosphere.

Diving bells generally carry two bell scrubbers, one for normal operations and one for emergencies. The bell battery and surface-supplied electricity power the emergency scrubber. The bell scrubbers come in various sizes and hold different charges of CO_2 absorbent.

Typically scrubbers hold a 5kg charge of CD grade CO_2 absorbent giving approximately 6½ hours scrubbing time. This 5kg charge can vary slightly with the inclusion of additives such as odour removers (Sofnofil) and trace gas absorbers (activated charcoal).

In a lost bell situation the divers would don their personal scrubbers. These are passive and powered by the action of breathing (lung powered scrubbers), so therefore require no external power input. In an emergency, having the luxury of the bells battery supply cannot be guaranteed. In previous lost bell situations onboard gas bottles, battery packs and other external bell equipment has been ripped off during contact with subsea assets.

Photograph 17

CD grade CO_2 absorbent

Considerations for lost bell risk assessment:

- Survival time and effectiveness of CO_2 removal is dependent on the CO_2 absorbent remaining dry and being the right grade of absorbent for the unit it is used in.
    - The bell scrubbers (primary and emergency) should be located above the bell design flood-up zone and potential bell flood-up area when descended (or whichever is the greater) .
    - All SP2s should be stored above the bell design flood-up zone and potential bell flood-up area when descended (or whichever is the greater) .
    - All CO_2 absorbent should be stored above the bell design flood-up zone and potential bell flood-up area when descended (or whichever is the greater) .
    - Consider using colour indicating CO_2 absorbent. This product was 'banned' many years ago. The ban was for one particular brand that is not currently used. (See Appendix 1)
- All CO_2 absorbent should be of the correct grade for the unit it is to be used. Reserve absorbent is usually for the SP2 personal scrubber.(Note this isn't 'spare' it is to be used in the recharge)
- Colorimetric tube are used to monitor the bell atmosphere foe CO_2 they do not give warning and would be extremely difficult to use when in survival mode in the bell
    - Consider battery powered CO^2 analyser with real time reading

6.3.2 Shivering and its Effects on CO_2 Levels and O_2 Consumption

Many studies have been carried out on the effects of shivering on oxygen consumption and carbon dioxide production in patients rewarming from hypothermic cardiopulmonary bypass.

Although cardiopulmonary surgery does not directly correspond to divers in a lost bell, the studies' results are relevant.

As the body begins to cool, it mobilises its heat-generating and insulating resources to resist cold. This response is characterised by peripheral vasoconstriction and increased metabolic activity in an effort to prevent a drop in the body's core temperature.

The active movement of the body tissues generates heat, CO_2, and H_2O. As the body continues to cool, the most obvious metabolic activity will be shivering thermogenesis.

The downside to uncontrolled shivering is oxygen consumption and carbon dioxide production. This is two to five times the normal consumption.

How far into a lost bell scenario uncontrolled shivering starts will depend on many factors;

- Amount of lean muscle
- Amount of body fat
- Individual's metabolic rate
- HeO_2 mix in bell
- The cooling rate of the bell/the amount of insulation / how much the bell flooded on the descent
- Depth
- Water temperature
- How chilled the diver was before donning his passive suit (Returning to the bell without hot water)

Considerations for lost bell risk assessment:

- The ratio of O_2 consumption to CO_2 production taken at 1:1 means that five times as much CO_2 is produced. This then severely shortens the expected duration of the personal scrubber and depletes the O_2 quicker than expected.
- The diving industry standard for oxygen consumption of 0.5 litres a minute per man, irrespective of depth is none applicable when in a survival situation.
- Oxygen consumption / Carbon dioxide production could be as high as 2.5 litres a minute per man
- Consider the amount of CO_2 absorbent required for the required survival time at the higher rate of CO_2 production.

6.3.3 Reserve CO_2 Absorbent

The personal CO_2 scrubbers in the bell hold a 2.5kg charge of 797 CO_2 absorbent. According to industry endurance calculations, the absorbent should last 10 hours.

After approximately 10 hours, all three divers will need to recharge their personal scrubbers. The reserve CO_2 absorbent within the bell (not always 797) is commonly stored in two 5-litre juice containers.

These juice containers hold approximately 4.5kg of absorbent each. Once all three divers have refilled them, a 1.5kg reserve is left, provided the cold and confused divers don't spill any. Fast-forward another 10 hours, and we're 20 hours into the incident.

Considerations for lost bell risk assessment:

- Survival time and effectiveness of CO_2 removal is dependent on the correct quantity and grade of CO_2 absorbent:
  - There should be sufficient absorbent to carry out recharges so the maximum accepted and proven life support capability endurance of that lost diving bell.
  - Any reserve CO_2 absorbent needs to be the correct grade for its intended purpose. Personal scrubbers use the smaller 797 CO_2 absorbent. Unfortunately it is commonly found that the reserve CO_2 absorbent is the larger CD grade intended for the bell scrubber.
  - CD grade CO_2 absorbent from the bell scrubber should not be used in the personal scrubber
  - A scrubber canister cannot be partially refilled because it will create 'dead pathways'.
  - The CO_2 absorbent not only cleans the divers breathing stream but also assists with heat production

6.3.4 Storage of Reserve CO_2 Absorbent

Reserve emergency CO_2 absorbent is usually stored in a suitable container. It appears that it is custom and practice that when the containers are filled, the lid is screwed on and sealed to stop the ingress of CO_2 (and water) and the activation of the granules. (This is incorrect as the granules require a flow over them to activate correctly).

When the container is sealed and subjected to high pressure during diving operations, it will form a solid mass, rendering it useless when needed.

Photograph 18

Photograph 19

CO_2 absorbent after time at depth within a sealed container.

Considerations for lost bell risk assessment:

- Any reserve CO_2 absorbent should be stored in a suitable container
- Any container should prevent moister ingress but not allow the contents to be crushed/pressurised to render it of no use
- Consideration needs to be given to trapped pressure during decompression
- Consideration should be given to the physical condition of the person and environment when opening the container and recharging a personal scrubber
- Procedures need to consider the temperature of the reserve CO_2 absorbent when it is put into use.
    - Cold CO_2 absorbent may only last 20% of its usual time
    - The diver will lose deep core temperature breathing from the cold sodasorb
    - CO_2 absorbent works best when warm

6.3.5 Marking Containers for Hazard Identification

The manufacturer of CO_2 absorbent display the corrosive hazard phrase on the supply drum. This is to comply with local and international chemical identification legislation.

When the bell scrubbers, and personal scrubbers are charged with CO_2 absorbent and the container with reserve absorbent should also display the appropriate hazard phrase.

Photograph 20

Photograph 21

Drum of CO_2 absorbent

Corrosive CO_2 absorbent particles and dust are known hazards inside the saturation system and the bell. Consider the consequences of a diver with chemical burns during the recharge of the personal scrubber. In particular, it is essential to know if CO_2 absorbent enters the breathing tract or eyes.

Photograph 22

CO_2 particles below scrubber

Photograph 23

Corroded deck plate below scrubber caused by CO_2 absorbent

Photograph 24

CO_2 dust on bellman's breathing equipment below scrubber

Considerations for lost bell risk assessment:

- The same chemical handling procedures apply in a diving system as they do elsewhere in industry
- Consideration needs to be given to divers PPE when handling chemicals. During a lost bell scenario the conditions will be poor, suffering a chemical burn to the hand or eye would be untreatable until after rescue
- Used CO_2 absorbent needs to be disposed of correctly.
- Loose CO_2 absorbent in the bell can prevent a seal on the bottom door

6.4 Oxygen Availability, Partial Pressure and Volume

The oxygen level inside the bell must be controlled at all times to prevent hypoxia (low O_2), anoxia (lack of O_2), and hyperoxia (high O_2). The recommended ppO_2 in the bell for routine diving operations is 400 – 800 MB. However, if the bell umbilical is severed, this level will drop due to the divers' metabolic consumption. Divers' metabolic consumption is calculated at 0.5 litres/minute per man, irrespective of depth.

