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A COMPLETE SUBMARINE ESCAPE AND RESCUE ORGANISATION

Robyn Walker

Abstract

A complete submarine escape and rescue organisation should allow the survivors of a submarine accident to exit the submarine, be rescued and be provided with appropriate medical treatment for resultant injuries. Survivors may leave the submarine in two ways. The first involves an “escape” where the survivors leave the submarine through an escape hatch and make a buoyant ascent to the surface. This is limited to a depth of 180 m. Alternatively the survivors can be “rescued” by a rescue vehicle and be transported back to the surface where subsequent decompression can be undertaken. Rescue is required to cover the depths from 180 m down to the crush depth of the submarine.

Predicted medical conditions in submarine accident survivors include decompression illness, gas toxicities, near drowning, traumatic injury, thermal stress, sea sickness and psychological trauma.

The Royal Australian Navy (RAN) has a commitment to provide a full submarine escape and rescue organisation for the benefit of the submarine arm. This paper discusses the development, and trial, of a medical contingency plan to treat 55 survivors of a submarine accident. The integration of a full rescue capability into this plan will be presented.

Key Words

Accident, bell diving, decompression illness, emergency ascent, hyperbaric facilities, surface decompression, transport, treatment.

Introduction

If a submarine becomes disabled and sinks how the crew gets back to the surface is dependent on a number of factors. These include the internal pressure of the submarine, the internal atmosphere of the submarine, the weather conditions and the state of readiness of the rescue forces.

There are two methods of leaving a disabled submarine, escape and rescue. Escape is where the survivors leave the submarine through an escape hatch and make a buoyant ascent to the surface. Escape may be using the single escape tower (SET) hooded free ascent method or by rush, or compartment, escape. SET escape, which reduces the time each individual is under increased

