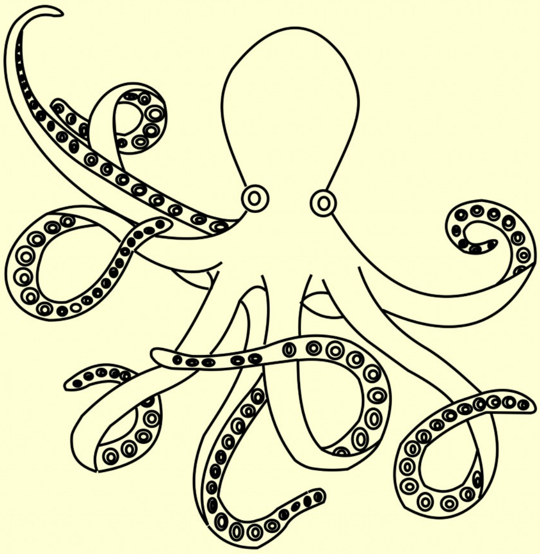

Diving & ROV specialists

Saturation diving handbook
Book 2 of 4
Gas supplies & chambers management

December 2022

Diving & ROV specialists is a branch of CCO ltd

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This document is the book number two of the ensemble of four books constituting the “Saturation diving handbook” described underneath.

Books	Description
Book #1: Definition and elements for preparation	The document describes the scope of saturation procedures, the NORMAM 15 PLC saturation procedures, and some elements to consider when organising a saturation diving project such as the necessary personnel, weather conditions, surface supports, systems of communications, work procedures with ROV, supply chain to be in place, etc.
Book #2: gas supplies & chamber management	This document describes safe practices and emergency procedures to manage the chambers and their supplies for safe successful operations.
Book #3: Bell procedures	This document describes the main rules for the organization of safe bell diving operations
Book #4: Diving accidents	This document indicates and explains the accidents linked to saturation diving procedures and how to solve and avoid these accidents

February 2021	*First publication*
August 2021	*Modified point 1.2.6 - Gas storage and distribution.* *Modified point 2.4.1 - IMCA D 050: Minimum quantity of gas required offshore.* *Added point 3.1.3 - Set a policy for electronic devices in chambers.*
December 2022	*Included the study “A review of accelerated decompression from heliox saturation in commercial diving emergencies” published by Jean Pierre Imbert and doctors Jean-Yves Massimelli, Ajit Kulkarni, Lyubisa Matity , & Philip Bryson.*

Important Note

This book is written with the only aim of informing people interested in diving activities of elements to take into account to prepare successful diving saturation operations.
I express my sincere thanks to the people and companies listed below who have supported this project and provided me with useful documents and advice.

Christian CADIEUX - manual author

- Sheldon Hutton - CEO/Chairman Ultra Deep Solutions & Flash Tekk Engineering, and the personnel Ultra deep solution and Flash Tekk Engineering
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- Comanex - Patrick Laboure (Managing Director)
- Parkburn systems, particularly Mr Shon Laird (Business Development Asia Pacific)
- Gareth Kerr - Director Fathom systems (Fathom system is a part of JFD group)
- Jord Lucas - Head of the diving department Total E&P
- Franck Muller - Diving specialist diving department Total E&P

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Tables of contents

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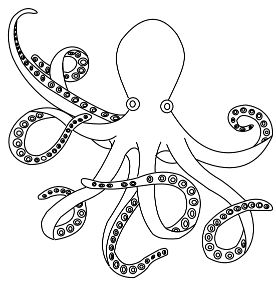
Important note

This book that gives an overview of the elements and procedures for gasses and chamber management that should be in place to organize saturation diving operations. It is based on the saturation manual published by CCO Ltd, elements indicated in the documents Diving & ROV specialists “Description of a saturation diving system”, and the diving study CCO Ltd “Implement NORMAM-15 saturation diving procedures”.
The reason for using the NORMAM-15 is that it has proved its efficiency for the organization of numerous deep dives in Brazil and other countries. So it is one of the safest saturation procedures currently available. It is confirmed in the “DMAC statement on deep saturation diving conducted using appropriate procedures”, published in March 2019.
However, people using a decompression process other than the Normam 15 can adapt the elements described in this document to the decompression procedures they use.
Note that we only suggest what we consider the best practices and favor the diffusion of every procedure we think relevant for people involved in diving and ROV operations, whatever the emitter. Also, we are not influenced by any third-party organization, as we are not a member of any.
The policy of Diving & ROV specialists policy is to publish only official and scientifically proved documents and never change the original structure of these publications. For these reasons, there is no change of the procedure published by the Brazilian Navy Directorate of Ports and Coasts and those of other competent bodies.
However, there have been some improvements in some diving procedures since the publication of the NORMAM-15/DPC. It is the same for the other guidelines taken as references. For this reason, some complementary procedures from other competent bodies or implemented by various teams working in the offshore industry have been added as reinforcements.

Note that in this document, the name “NORMAM-15/DPC” is reduced to “NORMAM-15” for convenience.



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1) Categories of saturation systems and elements controlled by the Life Support Technicians (LST)

1.1 - Categories of saturation systems

Saturation systems are built according the national and international standards and also the desires of their owners. As a result, they can be relatively simple or very complex. They can be classified into two categories:

1.1.1 - Portable saturations systems

They are designed to be installed on vessels of opportunity or a facility and be removed at the end of the operations.
For this reason, they are composed of elements that are containerised and designed to be easily transferred and installed. Their size is generally, but not always, limited to 9 or 12 divers accommodated in two or three chambers.
As an example, the portable system below which is built by LEXMAR is designed for nine divers and consists of:

- A diving bell designed for 3 divers with its launch and recovery system (LARS).
- A six beds deck decompression chamber with its entry lock and a similar one designed with three beds.
- Dive and a saturation controls plus the machinery and the necessary gas reserves.
- A Hyperbaric Rescue Chamber with its launching davit designed to evacuate the divers from the system.

These systems are frequently used due to the flexibility they offer and because a lot of small diving companies have not the resources to maintain a ship. Also, the seasonal aspect of the diving activities in several parts of the world has as result that it is often preferable to charter vessels of opportunity during the periods of high demands instead of maintaining specialized ships that cannot be employed in full during periods of low demand.

Note that even though such systems have some advantages, they have also their inconvenience:

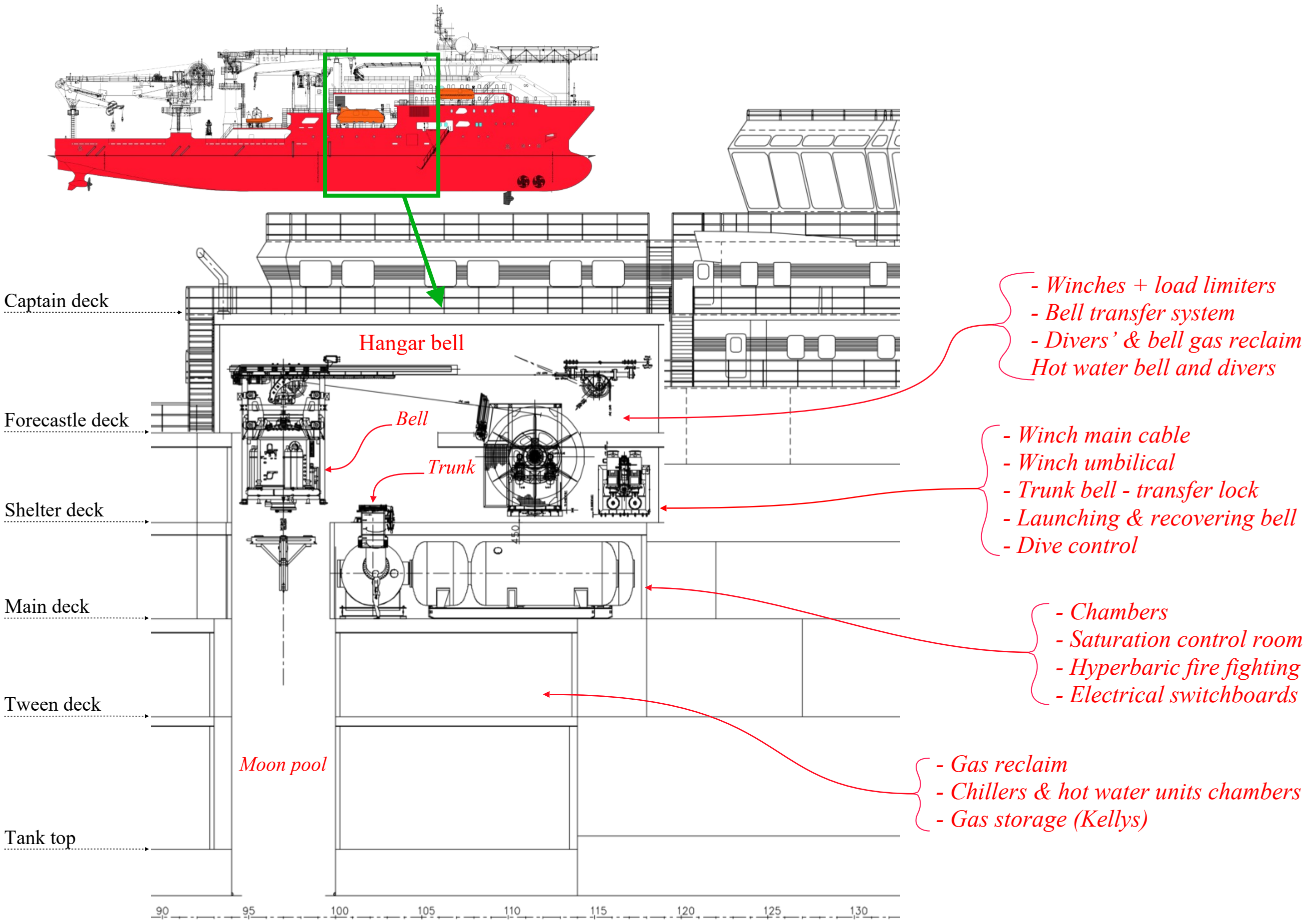
- Depending on their size, they may occupy a lot of deck space, which reduces the surface available for tools and cargo onboard the diving support vessel and often obliges the chartering of an additional cargo boat when construction jobs are undertaken.
- As these systems are on deck, they are not isolated from the weather conditions and from the noises arising from the diving operations and other activities. As a result, some mechanical and electrical systems are exposed to humidity and corrosion, and the rest periods of the divers can be disturbed by the surrounding activities. Also, the supporting personnel can be exposed to extreme weather conditions. In addition, these systems may be installed at the proximity of zones where conflicting activities are undertaken.
- Another inconvenience is that the installation of such systems require at least several days and sometimes several weeks and that an audit is necessary at each installation. As a result, they cannot be immediately available if they are not already installed and such mobilization has a cost that must be taken into account.

1.1.2 - Integrated or built-in saturation systems

They are part of the vessels in which they are installed in enclosed or semi-enclosed spaces that are organized on several levels and that are protected from the weather conditions. As a result, the deck space is available for cargo and tools.
They can accommodate up to 24 divers (sometimes more) in separate chambers.
The description below is based on a system designed and built by LEXMAR that is installed on Ultra Deep Solution Lichtenstein. This ship is a dynamic positioning diving support vessel of 120 m long for 25 m breath that has been designed by Marin Teknikk in Norway and proposes the latest marine and diving technologies.

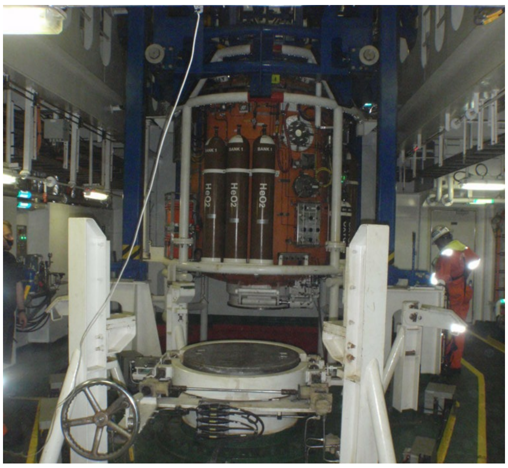
The saturation system is designed to accommodate 18 divers in four chambers. Two transfer locks are available to access the two closed bells that are used to transfer them from the system to the bottom. Also the system is equipped with two

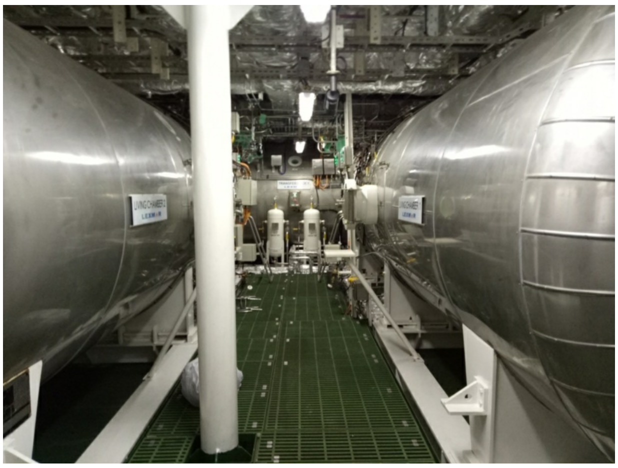
Self Propelled Hyperbaric Life-boats (SPHL) that are designed to evacuate 18 divers each.
The system is installed on four levels and the two bells are immersed using moon pools that are installed portside and starboard side at frame 97, which is situated at mid-ship. As a result, all the system is sheltered and the people operating it are protected from the weather conditions. The system is arranged as follows:



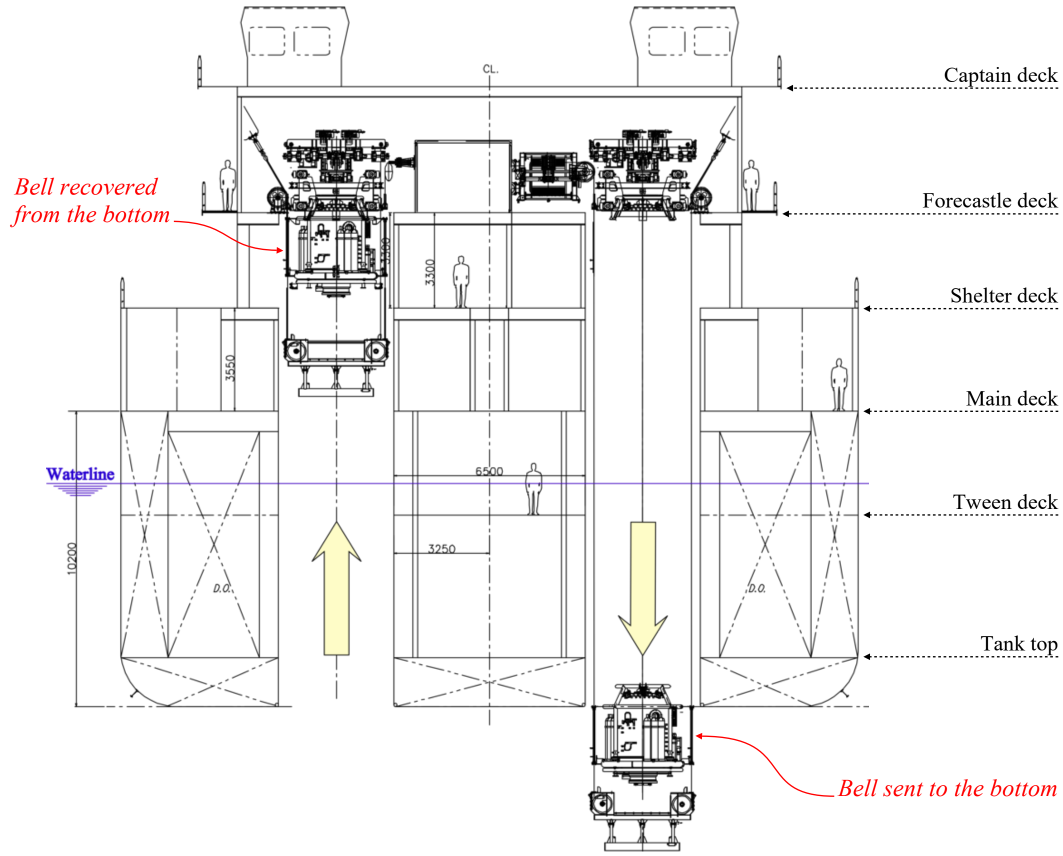
In addition to the deck that remains available for cargo and tools, built-in systems have the following advantages:

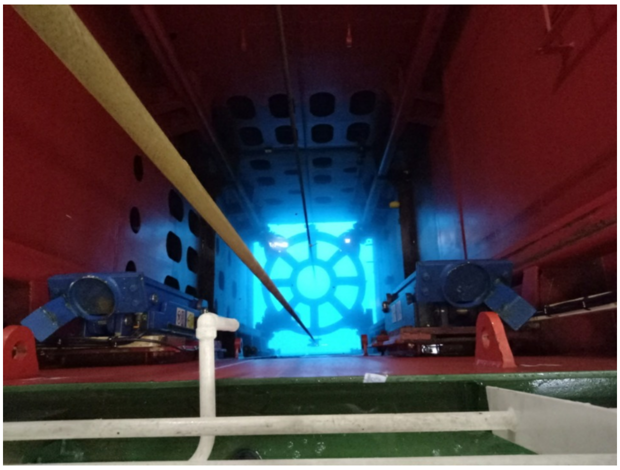
- The chambers that are installed in calm enclosed spaces allow full unbroken rest periods to the divers.
- The internal temperatures of the chambers are easier to control as the temperature of the room they are installed in remains constant. As a result, there are no external variations of temperature as for chambers on deck.
- Of course, the people operating and maintaining these systems work more comfortably. They are not confronted with parallel activities on deck that may conflict with the diving support activities, and they are not exposed to too cold or too hot conditions.
- The system is fully protected from dropping loads that may happen to portable systems that are installed on deck during crane operations.
- As the deployment of the bells is performed through the moon pools that are at the center of the vessel and that the persons operating them are protected from the weather conditions, they allow diving operations in rougher seas than portable systems.
- Depending on whether they are installed in enclosed or semi-enclosed spaces their mechanical and electrical systems are not or less exposed to humidity and corrosion. Also, as indicated above, technical interventions are much more comfortable during extreme weather conditions.


Bell in its launching hangar


Chambers in their enclosed space

A twin bell system gives the advantage that continuous diving operations can be organized, which allows sending the second team when the dive time of the 1st bell run is completed and save the time used to prepare the dive and recover the divers as these operations are performed when the other bell is at work.
Also, the bell at the surface can be maintained when the 2nd is at work. The bells can also be used together or to assist each other in the case of one is trapped and cannot be recovered.





Moon pool (bell at work)

Bell above its moon pool

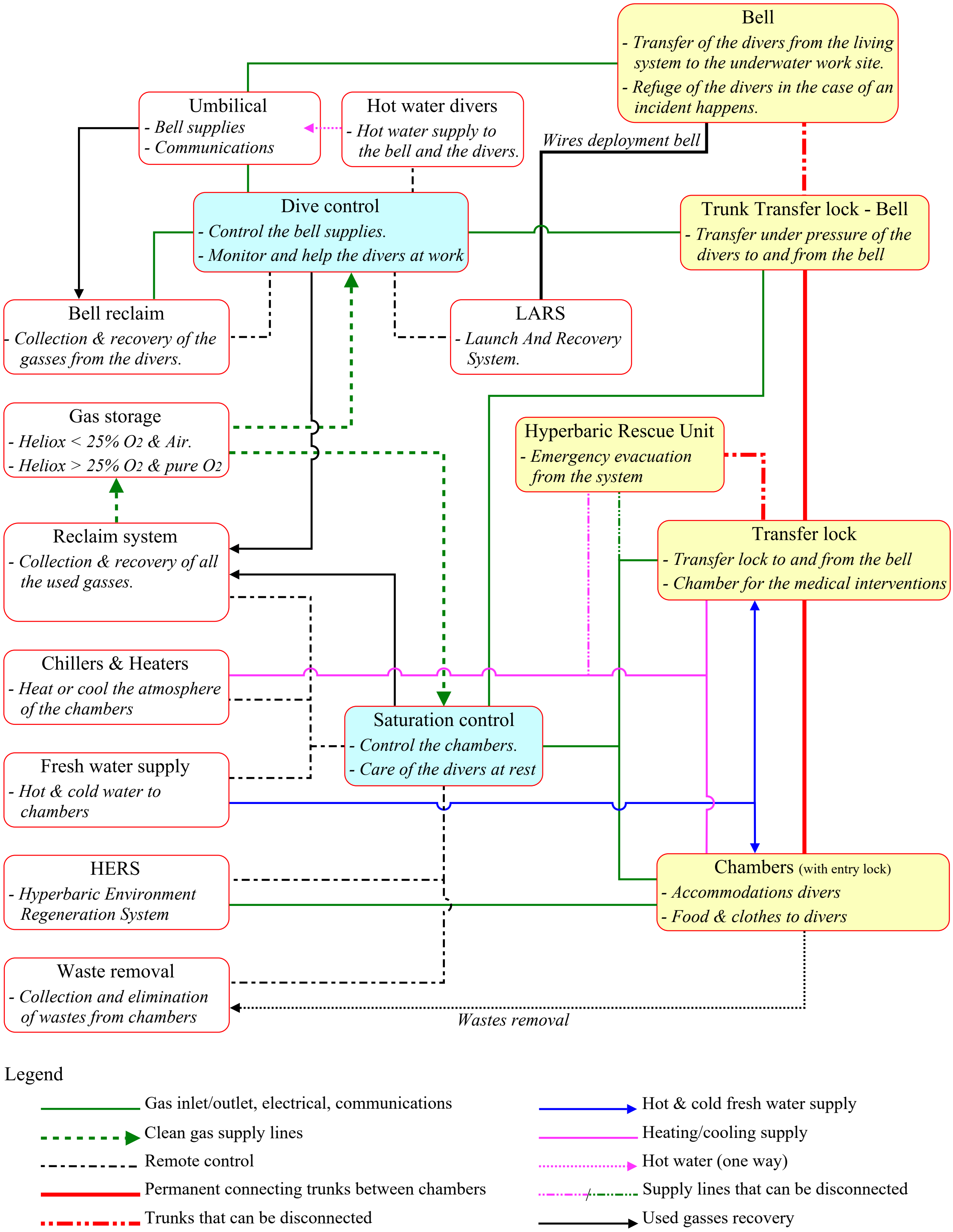
Hyperlink Table of contents

1.2 - Main elements of a saturation system controlled by the Life Support Technicians.

1.2.1 - Overview

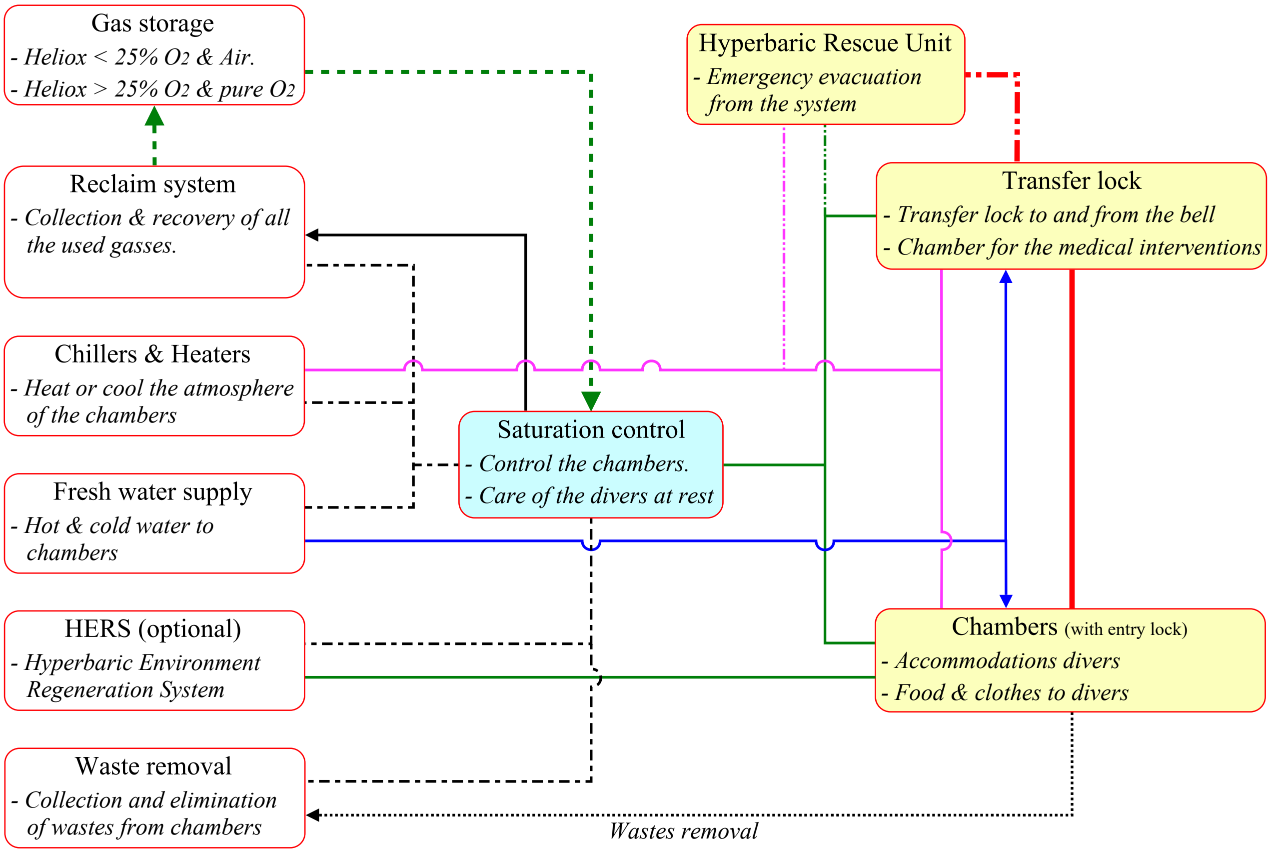
1.2.1.1 - System on board the vessel

It is essential to have an overview of the general design of a saturation system, and how the elements that compose it are linked together, to have a comprehension of their functions and conception. The best method for this is to draw a scheme that represents them and their interconnections. It is the purpose of the chart below, where the links between the modules are extremely simplified.
The life support technicians are in charge of managing all the elements that compose the system, except the bell, and its associated elements, that are always under the direct control of the diving supervisor.



1.2.1.2 - Hyperbaric Reception Facility (HRF)

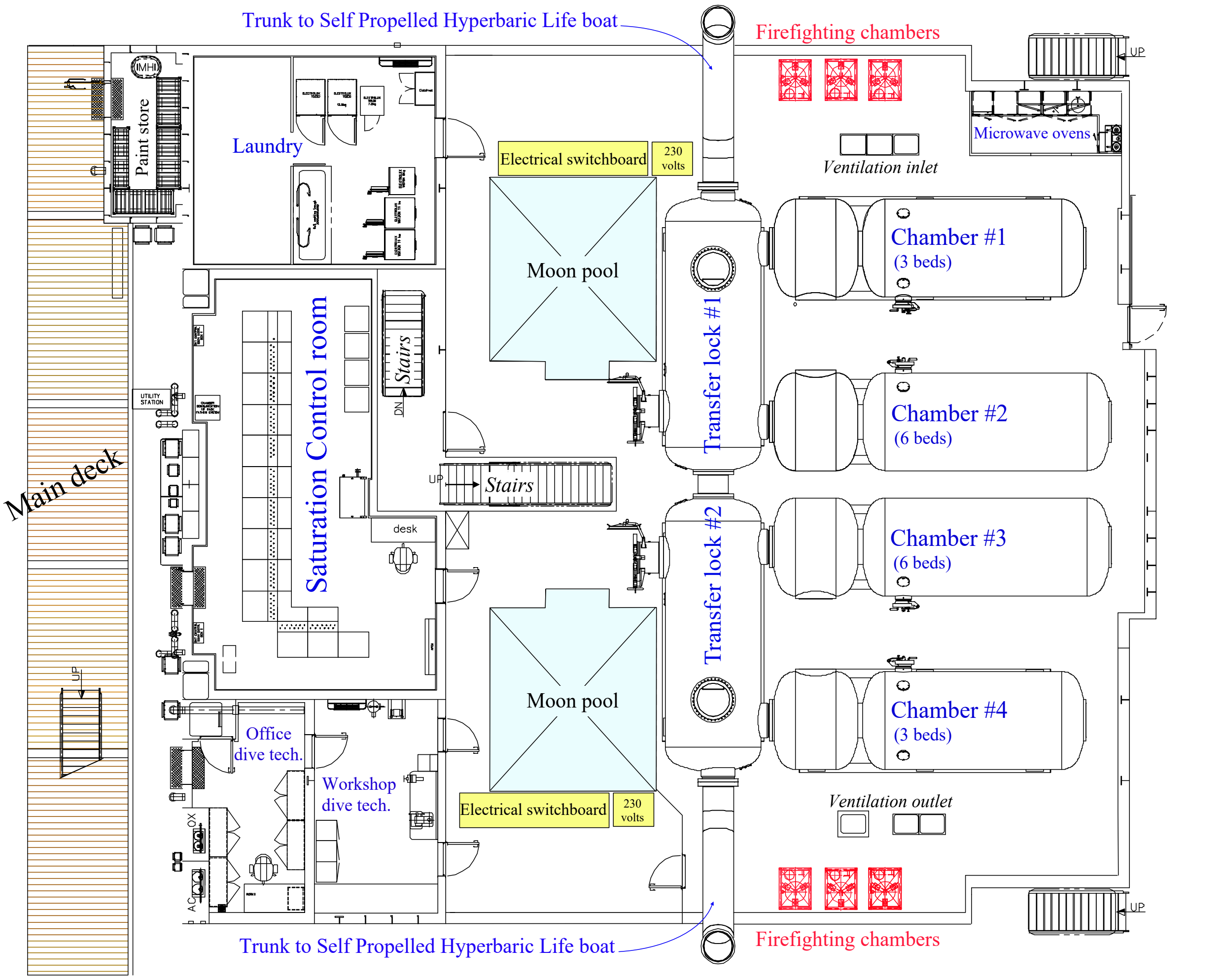
The Hyperbaric Reception Facility (HRF) is an ensemble of chambers situated onshore or on a rescue boat in which the divers are transferred in case of an abandonment of the surface support, should be considered a part of the saturation system. For this reason, the scheme of the modules that compose it are displayed below.
Note that the HRF cannot be controlled by the Life Support Technicians onboard the vessel. For this reason, it is usually done by a team assigned to this task.

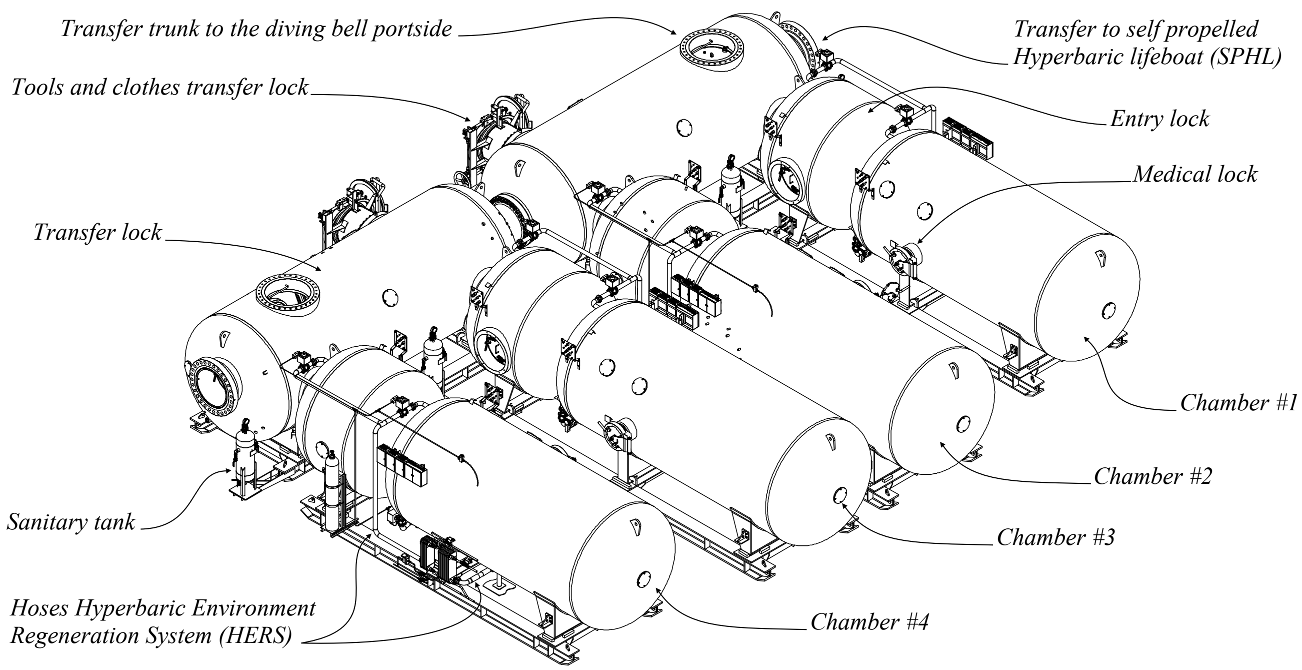


1.2.2 - Chambers

1.2.2.1 - General description

Chambers are the pressure vessels where the divers live during the saturation period. For this reason, they are designed to sustain the same pressure as the bell. They are linked together, to the bell, and to the hyperbaric rescue unit(s) provided to evacuate the system in the case of an abandon ship by "trunks". These trunks allow them to be isolated by double doors. The chambers are situated at the level of the bell or below it, depending on whether the access to the bell is through a lateral door or bottom door. The saturation control room is generally at the same level as the chambers.
The drawings below show the configuration of the chambers and control room of the UDS Lichtenstein. This system is composed of four living chambers and two transfer locks. As the transfers to the bells are performed through the bottom door, these chambers are installed at the level underneath the bell hangar.

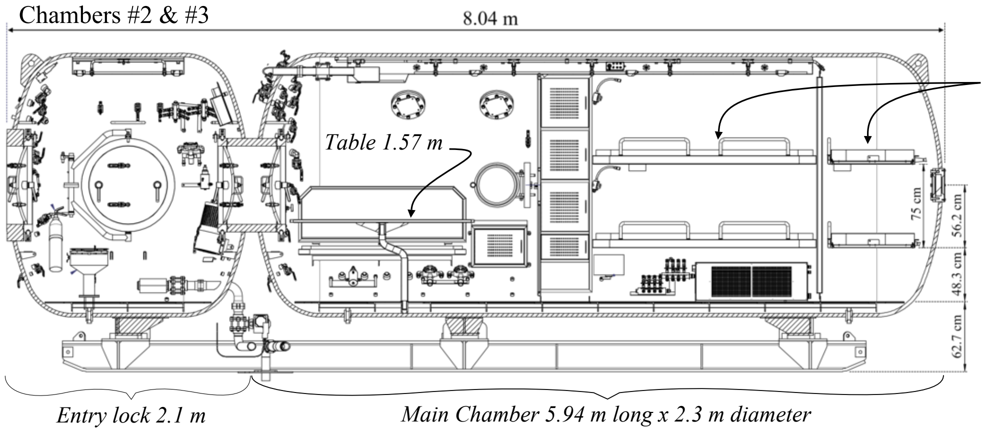


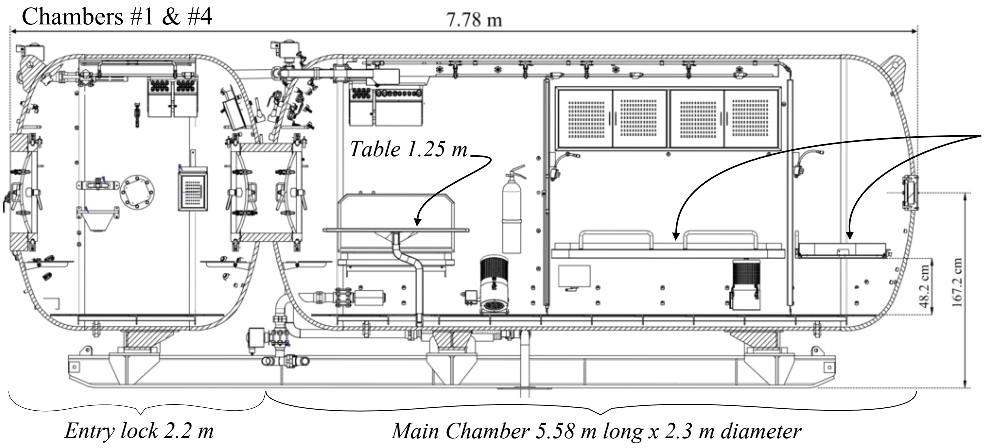


The system allows storing divers at several depths, depending on the way the project is organized. As an example, one team at 100 m and the others at 60 m. Also, that allows organizing crew changes with incoming divers compressing while out-going divers are decompressing. Also, a chamber can be used to recover an injured diver and his tender without decompressing the entire system.
Note that the chambers #1 and #4 are designed for three divers, and the chambers #2 and #3 are designed for six divers. Also, two self-propelled hyperbaric lifeboats (SPHL) designed for 18 divers each are available (1 starboard side and one port side). They can be accessed from either the transfer lock (TL) portside or the transfer lock starboard side.
The saturation control, laundry, and kitchen are at the proximity of the chambers. That allows the life support technicians to intervene rapidly in the case of a problem or for everyday tasks such as transfer of the food or the suits and tools.
The medical locks that are used to transfer medications and the food are on the sides of the chambers.
The transfer equipment locks are in direct proximity to the saturation control. They are used to transfer tools, diving suits, clothes, and objects that are too voluminous to be transferred using the medical lock.

1.2.2.2 - Living chambers and their entry lock

Chambers must be equipped with the elements to provide a suitable comfort to the divers such as beds, seats, table, cupboards, entertainment, communication to and from the external. Toilets, shower, and a sink must be provided in the entry lock to maintain proper hygiene. Of course, the breathed gas is monitored and renewed according to the needs, and heat and cooling systems are provided.





Chamber #1 - view from view-port

Chamber #1 - view from entry lock

Entry lock chamber #1

Note that in the system taken as a reference, the total length of chambers #1 & #4 with their entry lock is 7.78 m, and the total length of chambers #2 & #3 with their entry lock is 8.04 m, which is only 26 cm difference. The main distinctness between chambers (#1 - #4) and (#2 - #3) is that bunk beds are installed in (#2 - #3) to accommodate six divers. Also, the seats and the table are slightly longer in chambers (#2 - #3).

Similarly as with the bell, the pressure vessel forming the chamber must have been designed and built to a recognised international standard and be fit for the purpose of human occupancy. Note that IMCA D 024 says that it must be the case for any unit manufactured after the 1st of July 2014. Also, the design standard, serial number, date of manufacture, etc. can often be found hard stamped on a suitable part of the unit, in an accessible position. An identification plate that is usually installed on a leg or the body of the pressure vessel is used for this purpose and allows to trace the process of construction of the device. As an example, the plate below provides the following information:

- Name & address of the manufacturer
- Name of the client (brand)
- Construction project
- Design code (international standards used)
- Reference number client project
- Reference number manufacturer project
- Design pressure & temperature
- Empty weight
- Minimum design metal temperature
- Nominal capacity
- Hydro test pressure
- Corrosion allowance
- Radiography
- Head/shell nominal thickness
- Year of manufacture
- Size of the vessel
- Certifying authority and identification number
- Reference number of the final report

In addition to the above, the number of occupants the chamber is designed for must be indicated on it.
Also, chambers built for saturation must have minimal dimensions: IMCA says that since the 01/01/2015, their diameter should be at least 1800 mm (72 inches). However, the same guideline says that this requirement is not applicable for chambers manufactured before that date. NORSOK standard U100 is more stringent than IMCA and says that the inner height of the chambers must not be less than 200 cm over the deck plates (measured in the middle of the chamber) and that the internal volume must be at least 4 m³ per diver. Similar requirements are asked by classification societies such as DNV (Det Norske Veritas).

Note that the rules for the design and the maintenance of a chamber are the same as those applied to the bell. As a result, a lot of similar elements can be found on the external parts of the chamber:

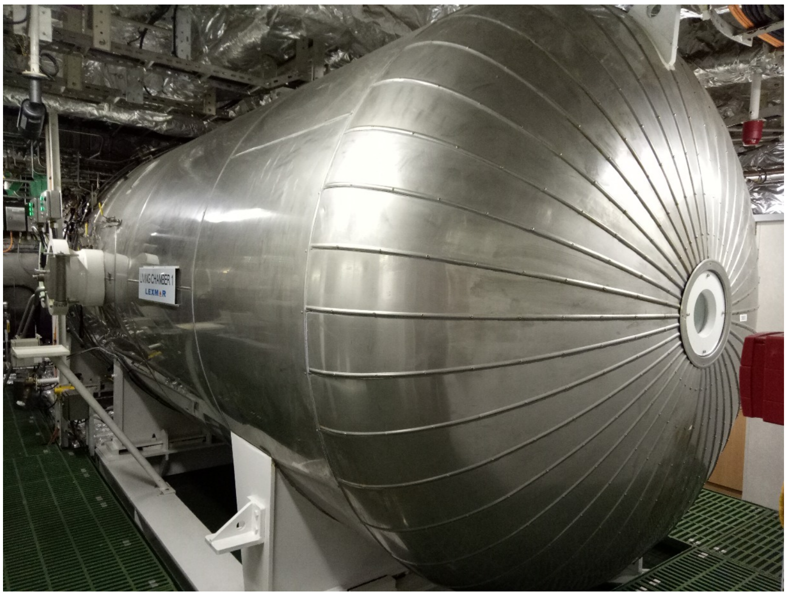
- Chambers used for saturation are usually fitted with insulation, which is protected from shocks and moisture by series of metal shaped sheets or composite materials *(see on the next page)*. This protection must be in perfect condition to ensure the absolute integrity of the isolating material, and that corrosion will not happen underneath it. Also, the visible parts of the pressure vessel must be protected by a suitable coating and their integrity not affected by corrosion.
- Chambers are fitted with numerous hoses and electrical cables that provide gas, water, electricity, communication, video, etc. Penetrators are used to seal the passages in the hull against leaks.
  IMCA D 024 says that electric penetrators must be certified by a competent person (IMCA D 018 category 3 or 4) as fit for purpose, and hollow penetrators (other than the bores of medical and equipment locks) must be fitted with protection valves or other devices to stop catastrophic pressure loss. These valves must be free from corrosion and should move freely through their full range of operation. Also, valves carrying oxygen, or mixes containing more than 25% oxygen *(NORSOK limit is 22%)* at a pressure higher than 15 bar must not be quarter turn (Due to the depths involved in saturation diving, the pressure of such gases will often require to be above 15 bar). The reason is that extreme heat can happen if the compression occurs quickly enough to create a pneumatic impact and adiabatic compression. These phenomenon result from the conversion of the mechanical energy when the gas is rapidly compressed from low to a high pressure. The following values from the American Society for Testing and Materials (ASTM) demonstrate that, depending on the pressure ratios, materials submitted to an immediate rise of pressure can be destroyed:

Initial pressure	***Initial temperature***	***Final pressure***	***Pressure ratio Pf/Pi***	***Final temperature***	***Comments***
1.013 bar	20 Cº	34.47 bar	34	530 Cº	Final temperature above auto-ignition temperatures of non-metallic materials
1.013 bar	20 Cº	137.9 bar	136.1	920 Cº	Final temperature above the melting temperature of brass (900 Cº)
1.013 bar	20 Cº	275.79 bar	272.1	1181 Cº	Final temperature above the melting temperature of bronze (1020 Cº)

To continue with oxygen and mixes above 25% oxygen *(remember that NORSOK limit is 22%)*, particles may aggregate inside the pipes and be ignited later on. For this reason, the valves and pipework must be cleaned for oxygen service when used for gas mixes containing more than 22% oxygen *(It is preferable to use this limit instead of 25%)*.

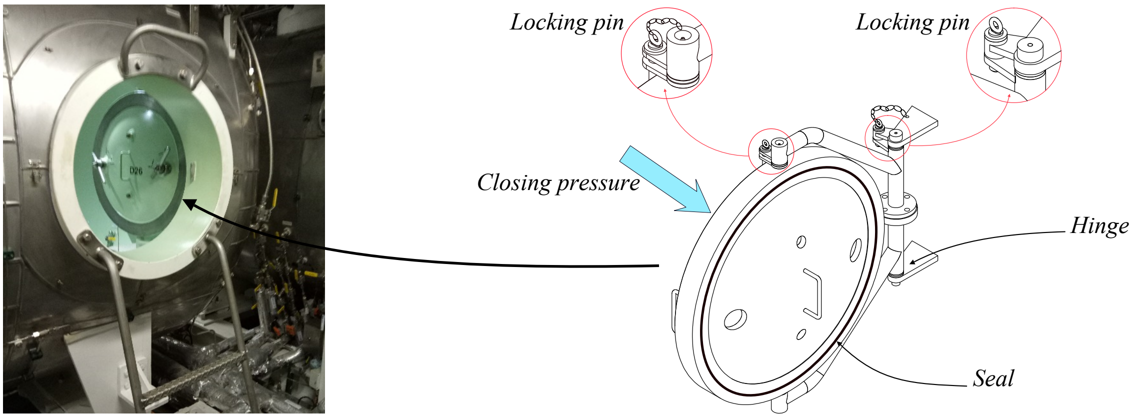
- IMCA says that all valves and penetrators must be marked with their function indicated. That can be seen in the photo below. Also, manufacturers generally provide additional penetrators by precaution *(see in red circles)*.

Marked hollow penetrators and their valves

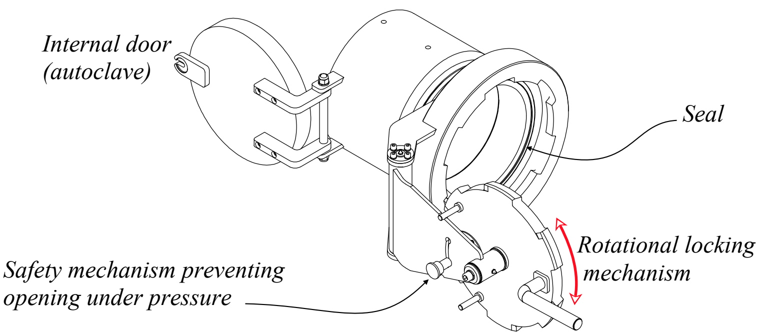


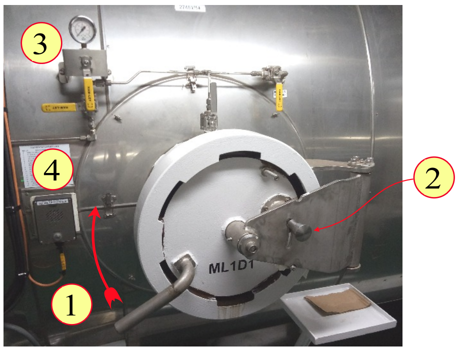
Protection of the isolation (made of stainless steel sheets)

- A door on the side of the entry lock allows accessing the chamber when it is not under pressure *(see below)*. This door must be marked with a dedicated number as the other doors of the system for identification purpose.
  As with the bell, this door is autoclave, so the pressure inside the chamber closes it. IMCA recommends that the seals on mating faces are clean, undamaged and covered lightly in silicone grease. Also, if the sealing area is painted, it must be in good condition. Locking pins are provided to secure this door when it is in open position.