The bell is fitted with an external oxygen cylinder (usually 50 litres). Unfortunately, there is no guarantee that the oxygen (and other externally mounted gas cylinders, through water communications, etc.) will still be attached during a lost bell incident. For the bell to be 'lost,' it will most likely have been involved in a catastrophic event such as a DP run-off/drive-on, resulting in the bell fouling subsea assets/structure, resulting in physical damage to the bell.

If the oxygen cylinder or external pipework has been damaged or removed, survival time will be reduced due to the inability to restore oxygen levels.

Considerations for lost bell risk assessment:

- Consider where the O_2 cylinder and buffer tank is mounted externally. Ensure that neither are mounted to the working side of the bell, i.e. the most likely side that would be 'driven-on' to a subsea asset.
- Consider where the O_2 pipework is and ensure it too isn't adversely exposed in the event of a drive-on to an asset
- The above also applies to HeO_2 OBG. Ensure that not all gas supplies and pipework are exposed to a single event. Once the catastrophic event has happened and the top-side life support services lost, the divers will be breathing from the OBG.

6.5 Lost Bell Procedures

There are a plethora of international, national and industry requirements to ensure that:

- A bell cannot be 'lost.'

If it is lost:

- The divers can survive the environmental conditions
- There is a robust and proven plan to rescue the divers
- All life support equipment is available and working

Procedures for lost bells are rarely, if ever, suitable or sufficient. Lost bell procedures should be contractor, vessel, and site/region specific. Below are some points to consider when developing lost bell procedures.

Considerations for lost bell procedures :

1. On a twin bell vessel, in a remote location, with self-rescue as primary recovery, consider the procedure if vessel DP is inoperable. Possibility that the bell was lost due to a DP failure therefore how will the bell recovery procedure be utilised if the DSV has no/downgraded DP?
2. It might not be possible or safe to carry out a buoyant ascent within or near a structure
3. Consideration needs to be given to how a lost bell incident occurred. The most likely scenario would be a drive on/drift on due to black ship or degraded DP. It would be unlikely an OIM (or insurance) would allow a vessel in the 500mz with that has DP problems or electrical problems. If this was the case it might negate an immediate twin bell rescue, ROV intervention or surface standby intervention.
4. On a vessel that utilises an ROV as primary means of lost bell recovery are there procedures and risk assessments for allowable ROV downtime due to WOW or maintenance?
5. It is known to deploy the surface standby diver though the bell moonpool to assist in the lost bell recovery. IMCA D23 allows this as long as there is a compliant method of deploying and recovering the diver, however, it is not necessary to supply the full requirements of D23 such as a standby diver or emergency/secondary recovery system.
   - If only two surface divers (day and night shift) what is the maximum safe depth the company will allow them to dive? How does the rescue diver get to the bell, as there might not be any bell wires?
   - Is there a twin lock DDC onboard or is the plan to decompress/treat the diver in the sat system? If so can the chamber be isolated?
   - Can the system support air and safely isolate chamber from the rest of the system, including treatment gas
   - Time in chamber will require an evacuation plan: can an air diver undergoing a therapeutic treatment get access to the SPHL?
   - Are there adequate on-deck divers to assist in the recovery operation? Team size should be based on 50msw depth and use of tools to remove cut/wires/umbilical
   - Are there approved umbilical length drawings to support diving through the moonpool?
6. Procedures should not state that someone locks out to clear wires etc. Without active heating this would be futile.
7. Is there training and drills for the use of the diver held transponder?
8. Ensure there is a watch in the bell (The tapping code requires, *release ballast in 30 minutes time).*
9. Critical actions such as cutting/ditching the wires and cutting the umbilical should be completed prior to the divers donning survival equipment. Critical actions should be completed as early as possible in the emergency, later on the bell occupants cannot be relied on to act rationally due to possible hypothermia

10. There will be no point closing the bell external door if the bell is on the seabed as there will be no further external pressure. Bell outer doors rely on rapid external pressure to seal them effectively. A stranded bell is on the seabed so pressure can't increase externally
11. Do procedures accurately describe the actions of the bellman? The swift action of the bellman is crucial in the survival of any diver locked out. There simply isn't time during a lost bell incident to start discussing the specific actions the divers should be carrying out in the bell. The first 2-3 hours of the emergency are critical and the actions and condition of the divers during this period will influence their chances of long term survival. The company should have identified all the hazards and risks in every job they do, including emergency tasks and have them procedurised so that those procedures guide employees to a safe solution.
    - Procedures should state valve actions
    - Wet clothing, suits, boots and none essential loose items should be ditched. The bellman's suit should be kept to insulate the door.
    - Use bailouts to flush the bell and then ditch.
    - The bell occupants should try to urinate prior to closing the door
    - Analyse the bell atmosphere for CO_2 readings so breakthrough of CO_2 absorbent is known so a safe atmosphere can be achieved for any recharge or if oral nasals have to be removed
    - Status of any electrical item i.e. lights, TWC, bell scrubber, analysers etc. There should be a schematic and assessment of power drawdown available.
12. Bell internal valves:
    - Is there an IMCA D77 priority valve checklist immediately available to the bellman and dive supervisor?
    - Does the IMCA D77 priority valve checklist consider a supervisor controlled blowdown?
    - Is there a valve status checklist for the bellman to ensure that life support is available once the bell emergency umbilical is fitted?
13. It is common in procedures to state that the bell is to be pressurised 5msw over bottom depth to obtain a seal.
    - If the bell is on the seabed there will be no requirement to pressurise a bell 5msw over bottom depth that has a castellated door
    - A non-castellated door will need a to be over pressured to obtain a seal, however, pressurising 5msw over bottom will not be sufficient to maintain a seal throughout the emergency. As the bell atmosphere cools the pressure will decrease and the seal will be lost.
14. If a buoyant ascent is planned:
    - Are there robust procedures to ensure the bell can be recovered from the surface quickly and placed on deck?
    - Is it possible to re-mate the bell back on the system?
    - Do procedures state that all loose equipment is ditched, as loose equipment in the bell presents a significant hazards to the bell occupants?
    - IMCA no longer require a seat for each diver, only the bellman. IMCA requires a means of restraining each bell occupant. How is this achieved in a buoyant bell with (potentially) only one seat?
15. Is there suitable tooling onboard to allow all wires / umbilical to be cut and cleared from the bell?
16. A risk assessment might indicate that a twin bell vessel does not require buoyant bells as the primary rescue should be by the other bell.
17. Are there procedures for a TWT, considering rescue bell size?

18. It is crucial to ensure all wires are clear and the umbilical is cut close to the bell otherwise:
    - The bell may not float upright due to the weight of wires and umbilical
    - The bell might invert midwater due to weight of wires or because the wires are fouled
    - The bell should be separated from the guide weight
19. Although IMO and IMCA require a standard layout bell external manifold, there is no mandatory requirement for contractors to carry an emergency umbilical.
20. There will need to be a procedure of how to get the divers out of the bell when on surface. Considerably easier with a side mating bell. Are there adequate restraining devices to prevent incapacitated divers blocking a bottom door?
21. Are there suitable first aid procedure for treating hypothermic divers? Any procedures should be approved by the company hyperbaric doctor. If the stranded divers are suffering from hypothermia, they should be re-warmed gradually. Connecting them directly to the hot water supply could lead to collapse. Surviving bell occupants require assessment prior to being removed from the bell as there is a potential that movement to the deck chamber will precipitate ventricular fibrillation.

6.5.1 Lost Bell Survival Competency

IMCA recognises the severity of a lost bell incident and gives some excellent advice in IMCA D17 Lost Bell Survival Trainers Guide, in particular the recognition that for equipment to be effective, it has to be used optimally and that divers are trained to take the most appropriate actions to assist in their own survival.

IMCA C003 Guidance on Competence Assurance and Assessment-Diving Division requires Bell Divers, Bell Diving Supervisors and Diving Superintendents to know the company lost bell emergency procedures. The competency standard requires evidence of 'Ability' and 'Demonstration', assessed by an approved Company Assessor.