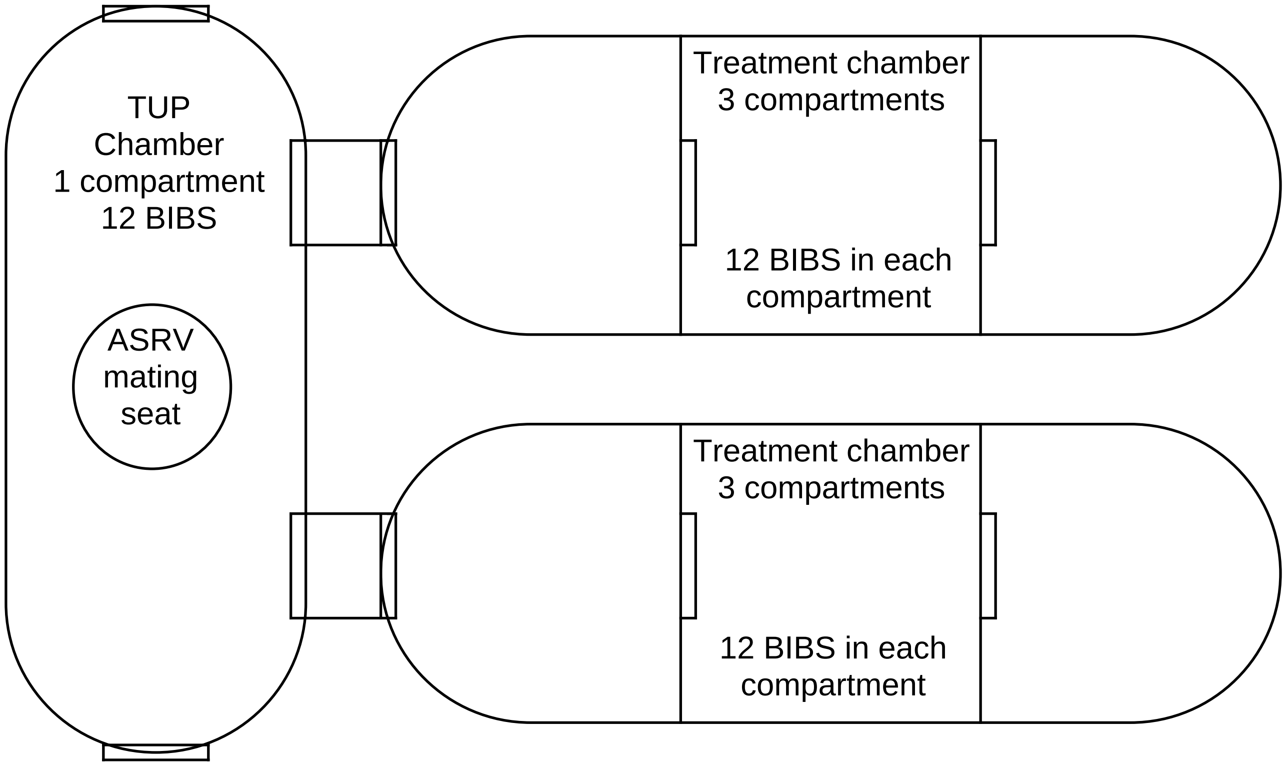

Figure 1. Schematic diagram of chamber complex.

pressure, is the preferred method having been carried out, as an exercise, successfully from a depth of 180 m. Rush escape is potentially survivable from depths of 60 m, but due to the length of time under pressure, because the compartment has to be flooded to outside pressure before the first member of the crew can escape, personnel can be expected to have a high casualty rate from anything but the shallowest of depths. Rescue involves the use of a submersible to transport the survivors to the surface where subsequent decompression can be undertaken. Rescue is limited primarily by the operating depth of the rescue vehicle.

Escape would be favoured if there were falling oxygen levels within the submarine or intolerable atmospheric constraints. Rescue would be the preferred option if there was no surface support for escapees or in the presence of severe surface conditions.

The RAN in association with the Australian Submarine Corporation has developed the Submarine Escape and Rescue Service (SERS) which comprises a rescue submersible, a chamber complex and an Extension of Life Support pod delivery system, a method of replenishing a disabled submarine. It consists of pressure proof cylinders small enough to pass through the escape tower. The pods contain oxygen candles, soda lime, food, water, medical supplies etc. They can be delivered to the submarine by a ROV (remotely operated vehicle) or a diver and "posted" through the escape tower to be received by the survivors.

The chamber complex (Fig 1) consists of a transfer under pressure (TUP) chamber to which the submersible mates. From there the survivors transfer to two treatment chambers each of which has three compartments. Each treatment compartment and the TUP chamber has 12 built-in breathing system (BIBS) outlets which can be used for oxygen or oxy-helium mixtures. As the two treatment chambers can accommodate 36 patients each the TUP chamber will not be used as a treatment chamber but as a method of access.

In the event of a submarine accident the SERS plus the SUBSUNK (missing submarine) medical supplies will be transported to the accident site by a ship of opportunity (any available suitable ship). Figure 2 is a diagram of the layout of the whole system on board such a vessel. While the majority of the hardware will be identical for both the escape and rescue scenarios the illnesses expected in survivors and the management of casualties will be different because of the different pressure exposures.

The Australian Submarine Rescue Vehicle (ASRV) is capable of carrying 8 people (Fig 3). One or two crew and 6-7 survivors. It is estimated that each leaving surface to leaving surface cycle will take up to three hours. This means it could take up to 10 cycles, or 30 hours, to rescue