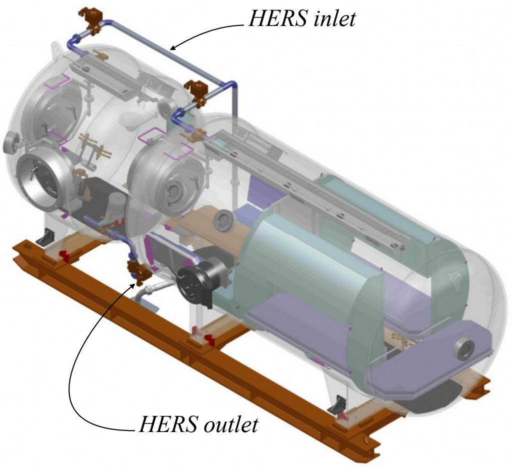


- A medical lock is fitted on the side of the main chamber to transfer the food and of course medicines if necessary. Opposite to the door above, this door works against the pressure, which means that it can be opened by the internal pressure if it is incorrectly closed or opened while the lock is under pressure. For this reason, IMCA says that a safety interlock system must be fitted to the clamping mechanism securing the lock outer door. Also, this interlock must make it impossible to open the mechanism/door if there is still pressure inside the lock and impossible to obtain a gas tight seal on the lock if the door/mechanism is not properly closed.
  As an answer, the door in the photo below must be rotated to be opened *(see #1)*. Also, a mechanism prevents this operation if the lock is under pressure *(see #2)*. It is often a small locking piston pushed out by the pressure inside the lock. A gauge is provided to control whether the lock is under pressure with vent valves *(see #3)*. Communications with the saturation control must be in place *(see #4)*.

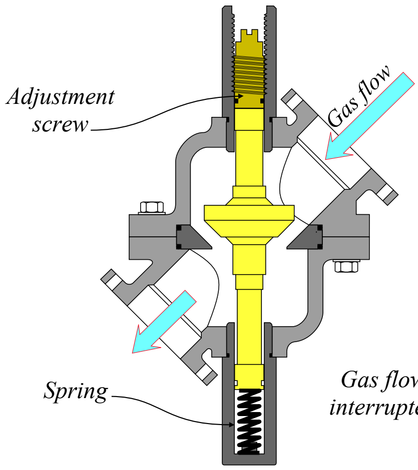




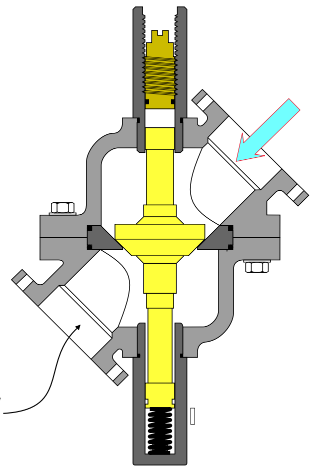
- The gas in the living chambers and their entry locks is regenerated by the Hyperbaric Environment Regeneration System (HERS), which removes the CO2 and moisture resulting from the respiration of the divers. This system uses pipes of approximately 6 cm diameter that are figured in the drawing below. IMCA says that such large piping should be fitted with a “non-return valve” for inlet and a “flow fuse” for exhaust at the hull penetration respectively. These can be fitted either externally or internally and are normally in place of the normal hull protection valve at that point.
  The function of the non-return valve is already explained in the previous topics *(see in bell & helmets)*. The “flow Fuse” is a check valve which is maintained open by a spring during normal operating conditions, and allows gas free-flow from the internal to the external of the chamber. During this normal operating condition and up to the trip point, the differential created by the flow across the valve is equal to or less than the spring force *(see ”flow fuse open” below)*. If a downstream pipe is ruptured or in case of a significant leak, the closing force increases sufficiently to counteract the spring force and close the valve, protecting the chamber occupants from depression *(see ”flow fuse closed” below)*.



HERS inlet & outlet

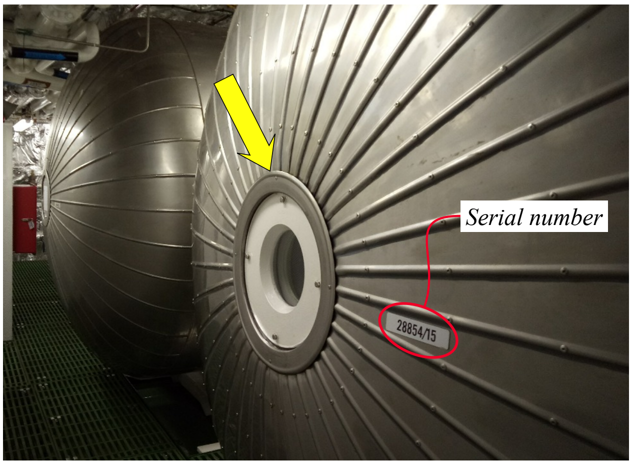


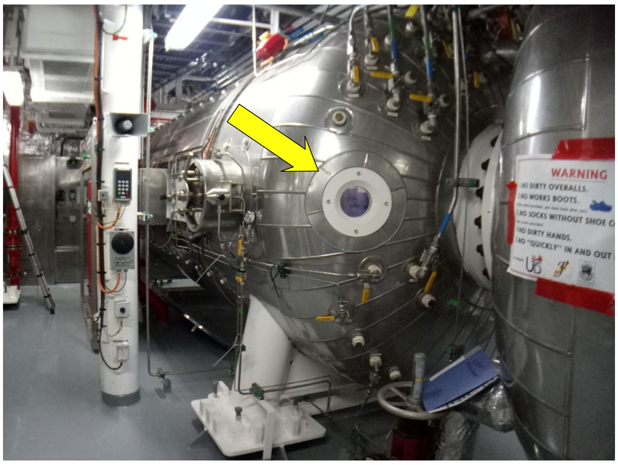
Flow fuse open



Flow fuse closed

- Viewports are installed to allow observing the divers in the chamber during the diving operation. For this reason, they should be accessible to the Life Support Technicians *(see the photos below)*.
  Also, viewports are used to illuminate the chamber with natural light when it is installed on deck. Units that are installed on the very top of the chamber can also be used to provide artificial light in the chamber through electrical bulbs that are above them. This system avoids the installation of electrical cables through the hull of the chamber or allows using alternative current 220 volts, which is forbidden inside the chamber. However, the inconvenience of this technic is that the heat generated by electrical light may damage the viewport if it is too powerful or too close. For this reason, IMCA D 024 says: *"Any external light assemblies must be designed and mounted in such a way that they will not damage viewports as a result of prolonged heat"*.





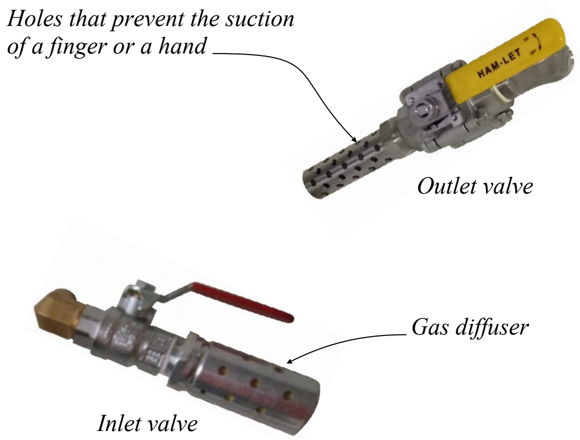
Viewports must be manufactured according to a recognized standard, and tested according to the “American Society of Mechanical Engineers” (ASME) Pressure Vessels for Human Occupancy (PVHO) procedures. The serial number or another identifying mark for each viewport fitted to the chamber must be visible. It can be engraved or be prominently marked adjacent to it on the outside of the chamber *(see an example in the photo above)*.
ASME recommends that the windows for human occupancy pressure vessels are fabricated from cast polymethyl methacrylate. In addition to its resistance to pressure and shocks, the advantage of this material is that it is more transparent than glass. As an example, it is still perfectly transparent with a thickness of 30 cm when seeing through glass windows of this thickness is not possible.
Viewports must be free of cracks or scratches that could affect their integrity. Also, their seat cavities must not be corroded, and the flanges that keep them in their seat cavity must not be corroded as well. Polymethyl methacrylate is a synthetic resin which is part of the methacrylate family, and the main inconvenience of these materials is that they degrade with the time. As a precaution, IMCA recommends renewing them every 10 years.
IMCA also says that a suitable protection must be provided when there is a risk of damage to a viewport from dropped objects or another physical impact. It can be plastic covers or an additional metallic protective structure.

- As with all pressure vessels, a relief valve of a suitable size must be in place on each chamber for venting the excess of gas in case of an over-pressurization.
- Firefighting means must be provided to protect and cool the chambers. They consist of extinguishers and water deluge systems. The models of extinguisher provided should be selected according to the categories of fires identified through a risk assessment. Deluge systems are usually controlled by the bridge and the chamber control room.

The rules applied for the internal parts of the chambers are also based on the same standards as the bell, except, as said in the introduction, living chambers are the part of the system designed to provide a maximum comfort to the divers during their rest time.

- The rule for the design and the condition of paint, penetrators, and hollow penetrators are those already described for the external parts. However, the valves must be arranged not to be operated by accident. For this reason, manufacturers group them in protected areas of the chamber and not in the direct vicinity of beds. They are generally in the half sphere that ends the chamber near the trunk.
  Exhaust devices, including those located in transfer trunkings and medical locks may create suction hazards that must be addressed to minimize the risk of injury to divers. For this reason, they must be fitted with guards or numerous holes that multiply their surface for suction so that it is not possible to have a finger or a hand aspired by the depression.
  Also, unprotected gas inlets emit loud noises and a direct flux of gas that may disturb the divers at rest in the chamber. For this reason, valves should be fitted with a diffuser that reduces these effects. However, this item is not mandatory for the inlets in transfer trunks. Diffusers are usually made of porous composite materials that absorb sounds and break the direct flow into numerous small gas flux.

Valves grouped at the extremity of the chamber



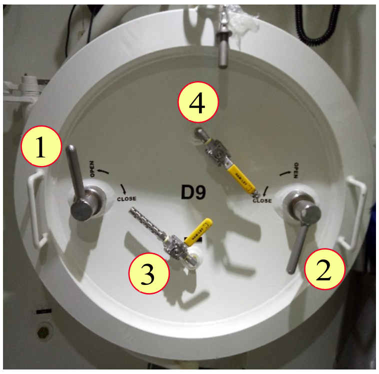
- NORSOK says that the chambers used as living and sleeping accommodation must be equipped with seats and individual bunks for the number of divers who use this part of the chamber complex. The beds must be designed to allow a minimum comfort and a minimum size of 200 X 70 cm is required *(see the photo below)*. Also they should be made of non flammable materials. IMCA also says that each bunk should be well designed and firmly supported, and that there should be sufficient lighting to allow the occupant of each bunk to read easily *(see the photo below).* In addition, curtains are usually provided to allow the diver having an unbroken sleep.

Beds size 200 X 70 cm and their curtains

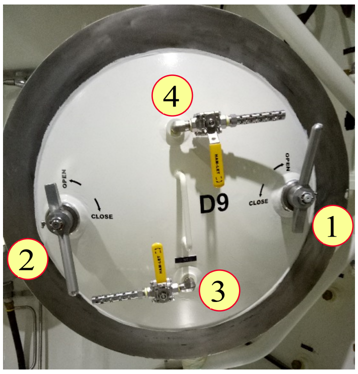
Bed light and communication box

- Note that last generation chambers are provided with a bulkhead and a door that isolate the sleeping zone from the area where the table is in place *(see the photos and drawing at the beginning of this point)*. This design allows the awake divers to prepare the next bell run, eat, or have another activity without disturbing their colleagues at sleep.
  NORSOK U 100 recommends noise levels limited to 60 dB in a sleeping chamber and 65 dB in a living one.
- Sufficient light should also be provided in the chamber to allow the divers to operate the valves, read the controls or documents, write reports, and have some entertainment. The lighting should also allow surveillance from the outside.
  NORSOK U 100 recommends 100 Lux in the chamber with 300 Lux in the reading areas.

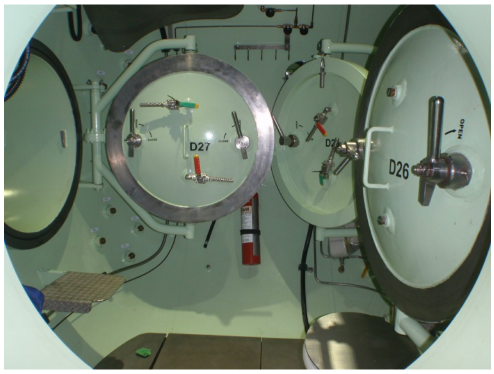
- The chambers are linked together by trunks that can be pressurized and deflated from the saturation control room. They are isolated by autoclave doors similar to the one used for the access from external already described at each end of the trunk. So the divers are protected in the case of depressurization or overpressure of the adjacent chamber. These doors are fitted with hatch dogs *(see # 1 & 2 below)* that can be operated from both sides to prevent them from opening in case of over-pressurization of the trunk. Also, two vent valves *(see # 3 & 4 below)* that are used to balance the pressure between the trunk and the lock the diver is in or is moving to. For this reason, a set of valves is closed on a side and opened on the opposite side of the door, and the 2nd set of valves is organized the opposite way. That allows opening the door from both sides as recommended in IMCA D 024.
  During the diving operation, the doors must be closed, and are opened only when a diver needs to transfer from a chamber to another one. The doors are immediately closed when the transfer of the diver is completed.



Door room side



Door trunk side



Doors entry lock (photo from external door)

- Primary and backup communications to and from the saturation control room must be provided in the chamber. It is achieved through intercoms and a sound-powered phone as a backup. However, other backup systems may exist. It is the case in the chambers of the system taken as an example where each bunk is equipped with a communication system with the entertainment block. These dedicated communications can also be used to transfer private phone calls to the divers in the chamber.
  Also, a depth gauge *(see #5 below)*, a thermometer *(see # 6)*, and a hygrometer *(see #7)* must be in place in each chamber. That allows the divers being informed of these parameters. Also, they may transmit these data if required by the Life Support Technician.
  These elements are sometimes grouped with the communication modules.

Communications grouped with gauges

Communications not grouped with gauges

- Floors also commonly called "deck plates" are installed to allow the divers walking on a flat surface. Also, the used water from the shower in the entry lock is captured under these items, with the water that may result from condensation. In the chamber. DMAC 26 "Saturation diving chamber hygiene" says that these items must be removed, cleansed, rinsed, and dried before starting the diving operations. However, it is also said that when the chamber is under pressure, bilges or floor areas beneath the deck plates should be drained, but should not be actively cleansed or otherwise disturbed during a saturation dive. The reason is that this part of the chamber is considered dirty, and a diver touching it can be contaminated by the pathogens that are contained only in this part of the chamber.

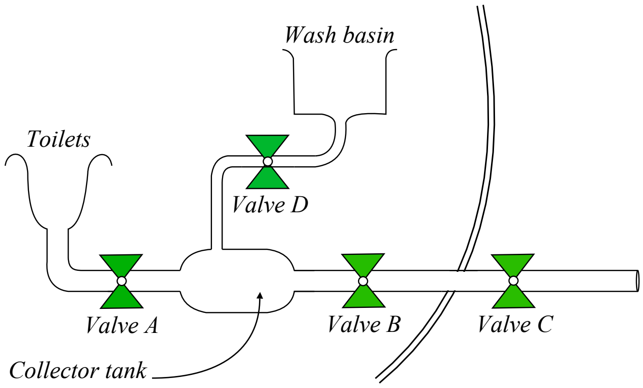
Bilge drain systems used in chambers are composed of a flexible hose that is connected to a spring-loaded ¼ turn valve that opens to the outside of the chamber. When this valve is opened, a depression is established that sucks the liquid outside the chamber. The extremity of the hose is narrower than its main bore to avoid it being plugged.
Spring-loaded valves are ball valves that are maintained closed by the pressure from a spring. Thus they open only when their lever is pressed. Their external safety valve should be closed when draining is completed to prevent leaks.

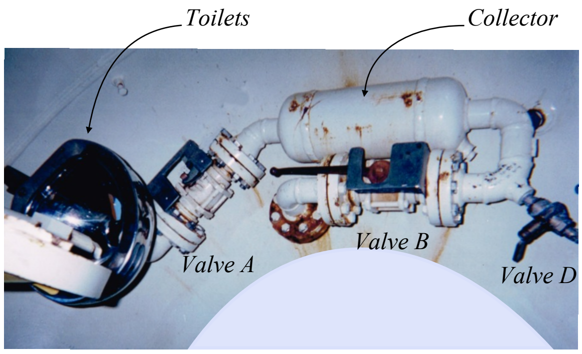
NORSOK and IMCA say that the chamber must have toilet facilities, shower, and wash basin at each living depth.

- Toilets used in chambers are of flush type installed in the entry lock. They are based on a series of receivers at normobaric pressure to which the faeces are pushed by the pressure inside the chamber. As a result, toilet flushing involve the operation of several valves inside and outside the chamber. Depending on the system, the potential main risks are:
    - Danger of the user being disembowelled.
    - Massive gas leak if all valves are open together.
    - Possibility of blocking the system or a valve by accumulation of paper, foreign body, etc.
    - Danger of projection of the tank content into the chamber atmosphere if the tank has not been emptied and purged and the chamber pressure is lower than in the tank due to decompression.

To address these potential accidents, the following elements must be implemented:
- Toilet systems should be designed with interlocking valves, to make sure that the toilet cannot be flushed while it is in use.
- There should always be a gap between the toilet seat and the toilet bowl to avoid any possible lethal suction effects.
- There must be internal or external holding tanks
- For the reasons indicated above, clear procedures must be established and always be followed.

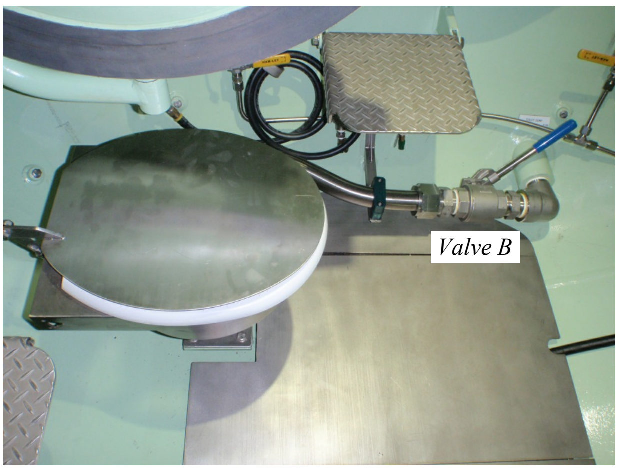
The example below shows an “ancient” system that is still in use:
- While standing by, or during utilisation, the 3 valves A, B, and C are closed.
- After utilisation (valves A, B, C and D closed), the user stands by the system and calls for an assistant outside the chamber.



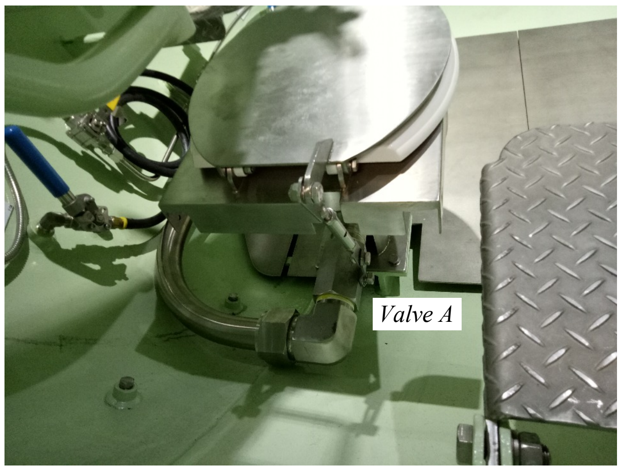


1. The Life Support Technician checks visually through the port that the bowl is clear, opens valve C and remains by the port for the duration of the procedure,
2. User opens valve B
3. User closes valve B
4. User opens valve A (or D)
5. User closes valve A (or D)
6. User opens valve B
7. User closes valve B
8. User cleans/rinses bowl U basin with a disinfectant mixture and the cycle 4-5-6-7 is repeated as required
9. On completion, the assistant outside the chamber closes valve C.

The example below describes a more modern system which is installed on the UDS Lichtenstein:
The principles remain the same, and the main difference is with valve “A” which opens and closes according to the position by the cover of the bowl. This system merely use a lever that opens and closes a big ball valve. other changes are that the receiver is wider and outside the chamber and that the valve B is a spring loaded ¼ turn valve.

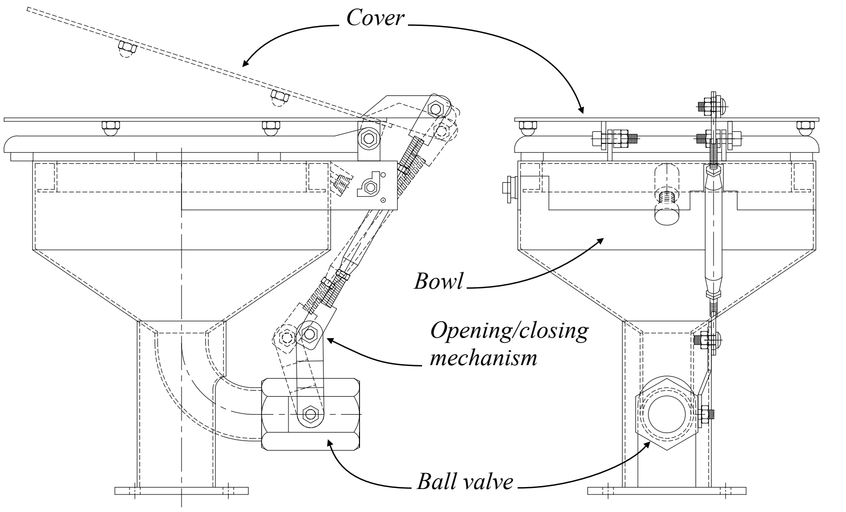


View from the top: Valve B is kept close by its spring



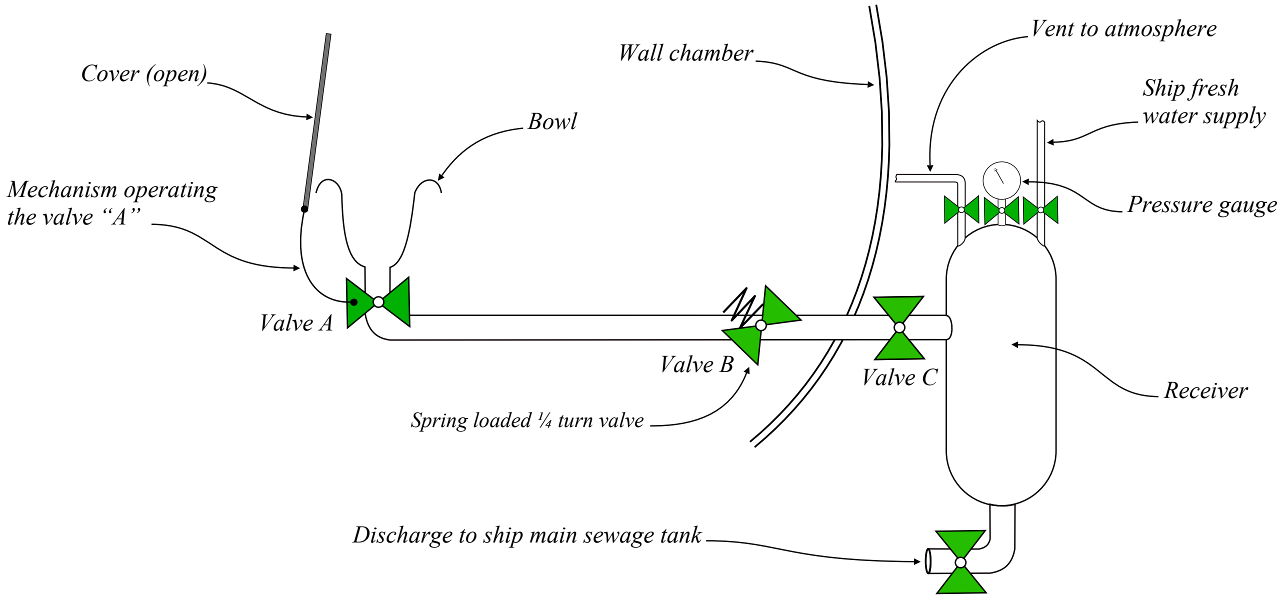
Valve A is operated by a lever connected to the cover

When the cover of the bowl is closed, the valve is open, and when the cover is open the valve is closed. Note that due to this mechanism, the lever of the valve is aligned with the body when the valve is closed and vertical when it is open.

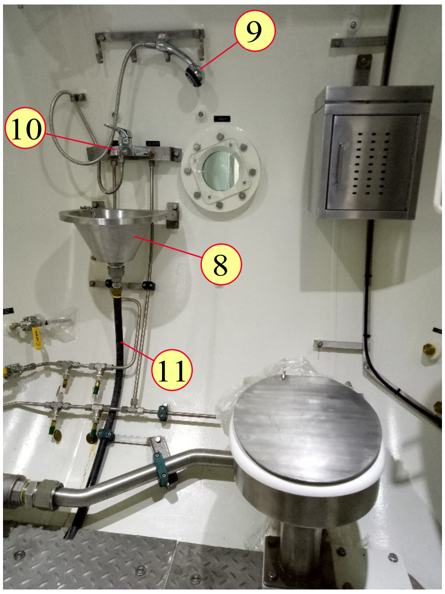


Opening/closing mechanism of the toilets

Receiver at the external



- Shower, and wash basin are also installed in the entry lock. They are supplied with hot and cold water that is pressurised above the ambient pressure of the chamber. Note that the hot water production and the pressurization system are more detailed in the next point.
  As already explained, the dirty water from the shower accumulates under the floor and is evacuated later using the bilge drain system. Note that some chambers are equipped with pre-installed copper pipes instead of the flexible hose already described. Depending on the model of the chamber, the water from the sink is also collected beneath the deck plate *(see in the photo below)* of the entry lock or in a receiver.



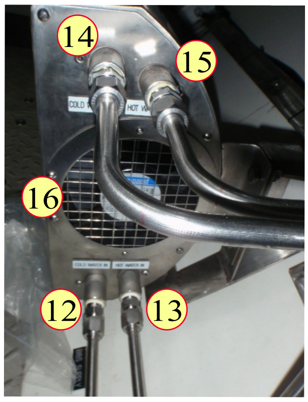
Note that DMAC 26 says that:

- The toilet, sink and shower areas, service-locks and their immediate areas, should be cleansed daily.
- Shower areas should be drained quickly after showering and the floor kept dry.
- Shower-heads should be removed and locked out for cleansing on the surface twice weekly.

Legends:
8 - Sink
9 - Shower
10 - Water inlet sink and shower
11 - Water outlet sink

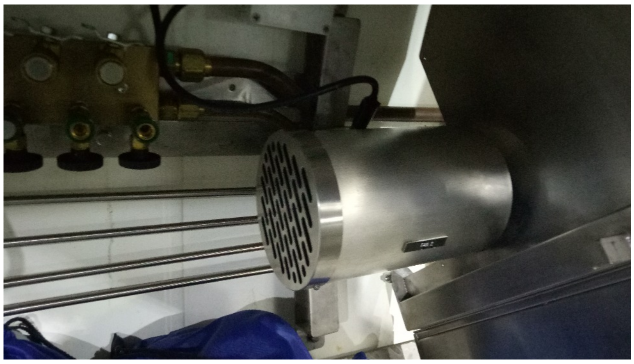
The atmosphere of the chamber must be adjusted at the ideal temperature and humidity levels. With the saturation systems taken as reference, it is done through devices that cool the gas to its dew point to remove the excess of moisture and then reheat it to the ideal temperature. These devices are fitted to the Hyperbaric Environment Regeneration System (HERS) outside the chamber. However, IMCA D 024 says that a secondary system should be available to control humidity and provide heating/cooling in the chamber. For this reason, a device composed of finned tube heat exchangers where cooling and heating mixes circulate and integrated electric fans that favor the circulation of the atmosphere through them (see the photos below) is installed at floor level. Note that some chambers are not provided with chiller & heaters fitted to the HERS system. As a result, in case the primary unit is a chiller/reheater inside the chamber, a second one must be available as a backup.

12 - Cold water inlet
13 - Hot water inlet
14 - Cold water outlet
15 - Hot water outlet
16 - Inserted fan



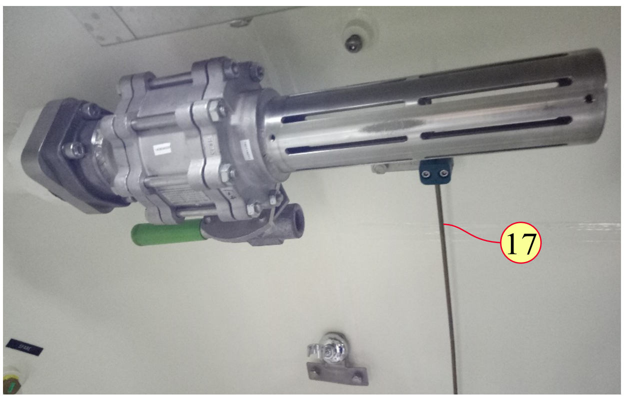
Additional fans are used to ventilate the chamber and increase the efficiency of the heating/cooling system. They are usually at floor level and at direct proximity of the heating/cooling element.

Fan #1 - Eating / recreational side

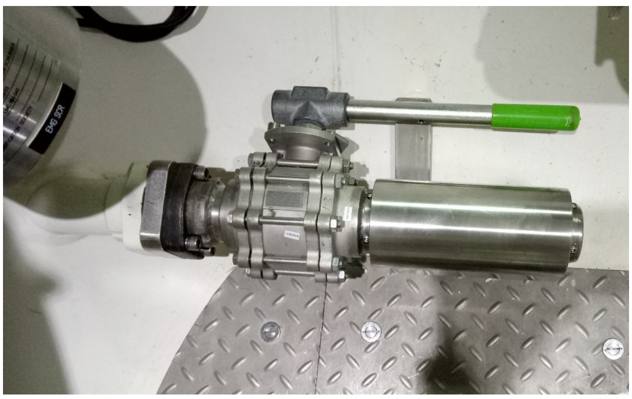


Fan #2 - Sleeping side

The chamber is supplied with gas through gas inlet and gas outlet valves that are operated from the saturation control room and can be isolated from both sides of the hull in case of a sudden leak. As helium is an expensive gas, it is recovered through the "gas reclaim system", which is described in another point.
Another system to recycle the gas is the Hyperbaric Environment Regeneration System (HERS) previously described, which function is to remove the humidity and the CO2 that result from the respiration of the divers. For this reason, it works continually, similarly to the forced ventilation systems commonly used in ships or some large buildings, and it is the reason it uses large pipes. Note that in addition to the "non-return valve" and the "flow fuse" that secure inlet and exhaust, the manufacturer of the system taken as a reference provides valves both sides of the hull. Also, to allow proper ventilation, the inlet is at the top of the chamber, and the outlet is at the floor level.



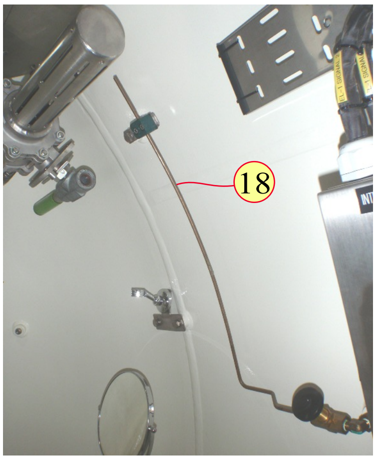
Gas inlet from HERS



Gas outlet to HERS

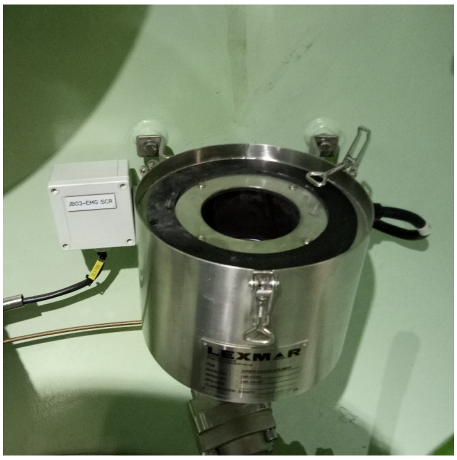
The oxygen consumed by the divers must be renewed. For this reason, a small hose 1/4" is installed with its opening at the direct proximity of the HERS inlet to obtain a proper mixing *(see #17 in the photo above and #18 in the picture on the next page)* Note that IMCA recommends this design.
Also, IMCA D 024 says that a secondary system should also be available to remove the CO_2 in excess. That is generally

achieved by scrubbers similar to those used in the bell. However, these scrubbers are not provided with combined heating systems such as those that can be found in some diving bells: They are composed of only a fan block, energized by 24 volts direct current, to which three or four securing clips attach the perforated canister which is filled with soda-lime. Note that replacement cartridges in sealed bags should be immediately available at all times.



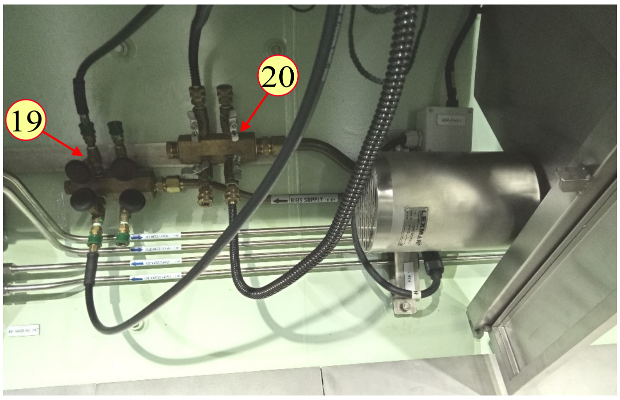
Oxygen supply hose

Scrubber

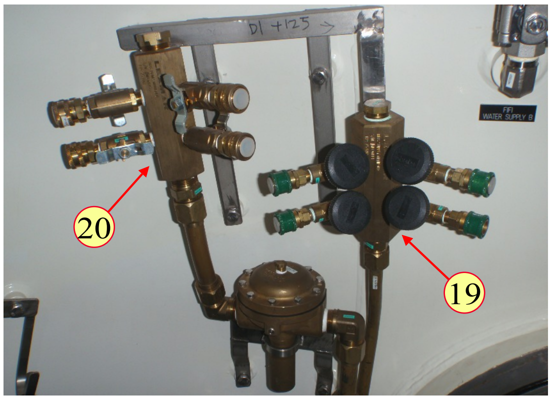


Fan block with the 3 clips

Built-in breathing system (BIBS) connectors and masks must be provided for each diver in each compartment of the chamber. Also there must be one spare BIBS connection and mask available in case of problem with one device. The masks provided are the same as those used in the bell and isolate the mouth and the nose of the user. The connectors are installed on separate manifolds: The gas inlet manifold *(see #19 in the photos below)* groups the gas inlet connectors and the gas outlet manifold *(see #20 in the photos below)* groups the gas outlet connectors which are of a different diameter than the inlet connectors, so it is not possible to confuse them. These manifolds are installed in strategic points and in areas where the are protected from shocks *(see the photos below)*.



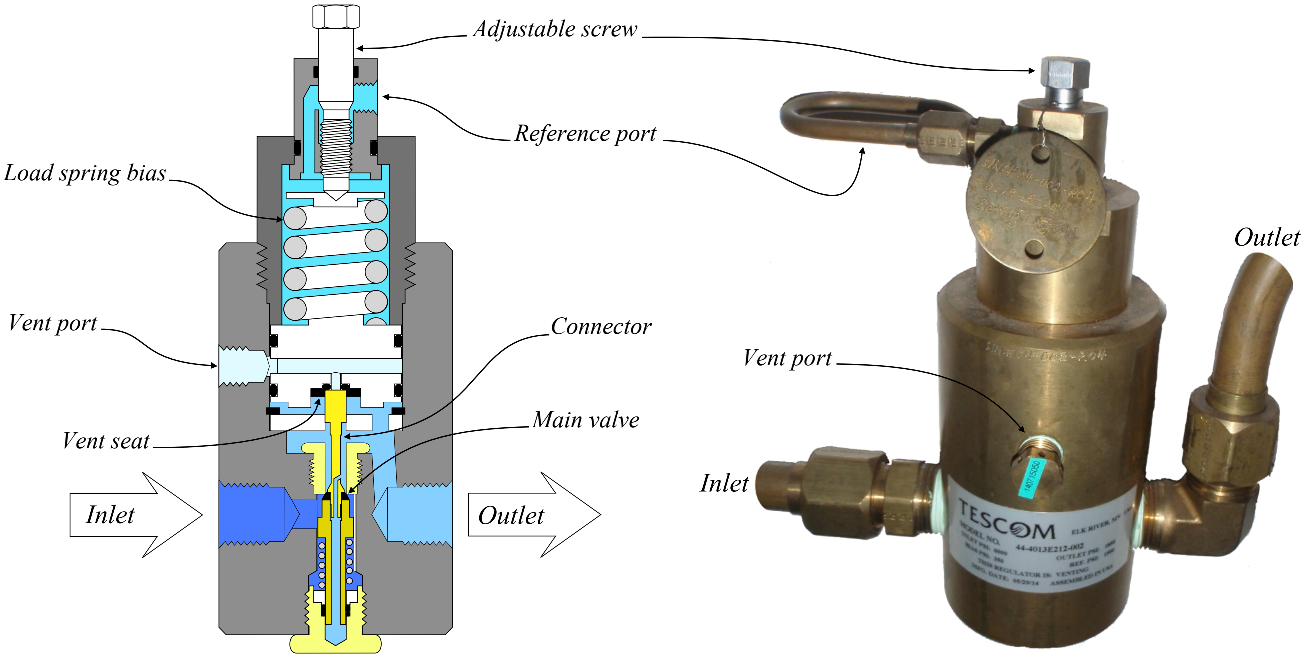
BIBS inlet and outlet manifolds under the bunks



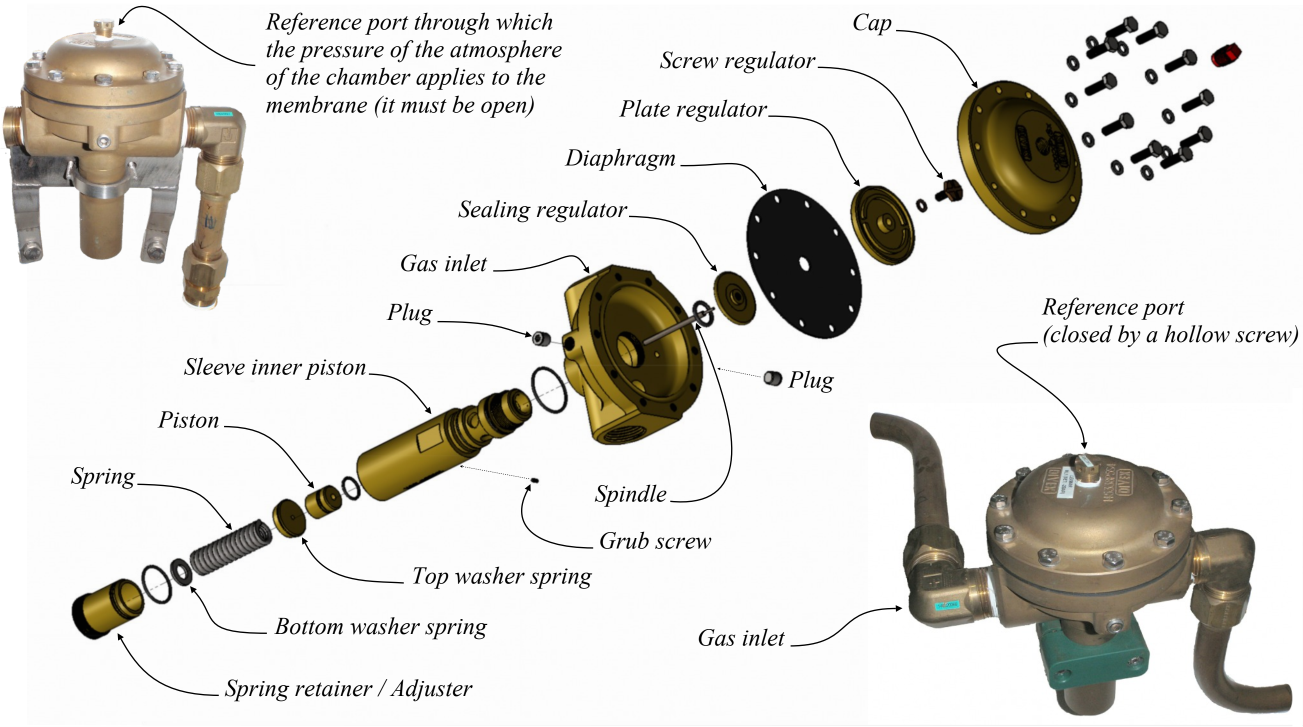
BIBS inlet and outlet manifolds in the entry lock

BIBS Inlet and outlet manifolds and valves. Also, note the valves an systems described previously

Depending on the model, the supply pressure for the mask generally ranges from 5 bar to 12 bar over the ambient chamber pressure. In the chambers use as reference, the gas inlet is provided by a piloted piston regulator *(brand: Tescom / Model: 44-4013E212-002)* which bias pressure is adjustable. As a result this regulator adjusts automatically its delivery pressure according to the pressure of the chamber and the divers do not need setting it up.

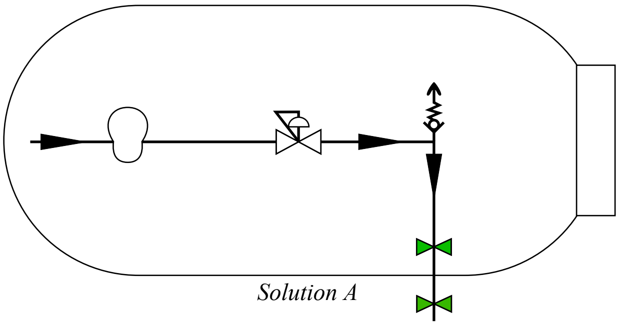


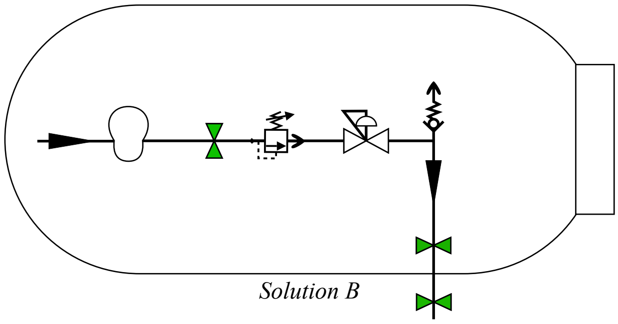
As already explained with the bell, the gas is recovered to the surface by the suction resulting from the differential pressure between the surface and the depth the chamber is stored. However, a too lofty aspiration may injure or kill the divers. For this reason, a back pressure regulator is used to reduce the differential pressure to only 1 bar, and limit the maximum suction to which the diver's lungs may be subjected in the event of a breathing mask mechanical failure.
The outlet from the mask is connected to the inlet of the back-pressure regulator, and its outlet is connected to atmospheric pressure.
The model used in chambers is different from the models that can be found in bells. In the diving system taken as a reference, the manufacturer (LEXMAR) has selected the back-pressure regulator designed by DIVEX (another brand of JFD group). This model, which is designed to operate a depth up to 450 msw, is composed of a spring housing, a mean seat assembly, and a loading dome *(see below)*.

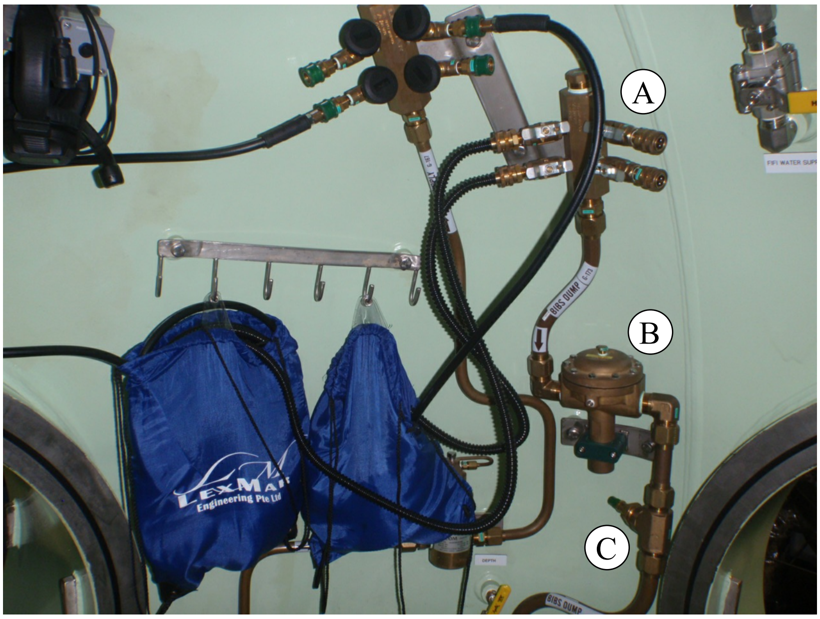


The manufacturer says that the back-pressure regulator (BPR) should be installed such that ambient chamber pressure is applied to the top of the diaphragm (through the reference port).
The regulator can be installed in the chamber or outside the chamber.
In the case of an installation in the chamber, it is possible to isolate the outlet of the BPR, using an outward relief valve *(see solution "A" in the drawing and the photo on the next page)*
If a valve is in place isolating the inlet to the BPR, a bypass relief valve set at 6 bar should be connected between the

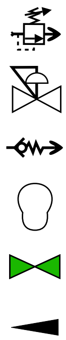
upper dome and the BPR inlet such that excess pressure can be relieved into the inlet of the BPR *(see solution B Below)*.