- It is unlikely that the diving supervisor has the 'ability' to manage a lost bell situation based solely on company procedures
- It is unlikely that the approved assessor is competent in lost bell survival to adequately assess the diving supervisor and diving superintendents 'Demonstration' requirement.
- C003 requires the Diving Superintendent to have 'knowledge' of lost bell operations and emergency procedures but there is no requirement for 'Ability' to manage it nor 'Demonstrate' it. Therefore, the Diving Superintendent needs to be an in-date IMCA CPD supervisor, assessed and approved to IMCA C003 D02 and issued a LOA.
- Company Roles and Responsibilities should clearly state who is in charge and responsible during a lost bell. The Superintendent might not be competent to C003 and there is no competency standard for an OCM, (the most senior company representative onboard).
- IMCA to consider adding module on Lost Bell Survival and Lost Bell Recovery to Trainee Closed Bell Supervisors course

7.0 Control Measures Summary & Potential Actions to Improve Survival Time

It is expected that offshore worksites will have in place operating procedures and practices implemented as a result of a formal risk assessment process.

An appropriate risk assessment process is required for all stages of a diving project and should include all bell emergencies. The relevant offshore personnel must be included at all stages of the risk assessment process.

Item	Potential Hazard	Control Measure Summary & Potential Action
1.0 Loss of thermal balance		
1.1	Divers locked out have no active (hot water supply) or passive heating	◆ Once the bell main umbilical is severed and surface life support has ceased the bell is 'lost'. The control measures to prevent a lost bell are many and are intrinsic to all closed bell diving operations. If divers are in the water, their active heating is lost. Divers should wear appropriate hot water suit under garment such as a one-piece neoprene wetsuit. ◆ Consideration will need to be given to thickness of neoprene to give appropriate thermal balance at depth ◆ Consider electrically heated under suits
1.2	Bellman will be out of thermal balance due to bell flooding on descent and unable to rewarm as there is no active or passive heating	◆ Once the bell main umbilical is severed and surface life support has ceased the bell is 'lost'. The control measures to prevent a lost bell are many and are intrinsic to all closed bell diving operations. The bell is heated by a bell heater, the heat source is the divers hot water supply, once the umbilical is severed the active heating is stopped. The bell will descend and flood, instantly chilling the bell atmosphere and partially submerging the bellman who will become instantly chilled. The bellman may have to release the 1st stage release within a partially flooded bell. ◆ The bellman should wear appropriate hot water suit under garment such as a one-piece neoprene wetsuit. Consideration will need to be given to thickness of neoprene to give appropriate thermal balance at depth/pressure.
1.3	Bellman out of thermal balance due to bell flooding because of severed umbilical.	◆ Ensure that there is an up to date 'IMCA D77' Checklist of Valves to be Operated in an Emergency (Posted in the bell in a prominent place and a copy in dive control) ◆ Ensure that the priority valves are easy to identify, illuminated by battery and have glow in the dark handles. ◆ Consideration needs to be given to bells that have a single hose supervisor controlled bell blow-down and vent ◆ Ensure that there is a valve checklist for when/if the emergency umbilical is attached

1.4	Time taken for bellman to release 1st stage drop weights to allow diver access to the bell (Divers will have no active heating)	◆ RA type of bell required at design stage; floater or sinker? ◆ Hierarchy of control-remove the need to release and use non-buoyant bell ◆ RA type of stage beneath bell; permanently attached or independent? ◆ 1st and 2nd stage release to be clearly identified within the bell ◆ Any tools needed for the 1st stage release should be readily available and included in bell checks ◆ Divers to operate the release of 1st and 2nd stage release during maintenance periods ◆ Video of 1st and 2nd stage release to be available as part of divers familiarisation and competency matrix ◆ 1st stage release procedure posted in bell (above the flood-up zone) ◆ When bell umbilical requires 'cut back' have divers use hydraulic cutter in bell and get video of umbilical being cut for familiarisation and competency
1.5	Cooling of bell to ambient water temperature *	◆ Consider revisiting active heating systems mentioned in IMCA D59 Diver Emergency Heating Report (1984). Emergency active heating systems and equipment has advanced since IMCA D59 was first issued (as AODC 26 in 1985) ◆ Note: IMCA CPD & IMCA D77 states "Active heating systems , coupled with passive individual insulation systems have been found to be necessary when diving to depths excess of 180msw"
1.6	Wet CO_2 absorbent in SP2 resulting in ineffective thermal regenerator	◆ See item 2.1 & 2.4
1.7	Wet survival suit/bag in SP1resulting in ineffective passive thermal protection	◆ SP1 (survival suits) need to be stored above flood up zone ◆ Explore active heating solutions (See item 1.5)
1.8	Ill-fitting SP1 survival suit	◆ Survival suit is PPE and should fit the wearer/user
1.9	Untrained in use of SP1 Survival suit	◆ Survival suit is PPE and the user should be trained and competent in its use ◆ Donning of suit within bell should be drilled ◆ Training in where 3 divers are positioned in the bell during emergency is important
1.10	Consumption of emergency rations	◆ Emergency rations are provided to give energy and heat production. To eat the rations the diver must removal the oral nasal thereby exposing themselves to bell atmosphere; cold gas and potentially higher CO_2 levels. ◆ RA type of rations with emphasis on ease of eating and calorific value

* IMCA requires thermal trials and a 'cooling curve'(IMCA D02/06). IMCA CPD (Unit 2, 2022 BDS Module 10-Lost Bell Recovery) states that a cooling curve is required for the bell for lost bell survival, although the document pertains to hyperbaric escape systems.

1.11	Type of emergency rations	• RA type of rations with emphasis on ease of eating and calorific value and consider potential for allergies, choking hazard (peanuts, boiled sweets & gum etc.) and practicality, for example not having drinks that require mixing.  • Consider use of high energy drink c/w straw system in face mask • Consider ease of opening packets (Hypothermic diver) • Consider bespoke ration pack for each diver based on BMR • Consider competent person approval of ration packs (DMA)

1.12	Ineffective items in SP2	• Ensure that any towel supplied in the survival pack is absorbent. New towels often are supplied unwashed or with conditioner that inhibits absorption
		• Consider urinary sheath c/w large urine bags with absorbent gel
		• Contractors should check their lost bell procedures and ensure that there are no discrepancies with the manufacturers recommendations. Manufacturers might recommend colour indicating CO_2 absorbent, which is not commonly used offshore in divers gas streams
		• Suitability of rations see Item 1.11
		• Water and composition of rations should as a minimum comply with IMCA D61 Item 11
		• IMCA CPD recommends the following:
		  ◦ Dry underwear (wool)
		  ◦ A light, swim/transfer suit with hot water connection

1.13	Missing or non-compulsory insulating equipment	• IMCA CPD Module BDS17 recommends that hammocks and insulation (inflatable mattress) is provided. • Risk assess the use/non-use of these items . Include the insulating properties and the hammock providing easier access by rescue divers