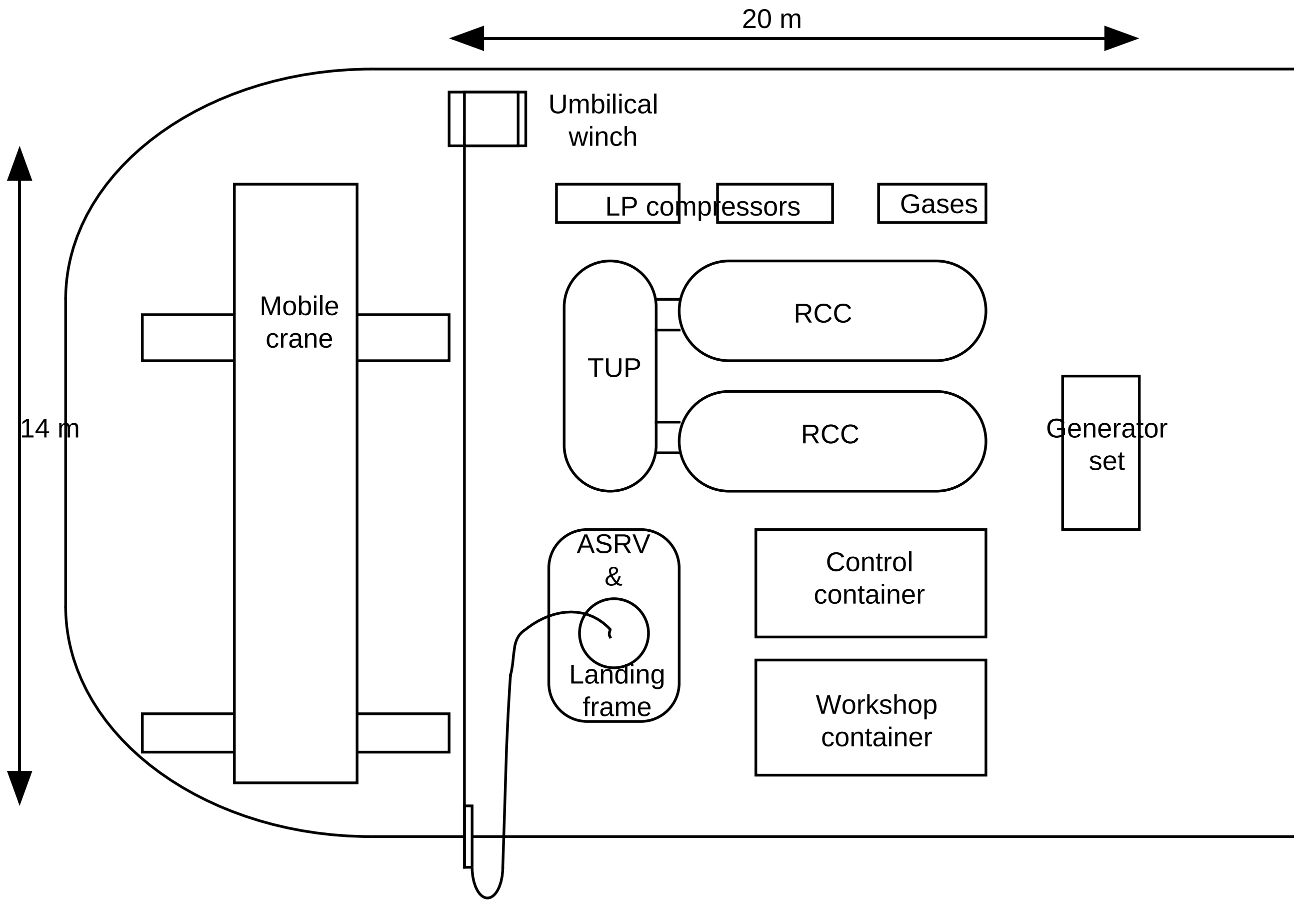

Figure 2. Diagram of deck layout on ship of opportunity.

the entire crew of 55. Over this 30 hour period it is possible the internal pressure within the disabled submarine could continue to rise. The ASRV is capable of performing transfer-under-pressure operations from a submarine with an internal pressure of up to 5 bar (40 m) and from depths down to the crush depth of the submarine.

SUBSUNK medical stores

The SUBSUNK medical stores have been packed in a manner designed for use in a “disorganised” emergency setting.

A dressings and triage kit contains large scissors for the removal of the Submarine Escape Immersion Suit (SEIS), thermometers, dressings and splints. A field medical report will be secured to each survivor at the triage point. Blankets and towels are packed in separate identifiable containers.

Items required for airway control, i.e. laryngoscopes, endotracheal tubes, cricothyrotomy kits, Guedel airways and suction catheters, are located in the red chest packed with the resuscitation medical officer’s kit. There are oxygen therapy sets available for 64 people. Oxygen is administered using a constant flow, non-rebreathing system with a reservoir bag. All the equipment required to administer oxygen, reducer, tubing, flow meter, non-rebreathing mask, bag etc., to 4 people is packed in a plastic bag. Sixteen of these bags are in the chests labelled oxygen sets. Oxygen is supplied on a pallet of G sized cylinders (48 litre water capacity) which are distributed as required.