Legends



Bypass relief valve

Back pressure regulator

Relief valve

Breathing mask

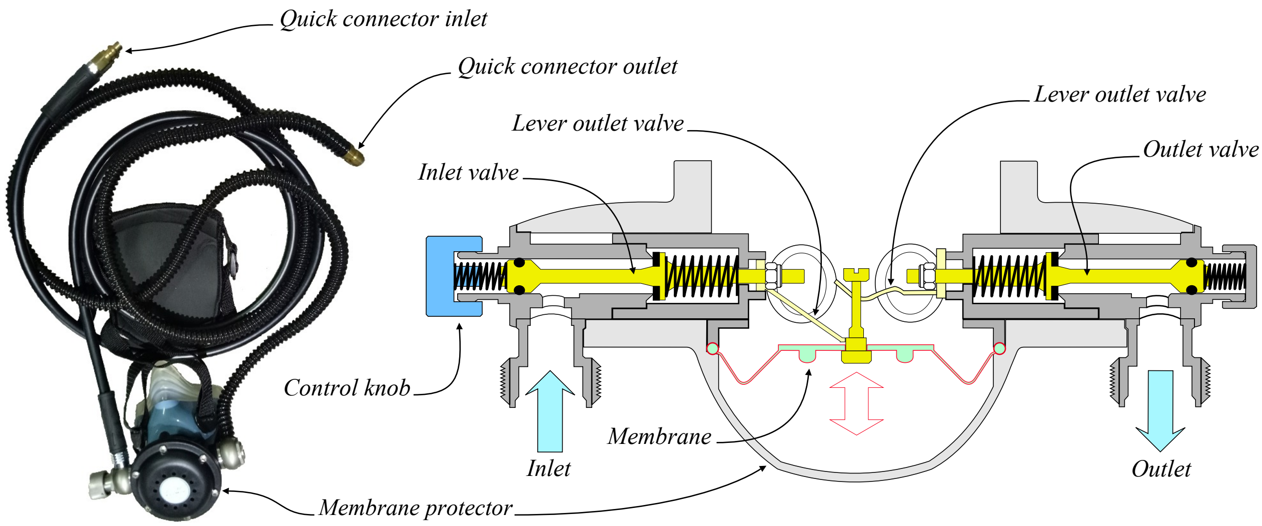
Valve

Direction flux

In the photo:
- *"A" = Manifold with connectors outlet breathing masks*
- *"B" = Back pressure regulator*
- *" C" = Relief valve*

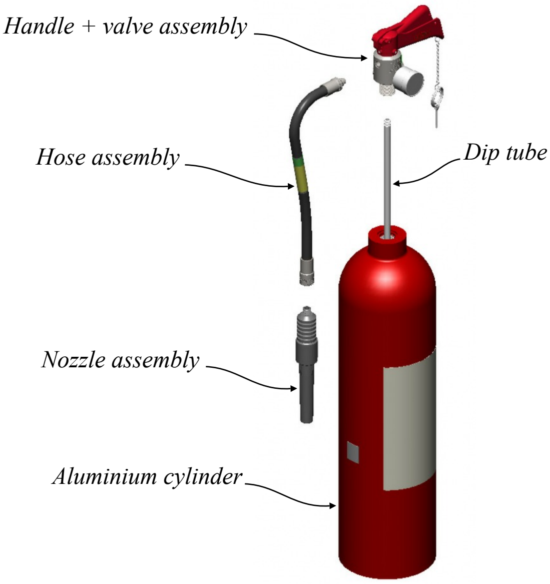
In the case that the back pressure regulator is installed outside the chamber, a tracking pressure (pilot) pipe that is connected to the inside of the chamber is fitted to reference port of the regulator *(see in the drawing in the previous page)*. Note that such tracking pressure connection hose *(see "reference port" in the drawing on the previous page)* is also necessary for the gas supply regulator if it is installed outside the chamber.

Breathing masks are systems that consist of one membrane connected by two levers to an inlet valve and an outlet valve. When the diver inhales, the movement of the membrane opens the inlet valve and closes the outlet valve. When the diver exhales, the movement of the diaphragm closes the inlet valve and opens the outlet valve. The sealing parts with the face are made of rubber or silicone.



Portable and fixed fire fighting systems must be installed in chambers. NORSOK standards U100 says:
Facilities for manned underwater operations shall have fire detection and firefighting equipment covering the entire plant both internally and externally. The equipment shall have adequate capacity to put out fires that might occur. Activation shall be possible both internally in the chamber and externally in chamber control independently.
There shall be facilities to maintain chamber cooling and control the temperature for the occupants in the chamber complex during an external fire. The above includes the Self Propelled hyperbaric Lifeboats (SPHL) and the SPHL launch areas.

Several national regulations and classification societies impose similar rules to those recommended by NORSOK. Also, most last generation saturation diving systems are equipped with means for fire detection, fixed firefighting systems, and at least one hyperbaric extinguisher in each chamber. However, some national regulations do not impose fire detection and fixed firefighting systems. As a result, some old saturation systems in use in these areas may be equipped with only portable firefighting means.
The hyperbaric extinguishers are usually of "Stored-pressure extinguishers" type that contains the extinguishing agent at the bottom with the rest of the vessel filled with the propellant gas. The main difference from the models used outside the chamber is that the pressure of the propellant gas, which is heliox, is approximately 100 to 130 bar for hyperbaric extinguisher instead of 12 - 17 bar with the models used in normobaric conditions.



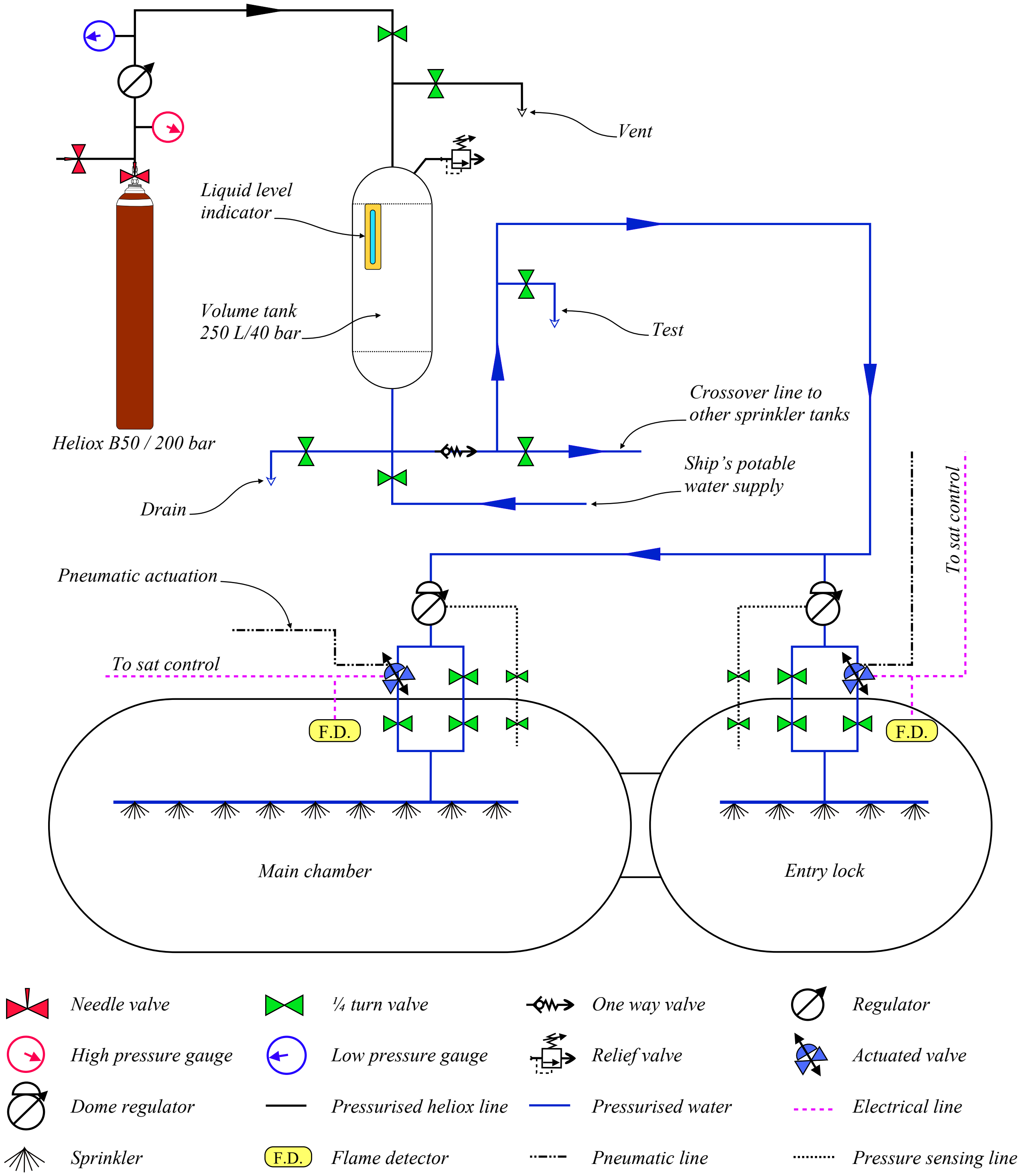
The extinguishing agent used in these extinguishers is an Aqueous Film Forming Foam (AFFF), which is suitable for fabrics, combustible solids, flammable liquids, and electrical fires up to 24 Volts. Note that its technical sheet indicates that this product is not considered harmful to aquatic organisms nor to cause long-term adverse effects in the environment. However, it is also recommended not to be in direct contact with this foam, so wear skin and eye protection and wear suitable respiratory equipment.
Opposite with some "stored-pressure extinguishers" designed for use in the normobaric atmosphere, some of the hyperbaric extinguishers are designed to be refilled on site. It is the case of the one proposed by Divex, who provides foam refill bottles and a dedicated charging fitting.

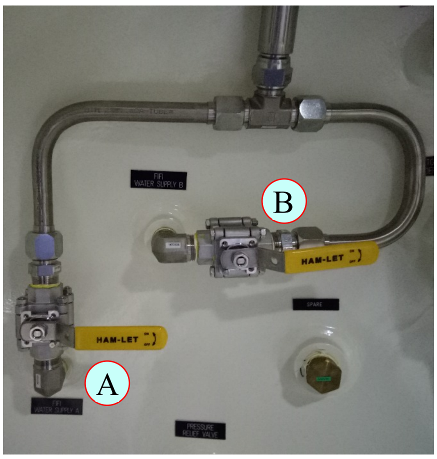
Three main systems can be used used to detect a fire: Flame detectors, heat detectors and smoke detectors.

- Flame detectors are optical equipment for the detection of flame phenomena of a fire. Several principles can be used: Ultraviolet (UV) detector responds to radiation in the spectral range of approximately 180 to 260 nm, a visible light sensor (for example a camera: 0.4 to 0.7 µm) is able to present an image, which can be recognized by a computer. These detectors are common in hyperbaric chambers.
- A heat detector is a fire alarm device designed to respond when the convected thermal energy of a fire increases the temperature of a heat sensitive element. These systems are very common outside chambers, but not inside.
- Most smoke detectors work either by optical detection (photoelectric) or by physical process (ionization), while others use both detection methods to increase sensitivity to smoke. These systems are also very common outside chambers, but not inside.

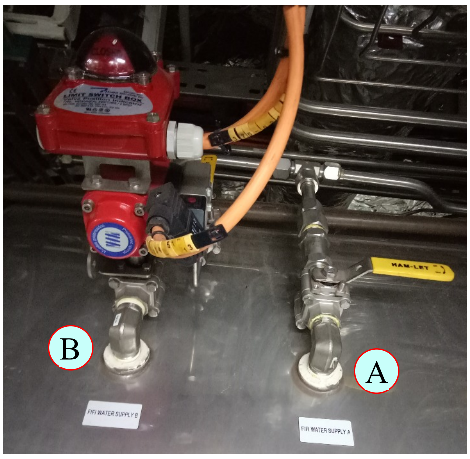
Fixed water deluge extinguishing system is highly recommended in chamber compartments that are designed for manned operations. Also, as indicated previously, these systems are mandatory in several countries.
The systems consist of water supplied to the chamber through a number of spray nozzles. In chambers that consist of more than one chamber compartment (lock), the design of the deluge system should ensure adequate operation when the chamber compartments are at different depths. The design should also ensure the independent or simultaneous operation of deluge systems.
A deluge system manual activation/deactivation controls should be located at the operator's console in the saturation control room and in the chamber. They should be designed to prevent unintended activation. Also, most modern systems are equipped with an automatic activation.
According to NFPA 99 - Health Care Facilities Code (National Fire Protection Association), the water should be delivered from the sprinkler heads sufficient to provide reasonably uniform spray coverage with vertical and horizontal or near horizontal jets. Average spray density at floor level should be not less than 80 litres per minute within 3 seconds of activation of any control.
There should be sufficient water available in the deluge system to maintain the flow as specified simultaneously in each chamber compartment (lock) containing the deluge system for 1 minute. The limit on maximum extinguishment duration shall be governed by the chamber capacity and/or its drainage system.
The system should have stored pressure to operate for at least 15 seconds without electrical branch power.
All electrical leads for power and lighting circuits contained inside the chamber should be automatically disconnected.

The drawing below summarizes the design of the deluge system described on the previous page.





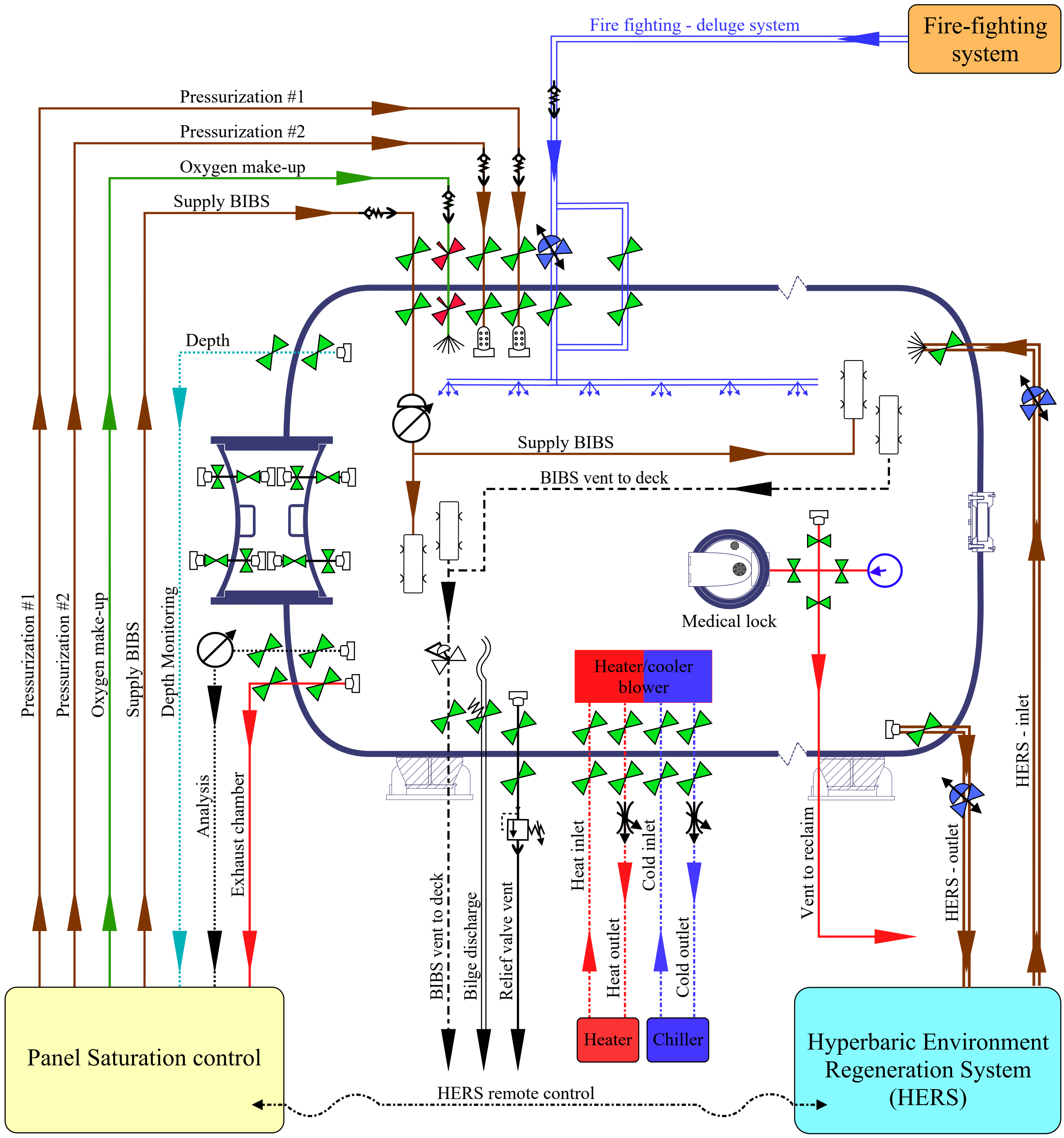
Internal manual (A) & actuated (B) valves



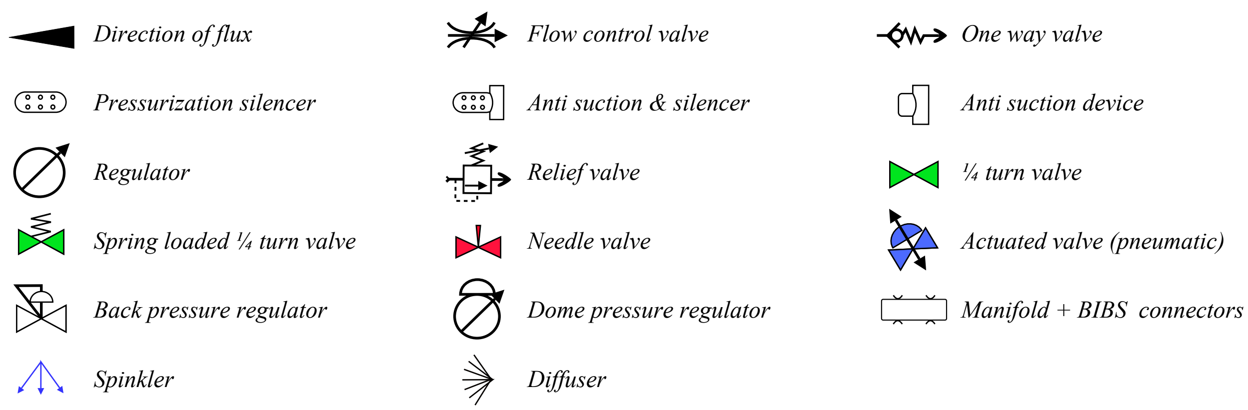
External manual (A) & actuated (B) valves

Volume tank & its pressurization sys.

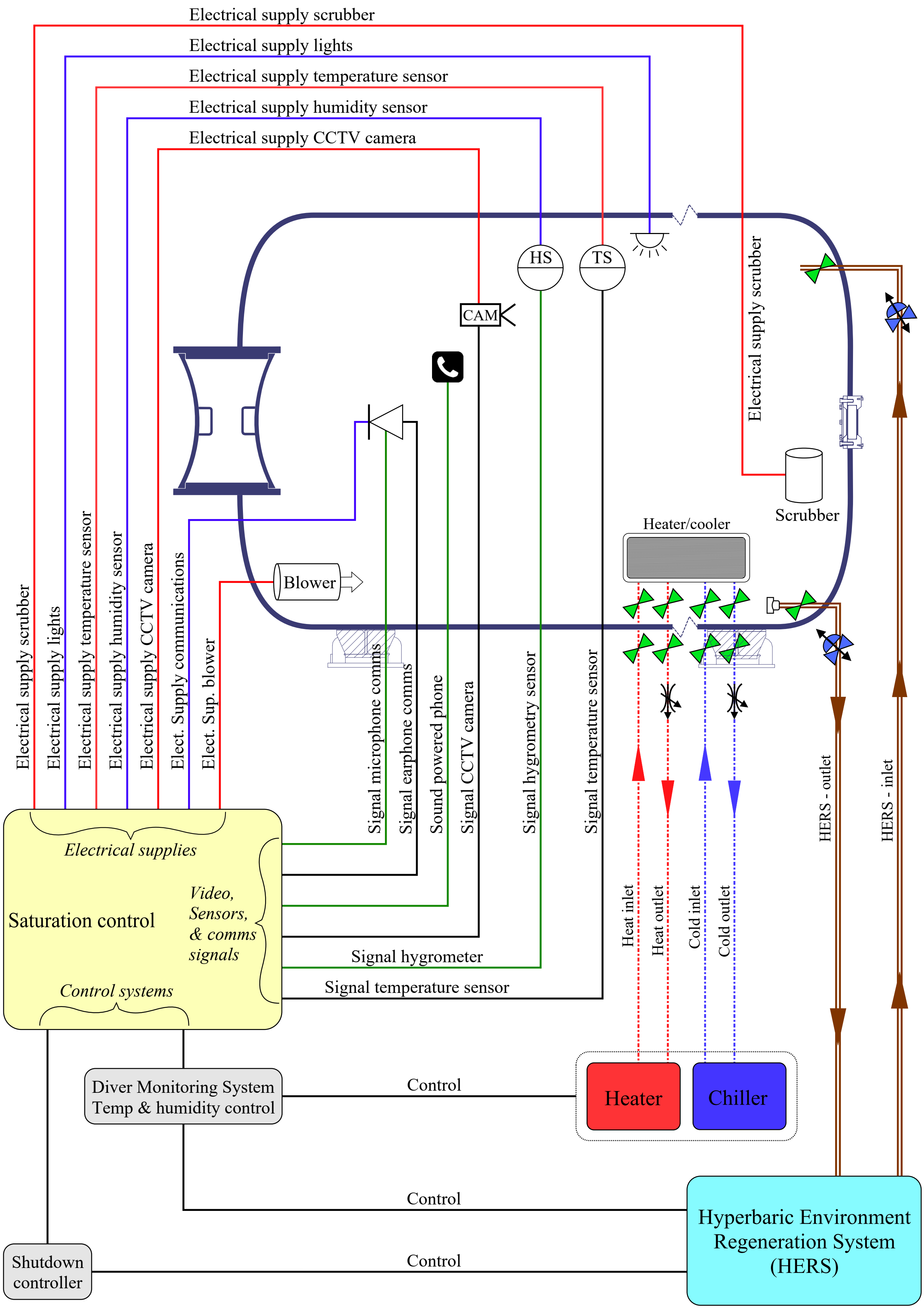
The scheme below summarizes the gas inlets and outlets and elements of the Environment Control Unit (ECU) of the main living chamber that are described on the previous pages.



LEGEND

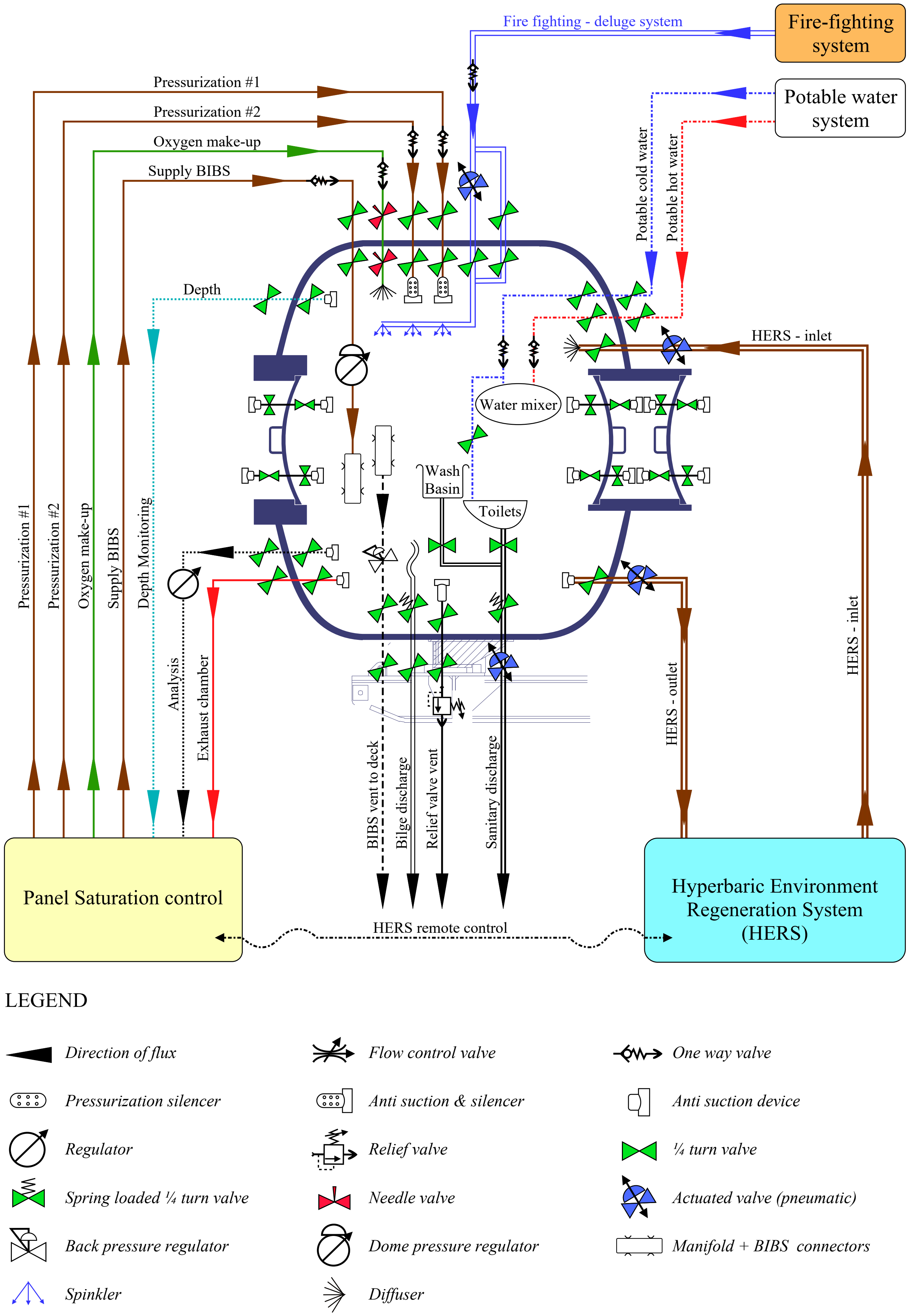


The Drawing below is the continuation of the drawing displayed on the previous page. It represents the primary electrically powered devices of the Environment Control Unit (ECU), lights, communications, and video circuits of the main chamber that are operated and monitored from the saturation control room.

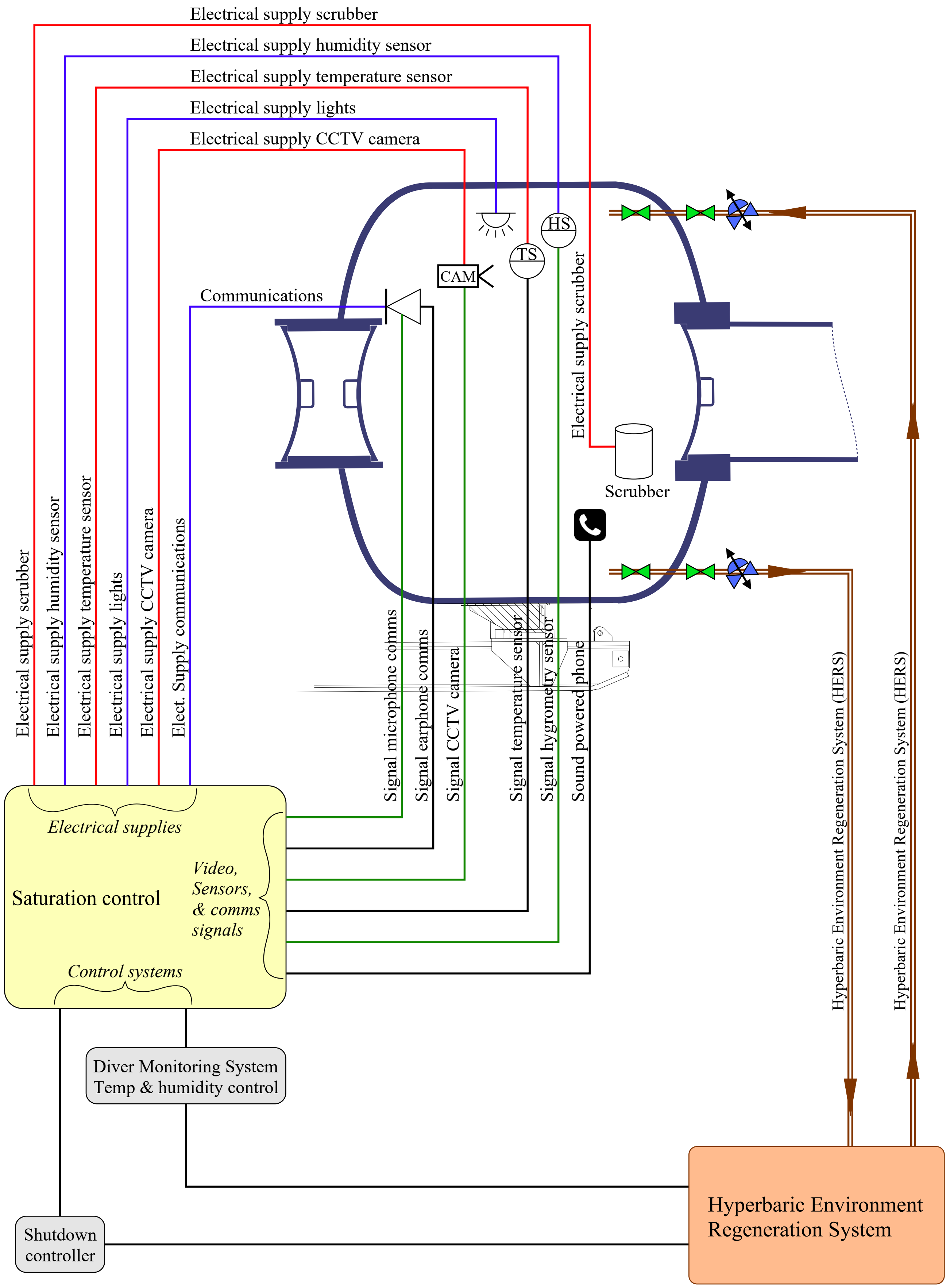


Hyperlink Table of contents

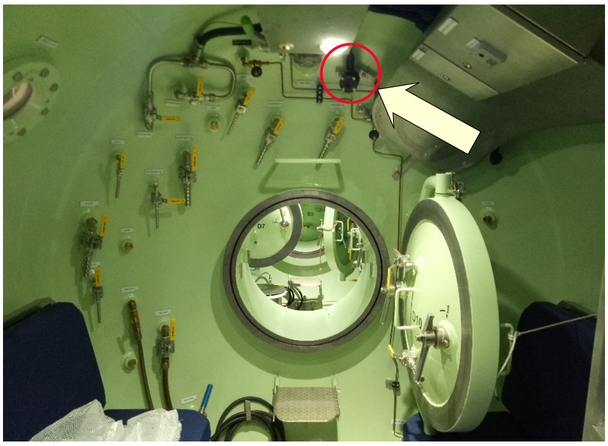
The scheme below summarizes the gas inlets and outlets and elements of the Environment Control Unit (ECU) of the entry lock that are described on the previous pages.



The Drawing below is the continuation of the drawing displayed on the previous page. It represents the primary electrically powered devices of the Environment Control Unit (ECU), lights, communications, and video circuits of the entry lock that are operated and monitored from the saturation control room.



Close Circuit Television (CCTV) cameras that are connected to the saturation control room should be installed in strategic points of all chambers to allow the Life Support Technician (LST) being aware of what happens in the chamber. They are usually installed at the top and the extremity of the room to witness *(see in the photo below)* so the LST has a panoramic visual of the chamber.
The models used can be underwater cameras that are also found in the bell, with the divers, or with Remotely Operated Vehicles (ROV). The advantage of using such cameras is that they are designed to work in harsh environments. Also, they generally provide high resolution, low light sensibility, and a wide-angle view.
Specific digital high definition CCTV cameras in dedicated housing are also used. The advantage of the last generation systems is that they can be panned and zoomed by the operator using the integrated touch-screen on the panel PC display.



Hemet/ROV camera

High definition camera in housing rated to 350 MSW

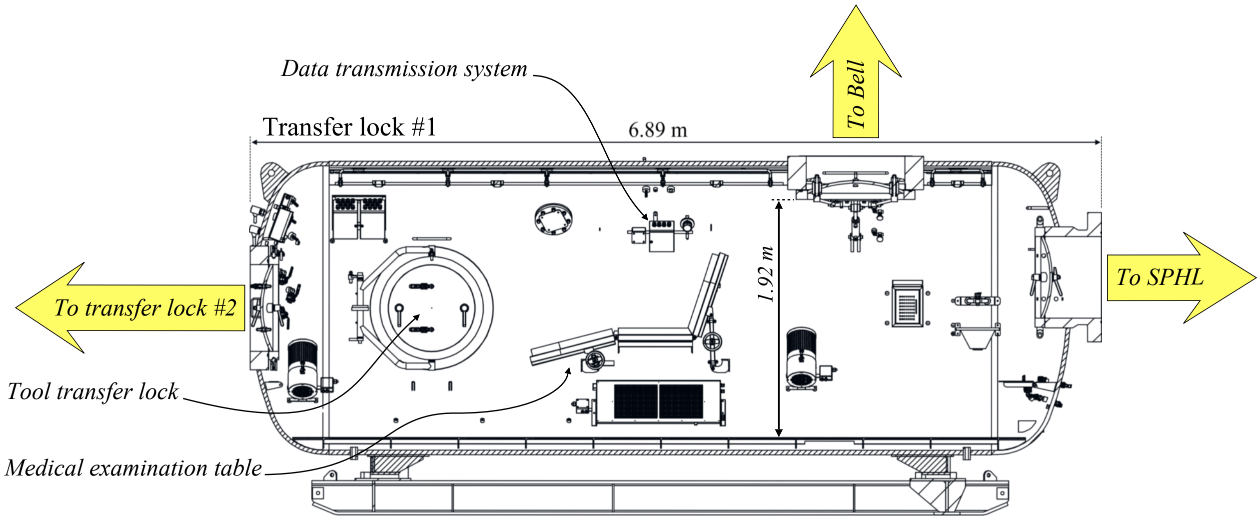
1.2.2.3 - Transfer lock

Transfer locks are chambers that allow moving from the living chamber to the bell and vice versa and transfer the tools and clothes. Note that with some small portable systems, the function of the "transfer lock" and the "entry lock" are combined in one chamber instead of two.
Also IMCA D 024 says that one compartment of the chamber system must be available to provide emergency medical treatment to an injured diver under pressure according the the recommendations from DMAC 28.
DMAC 28 says that this chamber must be accessible by any diver in the system within a reasonable time (30-60 min), taking into account any need to change chamber pressure, and should have the following:

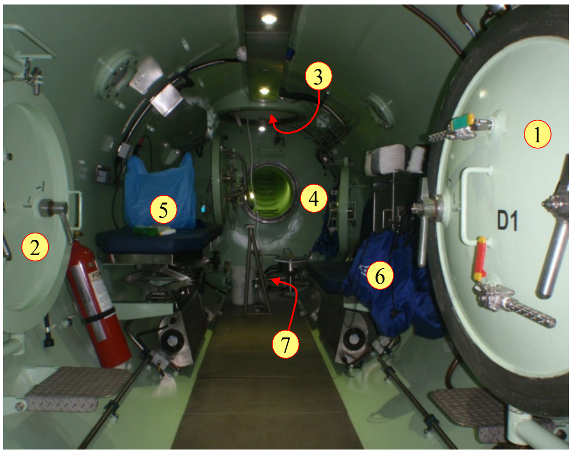
- A minimum internal diameter of 1.8 metres (6 feet) but preferably exceeding 2.15 metres (7 feet);
- The ability to remove, or move out of the way, bunks and other equipment normally fitted to the chamber but not needed directly for a medical emergency;
- A bunk for the patient which should:
- be waist high
- have access from at least one side and preferably both, from the head end, have a firm base and be able to tilt the patient to 30° both at the foot and head ends
- be provided with a mattress;
- A tray or working surface for medical instruments;
- A means for suspending IV drips overhead the patient (hooks or similar);
- A convenient medical lock of at least 300 mm diameter;
- A good communications system with connections in a suitable location for personnel beside the casualty;
- Suitable extra lighting for the area of the casualty. This may be the normal bunk lights fitted with long leads to reach the treatment area;
- Sufficient additional gas and electrical hull penetrations (in order to ensure that in an emergency appropriate gas and electrical supplies can be rapidly connected) as agreed with the specialist medical adviser (see sections below);
- Sink facilities (with foot or elbow operated taps) to be provided in the vicinity of the patient's bunk.
- The doctor onshore should be able to speak directly to the patient and person inside the chamber who is treating him. For this reason, communication links, which enable effective communication between the offshore worksite and medical support onshore, are essential and must be unscrambled.
- Electronic transfer of information, data, still and video images and speech using the Internet and satellite communications systems should be standard practice. Where available, direct video conference facilities between the chamber and doctor onshore provide the best method of communication.

The list above shows that the main chambers and their entry locks that are already congested are not adapted for this function and that a chamber that is large enough must be used for this purpose. Also, an injured diver may have to be transferred directly from the bell, and the transfer lock that is directly in communication with it and designed for the transfer of wet people is the most convenient. As a result, a medical examination table is provided in it with a diver medic kit. Also, a system that allows a doctor who is remote in his office visualizing the essential information of a patient in the chamber at the same time a medical intervention is practiced should be ready for use.

In addition to the above, and as it can be seen in point 1.2.2.1, the transfer locks are also the rooms through which the divers can transfer to another chamber and the SPHL. On large systems with two transfer locks, these chambers are linked together by a trunk allowing to move from a chamber to both bells, another chamber, or any self-propelled hyperbaric lifeboat (SPHL).



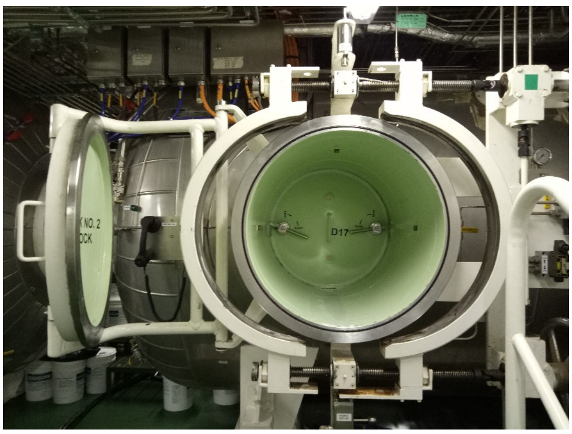
Note that a step is necessary to transfer to and from the bell

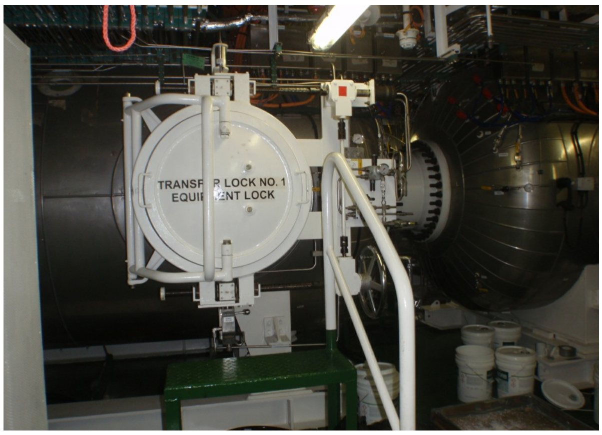


Transfer lock #1 from transfer lock #2 UDS Lichtenstein:
- *#1: Door trunk to transfer lock #2*
- *#2: Door tool transfer lock*
- *#3: Trunk to bell*
- *#4: Trunk to SPHL*
- *#5: Medical examination table*
- *#6: Breathing masks*
- *#7: Step to access to the bell trunk*

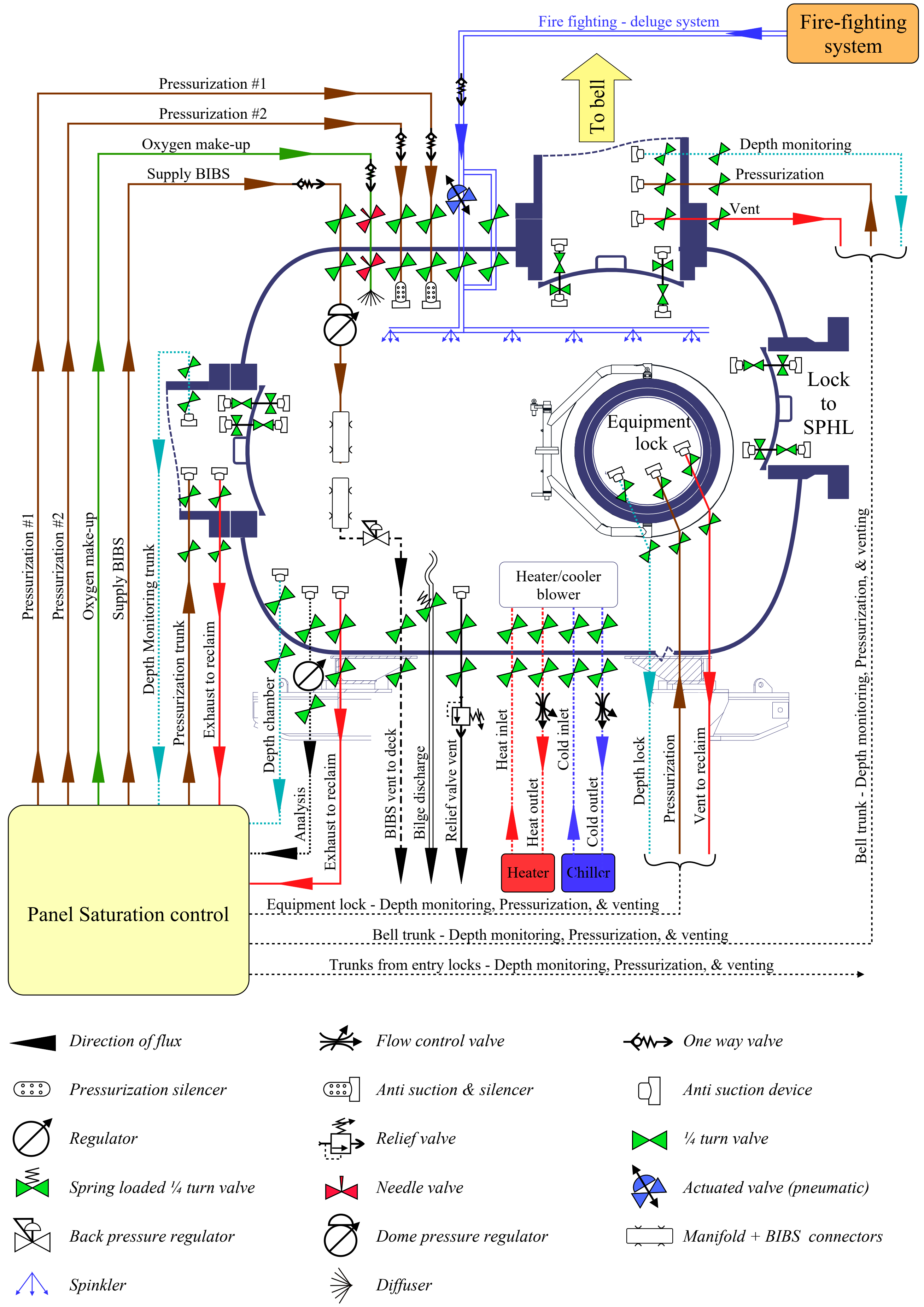
Medical examination table transfer lock #2 UDS lichtenstein
- *#8: Connectors of the system that allows a doctor who is remote visualizing the essential information of the patient*
- *#9: Communication block*
- *#10: heating / cooling element*

The tool transfer lock has a diameter of 800 mm or above. As with the medical locks its external door works against the pressure, so it can be opened by the internal pressure if it is incorrectly closed or opened while the lock is under pressure. For this reason, and similarly to the medical locks, a safety interlock system must be fitted to the clamping mechanism securing the outer door. Also, this interlock must make it impossible to open the mechanism/door if there is still pressure inside the lock and impossible to obtain a gas tight seal on the lock if the door/mechanism is not properly closed. Because this door is large, the mechanism used with the medical locks is replaced by a system that is very similar to those used to secure the bell to the transfer trunk *(see below)*.

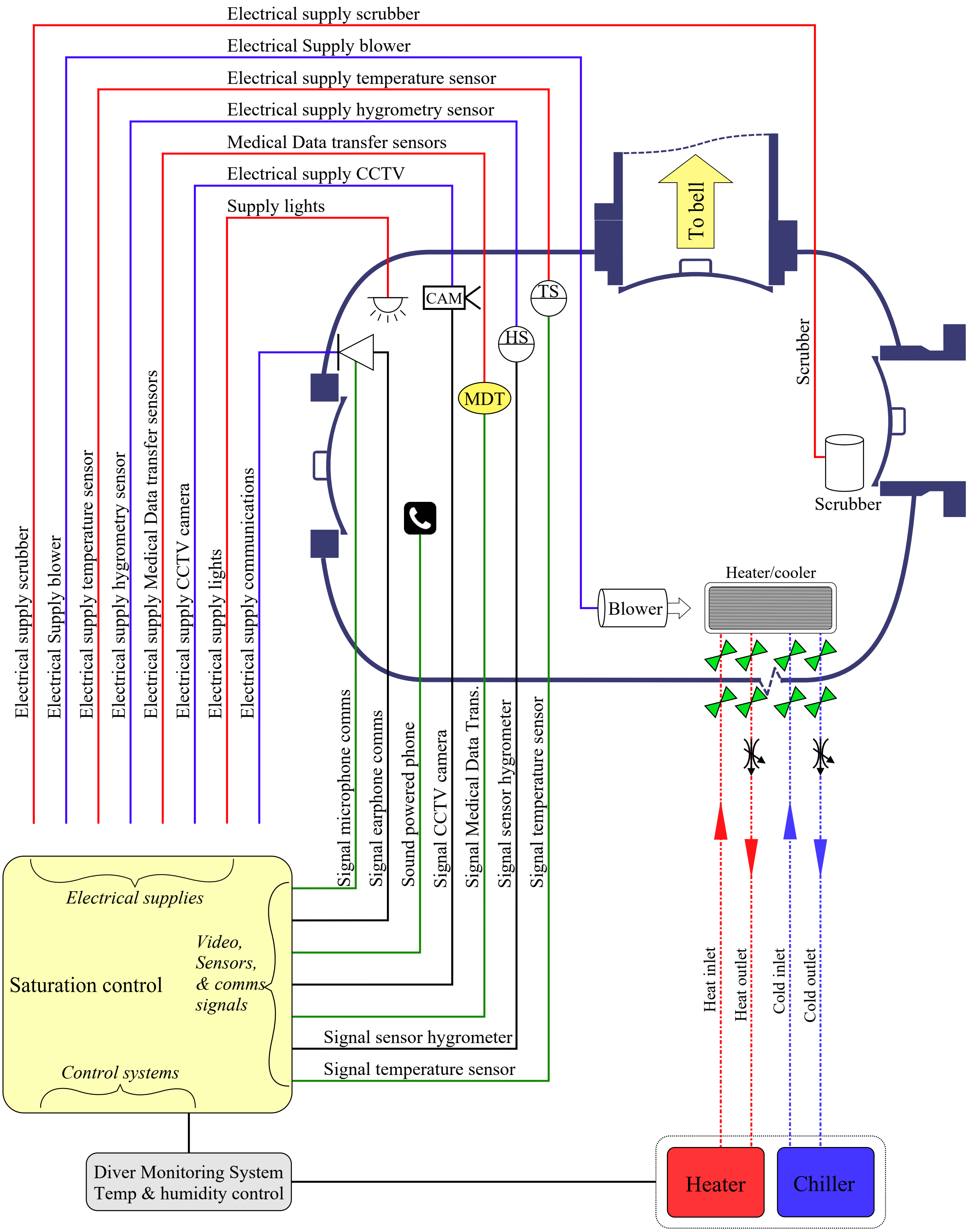




The gas supplies and exhaust are the same as those of the main living chamber. However, this chamber is not fitted to the Hyperbaric Environment Regeneration System (HERS). One of the reasons is that it is in direct communication with the bell and can be contaminated by pathogens and harmful chemical substances, which could be drawn into the complex circuit of this system, which is not designed to remove them. That would oblige to dismantle it in full to clean it. Another reason is that the divers do not stay a long time in this chamber, which is, as indicated, only used to transfer to and from the bell and must be adjusted to their storage depth before starting the bell run.



The Drawing below is the continuation of the drawing displayed on the previous page. It represents the primary electrically powered devices of the Environment Control Unit, lights, communications, and video circuits of the transfer lock that are operated and monitored from the saturation control room.



The rules regarding the organization of the valves, penetrators, floors, viewports, doors, light, etc. are the same as those applied with the other chambers.
Note that transfer locks are fitted with shower and toilets that can be used in parallel with those of the entry lock or as the only available devices with systems where the chambers are not provided with entry locks.

Important point:
In case of a transfer to a bell fitted with a bottom door, a step stool is usually necessary to access the hatch that is installed at the ceiling. This device must be strong enough not to be damaged and designed to be secured, so the divers will find it in place when returning from the bell run when the vessel is rolling and pitching.