2.0 Control of carbon dioxide level and absorbent		
2.1	Wet CO_2 absorbent (out with manufacturers parameters) rendering the CO_2 absorbent useless	◆ SP2s should to be stored above the designed flood up zone and potential flood up zone when bell descends to seabed. ◆ SP2 should be stored in a 100% water/moister resistant bag. The bag should have a relief valve to allow gas to escape during decompression. ◆ Reserve CO_2 absorbent should to be stored above the designed flood up zone and potential flood up zone when bell descends to seabed. Stored in suitable container
2.2	Incorrect grade of CO_2 absorbent for intended use	◆ Reserve CO_2 absorbent should be correct grade for intended purpose
2.3	Out of date CO_2 absorbent (Manufactures state out of date CO_2 absorbent should not be used)	◆ All reserve and CO_2 absorbent packs should be marked with expiry date
2.4	Inadequate quantity of CO_2 absorbent for intended purpose.	◆ Procedures and RA should identify the quantity of reserve CO_2 absorbent to fully recharge each personal scrubber. ◆ Allowance should be made for spillage ◆ Personal scrubbers are PPE and should be RA for suitability. There are personal scrubbers available that are pre-charged with adequate CO_2 absorbent for 24 hour endurance. Such as Thermo Save
2.5	Unsuitable container/procedure for storage of reserve CO_2 absorbent. 	◆ Any reserve CO_2 absorbent should be kept in a suitable container to prevent container being pressurised during blowdown and forming CO_2 absorbent in to a solid mass, rendering it unusable. ◆ RA and identify suitable container for storage of any reserve CO_2 absorbent ◆ Container should prevent moister/water ingress ◆ Any sealed container or procedures should allow for the escape of gas / pressure on decompression ◆ Container should consider physical condition of end user-potentially hypothermic
2.6	Use of Colorimetric tubes is reactive analysis. Diver will lose heat taking readings and as emergency is ongoing will be hypothermic.	◆ Consider battery powered real time CO_2 analyser.
2.7	Use of cold CO_2 absorbent. Cold absorbent may only last 20% of advertised time	◆ Procedures should identify all absorbents and ensure they are used in accordance with manufactures instructions or make allowances for sub-optimal endurance

2.8	Recharging of personal scrubber with corrosive substance within a confined space.	◆ When using CO_2 absorbent during normal operations the SDS PPE and control measures are followed, this is usually use of LEV, lower arm protection, safety goggles and strict disposal procedures. These controls are not planned for within a lost bell. ◆ Use hierarchy of control and remove the need to recharge the personal scrubbers by using scrubbers that have the required duration ◆ Consider redesign to include cartridge type refill ◆ Personnel must be trained in the use of each item of RPE. ◆ A particular type of rebreather is supplied from service company with electrical tape around the lower and upper seal. This would indicate that this design of RPE is inadequately designed. Contractor should ensure that RPE is fit for purpose. ◆ Supply appropriate PPE ◆ Consider used CO_2 absorbent disposal (Spilled granules may prevent a seal) 
2.9	Non-identified Risk Phrase substance. CO_2 scrubbers content not identified. 	◆ Ensure all containers of hazardous substances are identified (CHIPS/CoSHH)  
2.10	Poor oral nasal face fit with potential of ineffective seal allowing CO_2 from bell atmosphere and cold gas from bell atmosphere (by-passing thermal regenerator) 	◆ Consider the use of full facemask .A full face mask would also add insulation to the front of the head, which is the only part of the body left exposed once suited up. ◆ A full face mask would allow for a better seal and it would incorporate two seals. An oral nasal seal and face seal. The better seal would ensure all breathing stream is via warm gas through scrubber not cold bell gas with CO_2 ◆ The full face mask would be fitted with a spider strap which is more comfortable than current strap which has a tendency to go stiff and therefore uncomfortable. ◆ If oral nasal is used ensure ergonomically designed and face fitted in accordance with national regulations (or best working practice) ◆ RA consequences of facial hair and seal ◆ Personnel must be trained in the use of each item of RPE ◆ Full face masks are available with drinking ports 

3.0 Lack of oxygen partial pressure (ppO2) and volume		
3.1	Potential that external oxygen cylinder damaged or removed during impact with asset	◆ Consider where the O_2 cylinder and buffer tank is mounted externally. Ensure that neither are mounted to the working side of the bell, i.e. the most likely side that would be 'driven-on' to a subsea asset.(Same applies to HeO_2 OBG)
3.2	Potential that external oxygen pipework damaged or removed during impact with asset	◆ Consider where the O_2 pipework is and ensure it too isn't adversely exposed in the event of a drive-on to an asset
3.3	Potential that bell umbilical will damage external critical pipework	◆ If the bell drops or is driven-in to an asset the umbilical might be ripped off and in the process damage O2 pipework/cylinders. Consider the route of all hoses in this event
4.0 Lost bell location & communication devices		
4.1	Transponder and/or battery may have been damaged or removed during impact with asset	◆ Consider where the transponder is mounted externally. Ensure that it isn't mounted to the working side of the bell, i.e. the most likely side that would be 'driven-on' to a subsea asset.
4.2	Through Water Communications (TWC) damaged or removed during impact with asset	◆ Consider where the transponder is mounted externally. Ensure that it isn't mounted to the working side of the bell, i.e. the most likely side that would be 'driven-on' to a subsea asset.
4.3	Difficult for bellman to communicate via TWC whist wearing oral nasal or/and bellman removing oral nasal to communicate and thereby reduce core temperature	◆ A full face mask could incorporate a built in microphone and communication cable that plugs directly in to the through water communications. This would allow direct comms to the surface (and other divers) without having to remove the mask as in the case of the oral nasal currently in use.

5.0 Lost bell procedures		
5.1	Ineffective procedures for lost bell survival	• Develop procedures for all stages and all locations of a lost bell. The diving supervisor, onshore support and bell occupants need to know exactly what to do and when. There is not time to make it up on the spot.(IMCA CPD/IMCA D77 requires this) • There should already be 'critical valve' procedures. Are there procedures for opening valves when the emergency umbilical is attached? (If applicable)
5.2	Bell emergency umbilical not a mandatory requirement	• An emergency umbilical should be a mandatory requirement for all saturation diving DSVs.
5.3	Unsuitable nor sufficient lost bell risk assessment	• There should be a suitable and sufficient lost bell risk assessment for each stage of the lost bell, including causes of a lost bell.
6.0 Bell Selection		
6.1	Floater or Sinker? Both have advantages/disadvantages in a lost bell situation	• Robust risk assessment when ordering a new vessel with dive system • Robust risk assessment for operational bell (to isolate ballast release in floater) • Robust risk assessment for region of operations and depth of seabed • Consideration needs to be given to buoyant ascents. Risk assess if it is safe to carry out a buoyant ascent next to a structure.
6.2	Side door or bottom door mating bell?	• A side mating bell allows better access to hypothermic divers if bell is re-mated • Robust risk assessment for type of bell entry system
7.0 IMCA Tapping Code		
7.1	Consider that divers should have donned their survival suits early in the lost bell. With no TWC they will not know when/if an emergency umbilical has been installed (By surface diver or WROV)	• Add to the IMCA Tapping code: 1. Tapping code for opening of internal valves (as per checklist) to receive services from the emergency umbilical 2. Tapping code for closing of internal valves (as per checklist) so emergency umbilical can be removed

8.0 References

Author	Title
HSE RR516	Estimation of Diver Survival Time in a Lost Bell – OTH96516
K. Williams	A Review of Equipment and Procedures for the 'Lost Bell' Situation
HSE	RR814 Final report on the project to verify if co2 is likely to concentrate in the lower region of a diving bell
HSG 53	Respiratory protective equipment at work
L.H.Somers PhD	Thermal Stress and the Diver
SSS	Bell Survival Kit Information Sheet
HSC	Diving at Work Regulations 1997
Seaforth Kinergetics	Stranded Bell Diver Survival System
Divex	Kinergenics Bell Survival Kit
Divex	Divex Bell Survival Kit
DMAC 08	Thermal Stress in Relation to Diving
DMAC 20	Duration of Bell Lockouts
IMCA D17	Lost Bell Survival
IMCA D77	Guidance on Prevention and Mitigation of Lost Bell Emergencies
IMCA D59	Diver Emergency Heating Report
NMRI 95-39	Analysis of Volatile Contaminants in US Navy Fleet Soda Lime
HSC	COSHH Brief Guide
HSC	Personal Protective Equipment Regulations 1992
Health, Safety Practitioner	Respiratory Protective Equipment
EH75/2	Occupational Exposure Limits in Hyperbaric Conditions
IMCA	Emergency Bell Tapping Code
IMCA	DESIGN D24
	Professional Divers Handbook
HSE RR1052	The effect of wearer stubble on the protection given by Filtering Facepieces Class 3 (FFP3) and Half Masks
Anita Bean	Fitness on a Plate
	Dieticians Handbook
NMRI	The Effects of Hypoxia & Cold at Rest on Human Thermoregulation
F. Ralley, E,Wyands	The effects of shivering on oxygen consumption and carbon dioxide production in rewarming patients from hypothermic cardiopulmonary bypass
IOGP 478	Performance of saturation diving emergency hyperbaric evacuation and recovery
IOGP 468	Diving System Assurance
Web Pages;	molecularproducts.co.uk
	divex.co.uk
	Divernet.com
Photographs;	Photography No1-Internet, No4-Divex
	All other photographs-Author