There are four medical officer kits, containing drugs and diagnostic equipment, for use in independent locations. One of these is the Resuscitation MO’s kit containing airway management equipment. Another is the High Dependency kit. The other two are MOs’ kits for delayed management or low priority areas. The intravenous fluids have been organised into units; each unit containing a one litre bag of Hartmann’s solution, a giving set, an arm board and two cannulae. Tourniquets, sticking plaster (micropore) and skin sterilising swabs (alcowipes) are in the medical officers kits.

A separate surgical kit contains surgical supplies required for suturing and items required for the insertion of a chest drain. A trocar, Heimlich valve and sterile kit are located in the container labelled “chest drainage kit”. Urinary catheterisation trays containing all required items come in individual prepacked sterile trays. All medical items are packed individually so can be distributed to the areas where they are needed.

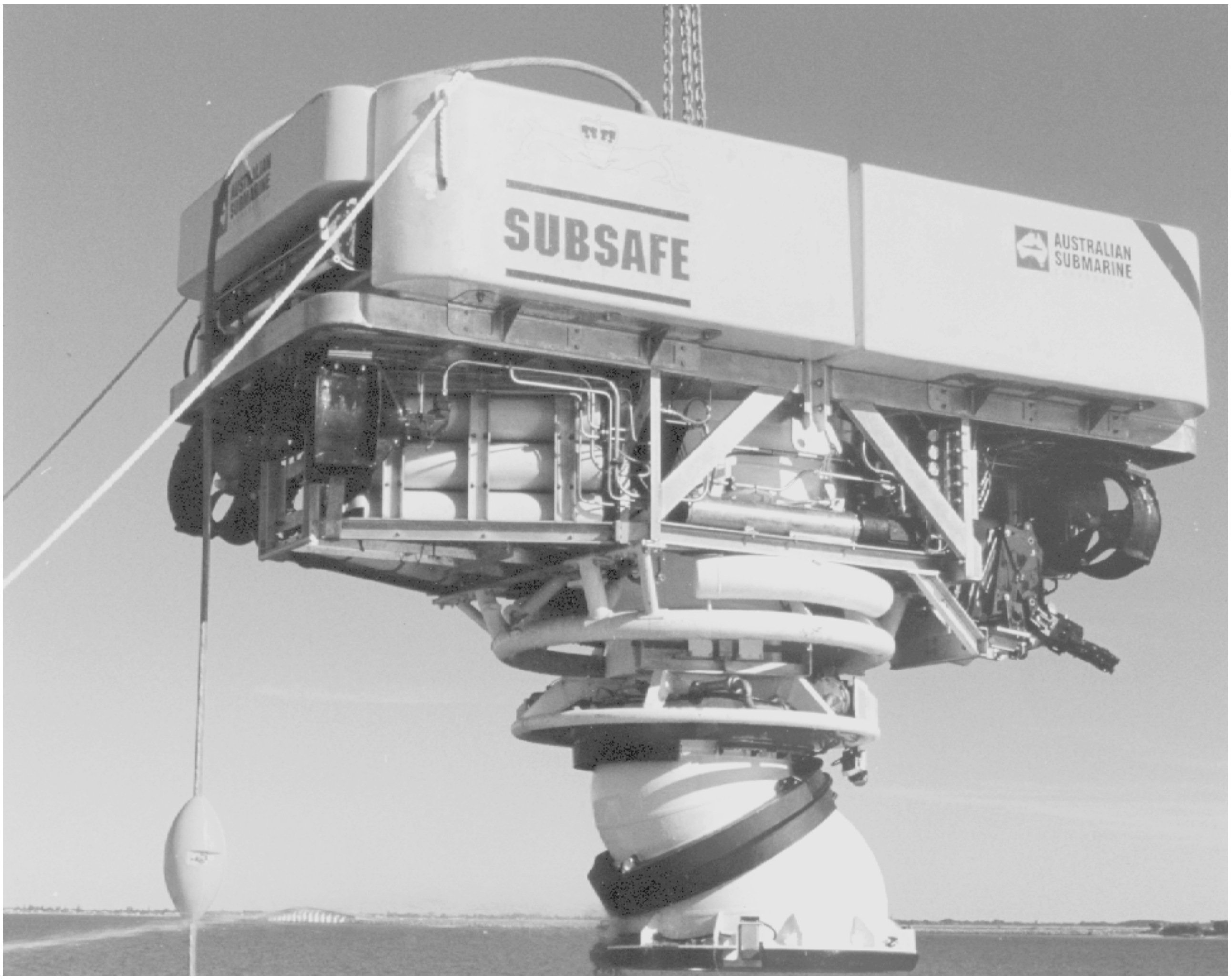

Figure 3. Australian Submarine Rescue Vessel. Photograph courtesy of Royal Australian Navy Photographic Unit.