1.2.2.4 - Maintenance

The maintenance of the chamber should be performed according to the recommendations of IMCA D 024 and from the manufacturer. The rules from IMCA D 024 are the same as those in place for other devices.

Part of the chamber	Items	Visual external + function test , calibration	Visual internal + external + gas leak test at max. Working pressure	Internal + external+ leak test 1,5 max. working pressure	Other
General	Chamber testing	6 months	2 ½ years	5 years	
General	Viewports	6 months	2 ½ years	5 years	10 years old max.
General	Fire fighting portable system	6 months			Manufacturer specifications
General	Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
General	Automatic fire detection	12 months			
General	Medical equipment (DMAC 15)	6 months			
External	Electrical equipment penetrators	6 months			
External	Interlock pipework	6 months	2 years		
External	Pressure relief valves	6 months	2 ½ years		
External	Communication	6 months			
External	ECU Flow fuse	6 months	12 months		
External	Pipework	6 months	2 years		
External	Electrical	6 months			
Internal	Communication	6 months			
Internal	BIBS system	6 months			
Internal	Sanitary system	6 months			
Internal	Fire fighting portable system	6 months			Manufacturer specifications
Internal	Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
Internal	Automatic fire detection	12 months			
Internal	Gauge calibration	6 months			
Internal	Integral test of the entire Environmental Control Unit (ECU)	6 months			
Internal	Valves & pipework	6 months	2 years		
Internal	Lights and cables	6 months			
Internal	Medical data transmission system	6 months			Requested by Norsok & IOGP

Note that the guidelines from IMCA must be applied at least every six months. However, this frequency can be increased. Also, the following daily, weekly, and monthly maintenance should be organized during the operations.

Daily maintenance:

- Careful visual inspection of the internal and external of the chamber.
- Close visual inspection of the medical and equipment locks and their O' rings.
- Visual examination and if possible function test of the components as per the initial pre-dive check list

Weekly maintenance:

- O-rings should be removed, cleaned, and re-greased with a film of silicone grease.
- Medical locks should be checked for cleanliness
- Cleaning of the chamber walls with an appropriate disinfectant.

Monthly maintenance:

- Close inspection of viewports, pipework, electrical wiring, hull penetrators, isolation.
- Close inspection and function checks of the interior lighting, heaters, and scrubbers.

After the dive:

- All the above + opening of the floors and full cleaning and disinfection.
- Rust removal if relevant.

1.2.3 - Water supply and waste removal

1.2.3.1 - Purpose

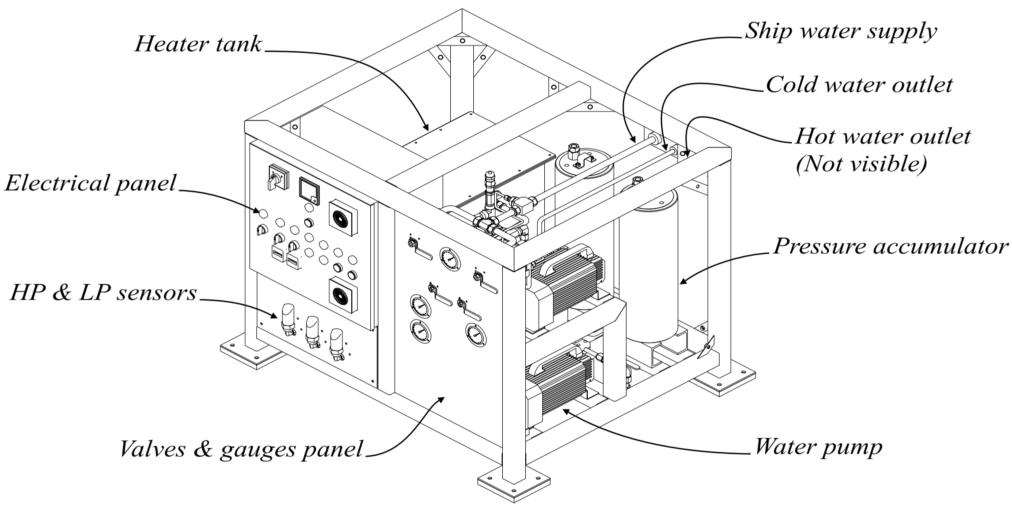
The bathroom of the chamber must be supplied with fresh water. However, this water must be pressurized above the ambient pressure to be able to enter it. Also, the chamber is designed to have an internal pressure that varies in function of the diving operation ongoing. For this reason, the system that distributes water must be designed to adapt to these conditions. Also, as indicated in the previous point, the used water that accumulates below the floor must be removed from the chamber and sent the sewage system of the ship as for the feces from the toilets. The items described below are designed for this purpose.

1.2.3.2 - Source and quality of the fresh water used in chambers

The freshwater distributed in the chambers is of drinking quality that must, at a minimum, conform to the guidelines provided by the World Health Organization.
This water can be directly transferred to the dedicated tanks of the vessel from a specific barge, another ship, or the jetty. Also, it can be fabricated onboard through reverse osmosis systems or generators that use the evaporating method.
Reverse osmosis systems use a semi-permeable membrane that allows molecules of water to pass and blocks the salt as well as all the organic compounds. With the machines that use the evaporation method, the seawater is heated to produce steam that is then cooled and stored in a proper water tank. The heat source is often the hot water from the cooling system of the engines. However, this water is at a temperature of approximately 70 Cº, which is insufficient to boil the saltwater. For this reason, the atmospheric pressure of the chamber where the evaporation takes place is reduced to obtain the relevant boiling point. When they are well maintained, these systems provide water with fewer germs than the water from the shore. Reverse osmosis systems allow to produce more water, and for this reason, they are the most used method on vessels where there is a significant need for freshwater production.
Storage tanks and distribution piping of the water to be used in chambers must be organized to prevent them from being contaminated. For this reason, they must be isolated from the other tanks and not located near any oil tank. Also, these systems, that must be part of the planned maintenance system of the ship should be inspected at regular intervals and disinfected with chlorine solutions. For this reason, they are designed in such a way to allow easy drainage and cleaning, and specific coatings are used to protect them from corrosion without affecting the quality of the water.
Regular analysis of water samples should be done at least every week on Diving Support Vessels. Also, some maritime organizations recommend cleaning the potable water storage and distribution systems every 12 months as a minimum. However, this frequency should be adjusted according to the provenance of the water.
Maritime safety organizations also recommend the use of filters and treatment equipment such as UV lamps to kill pathogens, pH neutralizers *(also called Acid Filters)*, and softeners that remove minerals such as calcium, and lime deposits, to improve the quality of the water.

1.2.3.3 - Potable water distribution system

The potable water from the vessel is distributed to the chambers through a “water machine” that consists of an assembly containing pumps, accumulators, an electrical power supply, and controls that distribute it at the relevant flow and pressure. As an example, the machines used with the saturations systems taken as references in this manual are able to deliver potable water at a flow rate of 8 L/min and a pressure up to 90 bar. Also, these machines are designed to produce hot water and for this reason, they are equipped with a water tank and one or several heating elements.
The cold water is taken directly from the supply circuit of the boat that delivers it at a flow rate of 20 L/min and pressures of 3 - 6 bar with the system taken as reference and is then pumped to the chamber. The hot water is stored first in the tank and heated up to 50 Cº before being sent to the chamber when required. A ball-float valve allows filling the tank and stopping the water inlet when it is full. Also, a level switch stops the pump and heating elements if the water supply fails.
Piston accumulators are installed downstream of the pump of each circuit to eliminate fluctuations in pressure and flow within the system. Also, they allow for small volumes of water to be supplied without starting the pump.
High-pressure sensors/transmitters that are set at the maximum allowable pressure *(90 bar with this example)* are installed downstream of the pumps to control the pressure of water stored in the accumulators.

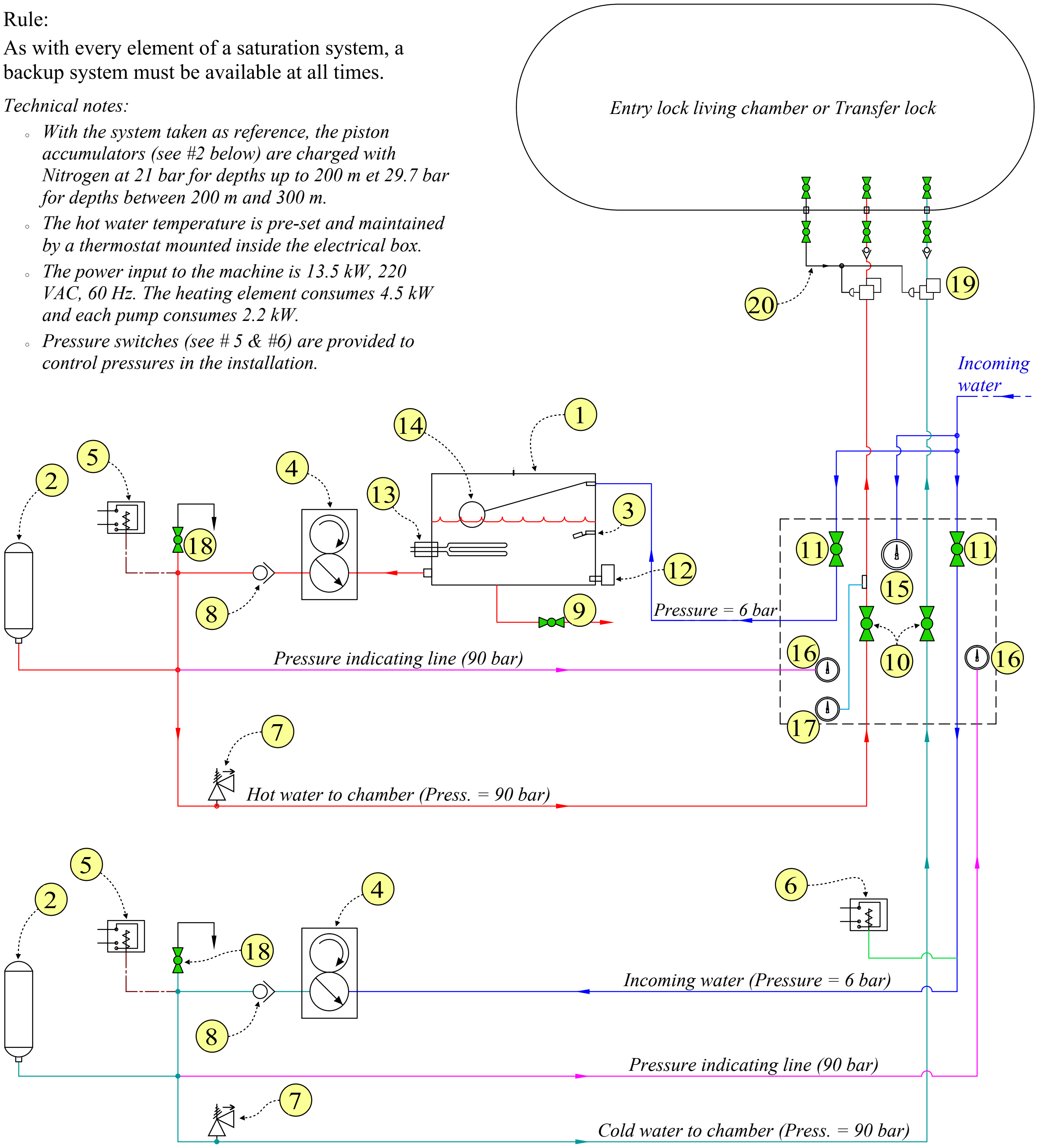


Dome-loaded regulators regulate the water supply to 5 bar above the chamber internal pressure through depth sensing lines. They are placed at the external of each entry lock or transfer lock to supply with water *(see #19 & #20 below and the photo on the next page)*. Pressure relief valves *(see #7 below)* are installed to protect the circuits from overpressure.

Rule:
As with every element of a saturation system, a backup system must be available at all times.

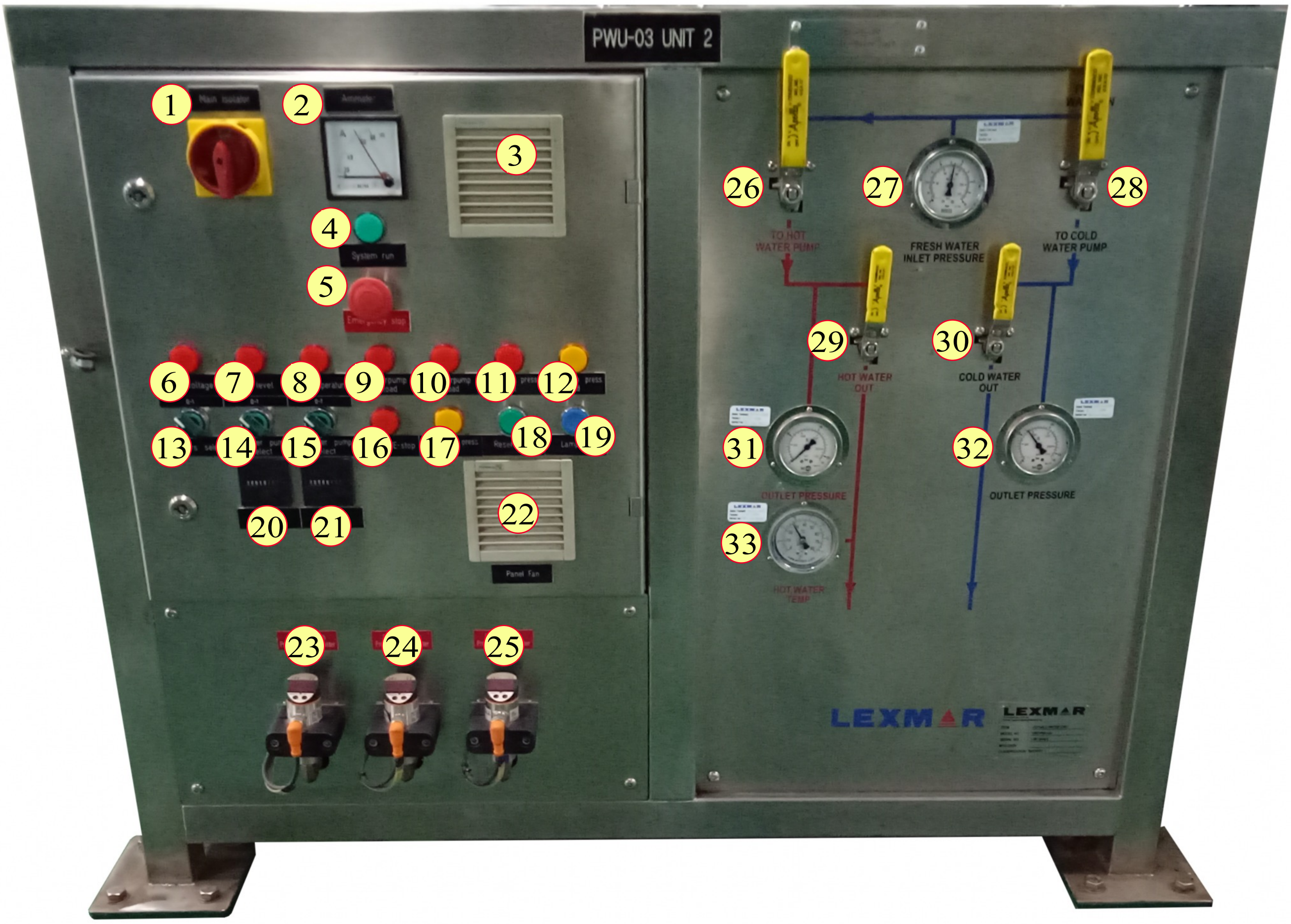
Technical notes:

- *With the system taken as reference, the piston accumulators (see #2 below) are charged with Nitrogen at 21 bar for depths up to 200 m et 29.7 bar for depths between 200 m and 300 m.*
- *The hot water temperature is pre-set and maintained by a thermostat mounted inside the electrical box.*
- *The power input to the machine is 13.5 kW, 220 VAC, 60 Hz. The heating element consumes 4.5 kW and each pump consumes 2.2 kW.*
- *Pressure switches (see # 5 & #6) are provided to control pressures in the installation.*



1 - Heater tank	*2 - Piston accumulator*	*3 - Water level switch*	*4 - Pump 90 bar and 8 l/min*
5 - HP pressure switch	*6 - LP pressure switch*	*7 - Pressure relief valves*	*8 - Non-return valves*
9 - Drain valve tank	*10 - Water outlet valves*	*11 - Water inlet valves*	*12 - Temperature sensor*
13 - Heating element	*14 - Ball-float valve*	*15 - Pressure gauge 14 bar*	*16 - Pressure gauges 140 bar*
17 - Temperature gauge	*18 - Vent valve*	*19 - Regulator*	*20 - Depth sensing line*
Potable water supply	*Cold water to chamber*	*Hot water to chamber*	*Pressure indicating line*
¼ turn valve	*Gauge*	*Non return valve*	*Piloted regulator*

The control panels of the machine taken as an example are organized as follows:



1 - Main switch (to turn on or off the power)

2 - Ampere meter (to read the current flowing into the machine)

3 - Panel cooling fan

4 - Light that indicates that the system runs

5 - Emergency stop push button

6 - Voltage fluctuation alarm light

7 - Water low level alarm light

8 - High temperature alarm light

9 - Hot water pump overload alarm light

10 - Cold water pump overload alarm light

11 - Hot line high discharge pressure alarm

12 - Cold line high discharge pressure alarm

13 - Heater switch (Lights when on)

14 - Hot water pump switch (Lights when on)

15 - Cold water pump switch (Lights when on)

16 - Emergency breaker pressed or circuit breaker tripped

17 - Cold water low suction pressure alarm

18 - Reset button for restarting the pumps after a fault

19 - Lamp test push button

20 - Running hours recorder - hot water pump

21 - Running hours recorder - cold water pump

22 - Panel cooling fan

23 - Cold water high pressure switch (set at 90 bar)

24 - Hot water high pressure switch (set at 90 bar)

25 - Inlet potable water low pressure switch (set at 2 bar)

26 - Hot water inlet valve

27 - Fresh water inlet gauge (from the ship)

28 - Cold water inlet valve

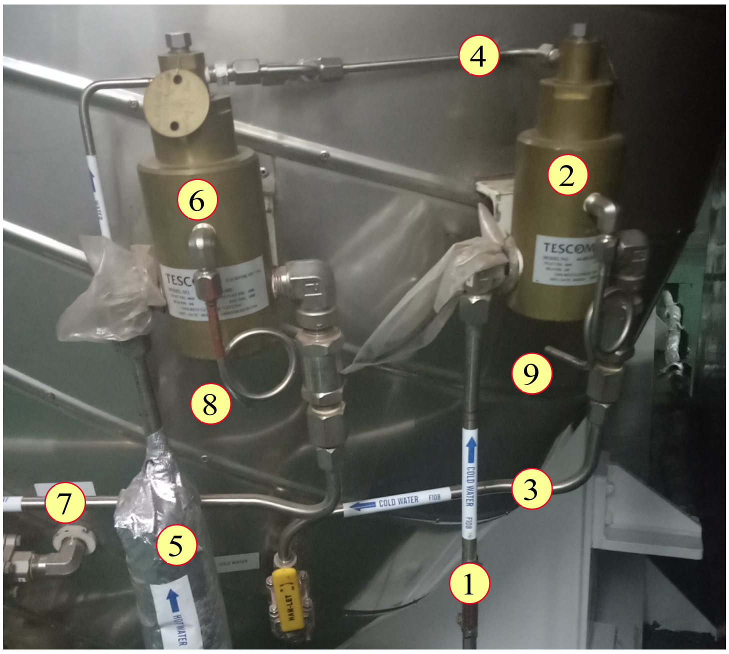
29 - Hot water outlet valve

30 - Cold water outlet valve

31 - Hot water outlet pressure gauge

32 - Cold water outlet pressure gauge

33 - Hot water temperature gauge

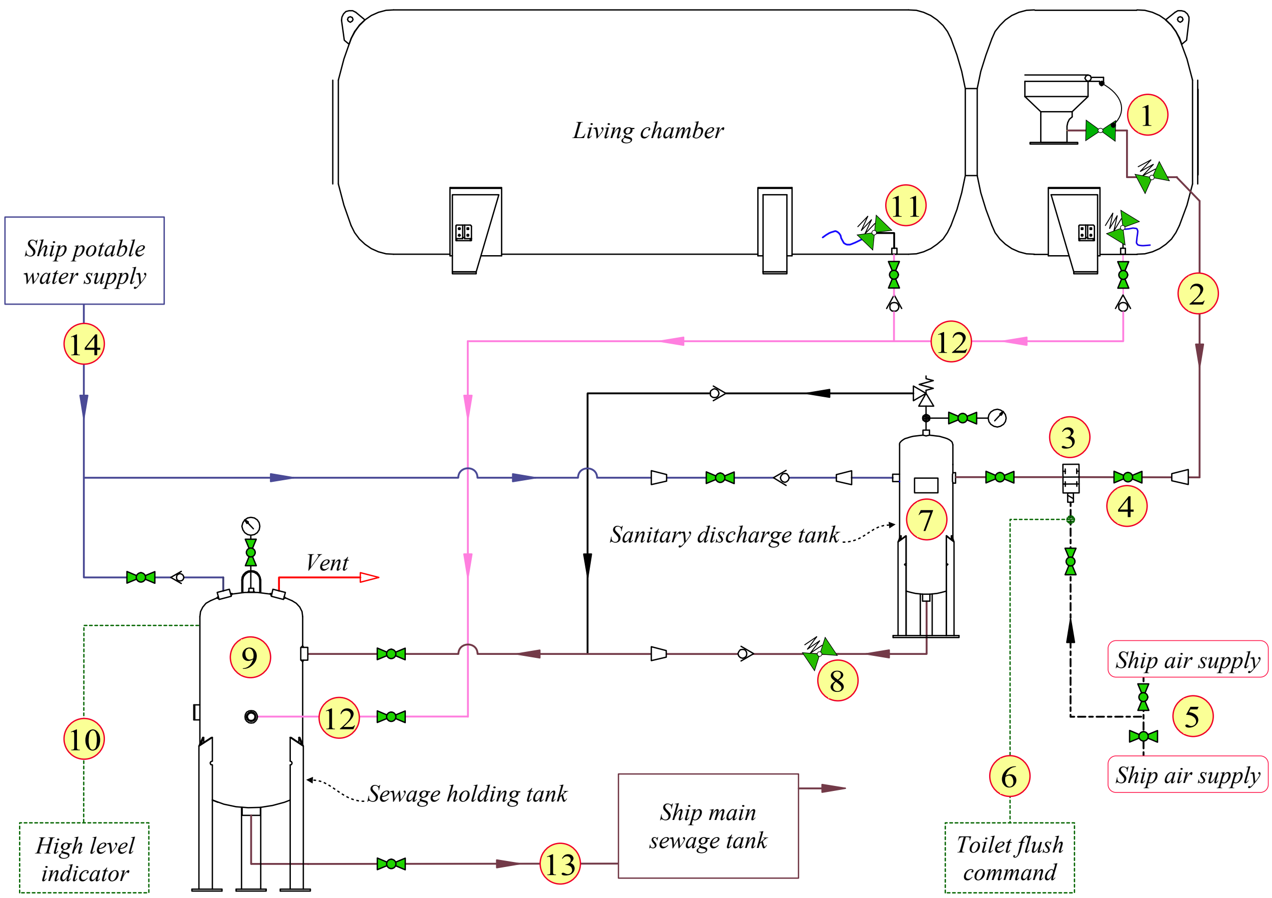


The photo on the side shows the regulators that stabilize the water supply to 5 bar above the chamber ambient pressure and their depth-sensing lines.
Note that the model of regulator used is the same as the one used with the Built-In Breathing Systems (BIBS) of the chambers.

- *#1 - Cold water inlet*
- *#2 - Cold water regulator*
- *#3 - Cold water from regulator to chamber*
- *#4 - Tracking pressure cold water regulator*
- *#5 - Hot water inlet*
- *#6 - Hot water regulator*
- *#7 - Hot water from regulator to chamber*
- *#8 - Vent hot water regulator*
- *#9 - Vent Cold water regulator*

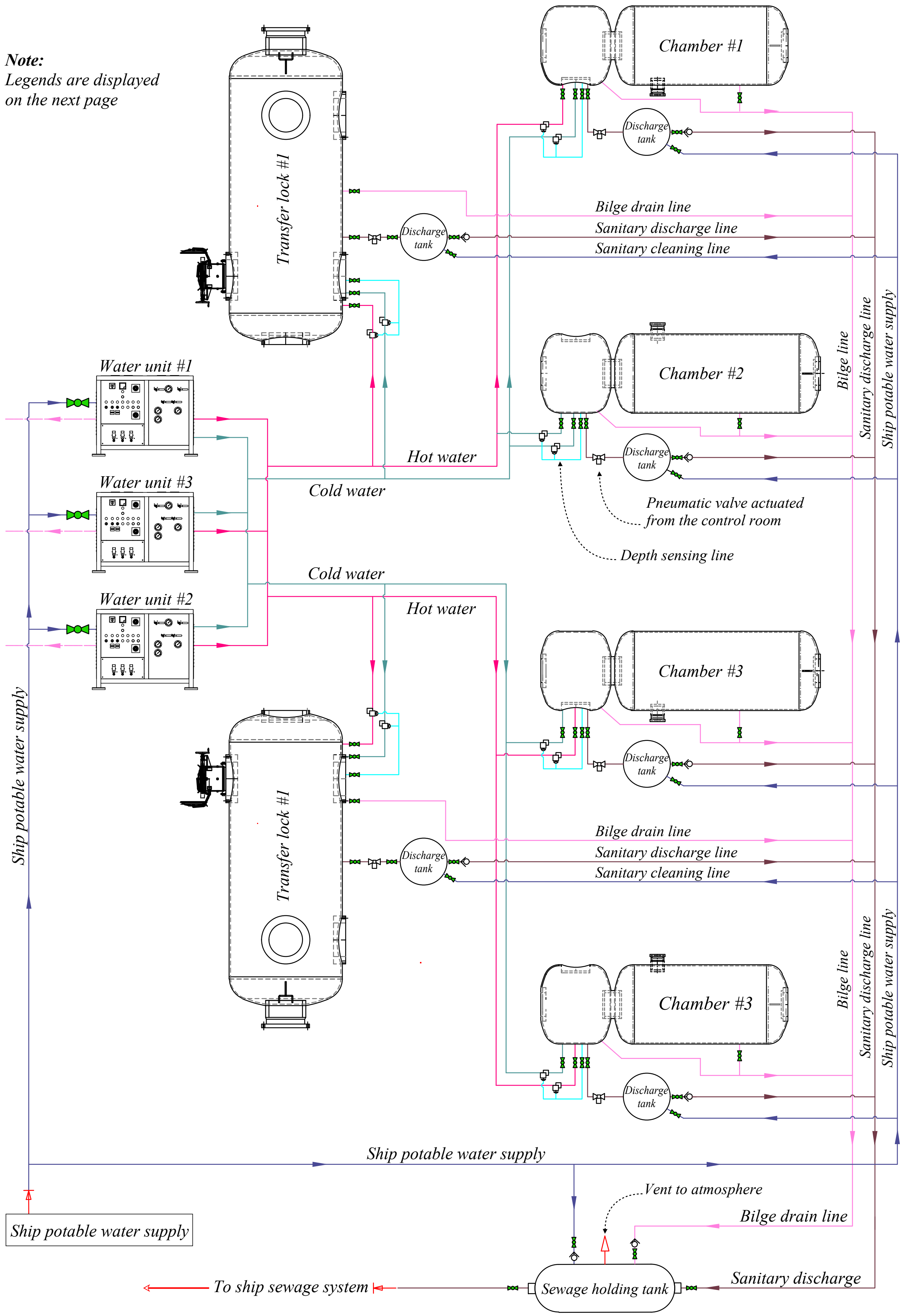
1.2.3.4 - Sewage system

The toilet and bilge drain systems already described in point 1.2.2.2 use parallel evacuation circuits that are connected to the “sewage atmospheric holding tank”.
As described in the previous chapter, the feces from the toilets *(see #1 below)* are evacuated to the “sanitary discharge tank” *(see #7 below)*, which is also called “collector tank”. With the last generation systems, pneumatic valves *(see #3)* that are powered by the air circuit from the ship *(see #5)* are actuated from the saturation control *(see #6)*. They allow the Life Support Technician to transfer the feces to the sanitary discharge tank from the saturation control room, and not be obliged to move to it to operate the classical ¼ turn valves. However, note that ¼ turn valves that are usually open are installed both sides of this item to isolate the elements if needed *(see #4 below)*.
The sanitary discharge tank is purged to the “sewage holding tank” *(see #9)* through a spring-loaded valve *(see #8)*. A high-level indicator *(see #10)* allows controlling the level of this tank from the saturation control room.
The water evacuated through the bilge drain system already described in point 1.2.2.2 *(see #11 below)* goes to the “sewage atmospheric holding tank” through a dedicated line *(see #12)*. When this reservoir is full, its content is transferred to the main sewage tank of the ship *(see #13)*. Both “sanitary discharge tank” and “sewage atmospheric holding tank” are cleaned by freshwater supplied by the ship’s system *(see #14)*.



1.2.3.5 - Organization of the systems described

The scheme below shows the organization of the elements described previously in UDS Lichtenstein and Picasso. Note that the manufacturer (Lexmar) provides three water machines that can be interconnected to have a backup is always ready in case of a breakdown and during maintenance. Also, each chamber is equipped with a sanitary discharge tank.



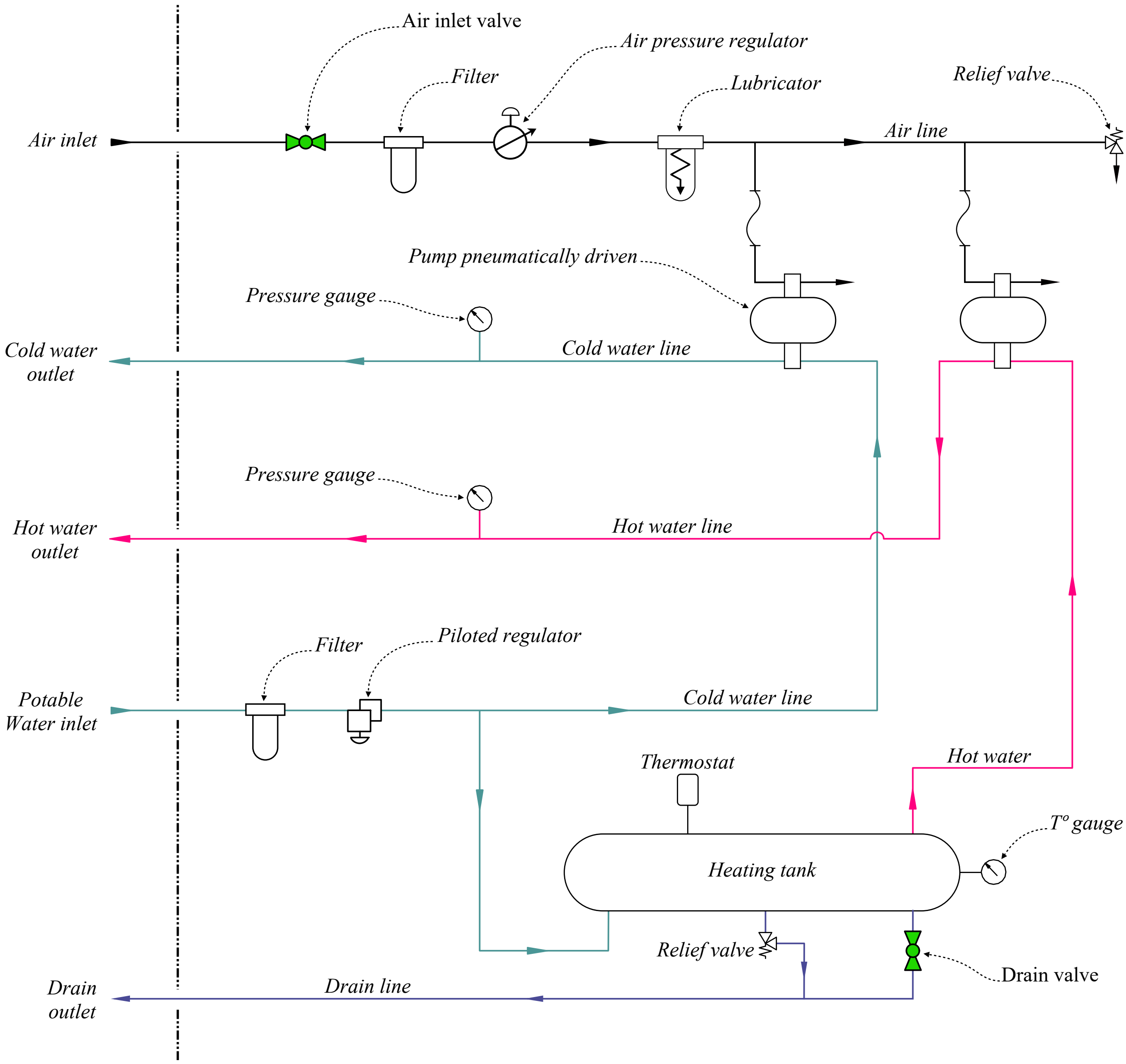
Legends of the scheme on the previous page

Potable water supply	*Cold water to chamber*	*Hot water to chamber*	*Depth sensing line*
Bilge drain line	*Sanitary discharge line*	*Pneumatic actuated valve*	*Quarter turn valve*
Regulator	*Non return valve*	*Sanitary tank*	*Spring loaded valve*

1.2.3.6 - Variations of the design of the systems

As explained in point 1.2.2 "chambers", there may be some differences regarding the organization of the systems discussed that use anyway the same physical principles.

- As a reminder of what is said in this point regarding the evacuation of the feces, some systems of the old generation are equipped with a small collector tank inside the chamber instead of the sanitary tank outside the chamber. Also, the water from the sink is evacuated through this collector to the sewage system. Depending on the manufacturer, this organization can be used with new systems.
- Water machines can also be slightly different. As an example, DIVEX (a brand of JFD group) proposes a model in which the water pumps are air driven. These pumps are pressure ratio piston pumps which deliver an output water pressure ten times the input air pressure; thus, they can provide 65 bar water pressure from 6.5 bar input air pressure. The pump air pressure is set and controlled by a regulator that is adjusted to vary the output pressure of the water pumps. A gauge attached to the regulator allows monitoring the air pressure delivered. A lubricator is installed on the line to lubricate the pistons of the pumps.
  The manufacturer says that this machine which scheme is displayed below, can provide 7,6 litres of cold and hot water per minute at a maximum pressure of 68 bar. The outlet pressure of each stream is indicated by the water pressure gauges. The temperature of the hot water delivered varies between 30 and 75 C°.



1.2.3.7 - Protection and ease of access

The equipment should be protected from physical damage and be organized such that they can be easily accessed. As a result, maintenance and repairs must be possible without exposing the technician to any risks. Also, precautions should be in place to avoid pollution to the environment and damage to the surrounding equipment in case of unexpected spilling of the content of the pipes.
That is usually easier to organize with built-in systems where the water machines can be installed in a dedicated room. Also, the sanitary discharge tanks can be arranged alongside the chambers without specific guards as these chambers are situated in a room with the access restricted to only the diving system technicians, and life support technicians, where they are protected from the weather conditions and potential shocks.

Water machines in their dedicated room

Sanitary discharge tanks (without specific protection)

Mobile saturations systems have the inconvenience that their components are installed on an open deck where they are exposed to the environmental conditions and shocks.
For this reason, the manufacturers protect the water machines in containers and provide guards to protect the sanitary discharge tanks. Also, these tanks can be installed inside the chamber as indicated in point 1.2.2.2. Note that potable water and effluents may be supplied and removed through flexible hoses that must be protected. For this reason they should be routed in such a way that they cannot be damaged. Also, these hoses may carry pathogens and should be disinfected prior to start the installation.

1.2.3.8 - Problems that can be encountered with portable saturation systems

In addition to the problems indicated above, portable systems can be installed on vessels of opportunity that may not initially be designed for diving operations as real diving support vessels equipped with built-in systems.
Although these saturation systems are smaller than those taken as references in this discussion, the potable water supply, and the removal of feces and used water can be a problem on these diving supports. That can also be the case with operations organized from a facility.

- In such conditions, the water supply must be organized to distribute potable water that conforms with the "guidelines for drinking water quality" from the World Health Organization (WHO) at the pressure and flow recommended by the manufacturer.
  If the surface support can supply the requested water, it must be analyzed to ensure that it conforms with the requirements indicated above. If it is not the case, mobile purification or production units may have to be used. These transportable plants that are usually based on reverse osmosis systems are designed to be easily moved and operated in hostile conditions. They can be found in the catalogs of brands such as Futuretech, Ampac, Veolia and many others.
  A dedicated drinking water storage tank may have to be installed at the proximity of the installation.
- Regarding sewage, MARPOL *(International Convention for the Prevention of Pollution)* says that the discharge of sewage into the sea is prohibited, except when the ship is discharging comminuted and disinfected sewage using a system approved by the administration at a distance of more than three (3) nautical miles from the nearest land, or sewage which is not comminuted or disinfected at a distance of more than twelve (12) nautical miles from the nearest land, provided that, in any case, the sewage that has been stored in holding tanks shall not be discharged instantaneously but at a moderate rate when the ship is en route and proceeding at not less than four (4) knots and a rate of discharge approved by the administration and based upon standards developed by the organization. Or, the ship has in operation an approved sewage treatment plant that has been certified by the administration to meet the operational requirements, with the test results of the plant that are laid down in the ship's International Sewage Pollution Prevention Certificate. Additionally, the effluent must not produce visible floating solids nor cause discoloration of the surrounding water.
  As a result of the text above, wastes from the dive system cannot be thrown to the sea as it was commonly practiced in the old-time. If the throwing out canalization cannot be connected to the sewage station of the surface support, the effluents must be stored in a specific container that will be transferred to a specialized plant onshore.

1.2.3.9 - Fire fighting

The firefighting systems used are those described in the previous chapters. Nevertheless, the different elements are not situated in the same room. As a result, the fire fighting systems that protect them may be those that are also dedicated to other parts of the saturation system; As an example, the sanitary discharge tanks can be near the chamber or inside the entry lock. Thus this element and its pipe works can be protected by the firefighting system that is in place to protect the chamber. Water machines are often in the same room as other pieces of machinery and can be protected by the deluge system in place in this room. However, additional portable systems may be necessary. Also, some parts of the system may be installed in dedicated rooms where dedicated fire fighting systems are required. It is generally the case with portable saturation systems.

1.2.3.10 - Routine maintenance and inspection

The maintenance of the system is linked to its conception and relevant guidelines are usually provided by the manufacturers. They indicate daily, weekly, Monthly, six-monthly, and yearly basis inspections and interventions. As with other equipment the maintenance performed should be recorded.
IMCA D 024 does not provide specific guidelines regarding these machine. However the rules provided for systems using the same mechanical and physical principles can be used. Note that IMCA D 024 is initially designed for 6 months and yearly audits. However, as previously said, this frequency can be increased.

Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure*	*Other test*
Pipe works & fittings	6 months	24 months		Leaks: Daily
Valves	6 months	24 months		Function test: Daily
Pumps	6 months			Oil level: Weekly
Surge damper	6 months			Manufacturer specifications
Heater tank	6 months	6 months (internal check)		Leaks: Daily
Heater element(s)	6 months			Cleaning: 6 months
Float valve heater tank	Monthly			Manufacturer specifications
Level switch heater tank	Monthly			Manufacturer specifications
Electrical systems	6 months			Electrical leakage: Monthly
Low pressure switch (cold pump shutdown)	Monthly			Manufacturer specifications
High pressure switch	Monthly			Manufacturer specifications
Relief valves	6 months	30 months		
Temperature gauges	6 months			
Pressure gauges	6 months			
Accumulators	6 months	Yearly	5 years	Manufacturer specifications
Alarms	6 months			Manufacturer specifications
Fire fighting portable system	6 months			Manufacturer specifications
Fire fighting fixed system	6 months			Manufacturer specifications
Automatic fire detection	12 months			Manufacturer specifications

Regarding the daily, weekly, and monthly inspections, note the following:

Daily maintenance:

- Visual inspection of all pipeworks and fittings for signs of leaking.
- Check for unusual noises and vibrations when the machines are started.
- Review the elements in service according to the pre-dive check list.

Weekly maintenance:

- Check the level of oil in the pumps and top up the oil as required (use the oil recommended by the manufacturer). Note that the oil change of the pumps should be done according to the specification of the manufacturer.
- Function test of the pressure switches and thermostat of the potable water unit.
- Visual inspection and function test of the valves.
- Disinfection of the discharge tanks and lines.

Monthly maintenance:

- Check the surge damper of the potable water unit.
- Function test of all valves and pressure gauges.
- Electrical isolation and leakage checks.
- Check for pathogens in the water supply lines and preventive disinfection.

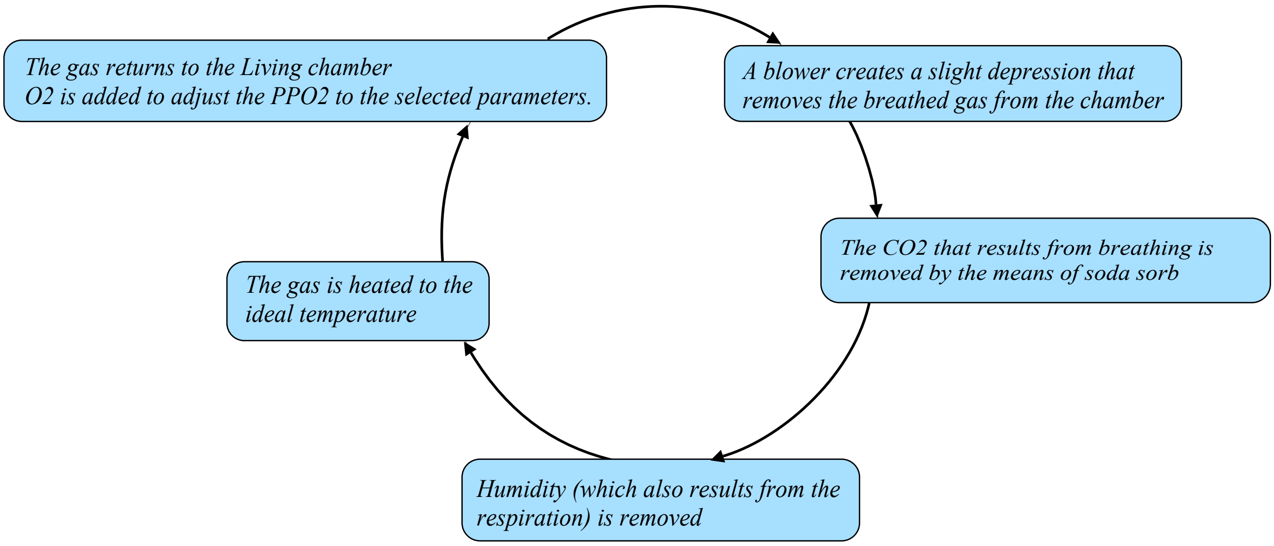
1.2.4 - Hyperbaric Environment Regeneration System (HERS)

1.2.4.1 - General design

The Hyperbaric Environment Regeneration System (HERS) is a closed circuit where CO_2 and humidity in excess are continuously removed from the living chambers.
As already said in point 1.2.2.2, this system works similarly to forced ventilation devices used to renew the atmosphere of rooms of ships or some large buildings. Thus, the gas circulates into the system as a result of the little depression and overpressure provided by a blower, which remains very close to the pressure of the chambers to which it is linked.
As some parts of the system may be at different depths, each living chamber is provided with its dedicated Hyperbaric Environment Regeneration System (HERS) unit. Also, a standby unit must be readily available should one of the dedicated units be out of service.
As an example, the Environmental Control system of UDS Lichtenstein consists of the following components

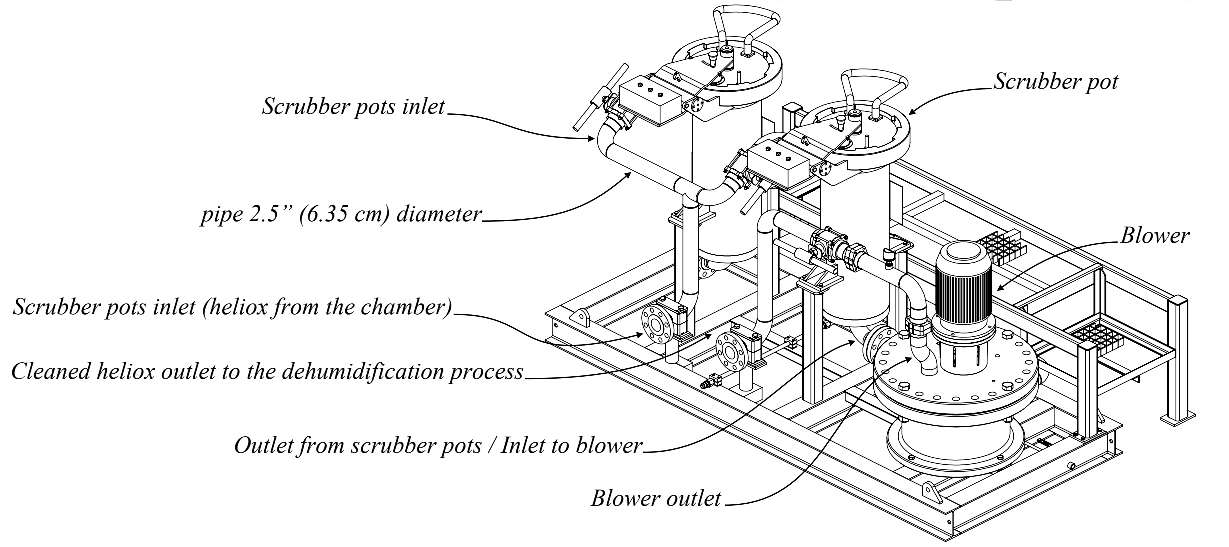
- Five Blower Pots complete with a regeneration blower
- Five CO2 Scrubber Pots
- Two Chiller Control Unit complete with Tank and Pumps (1 x main with 1 x back-up)
- Two Heater Control Unit complete with Tank and Pumps (1 x main with 1 x back-up)
- Gas conditioning heat exchangers

The Hyperbaric Environment Regeneration System (HERS) is external to the chamber to allow easy maintenance and servicing controls the CO2 concentration in the environment gas within the Chambers. Temperature and humidity are controlled by the Hyperbaric environment Control Systems (HECS). However, note that other systems that use the same technical principles can be organized differently as the system described below. Also, some manufacturers (as an example Comanex) propose units that can be integrated into the chamber. The gas is renewed as follows:

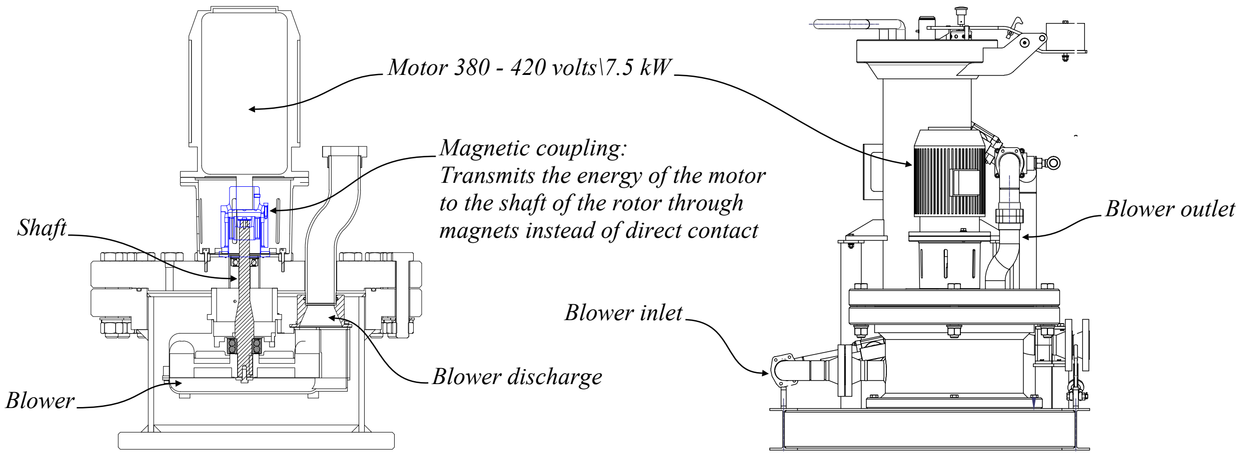


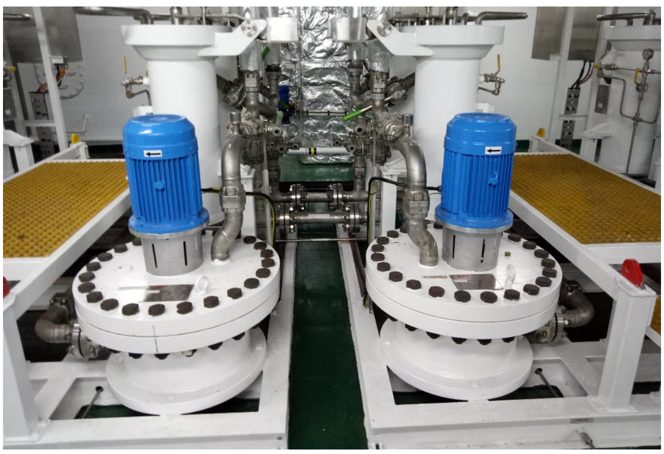
- 1 - The breathed gas is drawn out of the living chamber by the blower and enters the scrubber pot of the HERS through a pipe work 2.5” (6.35 cm) diameter.