Appendix 1 Indicating CO_2 Absorbent

Some contractors have withdrawn the use of indication CO_2 absorbent. The 'ban' would have been based on the US Navy's 51-page report, best summed up by the Commanding officer of the Naval Medical Research Institute;

Naval Medical Research Institute
8901 Wisconsin Avenue
Bethesda, MD 20889-5607

NMRI 95-39 June 1995

ANALYSIS OF VOLATILE CONTAMINANTS IN U. S. NAVY FLEET SODA LIME

Contamination was suspected of U.S. Navy Fleet soda lime (High Performance Sodasorb®) when an ammonia-like odor was reported during its use in August 1992. This material contained indicator dye and was used for carbon dioxide absorption during diving. This incident had a major impact on the U.S Navy diving program when the Navy temporarily banned use of Sodasorb® and authorized Sofnolime® as an interim replacement. The Naval Medical Research Institute was immediately assigned to investigate. Testing involved sampling from the headspace (gas space) inside closed buckets and from an apparatus simulating conditions during operational diving. Volatile organic compounds were analyzed by gas chromatography and mass spectrometry; ammonia and amines were measured by infrared spectroscopy. Significant amounts of ammonia (up to 30 ppm), ethyl and diethyl amines (up to several ppm), and various aliphatic hydrocarbons (up to 60 ppm) were detected during testing of both Sodasorb® and Sofnolime®. Contaminants were slowly removed by gas flow and did not return. The source(s) of the ammonia and amines are unknown, although they may result from the breakdown of the indicator dye. Hydrocarbon contamination appeared to result from the materials of which the bucket is constructed. Based on these findings, the U.S. Navy is expected to phase in non-indicating soda lime that will be required to meet defined contaminant limits. This report presents: 1) in-depth description of procedures used during the investigation for contaminant analysis and 2) detailed results from all samples tested.

Consideration should be given to using indicating CO2 absorbent in personal scrubbers.

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Appendix 2 Lost Bell Procedures: Bellman Internal Checks

Lost bell procedures will be vessel—and site-specific. During audits, it is often found that there is a lost bell procedure. However, the procedure does not state what action the divers in the stricken bell are to carry out for their survival.

Example:

Bellman's Lost Bell Checklist (From obtaining a seal)

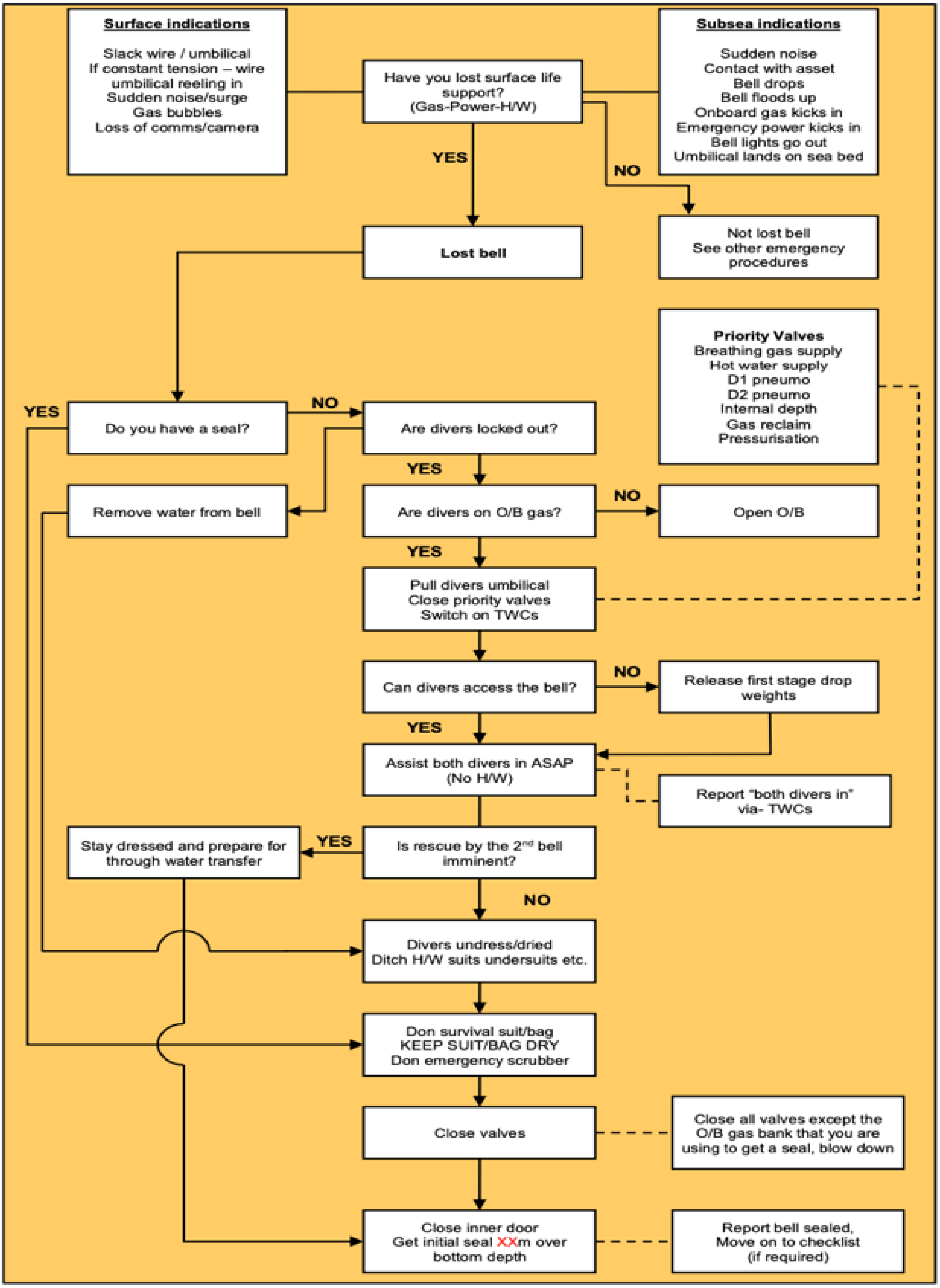
Action

1. Increase XXm over the bottom (XXm to be decided and depending on the type of bottom door)
2. Ensure TWC is on and left on
3. Increase PPO_2 to 900mb
4. Ditch equipment. Drain bailout into bell before ditching. (Keep suits to insulate top door & TWT)
5. If communications cannot be established Hydraulically:
   a) Cut bell Umbilical
   b) Release Guidewires
   c) Release Main Wire Pin
6. Bilge out
7. Close all valves except (Follow the priority valve checklist)
   a) O/B Gas Bank A
   b) O/B Gas Bank B
   c) O/B Gas Bank C
   d) Emergency Internal Depth
   e) Bottom Door Equalisation: A
8. Dry Bell walls
9. Urinate before closing the door
10. Ensure availability of;
    a) CO_2 tubes & pump
    b) Torch
    c) Tapping code
    d) Reserve CO_2 absorbent
    e) Have visual of the PPO_2 meter
    f) Watch is available
    g) Polythene bag for used CO2 absorbent
11. Check divers are comfortable
12. Get undressed & dried off
13. Insulate door with H/W suit and Undersuit (ditch all diving equipment)
14. Dress in a survival Suit / Bag
15. Inform dive control of the status
16. Don personal scrubber
17. Switch off the bell scrubber
18. Leave one light on