Expected medical conditions

Survivors will have a range of medical problems depending on the cause of the submarine sinking, the time the submarine has been at depth, the internal pressure of the submarine, the condition of the atmosphere inside the submarine and, for escapees, surface conditions.

Medical problems may include:

TRAUMA

This will include fractures and lacerations which may not prevent successful tower escape.

BURNS

A fire on the submarine can lead to it becoming disabled and some survivors may have burns.

TOXIC GAS EFFECTS

A fire may produce toxic gases that can lead to hypoxia as well as toxic effects. These can include CO poisoning, low partial pressures of oxygen and increased percentage of carbon dioxide. Salt water in the battery compartment can cause liberation of chlorine gas, a potent toxin, leading to acute bronchospasm, pulmonary oedema and eye irritation. The lung effects may lead to an increased incidence of arterial gas embolism.

HYPOXIA

Most people remain conscious breathing an oxygen partial pressure of 0.12 bar or greater. Below 0.16 bar progressive symptoms of hypoxia develop, increased breathing rate, laboured respiration, clouded thought processes, decreased awareness of surroundings and finally unconsciousness. As the internal pressure of the submarine rises, the percentage of atmospheric oxygen needed to maintain an adequate partial pressure falls.

HYPEROXIA

Oxygen can be toxic. Partial pressures above 2 bar can lead to central nervous system toxicity with grand mal seizures. Breathing oxygen at lower pressures, above approximately 0.5 bar gradually leads to symptoms of pulmonary oxygen toxicity. The rapidity of onset of the relative symptoms increases as the partial pressure of oxygen is increased. Symptoms of pulmonary oxygen toxicity include chest tightness, cough, chest pain, shortness of breath and a fall in vital capacity. The severity of oxygen toxicity symptoms is important in selecting a decompression schedule.

ATMOSPHERE CONTAMINATION

Toxic gases arise from many sources and include products of incomplete combustion (carbon monoxide, phosgene), salt water contamination of the battery (chlorine), chemical spills and products of respiration (carbon dioxide). The biologic effects of toxic atmospheric contaminants are usually proportional to their partial pressure.

COLD

A sunken submarine quickly cools to the surrounding water temperature and at depth the submarine internal temperature may only be 5°C. Survivors on the surface in exposed conditions are also in danger of hypothermia.

PRESSURE

Most events which lead to a disabled submarine (DISSUB) will involve some internal pressure increase above 1 bar. This may occur with flooding, high pressure air leaks, salvage air and the use of emergency air breathing systems. If this increase in pressure is maintained for a sufficiently long period of time a decompression obligation will result.

DECOMPRESSION ILLNESS

This includes arterial gas embolism and decompression sickness. The risk of the latter will increase as the internal pressure in the submarine increases and the former increases with conditions that increase gas trapping such as the effects of irritant gases.

NEAR DROWNING.

Some escapees will be suffering the effects of salt water aspiration and drowning. These survivors will require varying degrees of respiratory support.

ESCAPE SCENARIO

Survivor movements

Survivors are brought to the rescue ship in inflatables, lifted onto the ship (kept horizontal) and transported to the triage area. Triage is performed into four groups.

SERIOUSLY ILL

These require immediate resuscitation and/or recompression.

LESS SERIOUSLY ILL

These form the second priority group.

MINOR PROBLEMS

These only need delayed treatment or even no treatment.

DEAD

These require to be placed where their bodies will not interfere with the treatment of the living.

The survivors are then transported to the appropriate treatment area according to their assigned priority. All survivors will be given 100% oxygen using a rebreathing circuit and intravenous fluids.

Treatment protocols

During a SUBSUNK event the decisions must be made about who should be treated, how they should be treated and how urgently they should be treated. All patients need to be resuscitated before being placed in the RCC.