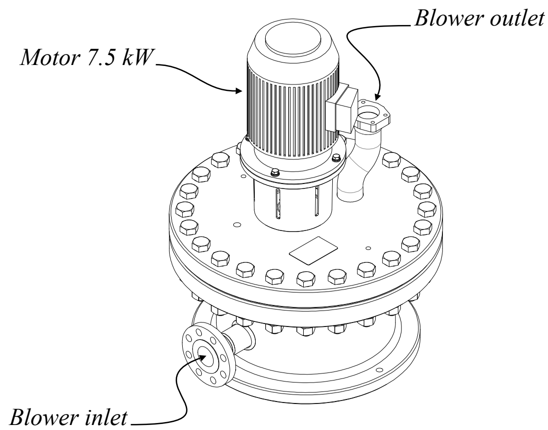
As already indicated in point 1.2.2.2, the chamber outlet is situated near the floor to collect the maximum CO2, which is a heavy gas. Opposite, the inlet is situated at the top of the chamber. This configuration allows good ventilation.



The hyperbaric blower, which is driven by a 7.5 kW electric motor is mounted in a pressure housing that is completely sealed. It generates a pressure that creates a flow of gas circulating in the system.



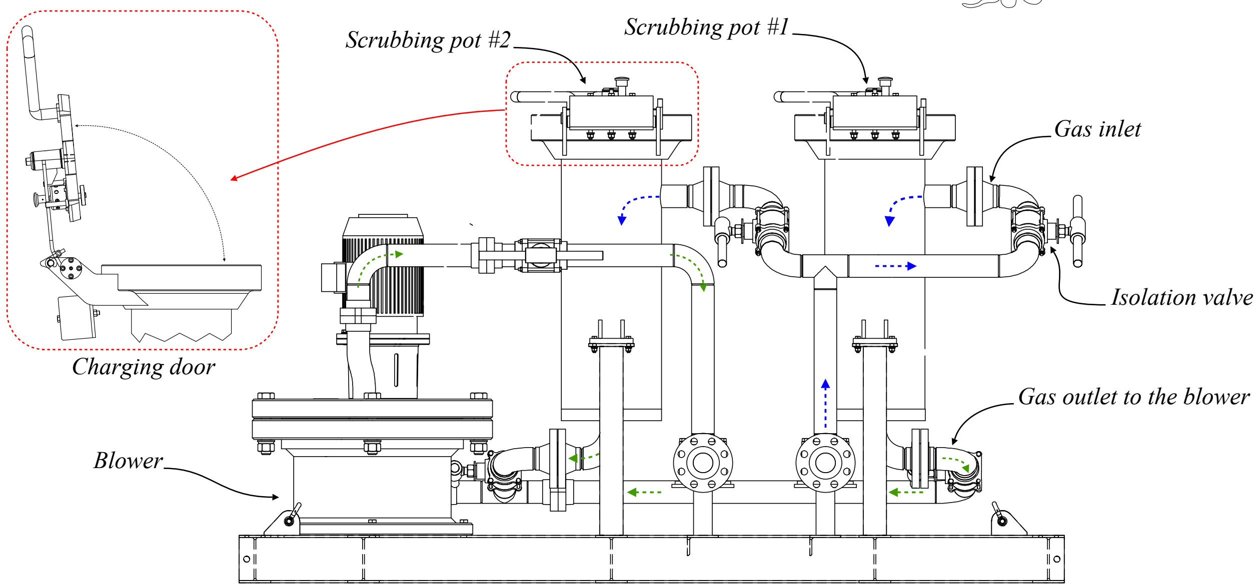


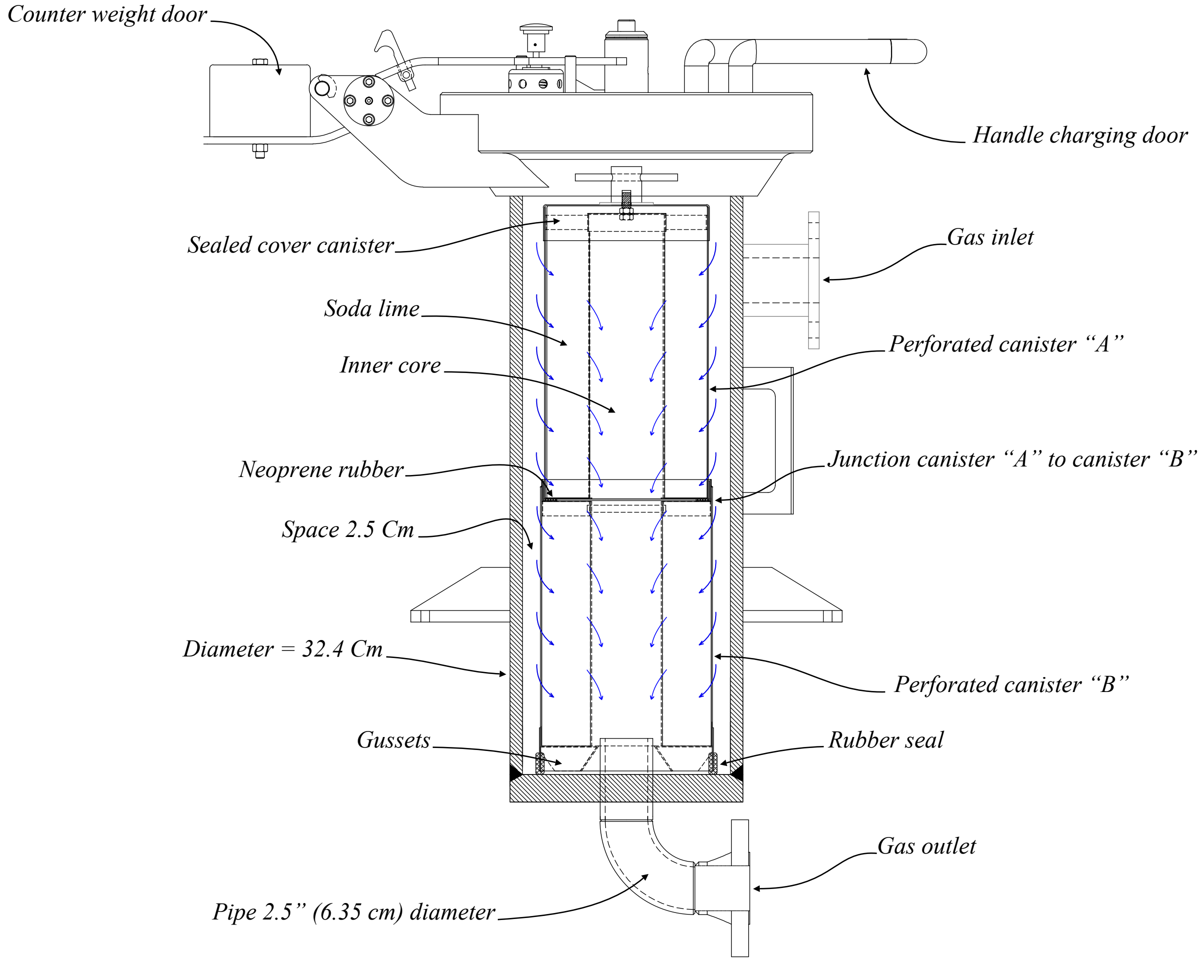


- 2 - The gas enters a scrubbing pot, consisting of two Sodasorb scrubbing canisters, that removes the CO2.

Each blower has two associated scrubber pots mounted on the same skid. Interconnecting pipework and valves are arranged so that one scrubber pot is online whilst the other is on standby. As a result, the second scrubbing pot can be brought on-line while the first unit is isolated for change-out of the exhausted scrubbing medium.

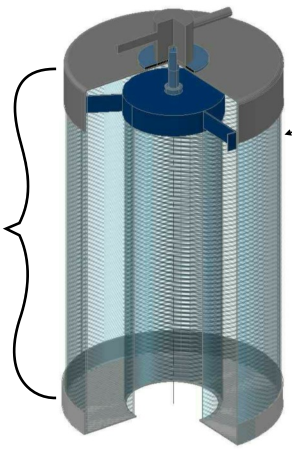
Each scrubber has 2 stainless steel canisters that are perforated to let the gas pass through them and are filled with 10 kg soda sorb each. The gas exits the scrubber through the pipe at the bottom.





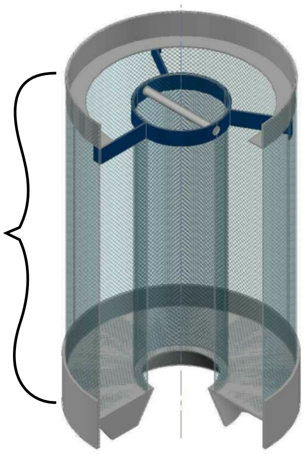
Canister "A"

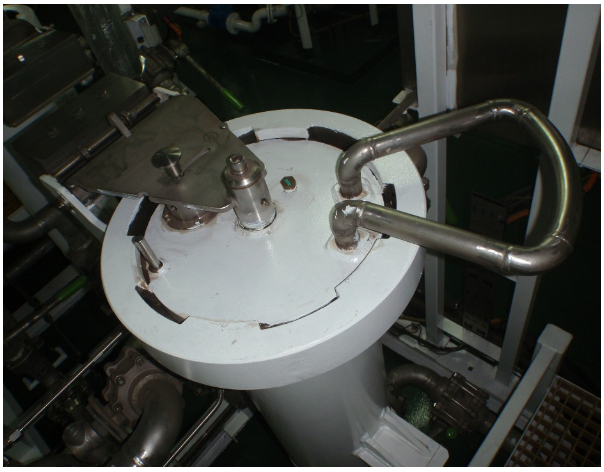
- *Empty weight: 7.1 Kg*
- *Volume soda lime: 12.7 litres*
- *Weight soda lime: 10.34 kg*
- *External diameter: 22.8 cm*
- *Total weight:17.44 Kg*

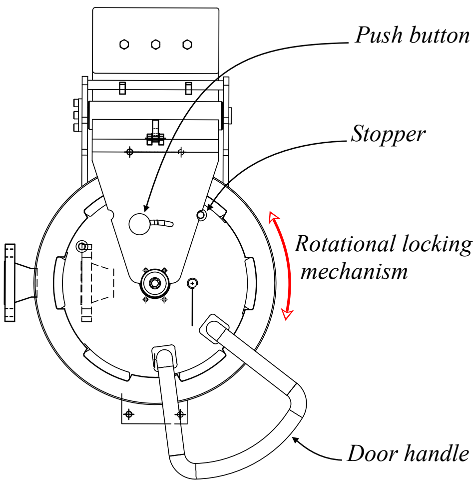


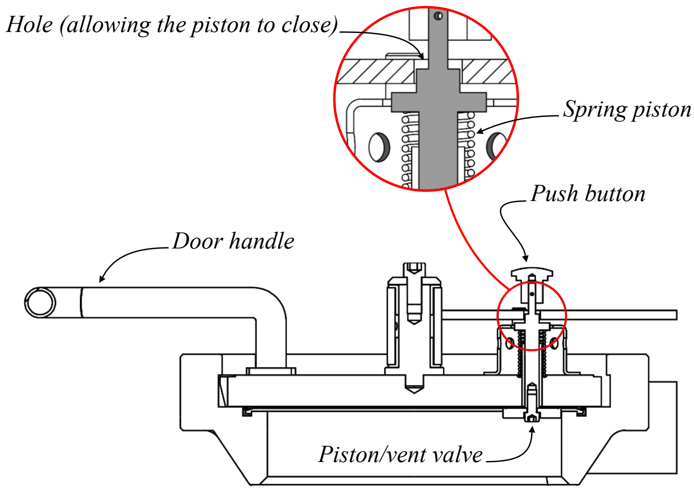
Canister "B"

- *Empty weight: 7.5 Kg*
- *Volume soda lime: 13.2 litres*
- *Weight soda lime: 10.79 kg*
- *External diameter: 23.9 cm*
- *Total weight:18.29 Kg*







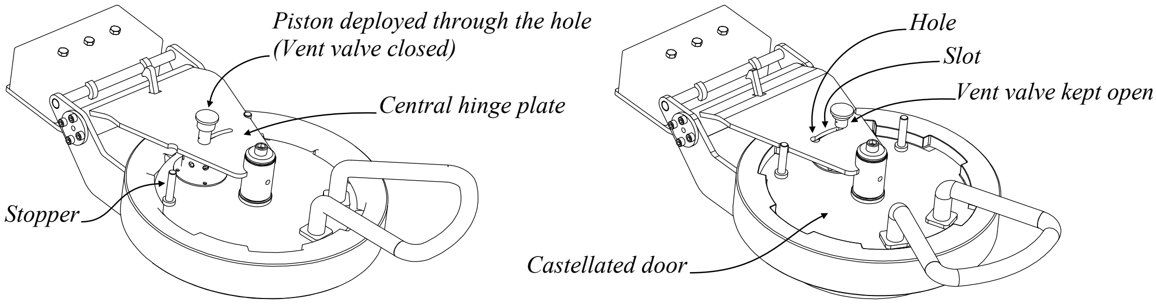


The charging door of the scrubbing pot works against the pressure.
For this reason, a safety interlock mechanism is in place to prevent this door from opening while the scrubbing pot is under pressure. It consists of a small locking piston/vent valve that is pushed out by the pressure inside the system and a spring to block the opening as long as the internal pressure is not released. Also, the rotational closing mechanism with a castellated cover prevents any accidental opening.

- The following procedure is required to open the door:
  - A push-button is installed on the top of the piston/vent valve that must be pressed before opening the door by rotation (see in the drawing on the previous page). The manufacturer says that a 4.9 kilogram-force (48 newton) is necessary to push the piston while there is no pressure in the system. However, 11.31 kilogram-force (110.91 newton) is required while the remaining the pressure in the system is 5 PSI (0.34 bar), and 27.52 kilogram-force (269.88 Newton) is necessary if the remaining pressure is 10 PSI (0.69 bar).
    As a result, if the scrubber pot is still pressurized, the venting action is not possible, and the door remains locked.
  - When the scrubber pot is depressurized, the operator rotates the door clockwise, using the dedicated handle. The push-button must be pressed during this phase.
  - When the door is unlocked, the operator can release the push button, complete the rotation, and lift the door to open it. Note that the door is fitted with a counter-balanced hinge to facilitate its opening.

Table of contents

- The following procedure is required to lock the door:
  - The operator closes the door and rotates it anticlockwise up to the fully locked position. This position is usually reached when the stopper is in contact with the central hinge plate.
  - The vent valve (piston) closes automatically when the door is fully engaged. However, the scrubber pot cannot be pressurized as long as this vent valve remains open. That can be done only when the piston can deploy through a dedicated hole in the central hinge plate and thus close the vent valve (see the drawing below). This hole is arranged in such a way that the piston can pass through it only when the door is fully locked.



Door locked *Door unlocked*

- 3 - The cleaned gas continues through the first stainless steel brazed plate heat exchanger where it is cooled to its dew point to dehumidify it. A second heat exchanger is installed after it to reheat the gas to the ideal temperature.

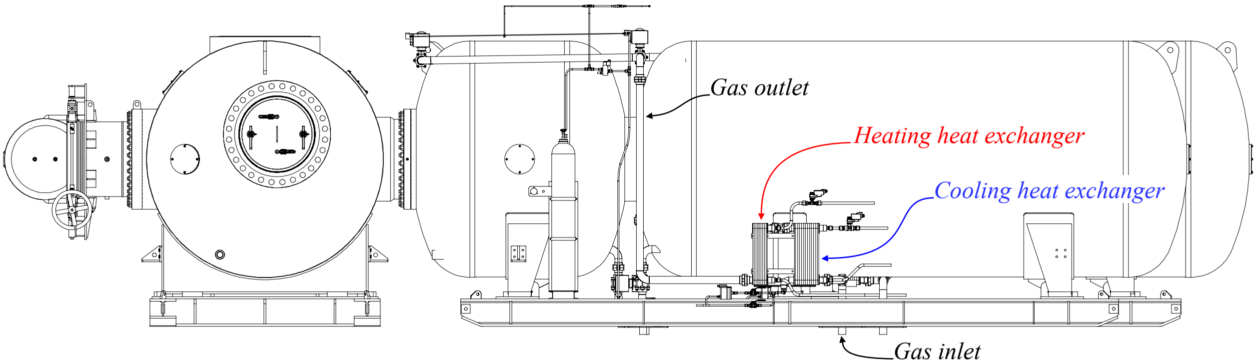
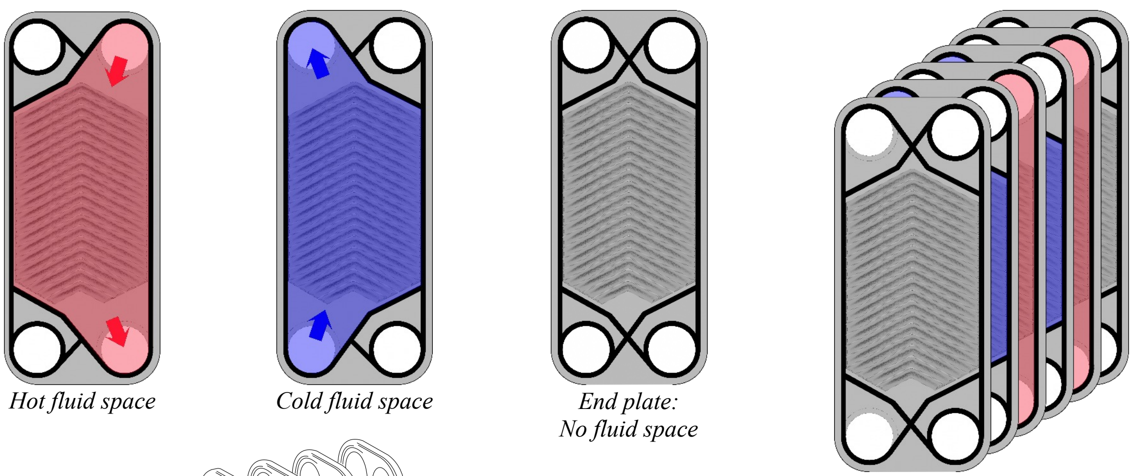
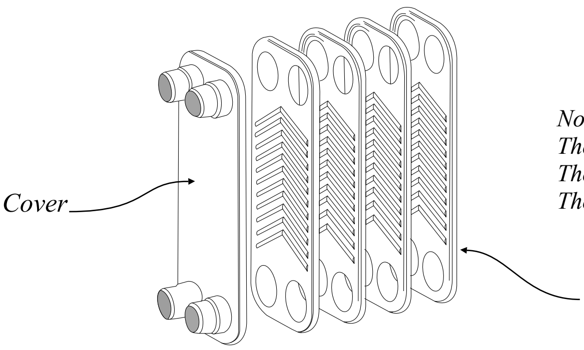


Plate heat exchangers are composed of thin nested metal plates that are assembled to create dedicated flow spaces of cold or hot fluid between them. These plates are arranged so that there are alternatively hot and cold spaces, so the exchange of heat and cold is performed by conduction through the metal these plates are made of. With some models, these plates are kept together by thread bars, and internal rubber gaskets are arranged in such a way that the cold and hot fluids cannot mix or escape. With some other models, these plates are joined around their periphery by brazing and thus are called "brazed plate heat exchangers".



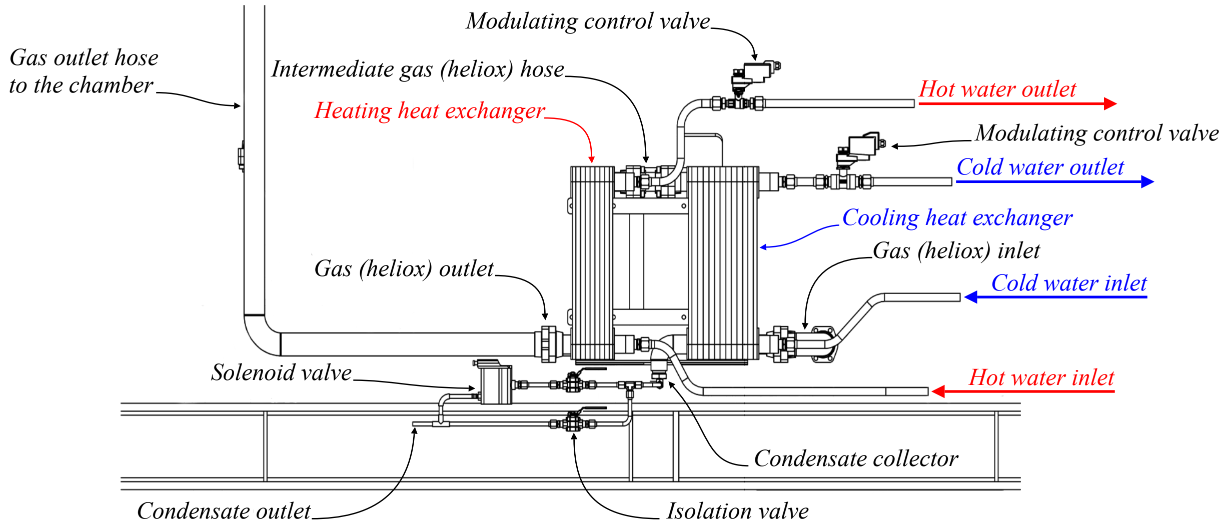
Hot fluid space *Cold fluid space* *End plate: No fluid space* *Fluid spaces arrangement*



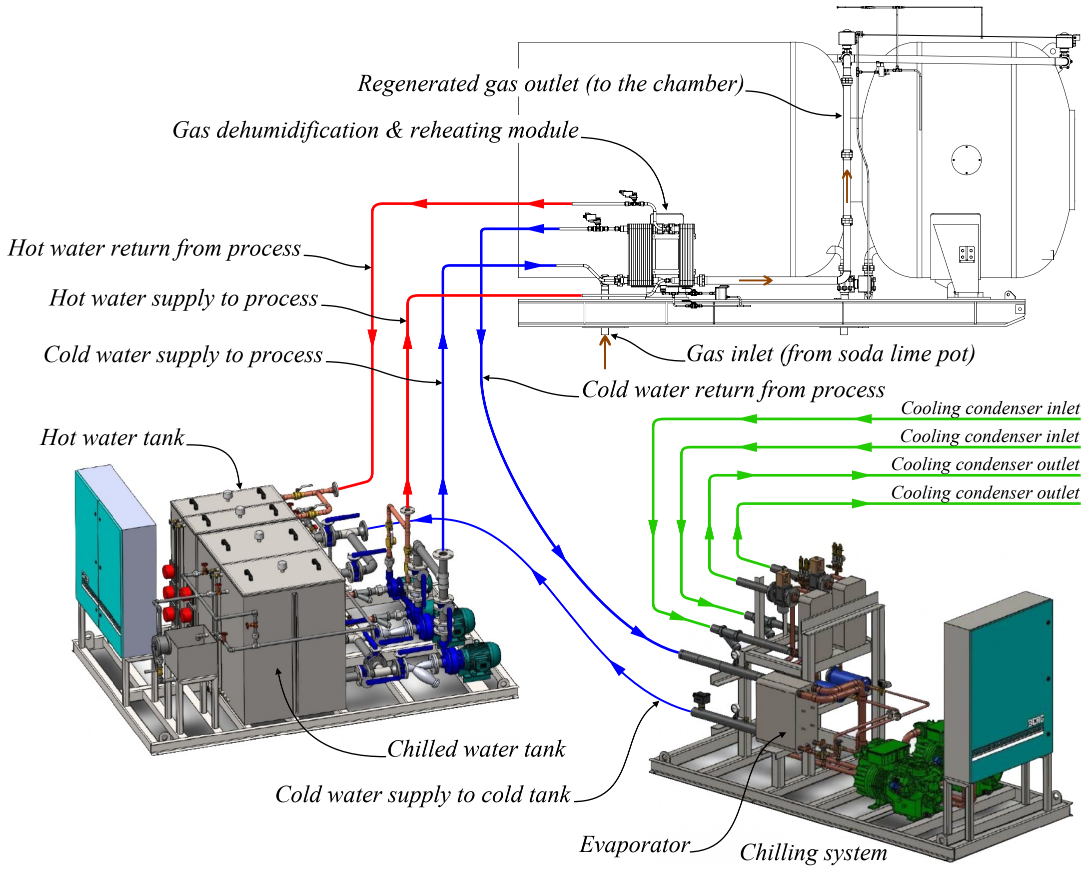
Note:
There is no fluid space between the cover and the 1st plate (end plate).
These heat exchangers offer high-efficiency with a compact size.
They are easy to install and maintain.

Brazed plate heat exchangers are joined around their periphery by brazing. They are reputed for their durability along with higher operating pressures and temperatures.

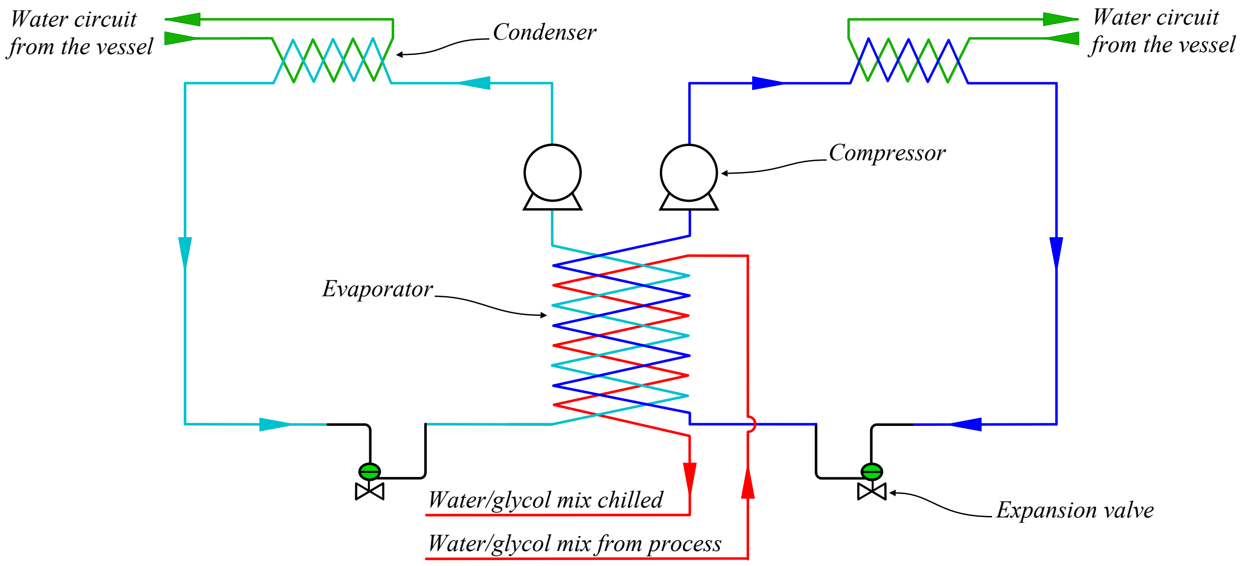
The cold fluid is a mix of water and 30% of propylene glycol. “Propylene glycol” is used by the chemical, food, and pharmaceutical industries as an antifreeze when leakage might lead to contact with food. This substance must not be confused with “Ethylene glycol,” which is also used for cooling circuits but is toxic. This cold fluid is supplied by a chilling system that is described next. The hot liquid used to reheat the gas to the ideal temperature is also provided by a machine that is described next.
A modulating control valve installed on the outlet hose manages the flow of the cooling fluid (water + 30% Glycol) through the exchanger. This valve is operated by a Proportional Integral Derivative (PID) controller that is situated in the saturation control and reacts according to the data from the temperature and humidity sensors installed in the chamber. A similar valve is installed on the reheating circuit.
The condensate resulting from this process is collected at the bottom of the device and drained outside the circuit through a solenoid valve that opens automatically when a preset level of water is reached. This valve quickly closes when the preset amount of condensate is ejected so that there is no gas lost. However, this system does not work correctly at shallow depths, so it must be isolated, and the removal of the condensate be performed manually. As an example, the valve provided in the system taken as a reference is provided by Bekomat (https://www.beko-technologies.com/en/) is designed to operate from 0.83 bar to the maximum pressure allowed in the chamber.

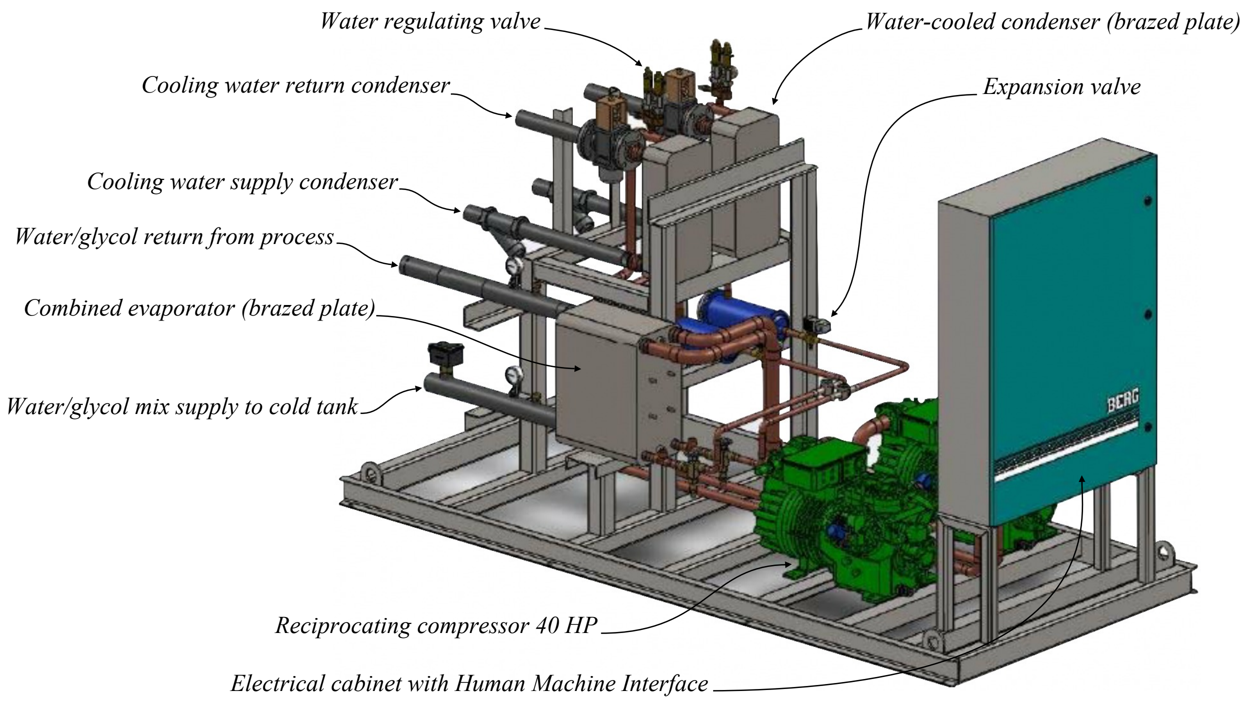


The environmental exchanger equipment is supplied by chillers that are composed of refrigeration compressors and water/glycol tank assemblies from which the cooled mix is sent to the cooling heat exchanger/moisture collector. Hot water tanks that are fitted with heating elements are used to produce and store the hot water sent to the heating heat exchanger. Pumps are provided to each unit to circulate the cold and hot mixes between each element. On the systems taken as examples, these elements are fabricated by Berg Chilling Systems (https://berg-group.com).



The chilling process is based on the principle of compression and decompression of a fluid that generates heat at compression and cold when decompressed. Each chiller is designed with an independent closed circuit of refrigerant that is composed of a compressor that raises the pressure of the coolant. This compressed refrigerant flows through a condenser, which is a heat exchanger where it condenses from vapour form to liquid form, releasing the heat resulting of the compression. In the system described, a continuous water flow from the ship is used to evacuate the heat released. However, air can also be used with other devices. From the condenser, the refrigerant goes through an expansion valve, where its pressure drops. From the expansion valve, the refrigerant goes to the evaporator, which is another exchanger where its rapid decompression results in vaporization and, thus, a cooling reaction that draws out the heat and cools the water/glycol mix coming from the heat exchanger of the chamber described previously. The vaporized refrigerant goes back to the compressor to restart the cycle. The cooled mix water/glycol is sent to the chilled water tank by a dedicated pump installed next to the tank, and then to the heat exchanger of the chamber from which it is pushed again to the evaporator, as described previously.
The temperature of the water/glycol mix is sensed through a temperature transmitter located in the tank. The compressor starts and stops as required to adjust the temperature according to the parameters entered in the software to maintain the temperature in the tank.
The two chillers in service in UDS Lichtenstein & Picasso are composed of two compressors of 40 horsepower (29.8 kW) and two condensers designed to withstand water pressure of 6 bar and a flow rate of 650 L/min from the water pumps of the vessel. However, the two circuits are combined in only one evaporator that is designed with three independent circuits *(See the schemes below)*. The working pressure of the system is limited to 4 bar.



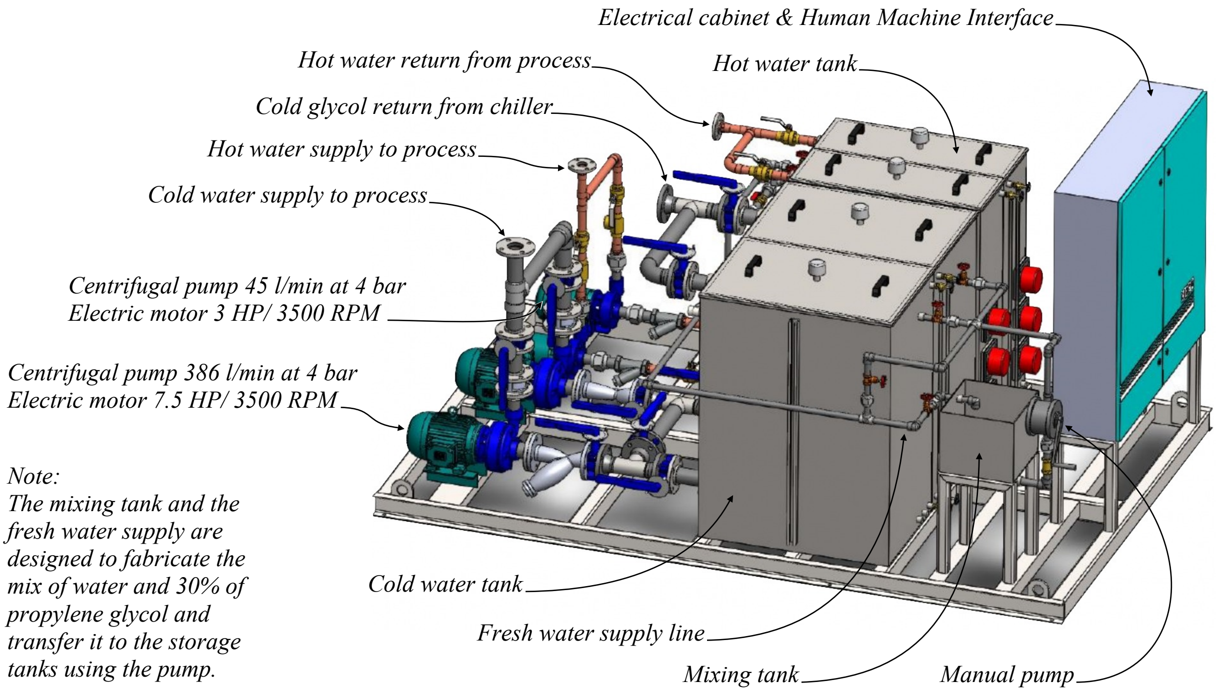


The standard of refrigerant used is R-134A, ASHRAE *(American Society of Heating, Refrigerating, and Air-Conditioning Engineers),* with toxicity class A1. This substance, which is named “1,1,1,2-tetrafluoroethane,” and which chemical formula is CH2FCF3, is part of the “Hydrofluorocarbons” (HFCs) family. These products are used as refrigerants in place of the chlorofluorocarbons that are today forbidden.

The safety classification “A1” indicates that toxicity has not been identified at concentrations less than or equal to 400 ppm, and flame propagation was not noticed during the tests in air at 21°C and 101 kPa (1.01 bar).

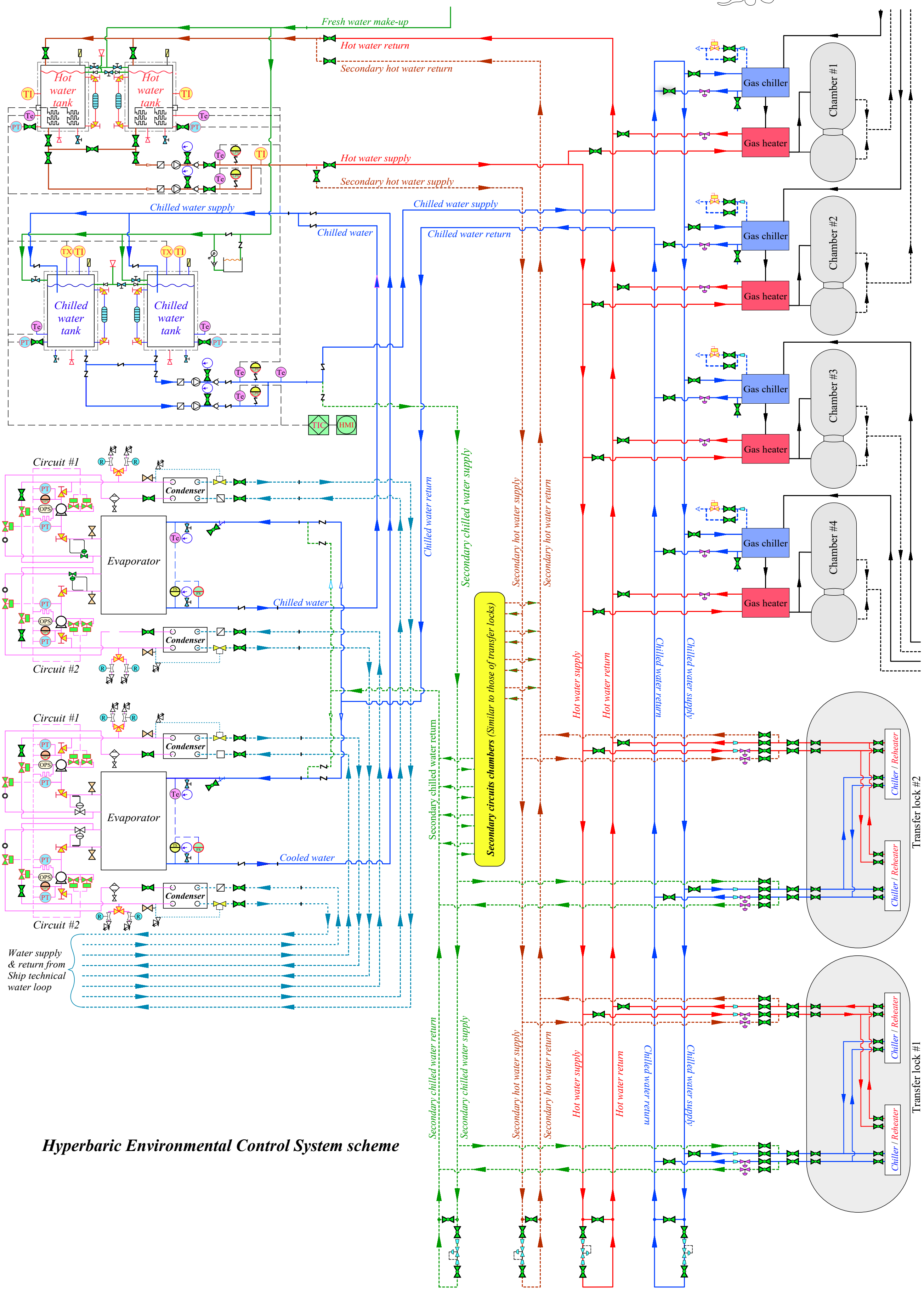
In the system taken as reference, the two chilled water tanks of 400 litres capacity each are installed with the pumps 7.5 hp (5.5 kW) that are designed to supply up to 385 litres/minute on the same skid as the two hot water tanks.
The hot water circuit is more straightforward as its main components are:
- The water storage tanks of 200 litres capacity each, and their heating units 72 kW each (one per tank), allowing to heat the water to 60 ºC. As with the cold circuit, a temperature sensor installed in the tank.
- The pumps 3 horse power (2.24 kW) that circulate the water at 45 litres/minute and a maximum pressure of 4 bar through the heat exchanger of the chamber already described.

Note that for both cold and hot water units, one pump is sufficient to circulate all the cold mix and hot water required with the second pump providing 100% redundancy.



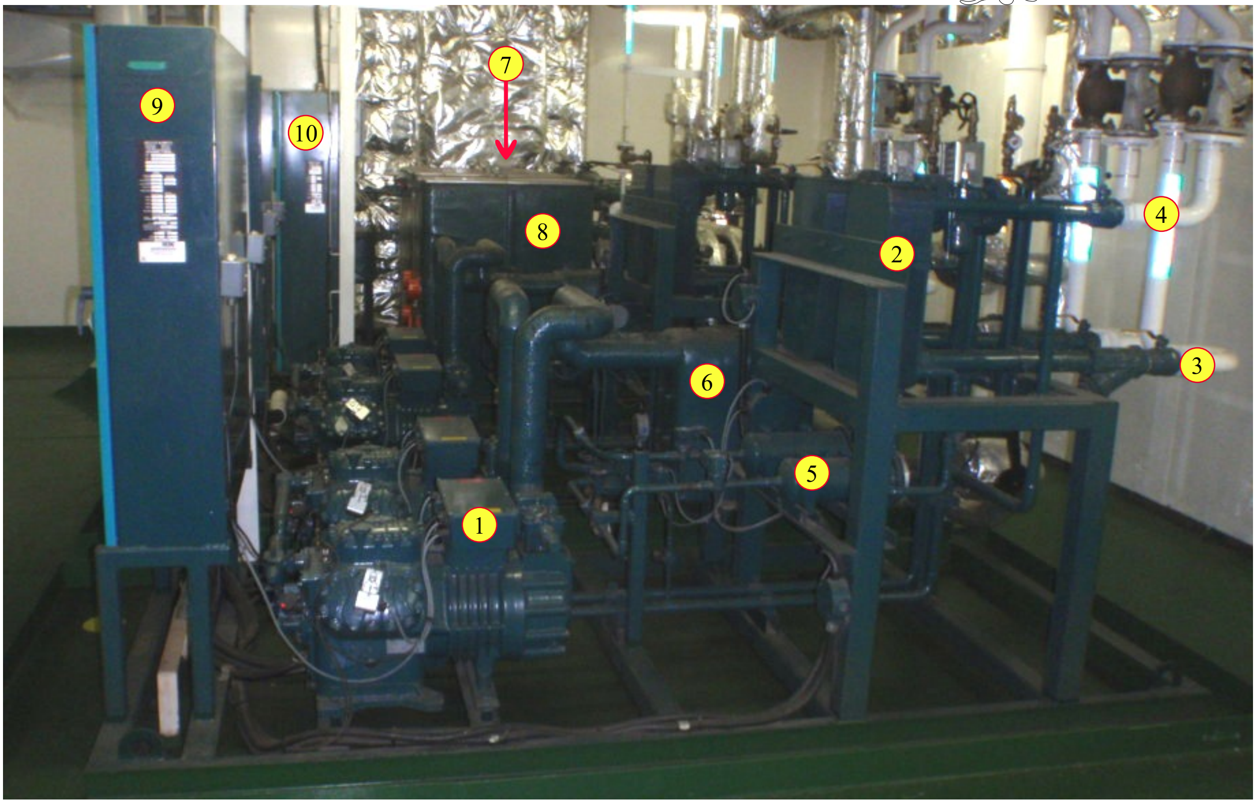
The scheme on the next page explains the ensemble of the dehumidification and re-heating systems, also called “Hyperbaric Environmental Control System”. The symbols below are used to identify the numerous components.

Two way modulating valve	*Strainer Y type*	*Relief valve*
Oil pressure switch	*Filter*	*¼ turn valve*
Pressure transducer	*Butterfly valve*	*Gate valve*
Temperature sensor	*Human Machine Interface*	*Angle valve*
Thermostatic expansion valve	*Temperature indicator control*	*Access valve*
Tank breather	*Strainer*	*Water from ship circuit*
Overflow	*Temperature transmitter*	*Closed circuit refrigerant*
Pump (electrical)	*Solenoid valve*	*Chilled water circuit*
Rupture disc	*Temperature indicator*	*Secondary chilled water circuit*
Flow switch	*Low pressure switch*	*Hot water circuit*
Back pressure valve	*High pressure switch*	*Secondary hot water circuit*
Reducer	*Sigh glass*	*Fresh water circuit*
Regulation valve	*Pressure indicator*	*Renewed heliox inlet circuit*
Hand pump	*Three way valve*	*Breathed heliox outlet circuit*
Auto-drain valve	*Compressor refrigerant*	



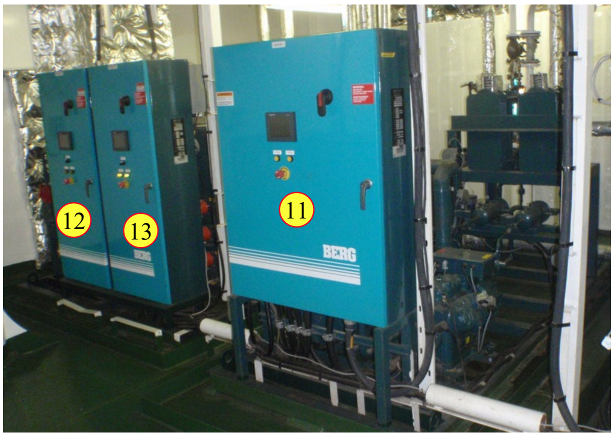
Hyperbaric Environmental Control System scheme

Due to lack of space on the page, the secondary supplies of the heat exchangers of the chambers, called “gas chiller” & “gas heater” in the scheme, could not be represented in full. These circuits that are figured by the yellow rectangle are similar to those visible with the transfer locks.
Besides, we can see that the transfer locks are provided with internal chillers and heaters instead of the external heat exchangers fitted to the living chambers that dehumidify and reheat the gas from the scrubber. So, they are not connected to the regeneration system. The reasons for this design are explained in *point 1.2.2.3**.*
Also, this scheme shows that chillers and water heating machines are shared. However, the dehumidification and reheating of the gas of each chamber are adjusted independently by the action of the modulating control valves installed on their heat exchangers.