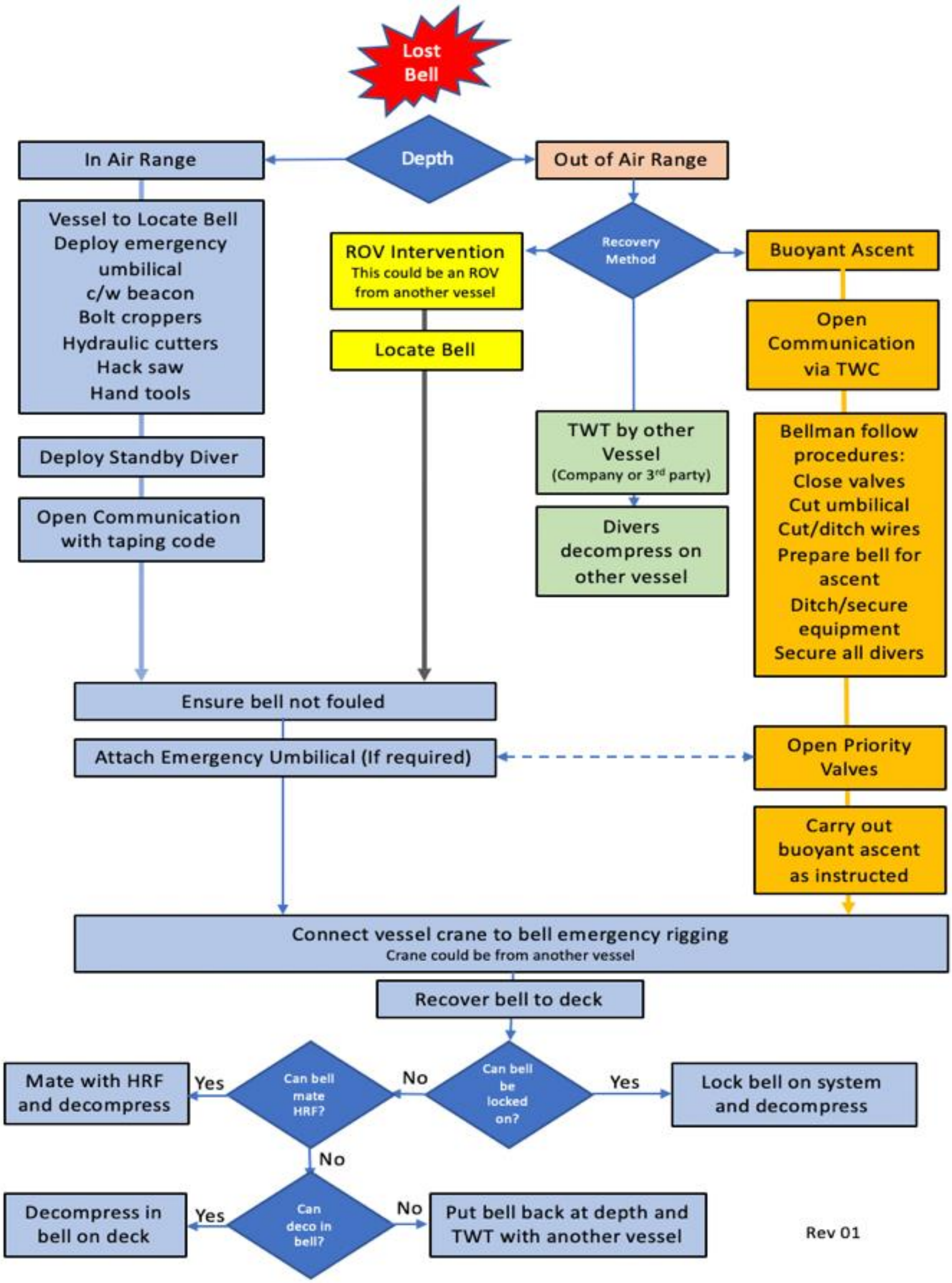
INFORMATION
Personal Scrubbers should last approximately 10 hours. But could be substantially less. Monitor CO_2 and O_2 Levels. Monitor internal gauge (Internal depth will decrease as bell cools) Switch on bell scrubber if CO_2 levels rise and check oral nasals are correctly fitted. Switch on bell scrubber prior to CO2 absorbent change and switch off afterwards. Work as a team to change out scrubbers Put used CO2 absorbent in bags Keep TWC on. Eat ½ a chocolate bar every hour Keep hydrated

Appendix 3 Lost Bell Procedures: Lost Bell to Obtaining a Seal

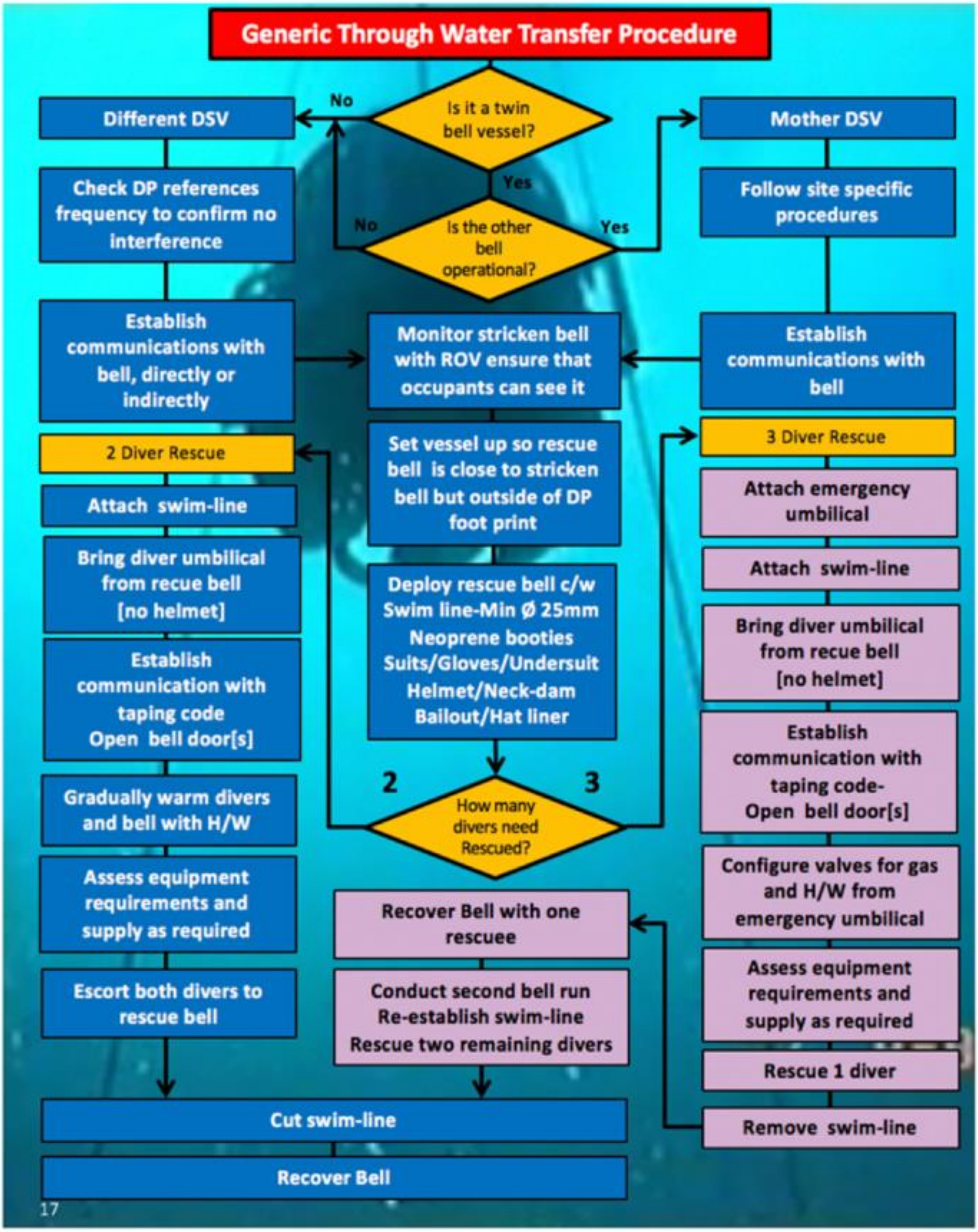
The recovery of a lost bell will be vessel and site-specific. Consider the following:



Appendix 4 Lost Bell Procedures: Lost Bell Recovery Options-Single Bell Vessel

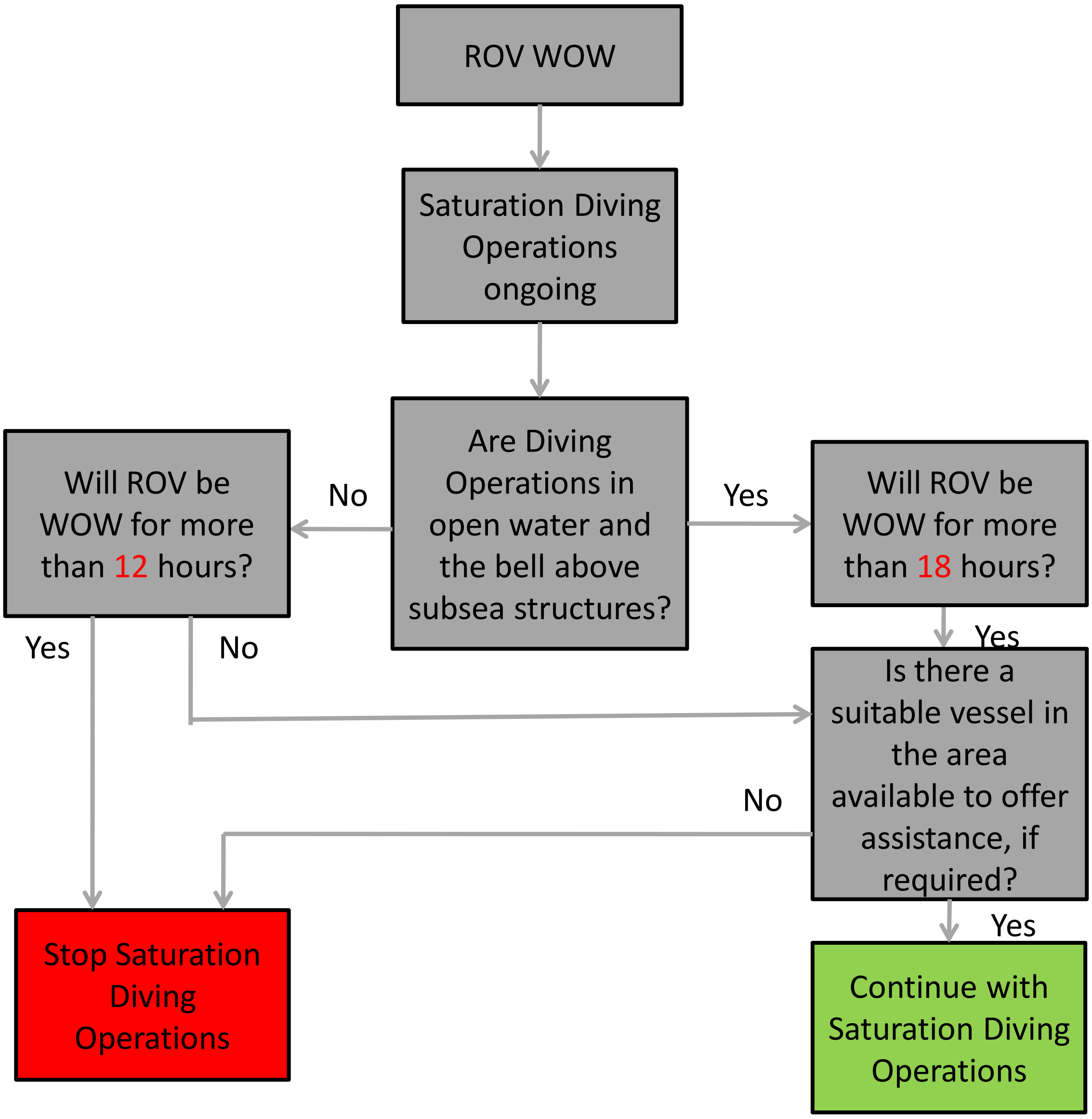


Appendix 5 Lost/ Stricken Bell: TWT Generic Procedures



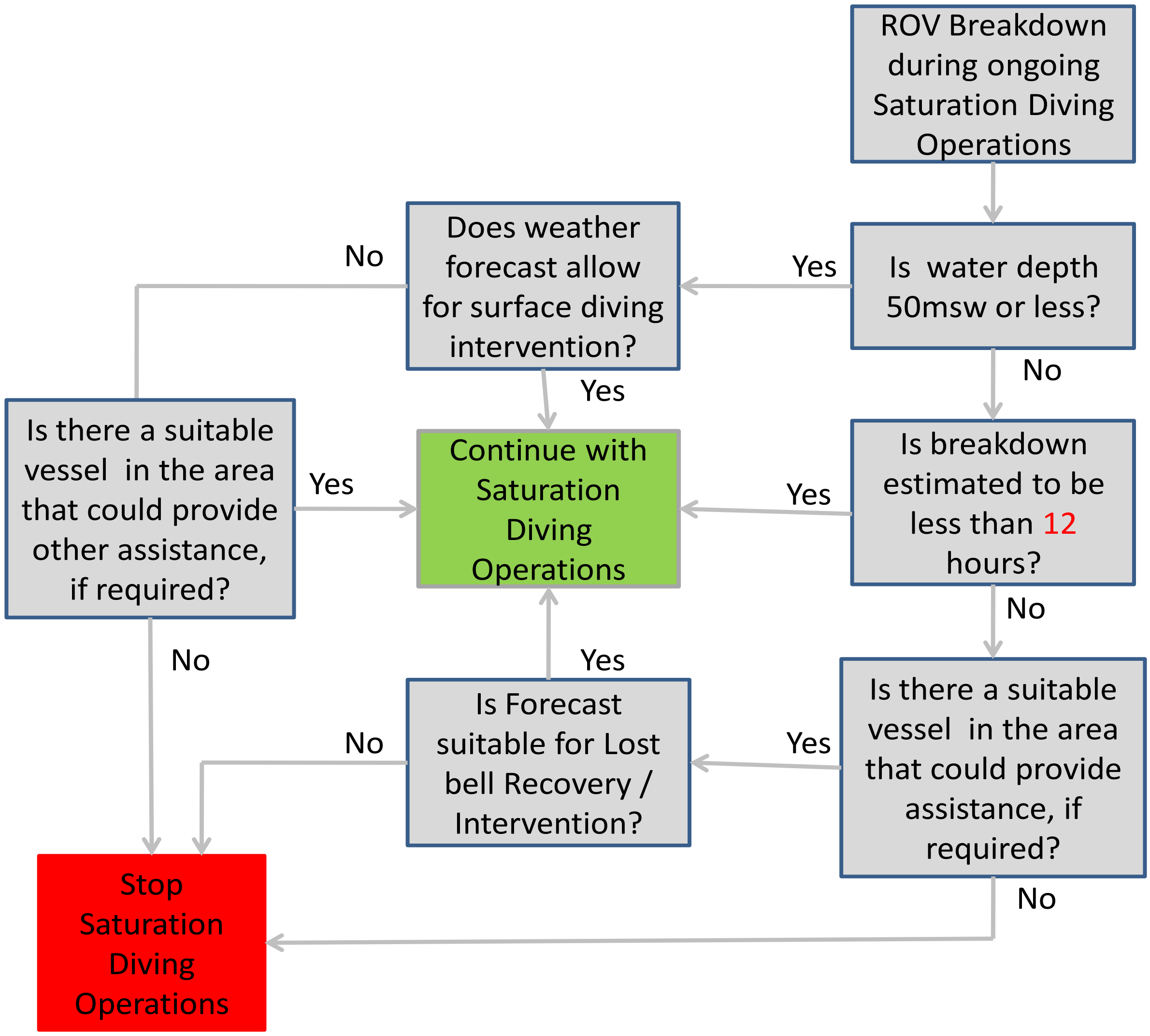
Appendix 6 ROV WOW During Diving Operations (ROV Intervention)

ROV Waiting on Weather during ongoing Saturation Diving Operations



Appendix 7 ROV Breakdown During Diving Operations (ROV Intervention)

ROV Breakdown /Maintenance during Continuing Diving Operations



Appendix 8 Newspaper Articles

Diving-bell was 'irretrievable'

FINANCIAL TIMES REPORTER

A DIVING company director yesterday admitted there was no way a stricken diving-bell on the bottom of the North Sea in which two U.S. divers died could have been retrieved.