Treatment groups

IMMEDIATE

This includes those suffering severe neurological DCI, those with rapidly progressive symptoms and signs and those with severe cardio-pulmonary DCI (“chokes”). Those who have a presentation and history consistent with arterial gas embolism (AGE) require early recompression. Even those who have apparently made a spontaneous recovery from AGE frequently deteriorate and early recompression is indicated.

DELAYED

In this situation where there are mass casualties and limited resources it is important to ensure that there is a recompression chamber available for those who require urgent treatment. Those with lesser symptoms such as joint pain or tiredness or minor paraesthesia which are stable may be given delayed treatment.

Treatment tables

The treatment table of choice for all survivors is an USN Table 6.

This table is as effective as those that involve deep air excursions and has the advantage that it is shorter. Any patients who do not respond quickly or significantly will be given an extended Table 6. Even those patients who apparently deteriorate further during the first 2 periods at 2.8 bar (18 m) on 100% oxygen will be given an extended Table 6, rather than having their treatment table changed.

Experience has shown that many of these patients will stabilise as the treatment progresses and then improve and those who do not may die. Whether this latter group would improve on any other treatment table is debatable and there is no clear evidence to support the suggestion.

The SERS recompression chambers are capable of supplying heliox (helium-oxygen mixtures) and it is possible to conduct a treatment using a table such as a COMEX 30 or RNZN 1A. These will allow the patient to be compressed to 4 bar (30 m) breathing 50/50 heliox. This offers a possible treatment for those who continue to deteriorate at 2.8 bar (18 m) on oxygen. However this will commit the RCC to a treatment which is longer and may preclude treating others simultaneously. Therefore the overall needs of all patients must be assessed before employing these treatment tables. These tables may well be used for survivors who escape last.

If the first 6-10 survivors all have serious DCI, requiring immediate recompression, it indicates that all survivors will require treatment, especially those who escape last. A Table 6 may not be logistically possible. The recommended treatment in this situation is 60 minutes at 18 m with a 30 minute ascent to the surface breathing oxygen throughout (18:60:30). There is evidence to indicate that this may be effective treatment for a number of survivors and will certainly prevent most deteriorating further. Those patients who remain symptomatic can receive follow up treatments.

Saturation therapy has been considered in the past but is only mentioned here to exclude its use except in extreme circumstances (i.e. failure of oxygen supply to the RCC). This therapy is labour intensive, long, requires considerable logistic support and is difficult to support when there is only one patient. There is the added disadvantage that medical support is difficult to provide to any patients that deteriorate due to conditions other than DCI. The SUBSUNK scenario involves multiple patients, small compartment recompression chambers, limited personnel and logistic support, seasickness and psychological trauma, let alone any other forms of trauma. Saturation therapy is inappropriate treatment except in extreme circumstances.

RESCUE SCENARIO

Survivor movements

After the ASRV has been successfully mated with the TUP chamber, it and RCCs will be pressurised and equalisation achieved. One doctor and one medic will be in the TUP to assist the survivors down the ladder to examine and treat them. The survivors will clean themselves and change into dry RCC approved clothing. Any medical procedures will be conducted in the TUP, time permitting. During this time the ASRV pilot will refill the variable ballast bags and prepare the ASRV for its next cycle.

After the ASRV has separated and the patients transferred into one of the RCCs the TUP is vented to the surface, cleaned and restocked.

Using the TUP as a large transfer lock, fresh medical attendants and ASRV pilots can be blown down (pressurised). When all the survivors are in the system one of the RCC locks would be used if further assistance was required.

Suggested management protocols

If a disabled submarine is pressurised the hazard of DCI in the survivors becomes an important component of how to conduct the rescue. The medical recommendations must address safe decompression and need to be tailored to the available assets.[1] Decompression of survivors from a pressurised disabled submarine falls into several categories.

0-1.5 bar

Saturated survivors rescued from an environment of 1.5 bar or less can be decompressed immediately to 1 bar.[1] They should be observed for symptoms and signs of DCI for 48 hours before any commercial flight.