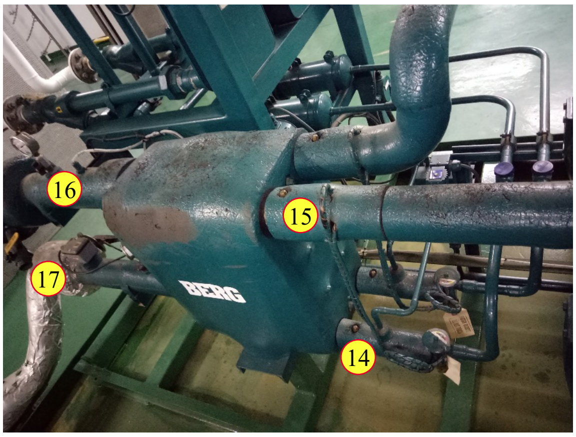


Side view of the chillers and water/glycol tanks of UDS Picasso:

1 - Compressor	*3 - Cooling water inlet*	*5 - Expansion valve*	*7 - Chilled water tank*	*9 - Electrical cabinet*
2 - Condenser	*4 - Cooling water outlet*	*6 - Evaporator*	*8 - Hot water tank*	*10 - Electrical cabinet*



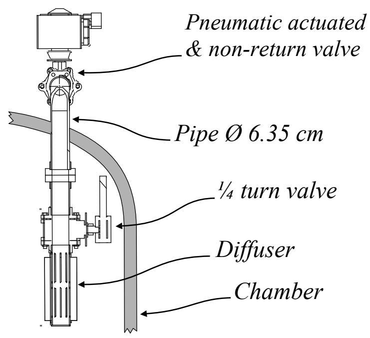
Electrical cabinets with Human Machine Interfaces
11 - Chiller #2
12 - Cold water tank
13 - Hot water tank



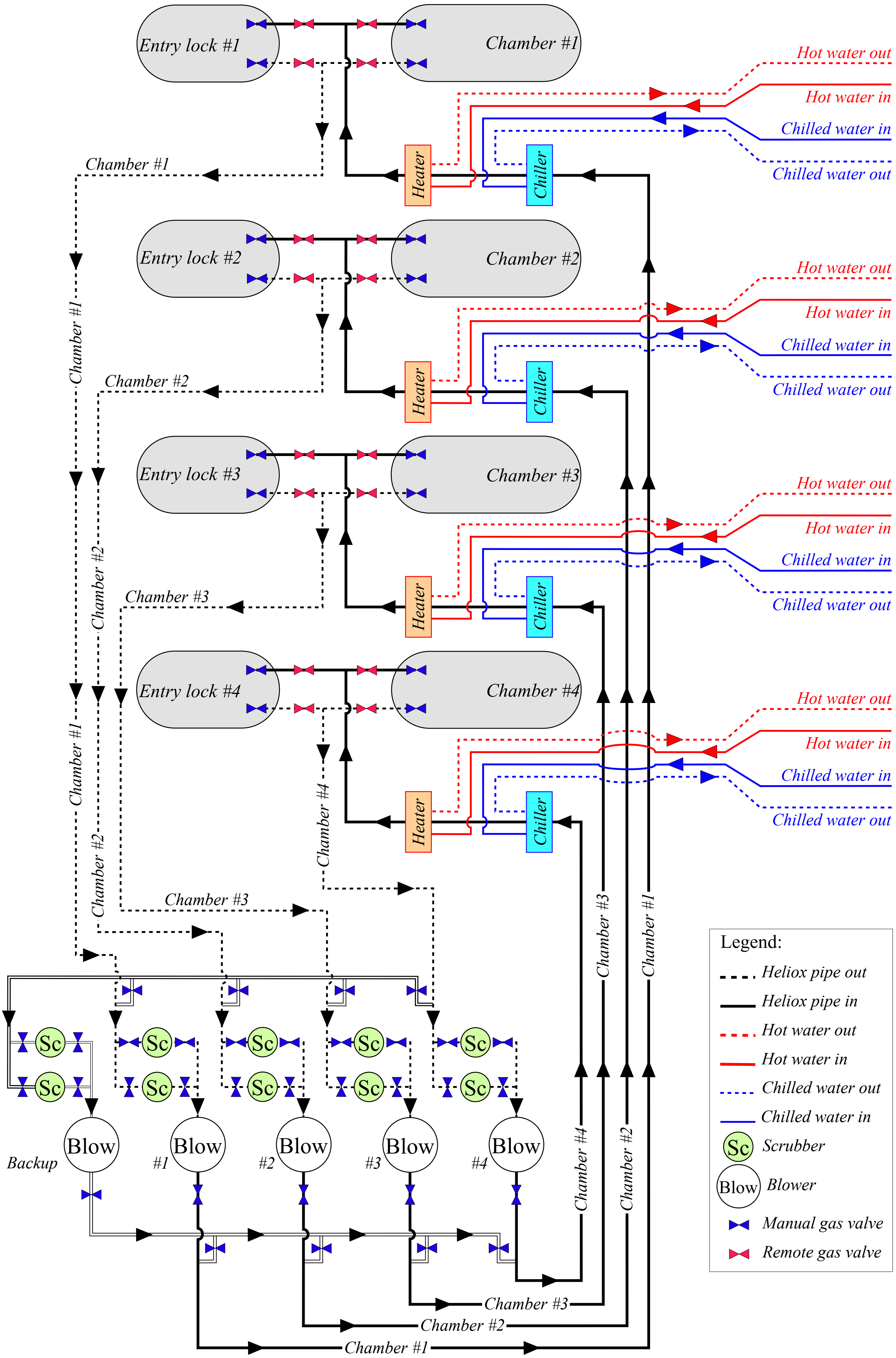
Evaporator:
14 - Refrigerant inlets (2 independent circuits)
15 - Refrigerant outlet to compressors (2 circuits)
16 - Mix water/glycol inlet (from process)
17 - Mix water/glycol outlet (to storage tank)

Note that the temperatures of the cold mix and hot water are electronically controlled through the algorithm of the temperature controllers installed in the electrical cabinets that can be set up and monitored through the Human Machine Interfaces that are visible in the photo above. As a result, each device is automatically adjusted in function of the parameters collected.

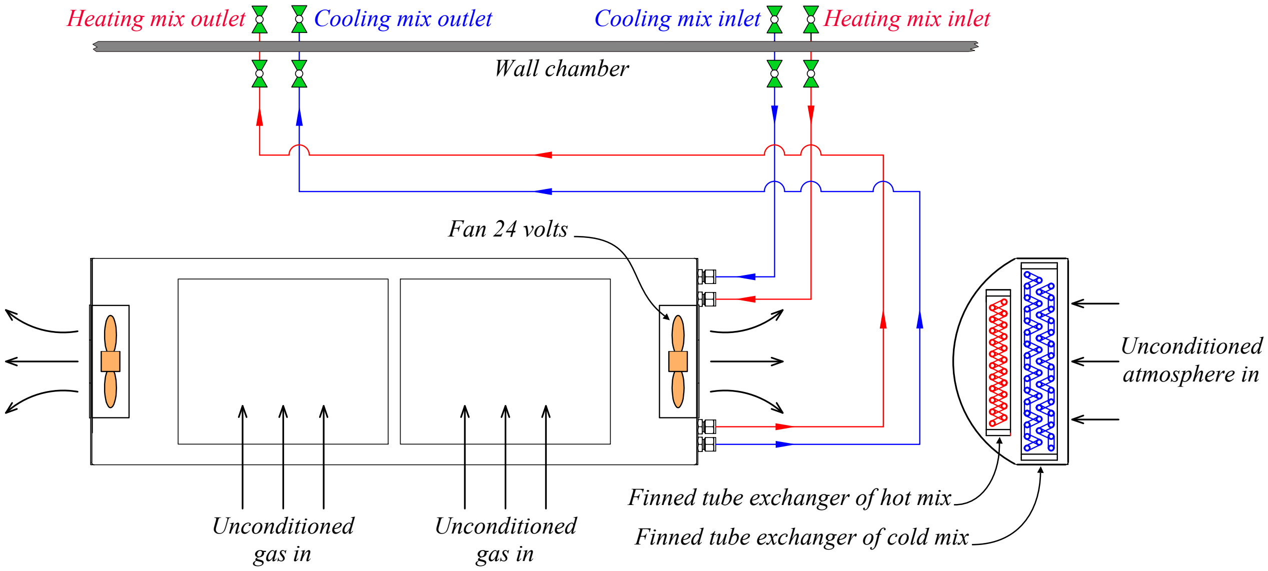
- 4 - The conditioned gas returns to the top of the living chamber through a pipe-work 2.5” (6.35 cm) diameter. With the saturation system taken as a reference, this pipe is fitted with a pneumatic actuated valve installed at hull penetration that is designed to close automatically if a rapid drop of pressure is sensed in the pipework. Thus, it operates as the non-return valve recommended in IMCA D 024. Note that a similar valve is installed on the exhaust pipe that acts as the “flow fuse” required by IMCA and described in point 1.2.2.2. Also, ¼ valves are provided inside the chambers so that the chamber can be fully insolated.
Oxygen is added to maintain the ideal PPO2 using the systems indicated in point 1.2.2.2. Note that with modern systems, the oxygen add is performed automatically.

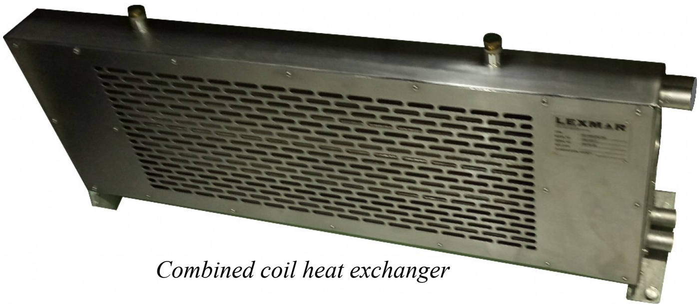


The drawing below summarizes the organization of the Hyperbaric Environment Regeneration System (HERS)

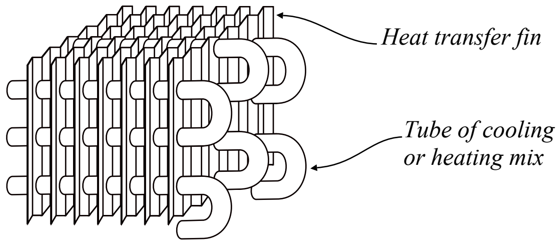


The secondary heat exchangers already described in point 1.2.2.2 and the scheme of the Hyperbaric Environmental Control System are composed of heating and chilling finned tube heat exchangers. Finned tube heat exchangers are composed of small tubes which surface of contact with the atmosphere of the chamber is extended through heat transfer fins. Such heat exchangers are commonly used with air conditioning systems and the cooling of engines of cars and airplanes. Two 24 volts fans are used to circulate the chamber atmosphere through the finned tube heat exchangers.
As indicated in the scheme of the Hyperbaric Environmental Control System, modulating control valves are installed outside the chamber on the outlets of both circuits. They are also operated by a Proportional Integral Derivative (PID) controller and provide the same functions as those of the external heat exchangers.



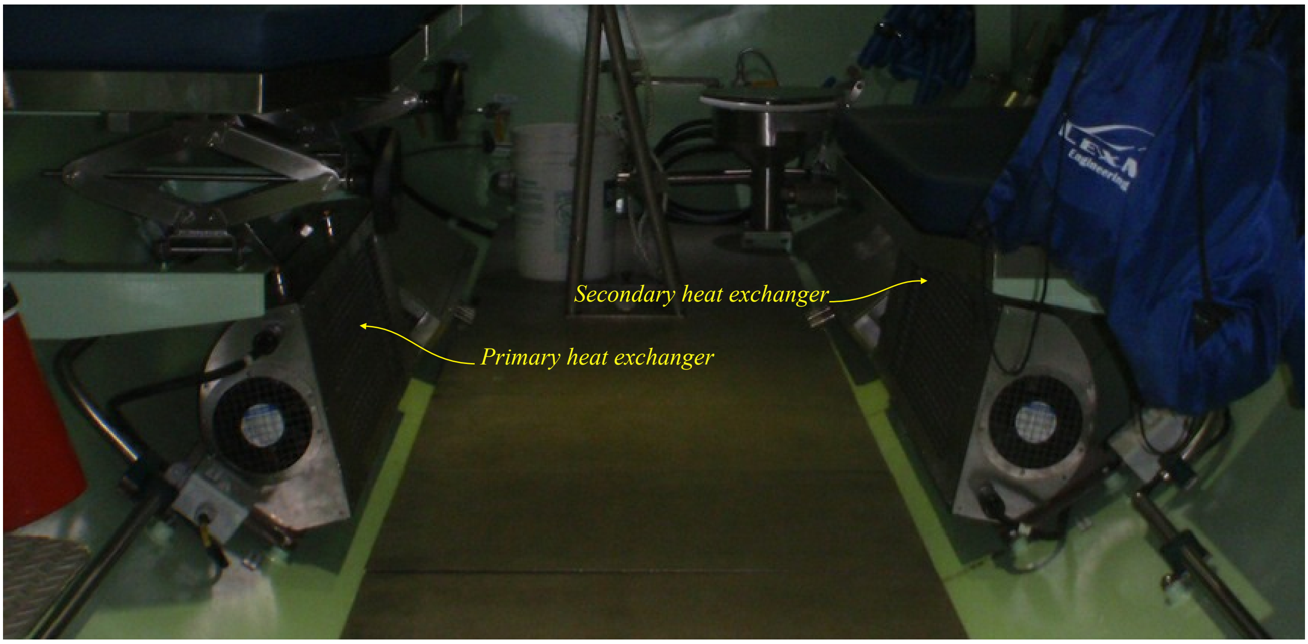


Combined coil heat exchanger



Detail of a coil heat exchanger

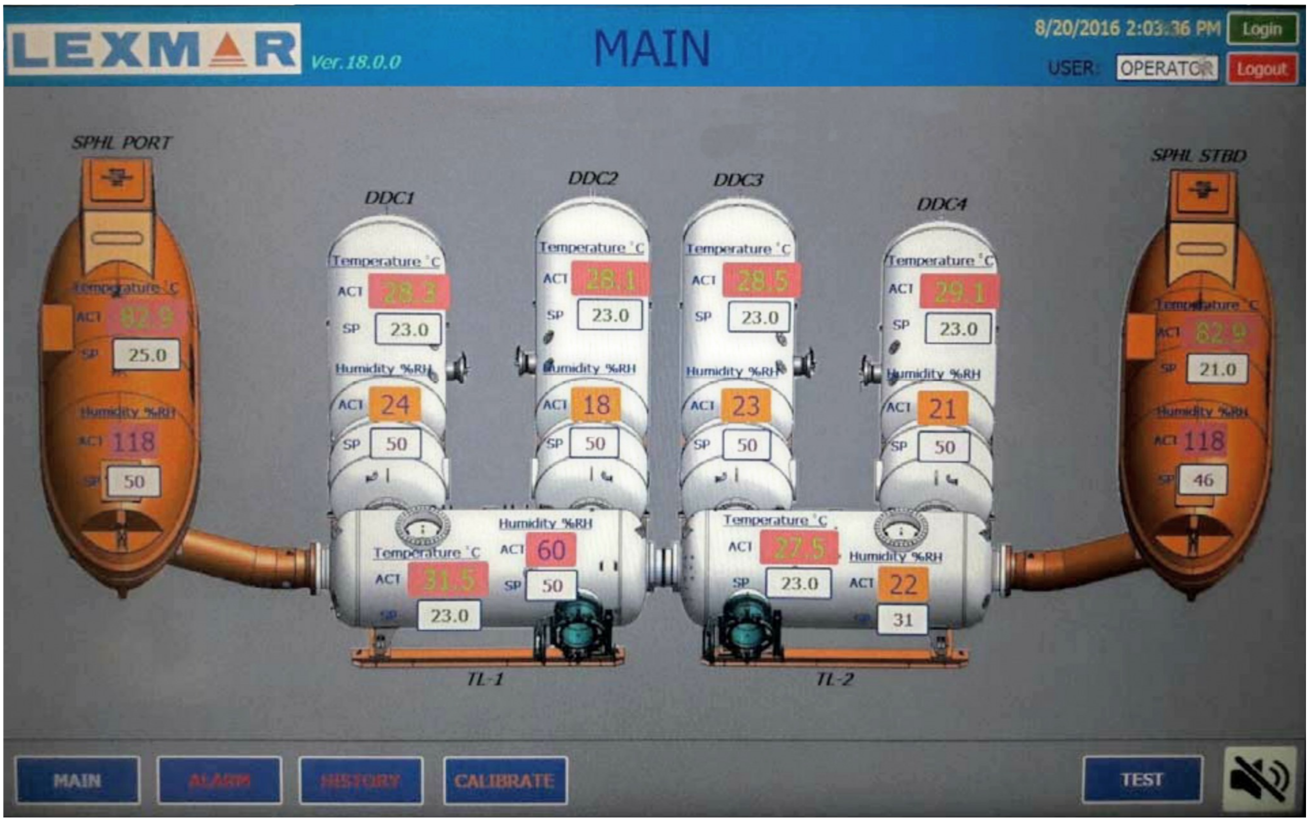
As already discussed, these heat exchangers are used as primary and secondary chilling and heating systems in the transfer locks of the systems taken as reference *(see the photo below)*.



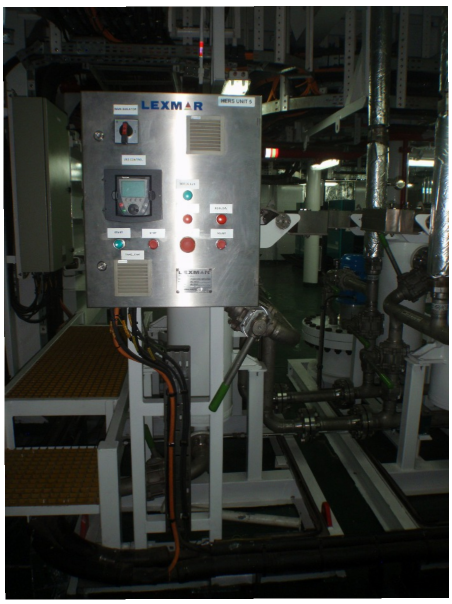
Note that some manufacturers install such devices in place of the primary external heat exchangers described with the saturation systems taken as references. As a result, the gas that returns to the chamber from the scrubber is still moistened, and its dehumidification is performed in the living chamber instead of into the heat exchanger.

1.2.4.2 - Human Machine Interface (HMI), and Remote control systems

With most modern systems, the temperature and humidity of the Chambers are controlled from the saturation control room through the Environmental Programmable Logic Controller (PLC), which is a computer that has been ruggedized and adapted for the control of the components described in the previous point. The CO_2 and oxygen values are monitored through the analysers.
The Life Support Technician (LST) can set up the desired temperature and humidity parameters and level of alarms of each part of the saturation system, except the bell through a touch screen panel. Also, this panel gives an overall vision of the temperature and humidity of the elements to control.



The dedicated temperature and humidity probes continuously collect the temperature and humidity in each chamber and transmit these data using 4-20 mA signals to the Environmental Programmable Logic Controller. These signals are immediately processed through the algorithm of the system that calculates the flow of cold and hot liquids into the dedicated heat exchangers of the Hyperbaric Environment Regeneration System (HERS) of each chamber. Signals (0 - 10V) are sent to the modulating valves on the output of the external Heat Exchangers to activate these devices that adjust the flow of the cooling and heating liquids to obtain the optimal dew point to remove the excess of moisture and get the desired temperature and humidity in the selected chamber.
Note that a Human Machine Interface is installed on each chamber scrubbing system *(see below)*, and that the parameters can also be controlled from this place. Also, a lot of saturation ensembles of previous generations are not equipped with remote commands. In this case, the setting up and control of the parameters are operated from the Human Machine Interfaces that are installed on the various elements that compose the system.



1 - main isolator switch

2 - Variable speed drive

3 - Start button

4 - Panel fan

5 - Stop button

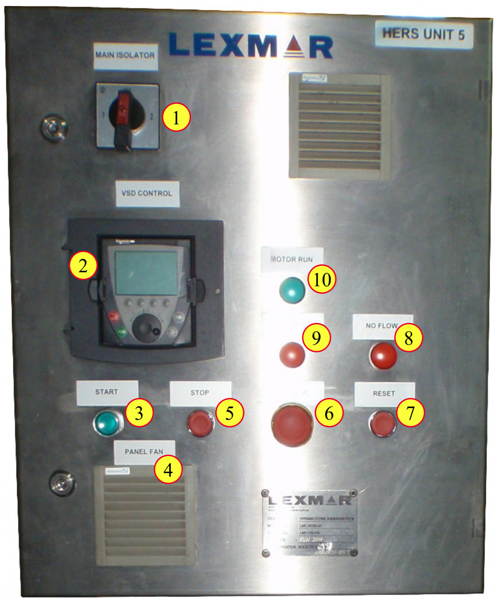
6 - Emergency stop button

7 - Reset button

8 - No flow warning light

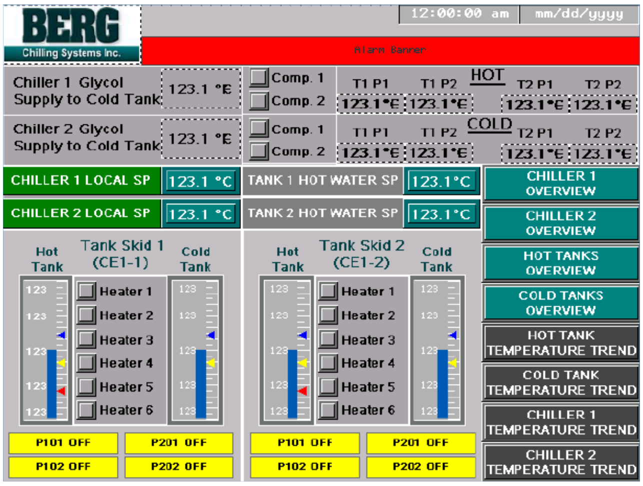
9 - Run fault light

10 - Motor run light

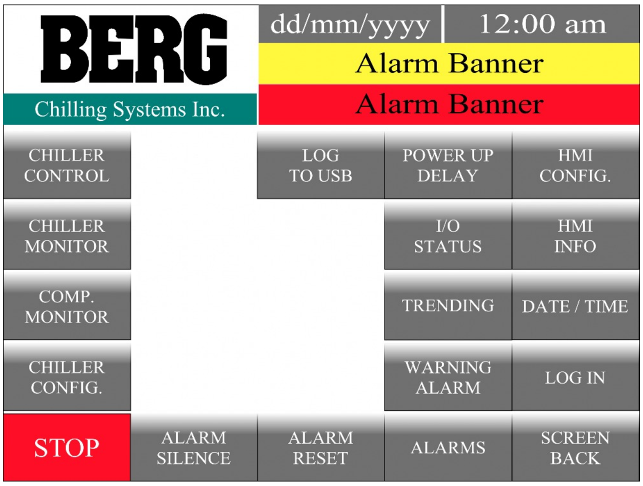


Hyperlink Table of contents

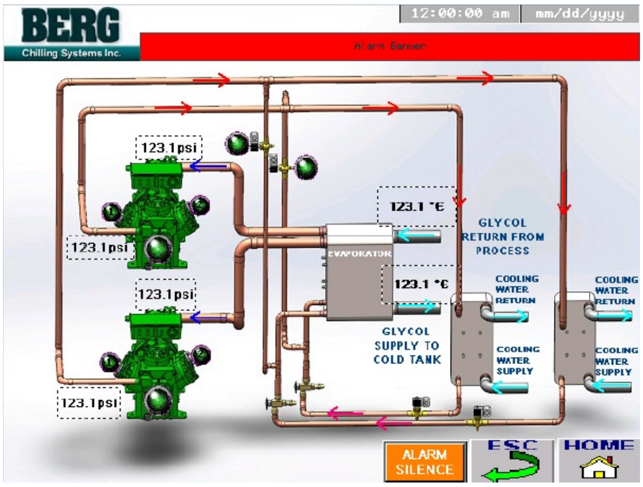
The chillers and the hot water production systems are controlled through the Human Machine Interfaces (HMI) installed in their electrical cabinet and the temperature sensors installed in each tank, as already indicated in the previous point. However, the operator screens can be viewed on any PC or wireless device on the network in real-time through Ethernet access. The number of controls that can be performed from the remote screens is configured through the Human Machine Interfaces (HMI).
With the web gate connected, the controller can send emails to programmed addresses when an alarm occurs. The email includes an alarm code, time, temperatures, and pressures. This feature can also be turned on or off from the HMI.
Relevant menus provide access to all areas within the Human Machine Interface program through the main screens of the chiller and the tanks *(See below)*. As a result, the parameters can be controlled from the saturation control room through a dedicated touch screen panel that can be used to set up the way the machines operate and display relevant information *(see below)*.



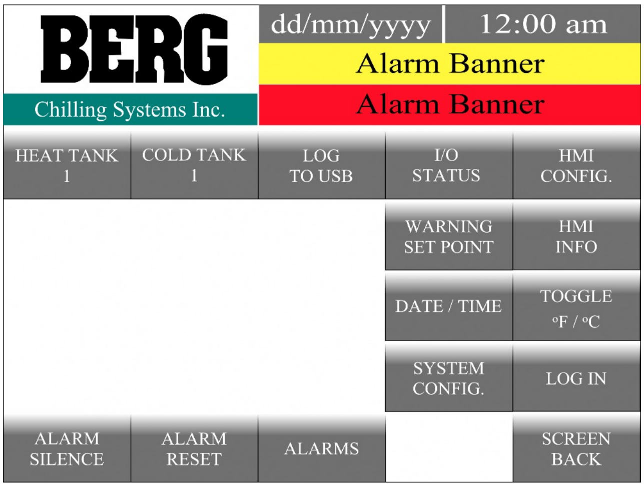
Alarm status display



Main screen Chiller



Temperatures and pressures chiller



Main screen tanks

Temperature of the cold water/glycol mix in holding tanks

Temperature of the hot water in holding tanks

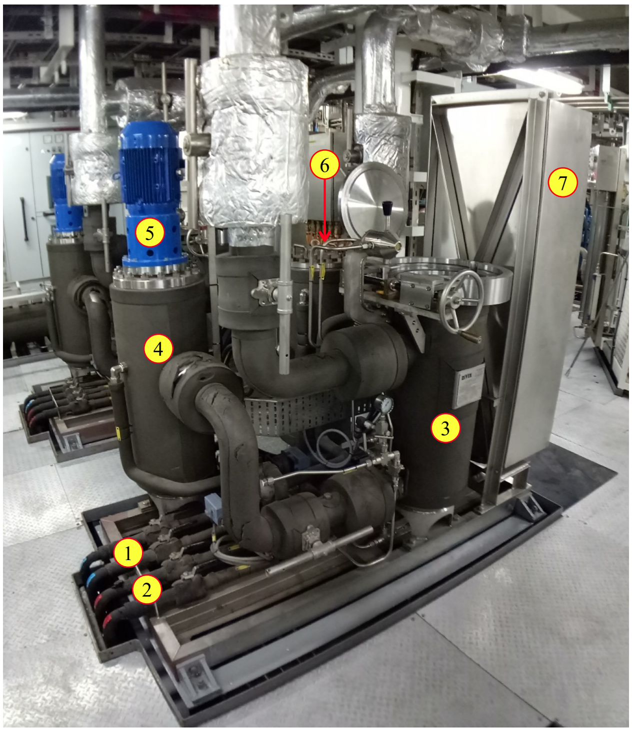
Note that the controllers used with the machines described above are Proportional Integral Derivative (PID) controllers. Such devices are used in industrial control applications to keep a constant temperature, flow, pressure, speed, and a variety of other applications requiring continuously modulated control. The working principle of these devices is that they continually monitor the difference between the desired setting and the measured process value to apply relevant corrections through an algorithm that consists of three primary coefficients; proportional, integral, and derivative, which are varied to get an optimal response. For this reason, the setting up of the parameters of these controllers require technicians with knowledge in configuration of software and electronic systems.

1.2.4.3 - Variations of the design of the reconditioning process described

The systems used as support in this study have been designed by Lexmar (JFD group).
There are other manufacturers who propose products with the same function. Nevertheless, we can say that their systems are based on the reconditioning process described previously:

- Soda-lime to remove the carbon dioxide,
- Chilling to remove the moisture, from the gas
- Reheating to adjust the gas at the desired temperature.
- Oxygen adds in the chamber to replace the one that has been depleted.

Of course, there are often some small variations of the design. As an example, the system in the photos below, which is designed by Divex, and installed in Ultra Deep Solution (UDS) Van Gogh, proposes the working steps described above with a slightly different configuration as the system Lexmar.

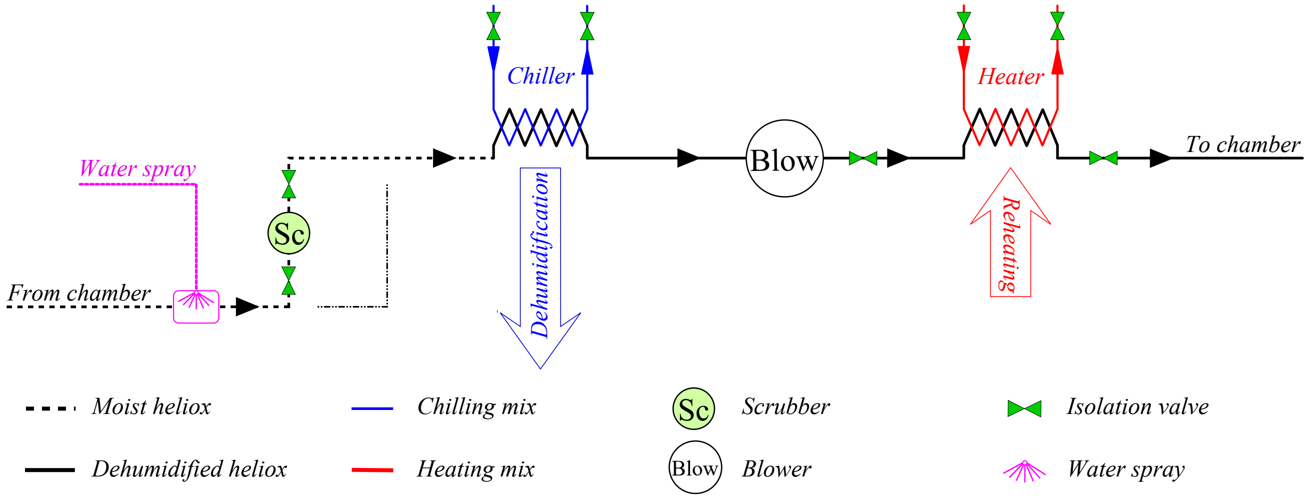


Description of the elements in the photos above:

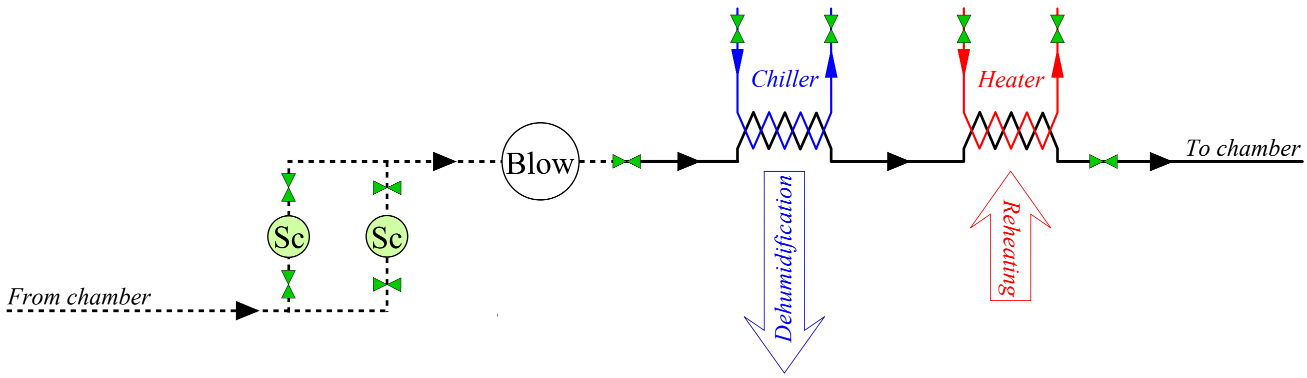
- 1 - Chilled mix water/glycol inlet and outlet: The chiller works with the same principle as the one described previously in this study. It is composed of two separate chilling circuits. However, it uses only one header tank, instead of two units with the system Lexmar.
- 2 - Hot-mix inlet and outlet: The heater is also based on the same principle of the system described in this study and provides two separate heating circuits. However, similarly to the chilling system described above, it uses a single tank instead of two units with the system Lexmar
- 3 - Scrubber designed for two canisters 8.8 kg capacity each. Note that the machine in the photo has only one unit. However, the manufacturer proposes an option with two units.
- 4 - Dehumidifier: It is supplied by the chilled mix and cools the gas to its dew point through a coil heat exchanger. Coil heat exchangers consist of a pipe where a chilled or a heated mix flows that is enrolled helically around the passage of the fluid to cool or heat. It is one of the most straightforward designs that is used in a lot of industries *(See the drawing on the next page)*. A Solenoid valve removes the condensate that is collected in the sump when it reaches a predetermined level.
- 5 - Blower: As with the one used by Lexmar, it is provided with a magnetic coupling that transmits the energy of the motor to the shaft of the rotor through magnets instead of direct contact. Its function is the same as in the system taken as an example in this study. However, it is situated after the dehumidification process and not before, as with the system taken as reference.
- 6 - Heater: As with the dehumidifier, this system uses a coil heat exchanger. When the heating process is completed, the gas moves back to the chamber.
- 7 - Electric cabinet with Human Machine Interface (HMI)
- 8 - Not indicated in the photos above, a water injection nozzle sprays a water mist into the gas inlet, before the scrubber, to increase the effectiveness of the soda lime.

Hyperlink Table of contents

The organization of the system described on the previous page can be summarized as follows:

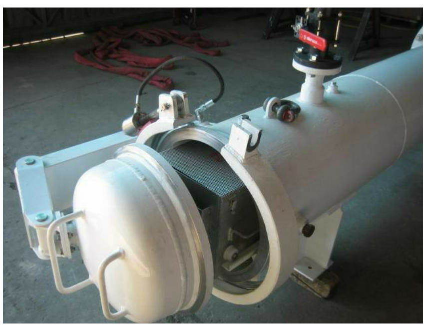


As a reminder, the organization of the system Lexmar is as follows:



Another example of a system using the process described in this study, but arranged differently, is the "external Scrubbing Unit" proposed by Comanex, where the elements indicated above are arranged in a horizontal pipe that can be installed along with the chamber it supplies. As with the systems above, it is divided into four sections:

- The blower that flows the gas from and to the chamber. It is situated in the broadest extremity (Ø 660 mm).
- The Soda-lime, which is arranged in three dedicated baskets with active charcoal. These consumables can be changed out through the door at the smallest extremity of the pipe (Ø 460 mm).
- The cooler, which is supplied with chilled water, reduces the gas temperature to its dew point. The condensate is evacuated by gravity through a penetrator.
- The heater, which is supplied with hot water, reheats the gas to the desired temperature.



Door for soda-lime change

- *Overall length: 4000 mm*
- *Shell: Ø 660/460 mm*
- *Flange: Ø 800 mm*
- *Weight: 1500 kg*

Blower (dome removed)

Note that some systems are designed with scrubbers outside the chamber and dehumidifiers and reheaters in the chamber. That proves that different solutions can be applied for the same process of regeneration of the gas.
The designers select these solutions in the function of the space available for the diving system. However, the essential qualities of a gas regeneration system remain its reliability and its ease of access for maintenance and everyday duties.

1.2.4.4 - Standards and rules

The complexity of these systems and the fact that they are under pressure and use high electrical voltages impose to build and maintain them with methodology and according to recognized international standards. Also, they are assemblies of numerous pieces. For this reason, as with the other parts of the saturation system, the elements that compose them should be precisely listed with details that indicate their function, manufacturer, model, type, serial number, working and test pressures, etc. The manufacturer and the classification society generally perform this process during the construction and the commissioning.
Note that IMCA D 024 says in section #11 that such equipment must be protected from physical damages. That means that they must be protected from potential shocks and dropped objects, but also the weather conditions. It is the reason that they usually installed in containers or safe areas of the ship where their access can be limited to only the technicians operating them. Also, these places must be organized in such a way that the components of the system are easily accessible for routine operations and maintenance and all kind of emergency repairs.
Besides, the personnel operating and maintaining them must not be exposed to hazards. For this reason, guards and warning signs such as those stating that an item of equipment may start, vent or stop automatically should be displayed in all sensitive points.
Firefighting systems and detectors must be provided. They are similar to those previously described for the external of the chamber and the dive control.
The system in the photo below is an example of the application of these requirements.

The standards and rules applied for the construction and the commissioning of these elements of the saturation system are similar to those used for the other parts. As a result, pipework, pressure vessels, electrical appliances and connections, fire fighting systems, alarms systems, etc., follow the rules and standards already explained in the previous points. However, note that particular items such as those used for the refrigeration systems should follow the standards of organizations such as ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers). Also, the design of the chilling and heating circuits and the liquids they use must be such that pollution of the chamber atmosphere by the chilling /heating mix cannot occur. A similar rule should be in place for the carbon dioxide absorbers, which canisters must be designed to allow the gas passing through the soda-lime but not let this product escaping.

1.2.4.5 - Maintenance

The hyperbaric environmental control system and associated hyperbaric regeneration system are critical life support systems that must be at their optimal working condition at all times. For this reason, regular audits and daily inspections of these machines are essential to detect potential problems. These audits and daily checks should be recorded in the planned maintenance system. Also, the technicians who are responsible for the operation and maintenance of these devices should attend relevant training on the service, the control, and safety features of the equipment they are responsible for and be familiar with the operation and maintenance manuals. Note that most manufacturers provide relevant formations and documentation to their clients.
As a result of the planned maintenance system, the spares to be maintained at a level consistent with the experience of running the system are identified, and the quantities to keep available can be determined by risk analysis. Also, note that the manufacturers usually provide lists of recommended spares.

IMCA recommends regular audits of the system components that should be organized as follows:

Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure*	*Other*
Welded pressure vessels	6 months	2 ½ years	2 ½ years (optional)	
Seamless pressure vessels (driers & filter housings)	6 months	15 months	5 years	
Interlock pipework	6 months	2 ½ years		
Blower (enclosure + fan)	6 months	2 ½ years	2 ½ years (optional)	Delivery rate: 6 months
Pressure relief valves	6 months	2 ½ years		
Bursting discs	6 months	2 ½ years	10 years	
Pipework & valves	6 months	2 years		
Non-return valve	6 months			
Flow fuse	6 months	12 months		
Gauges	6 months			
Electrical	6 months			
Automatic systems/ Electronic/ software	6 months			Manufacturer specifications
Chilling system	6 months			Manufacturer specifications
Heating system	6 months			Manufacturer specifications
Integral test of the entire Environmental Control Unit	6 months			Manufacturer specifications
Integral test of the entire Regeneration System	6 months			Manufacturer specifications
Fire fighting portable Systems	6 months			Manufacturer specifications
Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
Automatic fire detection	12 months			

1.2.4.6 - Dehumidification systems using silica gel

The dehumidification of modern saturation systems is based on the process described previously. However, previous generations of saturations systems were using Silica gel for this purpose, and some of them may still be in service. Also, even though they say that they do not sell any of them, a few manufacturers continue to propose this solution in their catalog.

Silica gel is a porous, granular form of silica, also called silicon dioxide (SiO_2), which synthetically manufactured from sodium silicate and is composed of tiny inter-connected pores that give it the capacity to absorb and hold water molecules. As a result of these properties, it is widely used as a desiccant. This product is said non-toxic and non-flammable. It is often used to protect foods, medicines, sensitive materials from moisture and for the desiccation of rooms and saturation systems.
Silica is usually commercialised as coarse granules or beads a few millimetres in diameter. These granules are normally translucent. However, those commercialised for the desiccation of rooms and saturation systems contain a substance that gives them a colour which changes according to the amount of water absorbed. This colour change property allows the Life Support Technician (LST) to see whether the silica gel has been saturated with moisture.
Cobalt chloride ($CoCl_2$) is an indicator of deep blue colour that becomes pink when the silica gel is saturated with water. It was the most employed indicator in the past. However, it has been classified as a toxic material by the European Union, and it is no longer allowed in this economic area.

Orange indicating silica gel, which is non-toxic and conforms to European Union requirements, is the last answer of the manufacturers to this toxicity problem. With this indicator, the beads appear orange when they are dry, and their colour becomes green when they become saturated with moisture.
Silica Gel can be reactivated indefinitely by heating it to temperatures between 120ºC and 150ºC during two to three hours.

Systems using silica gel are usually composed of two pots with auto-regenerating silica gel filters of approximately 65 litres each, where the temperature is controlled by means of heater elements.
These Silica gel pots are used in place of the first heat exchanger that cools the gas to its dew point to dehumidify it in the systems described previously. Only one pot is in service while the 2nd one is reheated and made ready for service when the first pot will be saturated with moisture.
To regenerate the silica gel, 2nd the pot is put in service and the 1st pot is isolated from the gas circuit and heated to the desired temperature. When the Silica Gel is regenerated, the pot is kept ready to be returned to service when the silica gel of the 2nd pot will need to be regenerated.
The systems in the photo below are composed of one scrubber 30 litres with a blower, and two silica gel pots 65 litres each that are installed each side of the blower. The ideal temperature in the chamber is often obtained by means of internal or external heater and chillers. Note that similarly to the new systems based on chilling system, several design can be proposed.

The main advantage of such systems is that they are compact, simple, and easy to install. Their inconvenience is that the Life Support Technicians are obliged to intervene to permute the silica gel pots, and follows up the regeneration of the one that is saturated with moisture.
Also, the systems that are still in service and those that are proposed in the catalogs of the manufacturers have not evolved these last years due to the lack of demand, and thus, have not been adapted to the new technologies described in the previous points.

1.2.5 - Chamber reclaim system

1.2.5.1 - Purpose

The Hyperbaric Environment Regeneration Systems (HERS) described in the previous point are designed to remove the gasses that result from the metabolism of the divers but not the contaminants from an external source. For this reason, the chambers are designed such that their atmosphere can be renewed if it has been polluted. That is usually done by opening the exhaust valve at the same time the inlet valve. Thus, new gas from quads or kelly tubes is introduced at the same time the old gas is dumped, which prevents a loss of pressure during this operation.
Also, the depths of the bells and transfer locks may have to be readjusted to the ambient pressure of the worksite. Besides, chambers and locks will have to be recovered to the surface at the end of the operations or for maintenance.
The problem with these operations is that the gas that is removed from the chamber is dumped outside it, which is not a problem with air, that can be pumped and stored at reasonable costs, but is a concern with mixes containing helium, that is a costly rare gas that cannot be manufactured. Also, the fact that helium cannot be made on-board obliges to store huge reserves of gasses that can be quickly impacted due to the high consumptions that are linked to the depths the divers are exposed during a saturation dive. As a result, the operational range of the system can be limited to only a few days. For this reason, a reclaim system that is designed to collect and fully recondition the gasses ejected from the chambers that compose the saturation system is usually in place.

1.2.5.2 - General design

The most used gas recovery system is composed of the "Gaspure" and "Helipure" systems, proposed by Divex (JFD group). They are components of the saturation systems taken as reference and intended to work as follows:

- The gas dumped from the chambers, entry locks, transfer locks, medical locks, equipment locks, and the bell mating trunks is routed to a three-way valve *(see #1 in the scheme on the next page)*. This routing is made directly via dedicated pipework or through the saturation control room panels. Also, the gas that is dumped from the gas reclaim system of the bell can be sent to this valve through specific exhaust circuits.
- This three-way valve allows routing the gas to a sealed gas bag where the dumped gas accumulates *(see #2)*. Besides, it enables dumping the gas overboard if necessary.
- When the gas bag is full, an infrared switch starts a compressor *(see #3)* to pump the gas trapped in the bag to an ensemble of filters that compose the Gaspure system *(see #4)* at the recommended pressure and flow rate. When the bag is nearly empty, another infrared switch stops the compressor. A back pressure regulator maintains the minimum system pressure at approximately 138 bar (2,000 psi), ensuring efficient operation of each element of the Gaspure system. An alarm panel, generally situated in the saturation control, indicates the parameters of the system, and whether the gas bag is full.