The admission from Mr. Brian Masterson, of Infabaco, came in the third day of a fatal accident inquiry at Aberdeen Sheriff Court.

The inquiry was told the main lift-wire to the bell had broken, the umbilical lifeline cable had parted, and that there was no room between the bell and the seabed for the divers to exit.

Drop weights on the bell's outside, which when released would allow the bell to rise to the surface, were lashed on. If the bell was on the seabed the weight could not have been released.

Mr. Malcolm MacNeill, Procurator Fiscal: "It was a diving system in which the main lift-wire had broken and there was no means in the system for bringing the bell back up again? Mr. Masterson: "On the day of the accident, that's very true."

Infabco, of Greenwell Road, Aberdeen, signed a contract for provision of divers with a company incorporated only 24 hours earlier.

Infabco and Offshore Co-ordinators of St. Helier, Jersey, were named as the divers' employers in the Procurator Fiscal's inquiry application.

Mr. Masterson, a chartered engineer, said the relationship between Infabco and the Jersey-based company was to make certain that when a contract was awarded to Infabco the company had sufficient personnel with correct qualifications to execute it.

Sheriff Douglas Risk: "Are you satisfied that Offshore Co-ordinators had sufficient expertise and organisation to satisfy your needs?" Mr. Masterson: "From recommendations made to me, yes."

Sheriff Risk: "Would it surprise you to know that the contract was signed the day after the company was incorporated?" Mr. Masterson: "No, I would not be surprised."

Sheriff Risk: "They built up their expertise in 24 hours?" Mr. Masterson: "Yes, quite possibly, in the same way as we did."

The inquiry is expected to last until Monday.

DAILY EXPRESS Saturday November 14 1981

Death case diving firm is accused

A DIVING company was yesterday accused of being more concerned "with speed than safety" following the death of two divers trapped in their crippled bell.

Sheriff Douglas Risk, of Aberdeen, criticised the Infabco Diving Company for running risks with the lives of their North Sea divers.

He accused the company's director, Mr Brian Masterson, of giving evidence at a fatal accident inquiry last May that was "obviously false."

One of the contributing factors to the deaths of the two divers was the inability of the rescuers to recover the bell until 17 hours later, the sheriff said.

He also referred to "friction" between the rescuers—an "unfortunate distraction" from the main business of recovering the bell.

Stranded

Yesterday's judgment follows an inquiry into the deaths of divers Richard Walker, 22, of California, and Victor "Skip" Guiel, 28, of Massachusetts.

They died of hypothermia trapped in their stranded bell which had become separated from their mother ship Wildrake in the Thistle oilfield off Shetland in August, 179.

The Infabco Company, of Aberdeen, was cleared of four charges of breaking diving regulations at a trial last December after the Crown failed to prove it was the employer of the two men.

Sheriff Risk found yesterday that Infabco had operational control of the divers and was the diving contractor.

A spokesman for Infabco said: "Infabco's policy has always been and remains that the safety of its divers is of paramount importance."

Love at

Willie s

jail cam

TWO military camp temporary jails closed by Home Sec William Whitelaw, a drop in the n prisoners.

Rollestone Camp bury Plain and B Camp, Nottinghams later this month, mons was told yest

The number of England and Wal 45,500 in July to start of Novem

Diver in stricken bell was alive, court told

FINANCIAL TIMES REPORTER

A DEEP-SEA rescue diver found a diver still alive in a stricken diving bell 500 feet below the surface of the North Sea, Aberdeen Sheriff Court was told yesterday.

Diver Edmond Frank, part of a two-man search team, found the bell at his second attempt. Its lift wire had broken near the Thistle A platform site off Shetland.

Mr. Frank said it was hard up against a single anchor leg mooring, upright on the seabed but slightly tilted with its emergency light on. When asked how he knew the diver inside was alive, he replied: "I saw him drawing for breath."

Infabco Diving Services of Hunters Green, Darlington, denies various charges relating to breaches of diving regulations after the deaths of two American divers in August last year.

The company denies failing to provide equipment in good working order, having a means of recovery not of sound construction, failing to secure permission from the Energy Secretary for divers to work below 125 metres and for the use of saturation diving techniques, and employing one of the divers without the necessary medical certificate.

Earlier, Mr. John Brook, diving deck foreman aboard the mother ship, Wildrake, told of attempts to lift the bell by its umbilical cable, which carried heat, power and communications, as well as by a secondary lifting rope.

The umbilical cable had 17 cables inside it taped together, but the tapes split and the internal cables were flattened as they became jammed against the inside of the wheel on the winch.

Then the wheel itself became jammed and the crew could not lower or raise the bell. A rope was attached to take the strain, but it "chewed" into the umbilical itself. The umbilical was finally freed, but a further attempt to use it to lift the bell was unsuccessful.

Mr. Timothy Newson, a diver on the Wildrake, said the umbilical was not strong enough to lift the bell. It was the secondary means of recovery, and the Norwegian equivalent of the Energy Department had said it was suitable.

The case continues.

A winchman aboard a Royal Hong Kong Auxiliary Air Force helicopter inspects a life raft for survivors of the Singaporean oil exploration barge which sank in the South China Sea, 105 kilometres from Hong Kong yesterday. Rescue operations continue for the crew members who are still missing. – Reuter

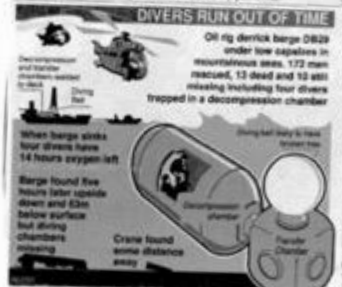
Survivors still reeling after Hong Kong typhoon ordeal

HONG KONG (AFP) – Many of the 172 people rescued from a capsized oil rig support vessel were still reeling here yesterday from their ordeal during Hong Kong's biggest rescue operation for 20 years.

[illegible]

Survivors say negligence caused oil barge disaster

HONG KONG (Reuter) – [illegible]



Sunken barge divers dead

HONG KONG (Agencies) – Hong Kong rescuers said yesterday hopes were fading in the search for 10 people still missing after a barge carrying 195 oil workers sank off south China.

[illegible]

LF NEWS

VOL. 13 NO. 305 FRIDAY AUGUST 16, 1991, SAFAR 6, 1412

A rescuer (left) and a survivor from the sunken Singaporean oil exploration barge are winched aboard a Royal Hong Kong Auxiliary Air Force helicopter yesterday. The barge carrying oil workers sank in heavy seas, southeast of Hong Kong. – Reuter

Divers trapped as barge sinks

HONG KONG (Agencies) – Diving experts searched feverishly in the early hours of today for a chamber with four divers aboard which was dragged to the bottom of the South China Sea when a barge capsized with nearly 200 oil workers aboard killing 13. With less than five hours to go before the divers' oxygen was expected to run out, rescuers had not found the chamber under the mountainous seas whipped up by Typhoon Fred 105 km southeast of Hong Kong, the barge's owners said.

The divers, believed to be three Britons and a New Zealander, are among eight still missing after the barge sank off the south China coast yesterday. [illegible]