1.5-1.75 bar

Survivors rescued from 1.5-1.75 bar are at a low, but definite, risk for DCI. They can be decompressed directly to the surface, but, if circumstances dictate, this should be done with a chamber close by in case recompression is necessary.[1]

1.75-2.8 bar

Survivors from depths up to 18 m (2.8 bar) will require an air saturation decompression.[1]

2.8-5 bar

Survivors rescued from these depths are the most difficult to handle for several reasons. Air saturation tables are limited to relatively shallow depths because of oxygen toxicity and survivors at these depths are likely to have developed significant pulmonary oxygen toxicity. In usual occupational diving operations the limiting factor for nitrox mixtures is nitrogen narcosis, restricting the depths for normoxic mixtures to less that 50 m (6 bar). On the North Sea oilfields heliox mixtures are used below 50 m, however, switching to heliox for decompression after an air saturation can cause isobaric gas exchange supersaturation and DCI.

No tables have been developed for the decompression of divers saturated on air from these depths. The USN Time Constrained Decompression Tables[1] are statistically derived, highly informed, but unconfirmed, estimates of the risks associated with decompression from an air saturation. The tables provide several alternative schedules for decompression on air from various depths. The most lengthy (conservative) schedule for each depth is associated with a 1% or less predicted bends incidence. Other schedules have faster overall decompression times at a cost of a higher incidence of DCI, in some cases nearly 80%.

USN Treatment table 7 is an oxygen/air table usually reserved for cases of unresolved or life threatening DCI. It involves a minimum stay of 12 hours at 18 m (2.8 bar) and then a slow decompression back to the surface. The probability of DCI occurring in an individual breathing air throughout a Table 7 has been estimated at 0.2 %; an important consideration for both the medical attendants and the survivors.

In the absence of tested decompression schedules it is planned that survivors from depths between 18-40 m (2.8-5 bar) will commence decompression at a rate of 1 m/hour and continue in accordance with table 7 from 18 m to the surface. The chamber atmosphere will initially be air. It is planned to let the survivors breathe down the oxygen content to maintain a partial pressure of oxygen no greater than 0.5 bar. Oxygen will be added as necessary to maintain this level.

Patients will begin breathing oxygen as soon as possible after reaching 18 m. Oxygen breathing will be limited by pulmonary oxygen toxicity and the medical officer will be required to assess each patient's clinical condition individually. The medical attendants will breathe chamber atmosphere throughout. This decompression schedule will take over 60 hours from 5 bar, the maximum working pressure for the ASRV. Any cases of DCI which occur during these decompressions will be treated with the usual saturation practices.

It is estimated a minimum of five ASRV cycles will be required to bring out half the crew of the disabled submarine. If the internal pressure in the submarine remains constant, once the first 3 compartment complex is full decompression can begin. If however the internal pressure is rising, it is planned to hold each group of survivors in a separate compartment until the maximum pressure is known. Then it will be decided whether earlier rescuees will perform a downward excursion to the depth of the later survivors, or the later rescuees perform an upward excursion based on predicted safe limits.[1] The upward excursion limits are based on limited testing, so, for safety reasons, we will aim to restrict any upward excursion to 50% of the predicted safe limit for that depth. Decompression will then begin. The transfer under pressure (TUP) section will be used for the supply of food and sanitation purposes.

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NORMOBARIC OXYGENATION IN DIVE ACCIDENTS: A CHALLENGE FOR THE DEVELOPERS OF OXYGEN DELIVERY SYSTEMS

Jürg Wendling

Key Words

Accident, equipment, oxygen, rescue, transport, treatment.

Introduction

The value of immediate normobaric oxygenation (NBO) in the treatment of diving accidents is clear. The main treatment for decompression illness (DCI) is hyperbaric oxygen therapy (HBO). DAN Europe statistics[1] showed that 85% of the DCI cases treated with HBO had complete relief of symptoms. The two main factors influencing the final outcome are immediate treatment with NBO and liquids and the delay before recompression therapy.

In the US DAN statistics[2] about 70% of the patients with minor neurological symptoms or pain as pre-recompression symptoms were still symptomatic after treatment when the delay was more than 12 hours, while the percentage of residual symptoms was only 20% for a delay between 4 and 12 hours and about 10% for a delay less than 4 hours. The median delay before HBO treatment was 7 hours for AGE, 26 hours for DCS I and 20 hours for DCS II. Only 33% of DCI cases were given oxygen as first aid therapy during transport and only 6% of DCI cases got oxygen and fluids. In transit oxygen treatment increased the symptom relief rate before recompression by a factor of 2 to 8.