Gas bag (deflated)

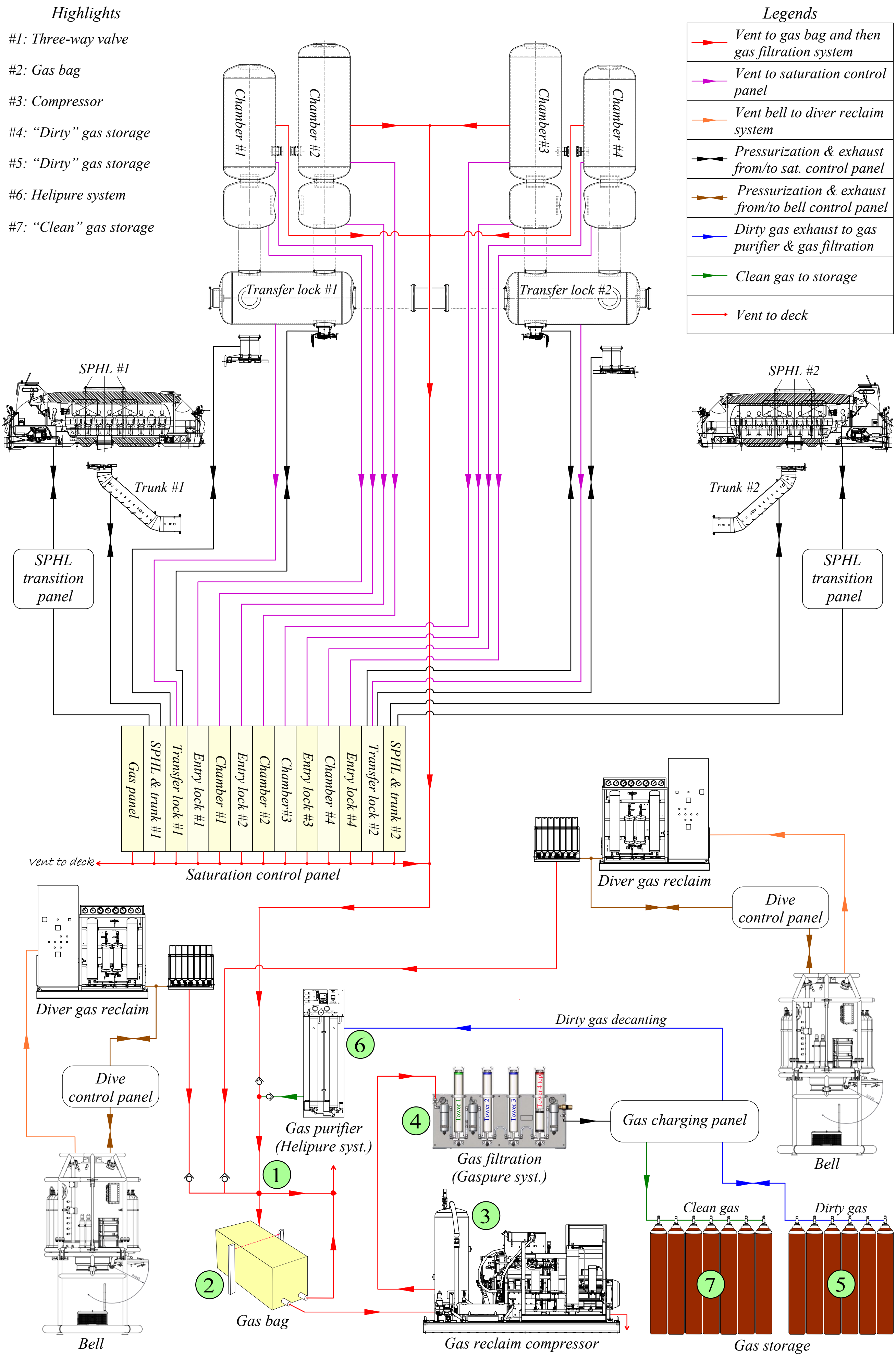
Gaspure filtration system

- The Gaspure System removes the following impurities at flow rates of up to 136 m³ /hr:

- Water vapour	- Particles	- Bacteria	- Carbon dioxide
- Carbon monoxide	- Hydrogen sulphide	- Sulphur dioxide	- Ammonia
- Mercaptans	- Nitrous oxides	- Heavy hydrocarbons	- Methane & light hydrocarbons

- The filtered gas is then routed to suitable high pressure gas storage where it is analysed and kept *(see #5)*. However, there may be a problem in re-using this gas because it contains significant quantities of oxygen and nitrogen plus other gasses that have been mixed with the heliox during the operations and must be removed. That is performed through the "Helipure system" *(see #6)*, which is a gas purification system based on porous membrane technology that allows removing these undesirable gasses to obtain a gas that can be safely reused to all depths. Thus, the "dirty gas" *(Helium with air and other gasses)* is decanted from the dirty gas storage tubes through the Helipure system that removes the undesirable gasses.
- The purified gas is then passed to the gasbag from where the compressor recompresses it and passes it through the filtration package from which it is stored to the clean gas banks *(see#7)*.

Scheme of the “chamber gas reclaim system” of UDS Lichtenstein and Picasso.



1.2.5.3 - Gas bag

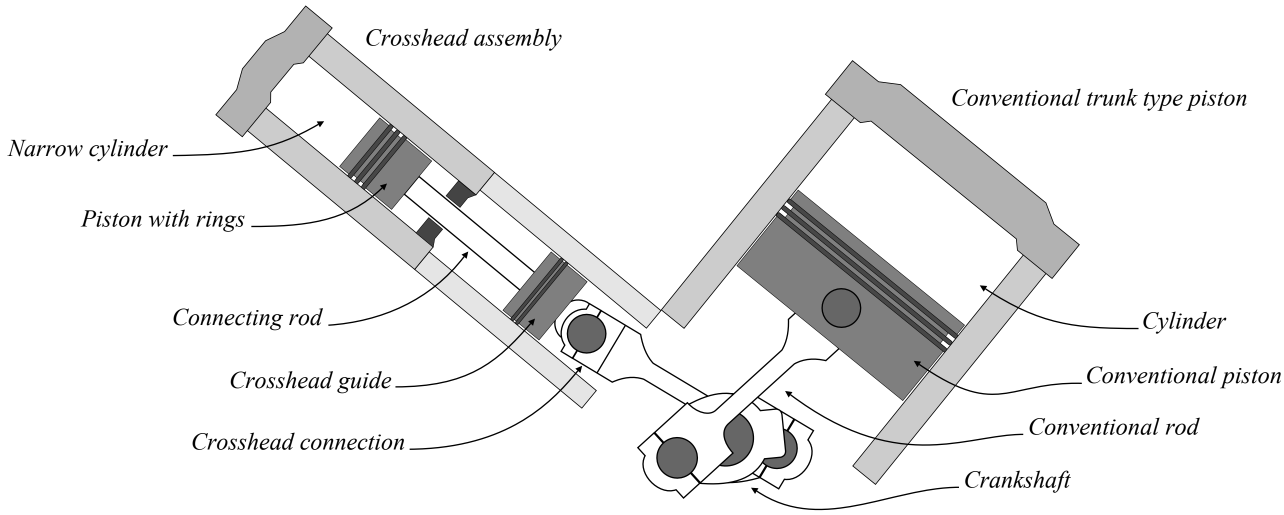
A Gas-bag is usually made of a vinyl cloth that is welded and to which the inlet and exhaust must be suitably sealed to be perfectly gas-proof. A relief valve protects this assembly from overpressure. It is fixed to the floor and installed in a dedicated cage that maintains it in shape and protects it from damage as it inflates. The gas bag is usually located in an isolated area with access is limited to only the nominated technicians not to be damaged.
As indicated previously, infrared switches are in place to start and close the compressor. They consist of infrared emitters that are installed on one side of the bag and reflectors that are aligned with the transmitters on the opposite side. When the bag is inflated, it cuts the infrared ray, which results that the switch is triggered. When the bag is deflated, the beam is reestablished, and the stop switch is activated.

Gas bag cage. Note the infrared reflectors along the wall

Exhaust connection. Also, note the welds of the tarpaulin

1.2.5.4 - Compressor

The manufacturer of the Gaspure system (Divex) does not supply a compressor with the system. However, he recommends to use the Gardner Denver model H-5437.1 Heliox that is driven by an electric motor 37 kW/440 VAC. This model that is designed for heliox mixtures not exceeding 21% oxygen is capable of supplying 110 m3/hour at a pressure of 200 bar and a speed of 1160 RPM.
It is a water-cooled reciprocating single-acting compressor designed with four-stages organized in "V" at 90º, with the 1st and 3rd stage lines on one crank throw, and the 2nd and 4th stage lines on the opposite crank throw of a counterbalanced crankshaft. A single combined suction and discharge concentric valve is fitted at the head of each of the four cylinders that are organized in two blocks that combine the 1st stage with the 2nd stage, and the 3rd stage with the 4th stage.
The first and second stage pistons are conventional trunk type, while the third and fourth are an integral piston and crosshead assemblies.
Note that a crosshead assembly is a mechanism used as part of the slider-crank linkages of reciprocating compressors to eliminate sideways pressure and wear on the piston *(see the scheme below)*. Also, it enables the connecting rod to move in narrow cylinders with long-stroke pistons without hitting the walls and blocking the rotation of the mechanism, which could happen with conventional trunk type pistons that are attached directly to the connecting rod.

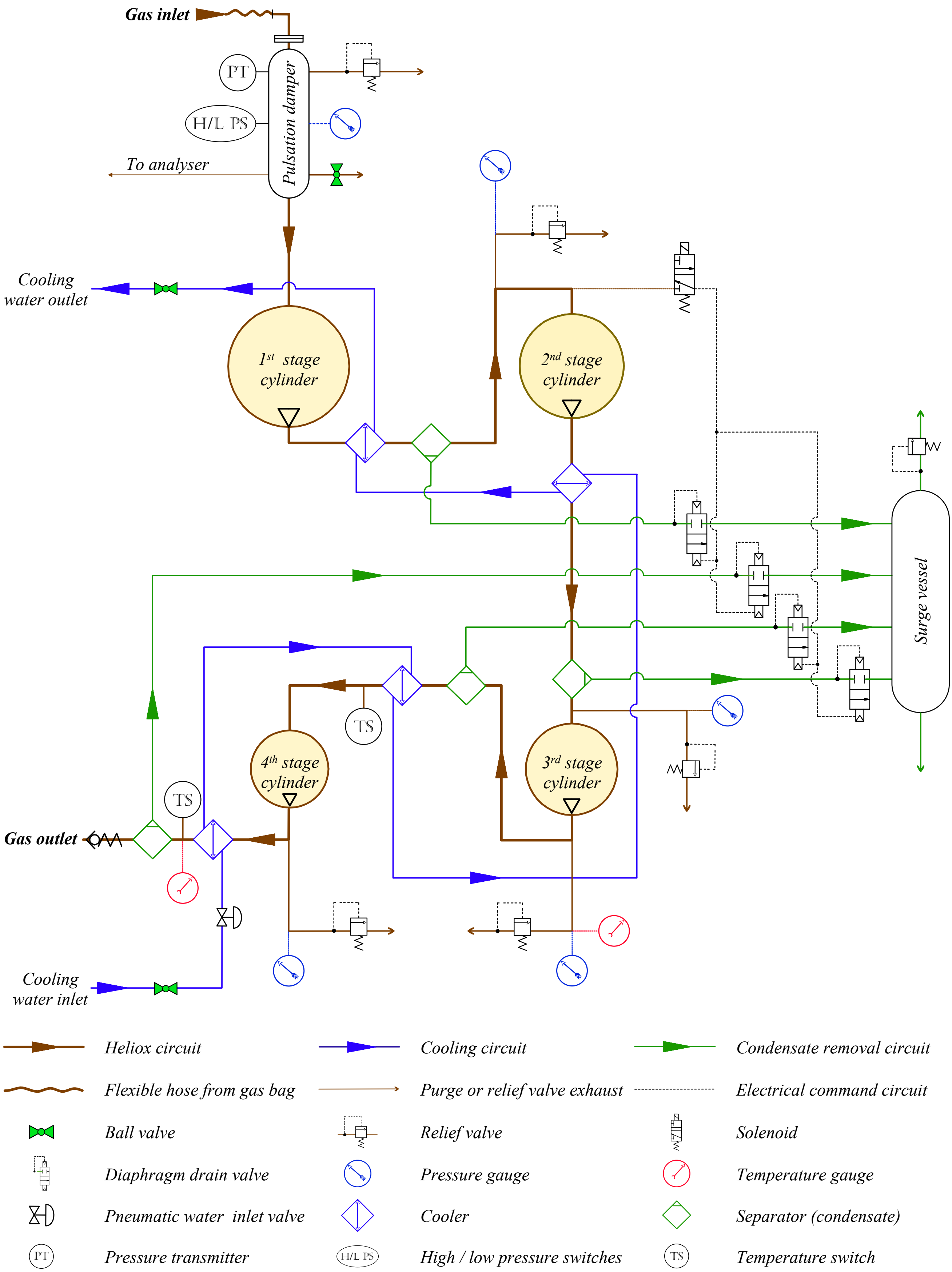


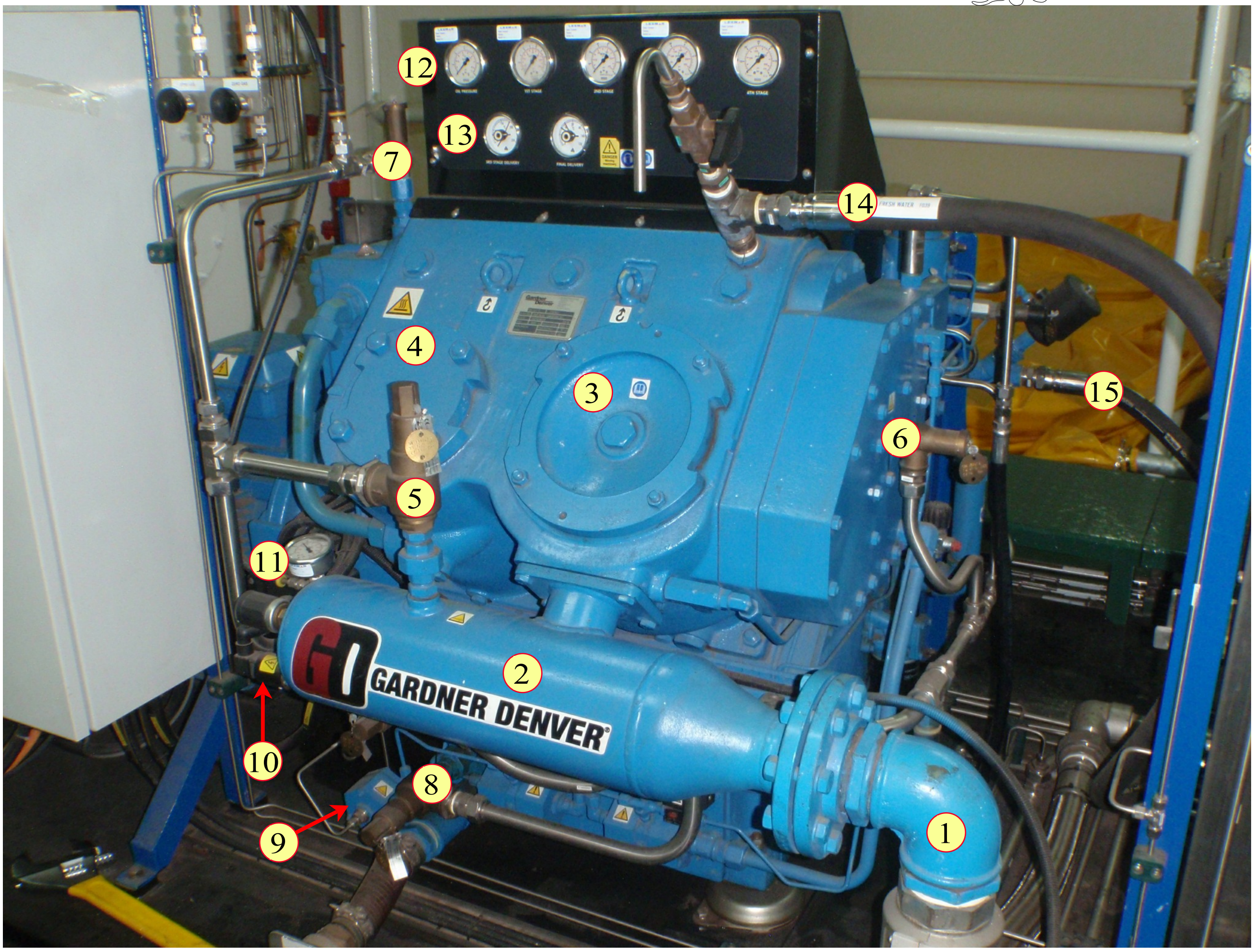
The cylinders, pistons, and valves are splash or spray lubricated through a forced feed system. The oil pump is driven from the crankshaft.
Inter-stage coolers are provided after each stage of compression and are designed for a water flow of 75 l/h/kW. They allow cooling the gas heated by the compression to within 5°C of the cooling water inlet temperature. Note that this machine accepts sea water. Also, gas temperature switches are fitted after the cooling elements of the 3rd and 4th stages to stop the compressor in case of over temperature of the gas stream.

Condensate separators are also installed after each inter-stage cooler. They are drained by automatic valves into a discharge surge vessel at approximately 10 to 20 minute intervals for a period of 5-10 seconds *(see in the scheme below)*. The drainage system while removing oil/moisture also acts as an unloading device to prevent the compressor from starting under load, by bleeding off automatically all the gas in the compressor through the condensate separators whenever the compressor stops.

Gas relief valves are fitted to prevent over-pressure in cylinders and coolers. Also, the cooling system is protected from accidental exposure to gas pressure by dedicated bursting diaphragms.

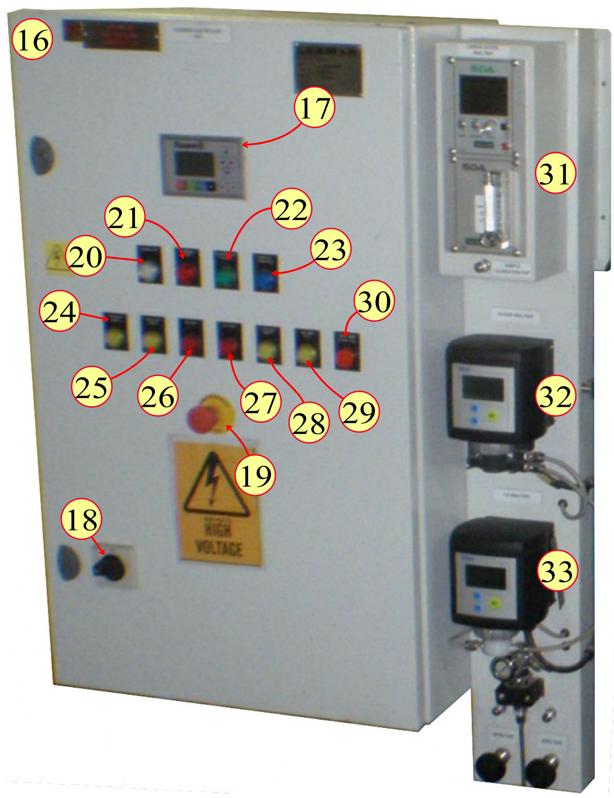
A non-return valve is located at the final discharge connection to prevent system pressure returning to the cylinders when the compressor is shut down.





- 1 - Air inlet	- 2 - Damper	- 3 - First stage cylinder	- 4 - Second stage cylinder
- 5 - Relief valve inlet	- 6 - Relief valve 1st stage	- 7 - Relief valve 2nd stage	- 8 - Relief valve surge vessel
- 9 - Diaphragm drain valve	- 10 - Pressure transmitter	- 11 - Pressure gauge inlet	- 12 - Pressure gauges stages
- 13 - Temperature gauges	- 14 - Cooling water inlet	- 15 - Fresh water outlet	- 16 - Electrical cabinet

The electrical cabinet *(see #16)* is installed on the same chassis as the compressor with the gas inlet analysers. The Human Machine Interface (HMI) *(see #17)* that allows controlling the machine is installed on its door with the following indicators and switches:

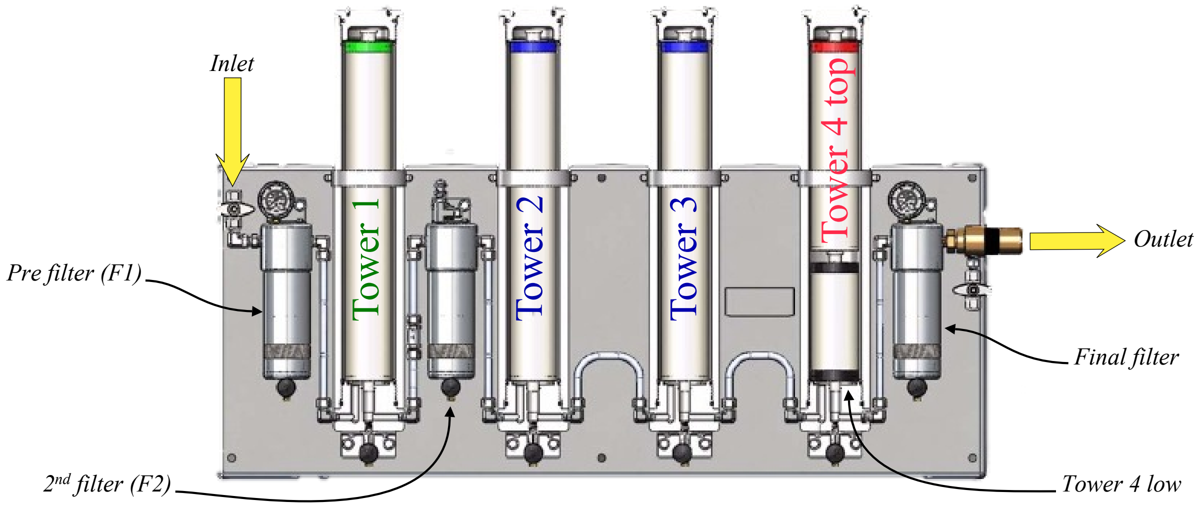


- 18 - Power switch	- 19 - Emergency stop switch
- 20 - Power on indicator	- 21 - Common trip indicator
- 22 - Compressor running	- 23 - Service required alarm
- 24 - Transfer mode indicator	- 25 - Reclaim mode indicator
- 26 - Alarm oxygen high	- 27 - Alarm carbon monoxide
- 28 - Gas bag empty alarm	- 29 - Gas bag full alarm
- 30 - Light not attributed	- 31 - Oxygen analyser
- 32 - CO analyser	- 33 - CO_2 analyser

Note that the machine is equipped with a protection system that switches it off if the oxygen percentage is above 21%, which is the maximum limit it is designed for.

1.2.5.5 - Divex Gaspure system

The gas compressor discharges the gas into the gas purification system where water vapour, particles, bacteria, carbon dioxide, carbon monoxide, hydrogen sulfur, sulfur dioxide, ammonia, mercaptans, nitrous oxide, heavy hydrocarbons, methane, and other light hydrocarbons are removed at a flow rate of up 110 m3/hr.
A back pressure regulator maintains the minimum system pressure at approximately 138 bar, for the efficient operation of each element of the system that is composed of the succession of filters below.



1. Pre-Filter (F1):
   It removes particles, both liquid and solid, down to a size of 1 micron. This filter is designed to remove large quantities of liquid water and/or oil. The maximum remaining oil content downstream of the pre-filter is 0.5 ppm using a typical compressor lubricant. This filter is suitable for use with mineral, synthetic and even degraded lubricants.
2. Tower #1 (green):
   It removes the carbon dioxide (CO_2) from the gas stream. This scrubber utilises granular soda lime in an absorbent bed. The absorption reaction of CO2 by soda lime occurs via the following reaction route:
   - $CO_2 + Ca(OH)_2 \longrightarrow CaCO_3 + H_2O$ (calcium carbonate + water)
     The reaction can be further broken down into three steps
   - CO_2 gas + $H_2O \longrightarrow CO_2$ in solution
   - CO_2 aqua + NaOH $\longrightarrow$ $NaHCO_3$ (sodium bicarbonate)
   - CO_2 aqua + NaOH $\longrightarrow$ NaOH + $CaCO_3$ (sodium hydroxide + calcium carbonate)

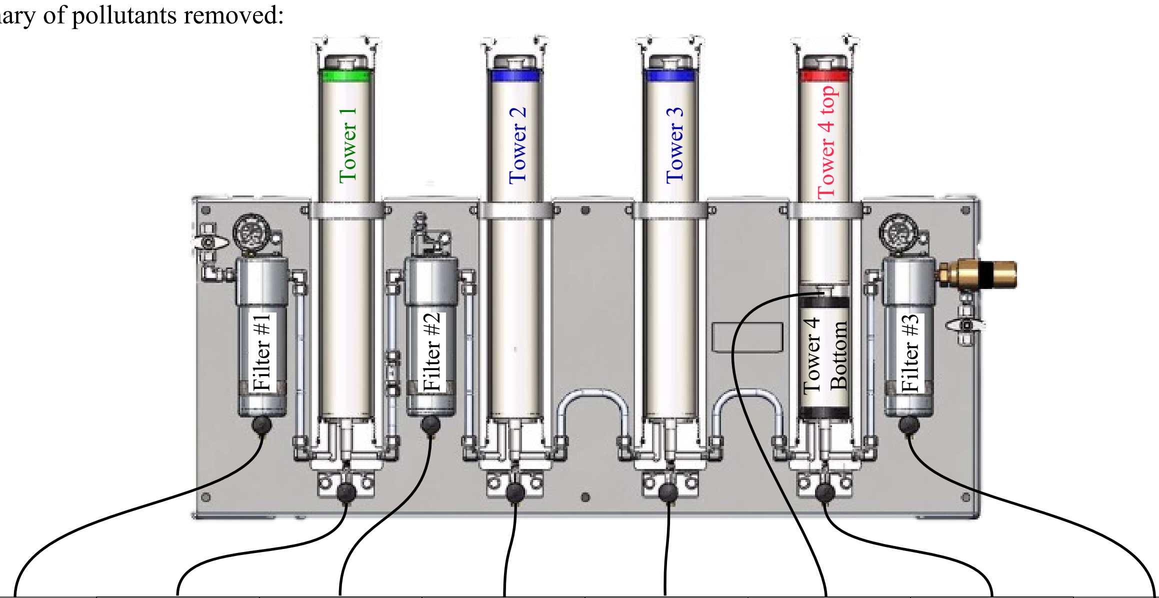
   The efficiency of soda lime increases in a moist atmosphere, so this is the first process carried out on gas. Water vapour present in the gas or produced by the reaction is removed in subsequent filtration stages.
   This tower also removes the majority of the Hydrogen Sulphide and some low molecular weight mercaptans. ("Mercaptans" refer to "thiols" which are sulfur with molecular structure analogue of alcohols).
   The CO_2 scrubber contains 3.3 litres of soda lime. The manufacturer says that canisters are easily changed and are available in pre-packed sets.
3. Second stage filter (F2):
   It removes particles, both liquid and solid, down to a size of 0.01 microns including bacteria. Translated into oil removal terms, it means maximum oil content downstream of the filter of 0.01 ppm.
   - The compressed gas passes first through the inner layer of the filter element consisting of an integral pre-filter material, which removes larger particles of dirt and liquid. This gives protection to the layer of high efficiency filter material, which removes even the finest of particles.
     - Solid particles are trapped permanently within the filter material.
     - The fine liquid particles, including aerosols, after initially being trapped by the fibres of the filter material coalesce forming larger droplets.
     - These droplets along with any large droplets already present in the compressed gas are pushed to the outer support of the element. Here they meet the anti-re-entrainment barrier, which collects the droplets as they break free and allows them to gravitate within its cellular structure forming a 'wet band' around the bottom of the filter element.
   - Clean filtered gas passes through the anti-re-entrainment barrier above the 'wet band' where the resistance to flow is less, leaving a quiet zone of zero gas movement in the bottom of the filter housing. Through this the separated liquid falls without being re-entrained and is removed by the drain on the bottom of the filter.

   The life of the filter elements is independent of the amount of liquid contamination present. However, dirt particles do eventually bind up the filter material and the elements must be replaced.

4. Towers #2 &3 (Blue)
   After filtration to remove oil and water droplets, the gas is passed through towers 2 & 3 (blue) where it is dried in order to prolong the life of the catalyst bed, and also absorbs a variety of impurities notably hydrogen sulphide, mercaptans and methane.
   The water content of the gas leaving theses towers is less than 0.3 ppm, giving a gas dew point -50 ºC (-58 ºF).
   Note that the drying effect of these cartridges is vital to the plant since the efficiency of all three reagents in Tower four are greatly reduced in moisture.
   These cartridges should be replaced when their useful life is completed.
5. Tower #4 top cartridge (red)
   The upper cartridge of tower #4 is composed of two sections:
   - The gas first passes through a broad band absorbent and oxidant, removing a wide range of impurities from the gas, in particular sulphur dioxide, ammonia, nitrous oxides, other light hydrocarbons and any residual methane or hydrogen sulphide.
   - The second section of this cartridge removes heavy hydrocarbons and will remove any remaining traces as well as remaining odours.

   The life of this cartridge is independent of the amount of contamination absorbed or oxidised. It must be replaced when its useful capacity is finished.
6. Tower #4 lower cartridge (Black)
   During situations where significant quantities of carbon monoxide may be present, a bed of catalyst is used to oxidise the carbon monoxide to carbon dioxide is utilised . The quantity of carbon dioxide formed in this way is insignificant in terms of overall gas purity. The catalyst bed will theoretically last indefinitely; however, the life of the bed is drastically reduced by moisture.
   Because of this fact, silica gel moisture indicating beds are provided above and below the catalyst bed. Always check for colour changes during every cartridge change. If crystals have changed from orange to white/faded yellow, replace immediately *(Remember that blue silica gel is no more accepted in the European community)*.
7. Final filter
   The filtering process is completed by the final filter that is identical to the pre-filter. The purpose of this filter is to remove the particles that may have passed through the other filters.

Summary of pollutants removed:



Filter #1 (Pre-filter)	Tower #1	Filter #2	Tower #2	Tower #3	Tower #4 - top	Tower #4 - bottom	Filter #3 (Final filter)
Removes particles to 1 micron	*Removes carbon dioxide (CO_2)*	*Removes particles to 0.01 micron*	*Removes water up to 0.3 ppm, & also H_2S, mercaptan, and methane*	*Removes water up to 0.3 ppm, & also H_2S, mercaptan, and methane*	*Removes impurities & hydrocarbons*	*Removes carbon monoxide (CO)*	*Removes particles to 1 micron*

When the gas has passed through these filters, it is normally less polluted than the air breathed by most people on earth, and several companies reuse it as it is. However, some gasses, mostly oxygen and nitrogen have not been removed:

- The remaining oxygen is the one that has not been consumed by the divers. If its percentage too high, the mix cannot be reused at some depths, and significant quantities of "new heliox" *(also called "fresh gas")* 2% or less may have to be mixed to adjust it. However, that could be insufficient for dives below 180 m.
- The remaining nitrogen results from the air trapped in the system during the first pressurization and anytime a lock of the complex is recovered to the surface for and usual task or maintenance. If a mix that already contains nitrogen is reused, this undesirable gas is added to the one already present in the chamber and its percentage

becomes significant. As a result the divers breathe a three-mix gas instead of the heliox for which the diving management procedures have been studied. It is the reason a lot of companies prefer using "new heliox' for the 1st pressurization.

- Also, other gasses such as argon may be present as a result of the operations undertaken by the team.

For these reasons and as indicated in point 1.2.5.2, the reclaimed gas should be purified to be able to be reused safely. It is the function of the system described below.

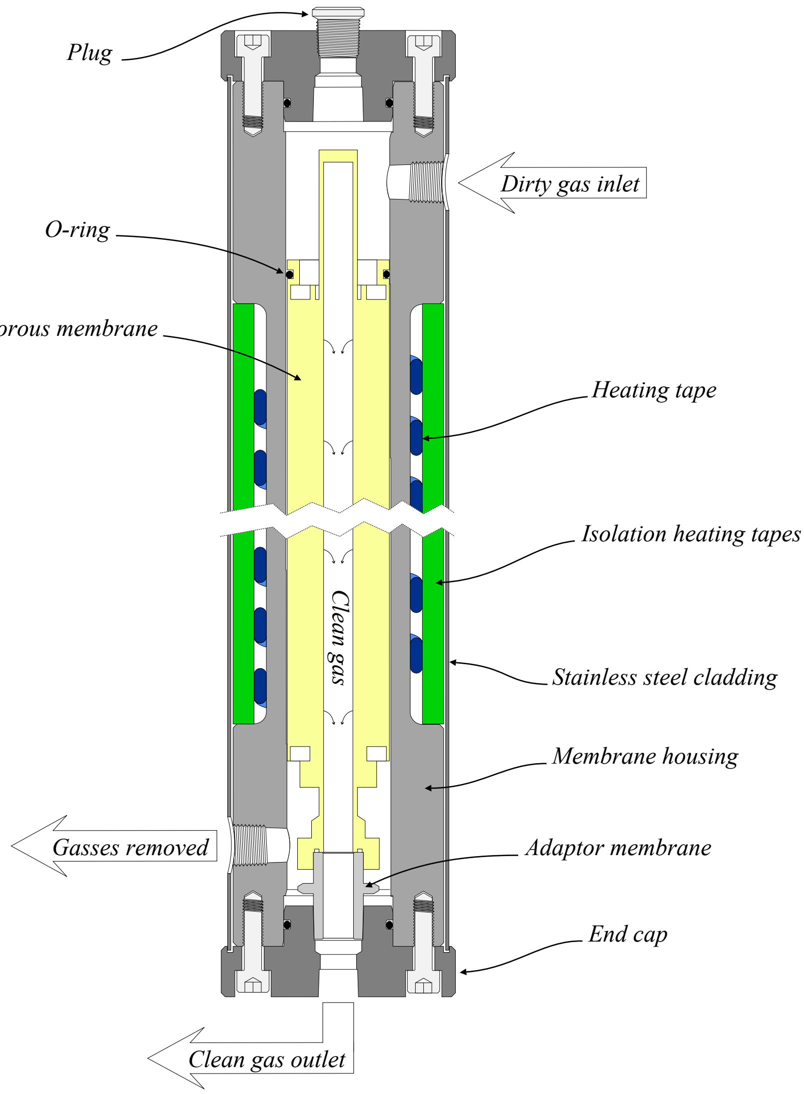
1.2.5.6 - Divex Helipure system

As already said, Helipure is a gas purification system based on porous membrane technology that allows removing undesirable gasses not eliminated by the Gaspure system, such as oxygen and nitrogen, to obtain a gas that can be safely reused to all depths. It is composed of two towers that are connected to the "dirty gas" bank and are usually installed at direct proximity of the filtration system previously described (see below) to which the exhaust is connected.

This system works as follows:

1. The "dirty gas" is routed to the Helipure system from its high-pressure storage banks through the pressurisation control system which limits the speed at which the membranes are pressurised and hence prevents damage.
   - This system consists of a dome loaded regulator, the loading pressure of which is controlled by a hand loaded regulator.
   - A restrictor limits flow from the hand loader into a buffer volume, connected to the dome. That limits the pressurisation rate of the dome, and hence, the downstream pressure of the dome loaded regulator.
   - A check valve in the circuit allows the buffer volume to vent down when the system is shut down readying it for the next pressurisation sequence.
2. The gas is then heated to 40°C, which is the optimum running temperature for the membranes.
   - The ideal temperature is obtained using an electrical heater with an electric temperature control and display.
   - A resistance thermometer measures the outlet temperature from the heater housing and this is then displayed on the controller.
   - The controller then compares the actual temperature with the desired temperature and switches on or off the heater as required.
   - A second temperature sensor located on the outside of the heater housing is used to check the housing temperature and switches off the heater should a fault develop.
   - A flow switch in the clean gas outlet, monitors for flow from the unit and also switches off the heater when no flow is indicated. That protects both the membranes from being overheated and the heater element from burning out.
3. When heated, the gas passes to the two membranes which are connected up in parallel in two stainless steel pressure vessels with bolted end caps to enable the elements to be entered and withdrawn.
   - The membrane element is internally secured to one end cap using a tube fitting and internally sealed to the bore of the pressure housing using a lip seal or O-ring. Due to this seal, gas entering the pressure housing is thus forced down the length of the membrane and permeate gas flows through the membrane into the central tube and out via the fitting.
   - To avoid the pressure housing acting as a heat sink and cooling the preheated inlet gas, trace heating

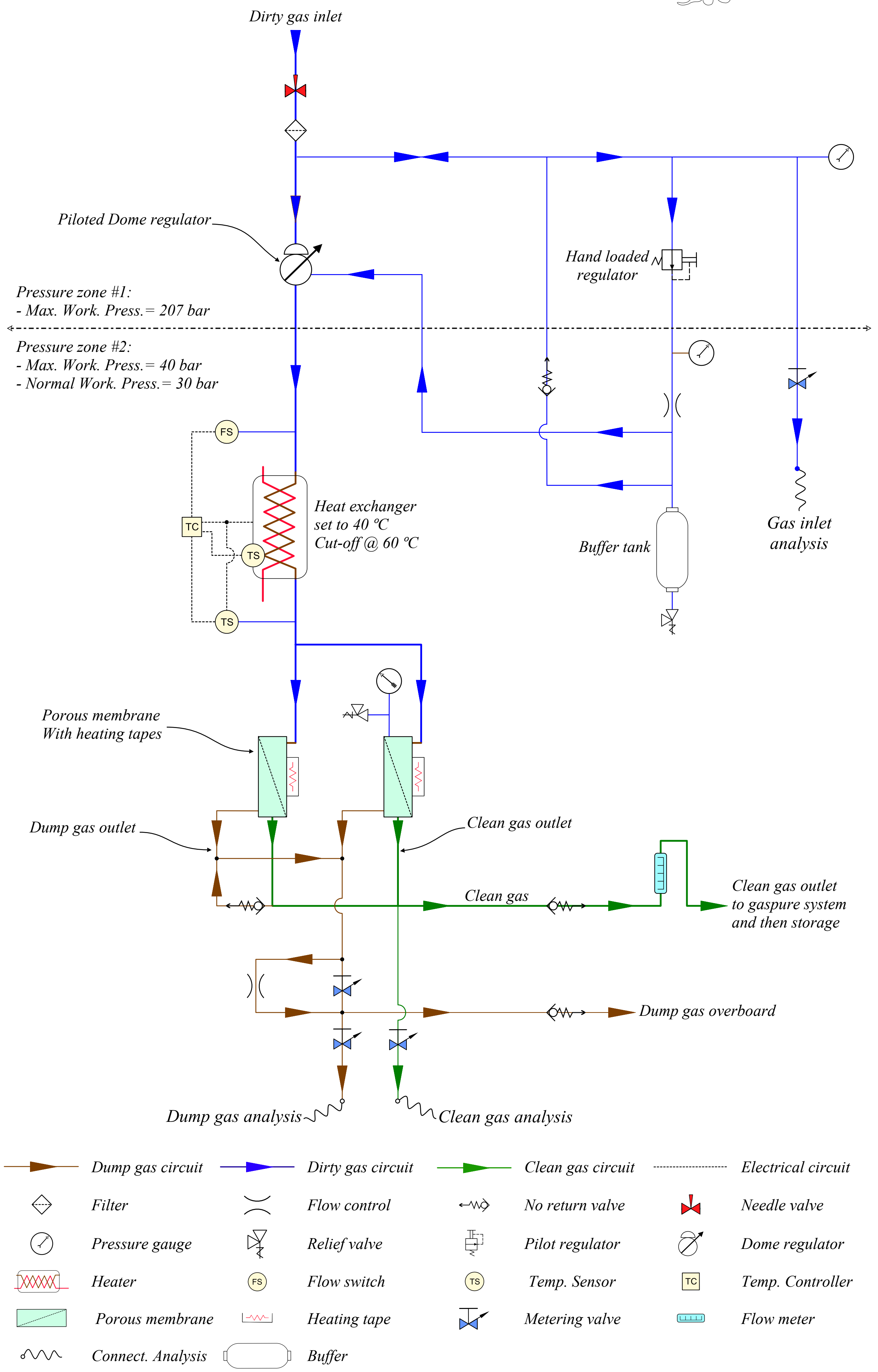
tapes are spirally wrapped along the external length of each pressure vessel. These self regulating trace heating tapes are preset at and are left permanently on.
When the power is switched on, a preheat time of 30 minutes is necessary to bring the housing up to temperature. The pressure vessel housing is thereafter continually kept warm. Insulation applied around the outside of the tape reduces heat loss to the atmosphere and a further cladding of stainless steel prevents mechanical damage to the insulation and heating tapes.



◦ The control panel is installed above the two stainless steel pressure vessels. It is organized as follows

- *1 - Gas inlet valve*
- *2 - Supply pressure*
- *3 - Regulation gas inlet*
- *4 - Pressure inlet membrane*
- *5 - Temperature control*
- *6 - Gas analyser*
- *7 - Gas inlet sampling*
- *8 - Clean gas sampling*
- *9 - Dump gas sampling*

4. The clean gas is directed to the gasbag of the Gaspure system via the outlet check valve. A flowmeter that is installed aside tower #2 allows monitoring its flow.
From the gas bag, the “clean gas” is routed to its dedicated storage banks through the Gaspure system. It can then be safely used.


Dirty gas inlet
Piloted Dome regulator
Hand loaded regulator
Pressure zone #1:
- Max. Work. Press.= 207 bar
Pressure zone #2:
- Max. Work. Press.= 40 bar
- Normal Work. Press.= 30 bar
FS
TC
TS
TS
Heat exchanger
set to 40 °C
Cut-off @ 60 °C
Buffer tank
Gas inlet analysis
Porous membrane
With heating tapes
Dump gas outlet
Clean gas outlet
Clean gas
Clean gas outlet to gaspure system and then storage
Dump gas overboard
Dump gas analysis
Clean gas analysis
Dump gas circuit
Dirty gas circuit
Clean gas circuit
Electrical circuit
Filter
Flow control
No return valve
Needle valve
Pressure gauge
Relief valve
Pilot regulator
Dome regulator
Heater
FS
Flow switch
TS
Temp. Sensor
TC
Temp. Controller
Porous membrane
Heating tape
Metering valve
Flow meter
Connect. Analysis
Buffer

1.2.5.7 - IMCA recommendations and requirements

Regarding the suitability of the system, in section 13 of the DESIGN document D 024, IMCA says: "*Any system intended for the reclaim of divers' breathing gas must be specifically designed for that purpose and be supplied by a manufacturer for that purpose, or if it is a special system, then there must be a clear written statement from a competent person that it is fit for purpose and fitted with all necessary safety devices*". This requirement that is not indicated in section 14 that describes the chamber reclaim system should also apply to it. Note that the competent person indicated should be a specialist appointed by an internationally recognized certification body.
Also, IMCA says that the operating procedures of the system must be readily available. They are usually provided through check-lists attached to each element of the system *(see the photo in point 1.2.5.6)*.

Regarding the protection of the equipment, ease of intervention and safety of the operators, the IMCA recommendations are similar as those indicated in the previous point:

- The systems must be protected from physical damages. Thus, potential shocks and dropped objects, and also the weather conditions.
- There should be installed in safe areas of the ship where their access can be limited to only the technicians operating them. Also, these places must be organized in such a way that the components of the system are easily accessible for routine operations and maintenance and all kind of emergency repairs.
- The personnel operating and maintaining them must not be exposed to hazards. For this reason, guards and warning signs such as those stating that an item of equipment may start, vent or stop automatically should be displayed in all sensitive points.
- Firefighting systems and detectors must be provided. They are similar to those previously described for the external of the chamber and the dive control.

Regarding the compressor, IMCA recommends or require the elements that have been indicated in the description of the compressor taken as example:

- Solenoid switches with alarm are recommended, but not required
- If a diaphragm type compressor is used, it must be fitted with a cracked plate detector, which will automatically stop the compressor in the event of failure. Note that the model recommended by the manufacturer of the Gaspure system (Divex) and studied in this presentation is the Gardner Denver model H-5437.1, which is a piston compressor. However, diaphragm compressors may be used with some installations.
- IMCA says that any compressor used for gas transfer, and not intended for use with gases containing over 25% oxygen, should be fitted with a protective device which will shut the compressor down if the oxygen percentage entering the compressor exceeds 25%. This requirement is classified as "B", so IMCA considers that there may be other ways of meeting this requirement. However, there is currently no other means of protection proposed by the manufacturer than the system indicated. Note that IMCA does not provide a guideline regarding protection from Carbon Monoxide (CO).
- IMCA requires that pipework should be suitable for the purpose, adequately installed, and protected from damage. As the compressor used with the reclaim system is permanently fitted, the requirements for charging whips do not apply. Also, when flexible hoses are used to interconnect the elements of the system, IMCA requires that they are supported at least every 2 metres. However, we can consider that 2 m between two support is too long, and that should be reduced to less than one metre as it is the case with the installation presented as an example.
- IMCA also says that it must be possible to identify the flexible hoses for their safe working pressure and the latest test date. Note that, with the installation described, these hoses are permanently installed and must be considered a part of the machine. Besides, and not indicated by IMCA, the function of each rigid pipe and flexible hose should be shown on it, and there should be an arrow that points the direction of the flux, as it is the case on the machines taken as examples.

Regarding the gas bag

- IMCA Says that it must be situated in a location where it can be fully inflated safely *(see the photos)*, and that there must be a suitable means of monitoring it to avoid over inflation. IMCA also says that It may be an audible and visible over inflation alarm fitted to the gas bag that must operate in the gas bag area, at the compressor location and in chamber control. A camera can also be used.
  Also, if it is possible to exhaust the diving bell contents to the gas bag, an alarm must be fitted in dive control. In addition, lights should be installed in the chamber control showing whether the compressor which empties the bag is running/idle.
- A relief valve or bursting discs connected to an overboard system should be in place to protect the bag from rupture if it is over filled. It is also required that an overboard valve or another system is installed to protect the bag from being overfilled in the case of a discharge of a greater volume than the capacity of the bag. These elements are visible in the scheme in point 1.2.5.2.
- It is indicated that there should be a procedure in place to monitor for bacterial growth in the gas bag. It can be performed by regular sampling of the outlet. Also, note that the "Gaspure system" removes bacteria.

Regarding pipework, and cylinders

- The requirement indicated with the compressor apply. Also, the exhaust must not vent into an enclosed space.
- In addition, the cylinders used for the dirty gas must be colour coded so they can be easily identified.

1.2.5.8 - Maintenance of systems

As all elements of the dive system, visual inspection and function tests of the element listed below, but not limited to, must be undertaken prior to start the system and during the operations.
- Condition of pipework
- Condition of the electrical systems
- Condition of the filter cartridges
- Condition of the gas bag
- Oil level of the compressor

The system must not be started or be stopped if a problem is detected.

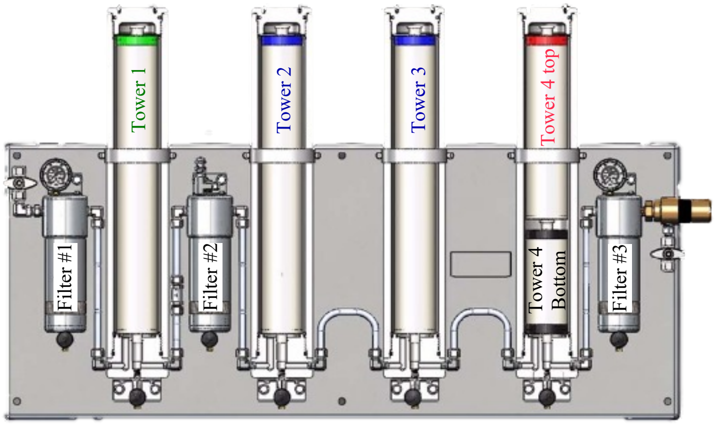
Also, IMCA D 024 recommends the following:

Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure*	*Other*
Fire fighting portable system	6 months			Manufacturer specifications
Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
Fire detection	12 months			
Cracked plate detectors of membrane compressors.	6 months			This type of compressor is not the model recommended by the manufacturer
Compressor automatic shut down system if more than 25% oxygen	6 months			
Relief valves compressor	6 months	2 ½ years		
Compressor pipework and fittings	6 months	2 years		1.5 max. working press: 1st install
Compressor gas receiver	6 months	2 ½ years		OR: Internal/external inspection: 30 months
Electrical compressor	6 months (2;3;4)			
Function test compressor	6 months			
Delivery and rate of pressure compressor	6 months			
Output purity of compressor	6 months (1;2;4)			
Buffer Helipure system	6 months	2 ½ years (3;4)		Internal & Ext. examination. + test max working press: 5 years
Analysers Gaspure and Helipure systems	6 months			
Pipework Gaspure and Helipure systems	6 months	2 years		1.5 max. working press: 1st install
Gas bag: relief valve	6 months	2 ½ years		
Gas bag: bursting disc	6 months	2 ½ years		Bursting discs renewal: 10 years
Alarm testing	6 months			
Analysers	6 months (1;2;4)			
Pipework	6 months	2 years		1.5 max. working press: 1st install

Regarding the planned maintenance of piston compressors, the manufacturers of the dive system and of the machine say the following:

- Daily maintenance:
  - Check the level of oil in the crankcase and top up as necessary.
  - Check the stage pressures, oil pressure and temperatures.
- Weekly Maintenance:
  - Check for oil, air or water leaks and rectify as necessary.
  - Examine the oil in the crankcase and ensure that it is not contaminated with condensate. Depending on the degree of contamination, the oil may appear emulsified (creamy in colour) especially if the recommended lubricant is not used.
    If emulsification takes place the oil must be changed and the crankcase cleaned. This condition is usually visible through the sight glass, oil level indicator and must be rectified immediately. Trace the cause of contamination, rectify, fit a new oil filter, and refill the crankcase with recommended oil.
  - If moisture forms without emulsification, the condensate may be drained from below the oil by means on the drain plug . The oil level should be replenished accordingly with clean oil. Crankcase oil contamination is often accompanied by an increase of the oil level, due to oil being supported by condensate fluid.
  - Check that the control systems are working correctly
- Monthly Maintenance or after 100 hours operations, or a major overhaul:
  - Drain sump, replace the oil filter, clean the sump & refill it with the recommended synthetic oil. In case of change of brand of oil, the compressor manufacturer should be contacted.
  - Clean the suction and delivery valves.
- One year from installation or last Service, or after 4000 hours operations:
  - Replace the bursting discs.
  - Replace the diaphragm of the drain valve.
- One year from installation or last Service, or after 9000 hours operations:
  - Replace the 1st stage valve.
  - Replace the 1st stage piston rings.
  - Deglaze the 1st stage liner.
  - Replace the 1st stage small end.
  - Inspect and eventually replace the big end bearings.
  - Inspect the crankshaft and replace the main bearings and oil seals.
  - Replace the oil pump.
  - Inspect and test separators.
  - Inspect the stage coolers.
  - Inspect the safety valves.
  - Test the pressure gauges, and also the temperature and pressure switches.
  - Test the non return valves.

Regarding the change of filters of the system Gaspure, Divex says that the disposable cartridge set is designed to process 2830 m³ *(100,000 standard cubic feet)* of gas before replacement is required, as indicated in the chart below. However, the cartridge of “tower #4 Bottom” *(CO removal)* has a maximum life of three years from the date of manufacture.



Compressor flow rate	*Running hours*
25 m³ /hr (15 scfm)	*100*
50 m³ /hr (30 scfm)	*50*
100 m³ /hr (60 scfm)	*25*
125 m³ /hr (75 scfm)	*20*

Regarding the system Helipure, Divex says the following:

The membranes in the Helipure will work efficiently for many years as long as the gas supplied to the unit is clean and free from moisture ideally -50°C dew point or below. All gas supplied to the unit which has passed through a gaspure system is -50°C dew point and filtered to 0.01 micron.

Set up a supply of 7 bar of dry air to each membrane in turn using a calibrated gauge. The clean gas flow from each *membrane should be less than 30 litres/minute flow rate measured by routing the gas through a test hose and into the sample flow meter on the panel.*

If either membrane has a flow rate well in excess of 40 litres/minute, replace the o-rings on the v.c.o fittings on the end of the faulty membrane. If this does not rectify the fault, the membrane may be damaged from exposure to higher than normal operating temperatures or by moisture in the gas and so should be replaced. All existing faults must be rectified before replacement of membranes as further damage is likely to occur.

New membranes must not be exposed to moisture or high humidity after removal from packing before installation in the Helipure housing.

1.2.6 - Gas storage and distribution

1.2.6.1 - Purpose and minimum quantity of gas required offshore

A lot of gas is necessary to pressurize the components of the saturation system described in the previous points.
Also, despite the efficiency of the new regeneration and reclaim systems, a part of the heliox used is lost during the normal operations that must be replaced in addition to the oxygen that is naturally depleted by the metabolism of the divers. This uncontrolled gas dumping outside the system results from the various manipulations such as food and tools transfer, disconnection of the bell, divers transfer to and from the bell during the dive, and also undetected small leaks. It is commonly considered that this quantity is approximately 10% of the total volume in use. Note that every intervention that consists of bringing a lock previously under pressure to the surface results that the remaining quantity of heliox that is in it is irremediably lost when the door is opened. Also, despite a well-planned maintenance system, unforeseeable massive leaks may happen, which may result that huge quantities of gas that cannot be fabricated onboard can be suddenly lost. That obliges to plan for gas reserves taking these factors into account.

IMCA D 050 is a guideline that sets up the absolute minimum amount of breathing medium required to be kept at an offshore dive site before and during the dive. This document is not perfect, as demonstrated in the “Diving management study CCO Ltd #7”. However, it is today the reference in force that is the most used by the manufacturers to design systems with sufficient operational capabilities, and the Life Support Supervisors (LSS) to calculate the necessary gas to be provisioned for a project. It provides the following recommendations, which are reinforced here according to the “Diving management study CCO Ltd #7” recommendations. Note that this guideline classifies the gasses into two categories:

- “Consumable gasses” are provided for ongoing use and will vary in quantity available on use and re-supply
- “Reserve gasses” must be provided and kept to solve emergencies. They are therapeutic gas, Built-In Breathing System (BIBS) gas, gas reserves to compress the chambers, and others.

A - Surface orientated air diving

Gas purpose	*Classification IMCA D 050*	*Minimum requirement IMCA*	*Comments & additional precautions CCO Ltd*
Operational in water air + in-water decompression gas	Consumable	Sufficient gas should be provided for the bottom time and decompression, based on a breathing rate of 35 l/min at work & 25 l/min at rest.	Operational in-water gas and in-water decompression are grouped. There should be sufficient gas for two dives instead of one (working time + decompression).
Diver personal gas reserve (Bailout)	Reserve	10 m/min of umbilical deployed from the surface (basket) or the wet bell at emergency breathing rate.	Breathing rates from UK HSE report RR 1073 (50 to 75 l/min) should be promoted to the detriment of the IMCA rate of 40 l/min
Diver rescue air	Reserve	2 dives of 30 min bottom time to the maximum intended diving depth at emergency breathing rate.	Calculate with a breathing rate of 62.5 litres per minute instead of 40 litres/min (see above)
Wet bell / basket gas reserve	Reserve	Reserve to recover the divers from the longest and deepest planned dive at emergency breathing rate.	Calculate with a breathing rate of 62.5 litres per minute instead of 40 litres/min (see above)
Surface decompression gasses	Consumable	Sufficient gasses to compress both chamber’s locks of each DDC to the max. surface deco depth + 3 surface decompression cycles per chamber.	The surface decompression cycles include the full compression and decompression of the chamber + the gas used for flushing. Note that 20 - 25 l/min is the breathing rate
Calibration gasses (Analysers)	Consumable	No calibration gas required	Sufficient quantities for the calibration processes recommended by the manufacturer for the entire duration of the project + the same quantity as reserve
Therapeutic treatment gasses	Reserve	Sufficient gas to pressurize both locks of each DDC to the maximum possible treatment depth + 90 m³ Oxygen	The quantity of gas to pressurize the locks should be doubled + sufficient gas for 3 decompression of medics and 3 compressions of the entry lock. If a heliox table such as COMEX 30 is used: add 90 m³ heliox 50/50 + 90 m³ heliox 20/80.
Chamber scrubber		Not indicated in the procedure IMCA	Sufficient soda lime and Purafil for 3 surface decompression dives + the longer therapeutic treatment planned (0.25 kg/diver/hour) + the same quantity as a reserve.
Dive crew evacuation air	Reserve	Allows to evacuate the area at emergency breathing rate	Calculate with a breathing rate of 62.5 litres per minute instead of 40 litres/min (see above)
Diver transfer oxygen	Reserve	Allows to transfer the divers to the facility at emergency breathing rate	Calculate with a breathing rate of 62.5 litres per minute instead of 40 litres/min (see above)

B - Wet bell heliox diving

Gas purpose	***Classification IMCA D 050***	***Minimum requirement IMCA***	***Comments / Additional precautions CCO Ltd***
Operational in water gas + in-water decompression gas	Consumable	Sufficient for the working time and decompression, at a breathing rate of 35 l/min at work & 25 I/min at rest.	Operational in-water gas and in-water decompression are grouped. <u>There should be sufficient gas for two dives instead of one</u>
Diver personal gas reserve (Bailout)	Reserve	1 min of 10 min of umbilical deployed from the wet bell at emergency breathing rate.	Breathing rates from UK HSE report RR 1073 (50 to 75 l/min) should be promoted to the detriment of the IMCA rate of 40 l/min
Diver rescue gas	Reserve	2 dives of 30 min bottom time to the maximum intended diving depth at emergency breathing rate.	Emergency breathing rate of 62.5 litres /min instead of 40 litres (see above)
Wet bell gas reserve	Reserve	It must be sufficient to recover the divers safely from the longest and deepest planned dive at emergency breathing rate.	Emergency breathing rate of 62.5 litres /min instead of 40 litres (see above)
Surface decompression gasses	Consumable	Sufficient gasses to compress both chamber's locks to the max. surface deco depth + three (3) surface decompression cycles per chamber	The surface decompression cycles include the full compression and decompression of the chamber + the gas used for flushing. Note that 20 - 25 l/min is the breathing rate
Calibration gasses (Analysers)	Consumable	100 % He + 20% O2 (balance He)	Sufficient quantities for the calibration processes recommended by the manufacturer for the entire duration of the project + the same quantity as reserve
Therapeutic treatment gas	Reserve	Sufficient gas to pressurize both locks of each DDC to the maximum possible treatment depth + 90 m³ Oxygen	The quantity of gas to pressurize the locks should be doubled + sufficient gas for 3 decompression of medics and 3 compressions of the entry lock. If a heliox table such as COMEX 30 is used: add 90 m³ heliox 50/50 + 90 m³ heliox 20/80.
Chamber scrubber		Not indicated in the procedure IMCA Consumption: 0.25 kg/diver/hour	Soda lime and Purafil for 3 surface deco. dives + the longer therapeutic treatment planned + the same quantity as a reserve.
Dive crew evacuation gas	Reserve	Allows to evacuate the area at emergency breathing rate	Calculate with a breathing rate of 62.5 litres per minute instead of 40 litres/min (see above)
Diver Transfer oxygen	Reserve	Allows to transfer the divers to the facility at emergency breathing rate	Calculate with a breathing rate of 62.5 litres per minute instead of 40 litres/min (see above)

C - Saturation diving

Gas purpose	***Classification IMCA D 050***	***Minimum requirement IMCA***	***Comments / Additional precautions CCO Ltd***
Operational in-water gas	Consumable	Sufficient mixed gas should be available for the intended bell run plus the same quantity of gas to be held as a reserve.	Gas carried onboard the bell in cylinders should not be included in these calculations
Divers personal gas reserve (Bailout)	Reserve	10 m/min of umbilical deployed from the bell at emergency breathing rate.	Breathing rates from UK HSE report RR 1073 (50 to 75 l/min) should be promoted to the detriment of the IMCA rate of 40 l/min
Diver rescue gas	Reserve	2 dives of 30 min bottom time to the maximum intended diving depth at emergency breathing rate.	Emergency breathing rate of 62.5 litres /min instead of 40 litres (see above)
Closed bell onboard oxygen	Reserve	Sufficient oxygen for the metabolic consumption of all divers at 0.5 l/min per diver for the duration of the bell run and at least 24 hours at the end of the bell run (emergency).	
Bell onboard breathing gas reserve	Consumable	Emergency supply of breathing gas sufficient to support each working diver plus the bellman outside the bell for a minimum of 30 minutes at at emergency breathing rate at the maximum depth of the dive	Breathing rates from UK HSE report RR 1073 (50 to 75 l/min) should be promoted to the detriment of the IMCA rate of 40 l/min
Calibration Gasses to 100 m (Analysers)	Consumable	100% Helium; 10% O_2 and 1000 ppm CO_2, 20% O_2 & 4000 ppm CO_2.	Calibration gasses and frequencies according to the recommendations of the manufacturer and at least for 3 weeks of operations

Saturation diving (Continuation)

Gas purpose	*Classification IMCA D 050*	*Minimum requirement IMCA*	*Comments / Additional precautions CCO Ltd*
Calibration Gasses to 300 m (Analysers)	Consumable	100% Helium, 5% O2 & 500 ppm CO2, 10% O2 & 1000 ppm CO2, 20% O2 & 4000 ppm CO2.	Calibration gasses and frequencies according to the recommendations of the manufacturer, and reserves for at least for 3 weeks of operations
Chamber pressurisation gas	Consumable	Sufficient gas to pressurize the system is required for the planned operation to the maximum intended storage depth, plus at least an equal amount as a reserve.	
Chamber metabolic oxygen (Saturation + decompression)	Consumable	Sufficient oxygen for each diver metabolic consumption throughout the saturation period, plus that required to maintain the ppO_2 during decompression. This quantity should be doubled for safety reasons and held in two separate banks.	
Living Chamber BIBS	Reserve	Sufficient gas to allow each diver to breathe for four hours on BIBS (ppO2 400 mbar –1400 mbar) at the deepest depth.	
Therapeutic Gas	Reserve	Sufficient quantities of therapeutic gas for the depths involved as detailed in the company's rules	Refer to the therapeutic procedures selected (COMEX, US Navy, or others)
Soda lime and Purafil		Not indicated in this guidance Consumption per diver = 6 kg/day	Two weeks of autonomy without further supplies being received at a minimum (IMCA D 022).
Dive Crew Evacuation Gas	Reserve	Allows to evacuate the area at emergency breathing rate	62.5 litres / minute instead of 40 litres (see above)
Diver Transfer Oxygen	Reserve	Allows to transfer the divers to the facility at emergency breathing rate	62.5 litres / minute instead of 40 litres (see above)

D - Hyperbaric Rescue Unit (HRU) and Life support package (LSP) - *Life support package not used for decompression*

Gas purpose	*Classification IMCA D 050*	*Minimum requirement IMCA*	*Comments / Additional precautions CCO Ltd*
Calibration Gasses (Analysers)	Consumable	- 1 cylinder 100% He - 1 cylinder 20% O_2 & 4000 ppm CO_2 (balance He)	Calibration gasses and frequencies according to the recommendations of the manufacturer and at least 72 h + 1 day. HRU analysers pre-calibrated with onboard calibration gasses.
Pressurisation gas	Consumable	The gas quantities for the HRU are not indicated in this guideline. LSP: 16 cylinders 50 l @ 200 bar of 98%/2% HeO_2. LSP: 16 cylinders 50 l @ 200 bar of HeO_2 (PPO_2 200 - 1400 mbar).	Add the gas reserve of the HRU: Calculated by the manufacturer for 72 hrs with the maximum number of occupants. The gas mixture should conform with the chamber storage depth.
Metabolic oxygen	Consumable	HRU: Not indicated LSP: 16 cylinders O2 @ 200 Bar	Add the oxygen reserves of the HRU (72 hrs with the maximum number of occupants)
Chamber BIBS	Reserve	Sufficient gas to allow each diver to breathe for four hours on BIBS	(ppO2 400 mbar –1400 mbar) at the deepest depth.
Therapeutic Gas	Reserve	Sufficient quantities of therapeutic gas for the depths involved as detailed in the therapeutic tables	Refer to the therapeutic procedures selected (COMEX, US Navy, or others)
Soda lime and Purafil		Not indicated in this guidance Consumption per diver = 6 kg/day	HRU: At least 72 hrs of autonomy + 1 day LSP: At least 72 hrs of autonomy + 1 day

E - Hyperbaric Reception Facility (HRF)

Gas purpose	*Classification IMCA D 050*	*Minimum requirement IMCA*	*Comments / Additional precautions CCO Ltd*
Chamber pressurisation gas	Consumable	Sufficient gas to pressurize the system is required for the planned operation, plus at least an equal amount as a reserve.	

Gas purpose	*Classification IMCA D 050*	*Minimum requirement IMCA*	*Comments / Additional precautions CCO Ltd*
Chamber metabolic oxygen (Saturation + decompression)	Consumable	Sufficient oxygen for each diver metabolic consumption throughout the saturation period, plus that required to maintain the ppO_2 during decompression. This quantity should be doubled for safety reasons and held in two separate banks.	
Living Chamber BIBS	Reserve	Sufficient gas to allow each diver to breathe for four hours on BIBS (ppO2 400 mbar –1400 mbar) at the deepest depth.	
Therapeutic Gas	Reserve	Sufficient quantities of therapeutic gas for the depths involved as detailed in the company's rules	Refer to the therapeutic procedures selected (COMEX, US Navy, or others)
Soda lime and Purafil		Not indicated in this guidance IMCA	Provide at least sufficient reserve for the decompression from the maximum depth planned before starting the operations and double this value. Consumption per diver = 6 kg per day
Calibration Gasses to 100 m (Analysers)	Consumable	100% Helium; 10% O_2 and 1000 ppm CO_2, 20% O_2 & 4000 ppm CO_2.	Calibration gasses and frequencies according to the recommendations of the manufacturer and the duration of the decompression.
Calibration Gasses to 300 m	Consumable	100% Helium, 5% O2 & 500 ppm CO2, 10% O2 & 1000 ppm CO2, 20% O2 & 4000 ppm CO2.	Calibration gasses and frequencies according to the recommendations of the manufacturer and the duration of the decompression.
Dive Crew Evacuation Gas	Reserve	Sufficient to evacuate the area at emergency breathing rate	Breathing rate of 62.5 litres / minute instead of 40 litres (see above)

1.2.6.2 - Gas containers

The gases used for diving operations are transferred and stored in dedicated cylinders and tubes that, depending on their fabrication process, are designed to withstand maximum working pressures of 200 or 300 bar.

- Gas cylinders are seamless transportable pressure receptacles with a water capacity not exceeding 150 litres.
  The most common volume used in the diving industry is 50 litres or similar (229 mm Ø / 1535 mm height), nevertheless smaller capacities are also usual. They are made of steel, aluminium or composite materials.
  The fabrication of gas cylinders involves complex processes that are also those of diving cylinders, and are fully described in the diving study CCO ltd "Organize the maintenance of diving cylinders", that is available on the website CCO Ltd.
    - Steel cylinders that are made according to the standard ISO 9809 or equivalent can be produced by:
      - forging or drop forging from a solid ingot or billet, or
      - pressing from a flat plate, or
      - manufacturing from a seamless tube.
    - Aluminium cylinders are made according to ISO 7866 or equivalent. They can be produced by:
      - Cold or hot extrusion from cast or extruded or rolled billet
      - Spinning, flow forming, and cold drawing sheet or plate,
      - Open necking at both ends of an extruded or cold-drawn tube and non-welding techniques.
    - Composite cylinders are made according to ISO 11119-1 and ISO 11119-2 or equivalent. They are composed of:
      - An internal metal liner, which carries the total longitudinal load and a substantial circumferential load.
      - A composite over-wrap formed by layers of continuous fibres in a matrix, or a composite over-wrap formed by steel wire reinforcement,
      - An optional external protection system.
      - A suitable protective coating that is applied to the liner prior to the wrapping process to avoid adverse reaction between the liner and the reinforcing fibre.

    Two models of composite gas cylinders are proposed:
      - A hoop-wrapped cylinder is made of an aluminium or a steel bottle that is reinforced by composite materials wrapped around its cylindrical portion.
      - A fully-wrapped cylinder consists of the liner that is fully protected by composite materials. Thus, the cylindrical portion and the extremities are entirely covered.

Stamp marking codes allowing to identify a cylinder and establish its traceability should conform to ISO 13769 or a similar standard and provide the following details on its shoulder:

Description	Status	Example of sign
Standard: The Identification of the relevant construction standard to which the cylinder is designed, manufactured and tested.	Mandatory	ISOXXX
Country of manufacture: Capital letters identifying the country of manufacture of the cylinder shell using the characters of the distinguishing signs of motor vehicles in international traffic as specified in the United Nations *"Recommendations on the Transport of Dangerous Goods — Model Regulations"*.	Mandatory when different from the country of approval	CH *(CH means "Confederation Helvetique" = Switzerland. CH is used for the example as ISO is based in Geneva)*
Manufacturer's identification: Name and/or trademark of cylinder manufacturer.	Mandatory	MF
Manufacturing serial number: Alphanumeric identification number given or assigned by the manufacturer to clearly identify the cylinder. In the case of cylinders less than or equal to 1l, the manufacturing batch number may replace the manufacturing serial number.	Mandatory	7654321
Stamp for non-destructive examination (NDE): Where the cylinder is tested by and meets all the requirements of NDE in accordance with an ISO standard for gas cylinders (for example ultrasonic, magnetic particle, dye penetrant, acoustic emission) the following symbols shall be used: UT for ultrasound MT for magnetic particle PT for dye penetrant AT for acoustic emission.,	Nominative	UT
Test pressure: The prefix "PH" followed by the value of the test pressure in bars and the letters "BAR"	Mandatory	PH300BAR
Inspection stamp: Stamp or identification of authorized inspection body.	Mandatory	#
Initial test date: Year (four figures) followed by month (two figures) of initial testing, separated by a slash.	Mandatory	2009/08
Empty weight: The weight of the cylinder in kilograms, including all integral parts (e.g. neck ring, foot ring, etc.) followed by the letters "KG". This weight must not include the weight of the valve, valve cap or valve guard, any coating or any porous material for acetylene. The empty weight must be expressed to three significant figures rounded up to the last digit. For cylinders of less than 1 kg, the empty weight must be expressed to two significant figures rounded up to the last digit. For acetylene cylinders, it must be expressed to at least one digit after the decimal point. Example: Weight measured 0.964 kg 1.064 kg 10.64 kg 106.41 kg To be expressed as 0.97 kg 1.07 kg 10.7 kg 107 kg	Mandatory	62.1KG
Water capacity: The minimum water capacity, in litres, guaranteed by the cylinder manufacturer, followed by the letter "L". On request by the customer or owner of the cylinder for compressed gases, this capacity may be expressed as the nominal average water capacity with a tolerance of ±1.5%. In such a case, the symbol must be stamped in front of the value of the water capacity. In the case of liquefied gases, the water capacity in litres is expressed to three significant figures rounded down to the last digit. If the value of the minimum or nominal water capacity is an integer, the digits after the decimal point may be neglected. The actual determined volume may also be indicated on request by the customer or owner in special cases. For cylinders intended to contain acetylene, the stamped water capacity must be the actual determined volume, rounded down to three significant figures.	Optional for compressed gases	50L
Identification of the cylinder thread: e.g. 25E: thread in accordance with ISO 10920; or 17E: thread in accordance with ISO 11116-1. Note that thread from another standard such as EN144 may be indicated	Mandatory	25E

Description	Status	Example of sign
Minimum guaranteed wall thickness: Minimum guaranteed wall thickness in millimetres (as per the type approval test) of the cylindrical shell, followed by the letters "MM".	Mandatory *Excepted for composite cylinders and cylinders < 1 litre*	5.6MM
Temperature utilization: Applied by European manufacturers . It may be mandatory in the country of manufacture	Optional (ISO)	AIR
Identification of content: European manufacturers of diving cylinders indicate it in conformity with EN144 “pillar valves” (Air or NITROX)	Optional (ISO).	AIR
Working pressure: Settled pressure, in bars, at a uniform temperature of 288 K (15ºC) for a full gas cylinder preceded by the letters "PW".	Mandatory	PW200
Inspection stamp and date of periodic Inspection: Stamp or identification of authorized inspection body and year (last two or all four figures) and subsequently the month (two figures) of retest must be stamp-marked at the time when the periodic inspection is done. The year and month shall be separated by a slash (i.e. “/”). For UN cylinders, the inspection body marking must be preceded by the characters) identifying the country authorizing the inspection body, if that country is different from the country of approval for manufacture. Enough space must be provided on the cylinder for more than one re-inspection. For acetylene cylinders, these stamp marks must be marked either on the cylinder or on a ring that can be attached only by removing the valve.	Mandatory	# 14/11
Space for additional optional markings or for application of labels, e.g. name of cylinder owner.	_	_
Service life of composite cylinders: For cylinders of unlimited life, no stamp required. For cylinders with limited life, the letters "FINAL" followed by the expiry date comprising the year (four figures) and month (two figures).	Normative for composite cylinders	FINAL 20/19
Underwater use of composite cylinders: Composite cylinders which have met the specific test requirements for underwater use shall be stamp-marked with the letters "UW".	Normative for underwater composite cylinders	UW
International mark(s): These marks (UN, a, etc.) can only be applied to cylinders that conform to the international regulations such as the United Nations “*Recommendations for the Transport of Dangerous Goods — Model Regulations”.*	Mandatory if applicable	U N
Country of approval: Capital letter(s) identifying the country of approval of stamp mark No. 27, using the characters of the distinguishing signs of motor vehicles in international traffic specified in the United Nations *“Recommendations on the Transport of Dangerous Goods — Model Regulations”***.**	Mandatory	F

IMCA D 024 says that the last test date stamp should be painted over with a small patch of distinctive colored paint to aid location. If it is inaccessible, the cylinder serial number should be visible or else stenciled in a visible place.

- Tubes are seamless transportable pressure receptacles having a water capacity exceeding 150 litres but not more than 3000 litres. They are commonly called “kelly tubes” or “Kellys” in the industry. The models in use are usually made of steel and they are fabricated according the the standard ISO 11120. Their identification marks are those used with steel gas cylinders.

Gasses are usually delivered in Multiple Elements Gas Containers (MEGCs), which are assemblies of cylinders or tubes that are interconnected by a manifold and assembled within a framework. The Multiple Elements Gas Containers include service equipment and structural equipment that are necessary for the transport of gases and may be equipped with pressure relief devices. Three models are commonly used:

- “Quad” are banks of 4 to 16 seamless cylinders. Quads of 16 cylinders are often used by manufacturers to deliver gasses , except the calibration gasses that may be delivered in single cylinders or small quads.
- “Super-quad”, also called “large quad”, are bundles of more than 16 cylinders *(32 and 64 cylinders are typical)*. They allow transporting more gas than classical quads within an equivalent footprint.
- “Tube banks”, also called “kelly banks” are assemblies of tubes similar to quads and super quads. However, the tubes are often not interconnected and can be used individually.

These Multiple Elements Gas Containers (MEGCs) are classified as "Offshore containers" and should comply with the International Marine Organization (IMO) MSC/Circular 860 "Guidelines for the approval of offshore containers handled in open sea". Also, the European norm EN 12079, which is based on the above conventions and other EN and International Standard Organization (ISO) documents, is often used as an international industry-standard to approve offshore containers and is a reference of the IMCA guidance D 009.
This norm defines offshore containers as "Portable units for repeated use in the transport of goods or equipment, handled in open seas, to, from and between fixed and/or floating installations and ships".
Also, the gross mass of these containers is limited to 25 metric tons *(The " Gross Mass" is the weight of the cargo, including dunnage and bracing plus the tare weight of the container carrying this cargo)*.
These conventions and standards provide guidelines regarding the construction and the certification of these devices, such as:

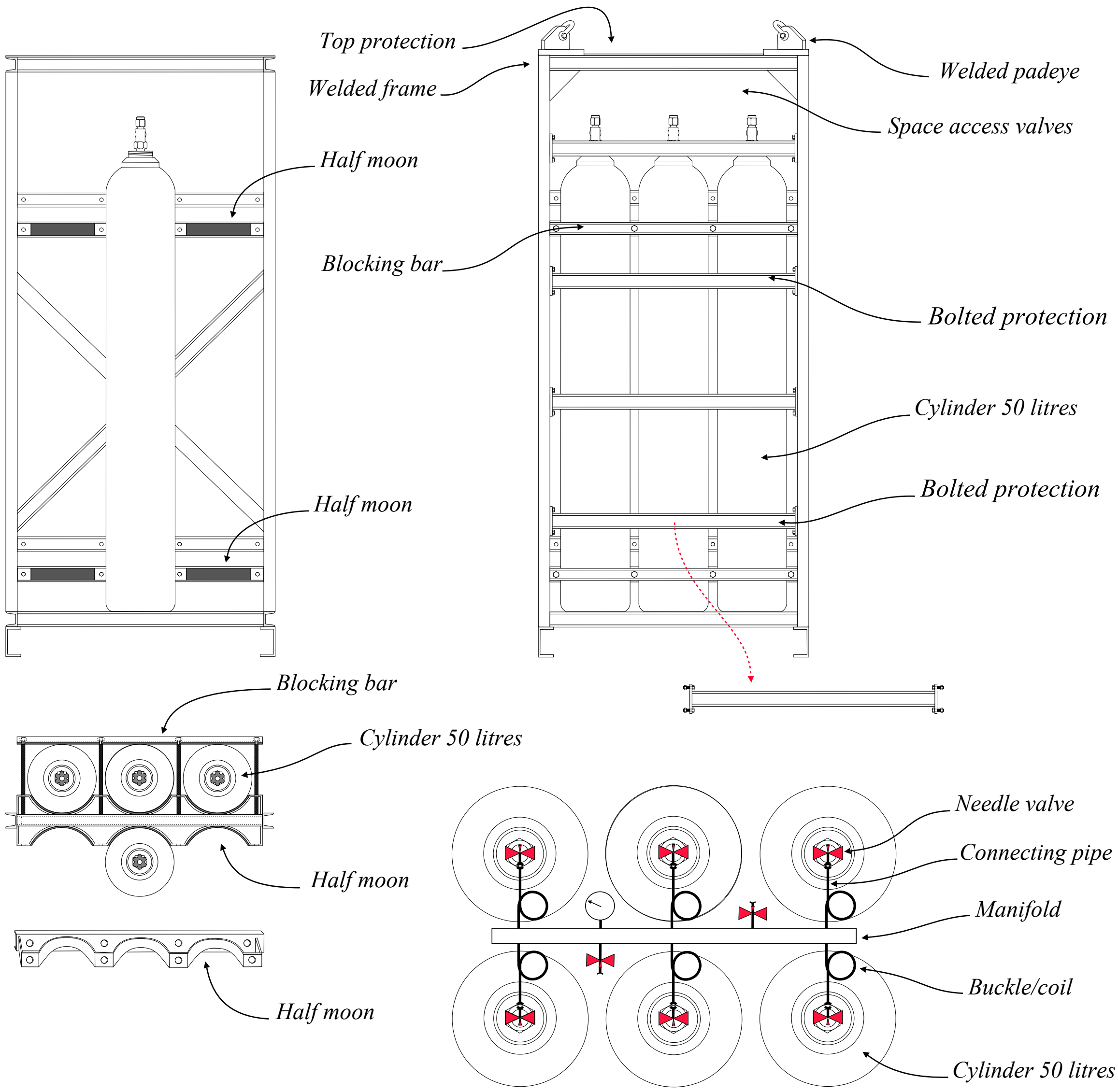
- Strength of structure, including design details
- Material specifications
- Welding and other joining methods
- Lifting set
- Supporting structures for other permanent equipment.

Guidelines for the tests and the inspection of these devices are also provided.

As a result, of these guidelines Multiple Elements Gas Containers used offshore should be designed as indicated below:

- Their structure and lifting devices must be designed to withstand impact loads *(dynamic loads of very short durations)* in addition to horizontal and vertical impacts stresses. EN 12079 indicates a dynamic factor of 3 and a design factor against breaking that should be equal to 2.
- EN 12079 says that protective beams should be placed at or near the location where the tank shell is nearest to the outer plane of the sides and should be spaced sufficiently close to give the necessary protection.
  IMCA D 009 recommends that depending on whether transportable quads are vertical or horizontal, they should be designed as follows:
  - Vertical Quads
    - As a minimum, the top face should be covered with a robust lattice for protection.
    - There should be an opening between the elements of the lattice of a minimum 150 mm x 150 mm to allow hand access to the valves, or alternatively free access to all valve handles must be available from the sides.
    - The maximum size of opening shall be such that a lifting sling when at its minimum bend radius, or any of the attached links, cannot inadvertently pass through the lattice.
  - Horizontal Quads
    - The top face of the quad should have solid or closely spaced robust lattice protection over all valves, fittings and pipework. No hand access is required from this direction.
    - The front (valve) face and the side faces, (from the shoulder of the cylinders to the open end,) should have protection for a distance from the top equivalent to the maximum distance that the lifting slings can hang down over the side or end.
    - The lattice should have an opening between the element of a minimum 150 mm x 150 mm to allow hand access. For the distance down from the top, equivalent to the distance that the lifting slings can hang down, the maximum opening should be such that a lifting sling when at its minimum bend radius, or any of the attached links, cannot inadvertently pass through.
- Top protections made of grating or plates must be in place. Note that IMCA D 009 says that removable or hinged covers, that are authorised with EN 12079 if they can be secured, are not safe for the following reasons:
  - Quads are moved around on the decks of ships and installations for housekeeping purposes. If the transit covers had been removed (which is very likely) then no guarding would be present.
  - Quads are often subject to rough handling in transit and are designed to be robust. Temporary covers would be very prone to damage.
  - Temporary or removable covers could easily come loose during transport due to inadequate fastening or physical damage. They would present a significant hazard if they fell off.
  - Emergency access to the valve handles is needed at all times in case of real or suspected leakage.
- When forklift pockets are provided, they must be installed in the bottom structure, have a closed top and internal dimensions of 200 x 90 mm and must be located such that the container is stable during handling and driving.
- Pad eyes are designed for the lifting of the container. They must be welded to the mainframe with full penetration welds, be designed to avoid damages from other containers, and be positioned such that sling fouling against the container is avoided during regular use.
  For this reason, they must not protrude outside the boundaries of the container other than vertically, be aligned with the slings to the centre of the lift, and allow for free movements of the shackle and sling termination. Also, they must match with the shackle used with a clearance between the shackle pin and the hole that is no more than 6% of the nominal shackle pin diameter, and the tolerance between the pad eye thickness and the shackle that does not exceed 25% of the inside width of the shackle.
  In addition to the mandatory pad eyes, large Multiple Elements Gas Containers may be fitted with ISO-corners fittings that are also called “corner casing” and allow handling containers with a specific lifting device and secure them together. However, EN 12079 says that ISO corners must not be used for lifting with slings at sea.

- Note that the gas cylinders must be secured so they cannot move and the pipework that interconnects them is protected from damages. Several procedures are used: As an example, some manufacturers push the cylinders against the protection frame using wedges in V that are driven in place and maintained in position through treaded bars. Other designs use half-moons fitted to the frame into which the bottles are individually blocked by bars or antagonist half-moons *(see the drawing below)*. Rigid pipes used to connect the bottles to the manifold are usually buckled/coiled to allow flexibility and absorb vibrations and shocks.



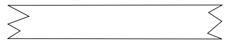
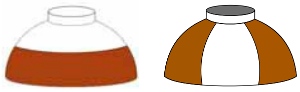
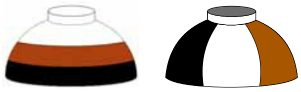
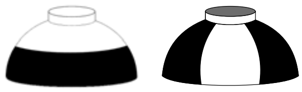
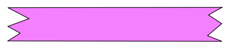
- Coatings, corrosion protection, and paint protection of offshore containers are to be suitable for the environmental conditions. Note that top protections made of plates should be coated with a permanent non-slip coating. Also, some reputed certification bodies recommend the use of primers composed of inorganic zinc/ethyl/silicate-based or equivalent to reinforce the durability of the protection.
- Offshore containers that have been designed, manufactured, tested and approved according to relevant guidelines should be clearly marked "Offshore Container" on an approval plate that provides the additional following information in conformity with the International Convention for Safe Containers (CSC):
  - Month/Year of Manufacture
  - Identification number
  - Maximum gross mass
  - Tare mass
  - Payload
  - Approval number
  - The relevant International Maritime Dangerous Goods (IMDG) code: Class 2.1 for oxygen & 2.2 for compressed heliox and air.
  - Offshore containers should be inspected at least annually, as deemed appropriate, by the approving competent authority. The date of inspection and the mark of the inspector should be marked on the container, preferably on a plate fitted for this purpose. The inspection plate may be combined with the approval plate

Note that these devices must be approved by relevant competent bodies such as governmental organizations and internationally recognized classification societies. Thus, homemade Multiple Elements Gas Containers cannot be used unless such organizations approve them.

1.2.6.3 - Identification of gasses in containers *(IMCA D 043, IMO A536, EN 1089-3)*

In addition to the identification marks indicated in the previous point, cylinders, quads and banks should be appropriately colour coded.
Colour coding is applied to complement the labels and purity certificates which are mandatory with the cylinders/quads delivered by the manufacturer and allow for a rough visual identification of the content of cylinders and quads from long distance. It is to be painted solely on the shoulders of the gas cylinders used individually or in short alternating bands 20 cm maximum on the frame of the Multiple Elements Gas Containers (MEGCs) where the shoulders of the cylinders or tubes may not be visible. The body of the cylinder may be coloured for other purposes and a lot of gas companies have their identification colour *(as an example L'Air liquide is blue).* The identification colour of the company should not conflict with the colour code on the shoulder.

The guidance IMCA D 043 *"Marking and colour coding of gas cylinders, quads and banks for diving applications"*, that conform to the resolution IMO A.536 *"code of safety for diving systems"*, and the standard EN 1089-3 *"Transportable gas cylinders. Gas cylinder identification (excluding LPG)",* says that the gas cylinders to be used individually and banks must be colour coded as indicated in the table below:

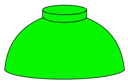
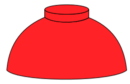
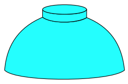
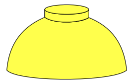
Gas	*Symbol*	*Cylinder shoulder*		*Quad upper frame / Frame valve end*	
Helium	*He*	*Brawn*		*Brown*	
Medical Oxygen	*O2*	*White*		*White*	
Heliox	*HeO2*	*Brown & white bands or quarters*		*Brown & white alternating bands 20 cm*	
Nitrogen		*Black*		*Black*	
Trimix Helium + Nitrogen + Oxygen	*HeO2N2*	*Black +white +Brown bands or quarters*		*Brown, white & black alternating bands 20 cm*	
Air or Nitrox	*N2O2*	*Black & white bands or quarters*		*Black & white alternating bands 20 cm*	
Carbon dioxide	*CO2*	*Grey*		*Grey*	
Calibration gas	*As appropriate*	*Pink*		*Pink*	

IMCA D 049 also say the following:

- Gas containers should be marked with the chemical symbol of the gas they contain, and the percentage of mixtures, quoting percentage of oxygen first. Also, their maximum working pressure should be highlighted.
- When the Multiple Elements Gas Container (MEGC) comprise cylinders containing different gasses such as those for therapeutic use, each cylinder must be marked and colour coded as appropriate.
- Gasses used for diving should be marked with the words " DIVING QUALITY " to differentiate them from gasses used for other purposes. Also, not indicated in the guidance, the oxygen to be used pure or to fabricate mixes that is of medical quality should be marked "MEDICAL" or "MEDICAL QUALITY".
- High percentages nitrox mixes may be planned to rescue the bell near the surface. However, such mixes have the same colour coding but not the same percentage of oxygen as air. For this reason the gas containers should be marked with " AIR DIVING QUALITY " or "% OXYGEN and % NITROGEN DIVING QUALITY ", as

appropriate. Note that the identification marks in use in recreational diving consisting of the word “nitrox” written in fluorescent yellow on a fluorescent green band can be added for better identification. This marking comes from United States standards colour codes where air is fluorescent yellow and oxygen fluorescent green.

The colour coding of calibration gas cylinders may vary. For this reason, it is important to identify the colour codes of hazardous gasses to avoid accidents. The standard EN 1089-3 indicates them as follows:

Gas type	***Colour***		***Gas type***	***Colour***	
Inert	*Bright green*		*Flammable*	*Red*	
Oxidizing	*Light blue*		*Toxic and/or corrosive*	*Yellow*	

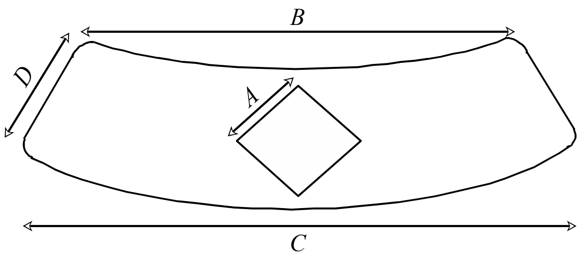
As a complement of the colour codes, precautionary labels should be attached and maintained so that they are clearly visible and legible for as long as the cylinders remain in the same gas service.
The purpose of precautionary labels on gas cylinders is to facilitate the identification of each cylinder and its contents and to warn of the principal hazards associated with the said contents. Such labels provide the following information:

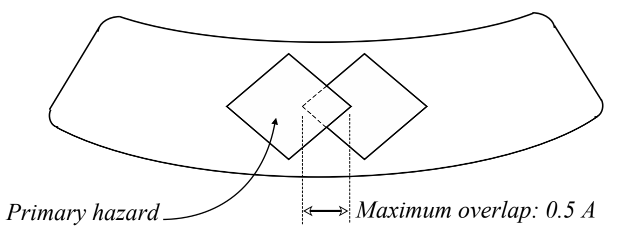
- Name of the gas or gas mixture
- Danger or Warning: International Maritime Dangerous Goods Code symbol and class for hazards *(see below)*
- Hazard statements
- Handling instructions
- Supplier identification and contact numbers

Other information such as those listed below, but not limited to, may be included for reference or because local regulations require them:

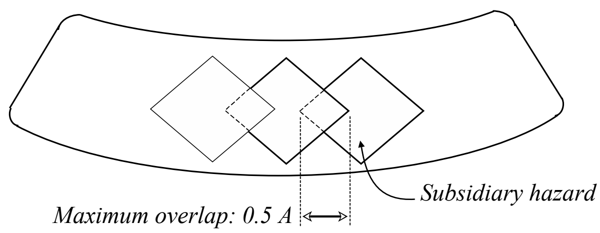
- UN number
- Chemical formula
- First aid advice
- Hazard chemical number
- Emergency respondent’s contact detail

These labels are affixed onto the shoulder of single cylinders. The hazard symbol of the label is within a diamond shaped box which recommended size is as in the drawing below. In cases that two or three hazard diamonds are necessary, the subsidiary hazard diamond is placed to the right of the primary hazard diamond, and partially covered by the primary hazard diamond, so it remains un-obscured.





Ø cylinder	***A***	***B***	***C***	***D***
< 75 mm	*10*	*45*	*60*	*23*
75 to 180 mm	*15*	*67*	*90*	*30*
> 180 mm	*25*	*112*	*150*	*45*



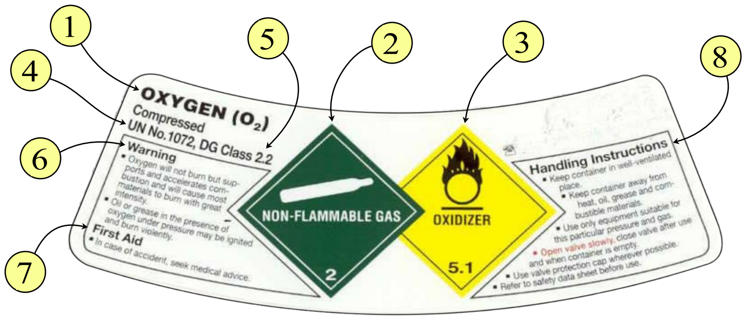
International Maritime Dangerous Goods Code classifies the hazards into the nine main classes displayed below that are also divided into sub-classes according to their characteristics - Note that gasses have three sub-classes:

Class 1: Explosives	*Class 4: flammable solids*	*Class 7: Radioactive*
Class 2: Gases	*Class 5: Oxidizing*	*Class 8: Corrosive*
Class 3: Flammable liquids	*Class 6: Toxic & Infectious*	*Class 9: Miscellaneous*
Sub classification of gasses		
Class 2.1: Flammable	*Class 2.2: Non flammable & Non Toxic*	*Class 2.3: Toxic*

Common gas cylinders hazard symbols

Hazard	Symbol
Non flammable compressed gas	
Oxidising gas	
Flammable gas	
Corrosive gas	
Toxic gas	

Note that gasses used for heliox diving have no more than two hazards.



Number	Information	Number	Information
1	Gas & formula	5	Primary hazard class
2	Primary hazard	6	Hazard statement
3	Subsidiary hazard	7	First aid advice
4	UN number	8	Handling instructions

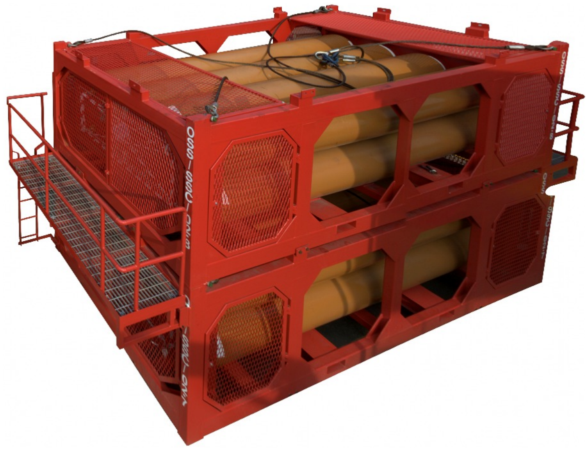
For cylinders and tubes that are grouped in Multiple Elements Gas Containers (MEGCs), either all-visible cylinders are labelled as suggested for single cylinders, or a label with a minimum size of 100 mm x 100 mm is visible on each side of the Multiple Elements Gas Container. A label as suggested for single cylinders should also be installed close to the withdrawal connections.

The super-quads above are examples of colour coding and content identification that can be encountered on worksites. Note that the words “Diving quality” recommended by IMCA D 049 are missing.
Also, IMCA D 049 says that when the cylinders or tubes are completely encapsulated within the framework and only the valves or connection points protrude through the face of the bank, round flags of at least 20 cm diameter painted in quarters or thirds with the appropriate colour coding and are immediately adjacent to the valve/connection point of each cylinder can be used. Nevertheless, it often happens that the colour coding is painted on the corresponding emplacement of each tube as in the photo above. Note that because the composition of the mixes stored in permanent installation vary according to the ongoing project, their percentages are usually noted on removable stickers *(see circulated in red)*

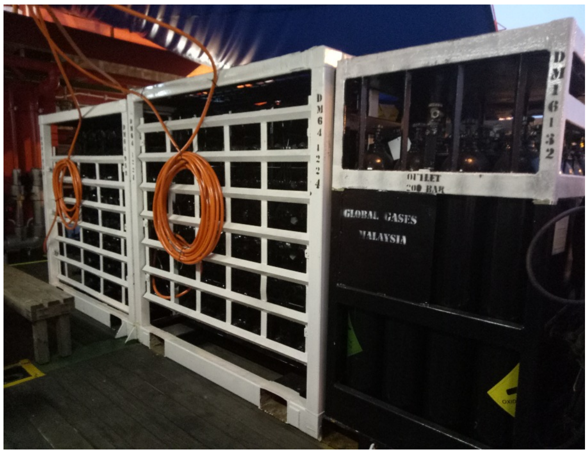
1.2.6.4 - Storage and distribution of the gasses

Depending on the nature of the gas and whether the saturation system is built-in or a portable unit, the gas delivered is transferred to the high-pressure reservoirs that are installed in specific areas or stored on deck. It is also usual that the quads and super quads are directly put on line upon their delivery once the quality checks are completed.
Portable saturation systems are usually installed on the deck. For this reason, the Multiple Elements Gas Containers (MEGCs) that feed them are commonly installed at their proximity. Like the other elements of the diving system and other cargo, they must be sea fastened and protected from shocks and other hazards.
Sea fastening involves complex calculations taking into account the environmental parameters, the forces suffered by the ship in the environment, the effects the ship’s motion to the cargo. Note that the forces applied on the load depend on factors such as size, weight, and center of gravity. Pre-installed fastenings may be present on Diving Support Vessels. In this case, the gas containers must be secured using the recommended procedure. However, such fastening points may be

missing or unsuitable on surface supports not originally designed to accommodate a dive system. In this case, the sea fastening has to be calculated and approved by competent persons, and the welds should be checked using relevant Non-Destructive Testing (NDT) procedures. Note that multiple gas tube containers are voluminous and heavy *(see below)*.
When Multiple Elements Gas Containers are secured by welded sea fasteners, direct welds to the frame must be banished as repetitive heating affects the metal. Instead, welded sea fasteners must be calculated to block the container or be fitted to it by bolting or a similar arrangement.

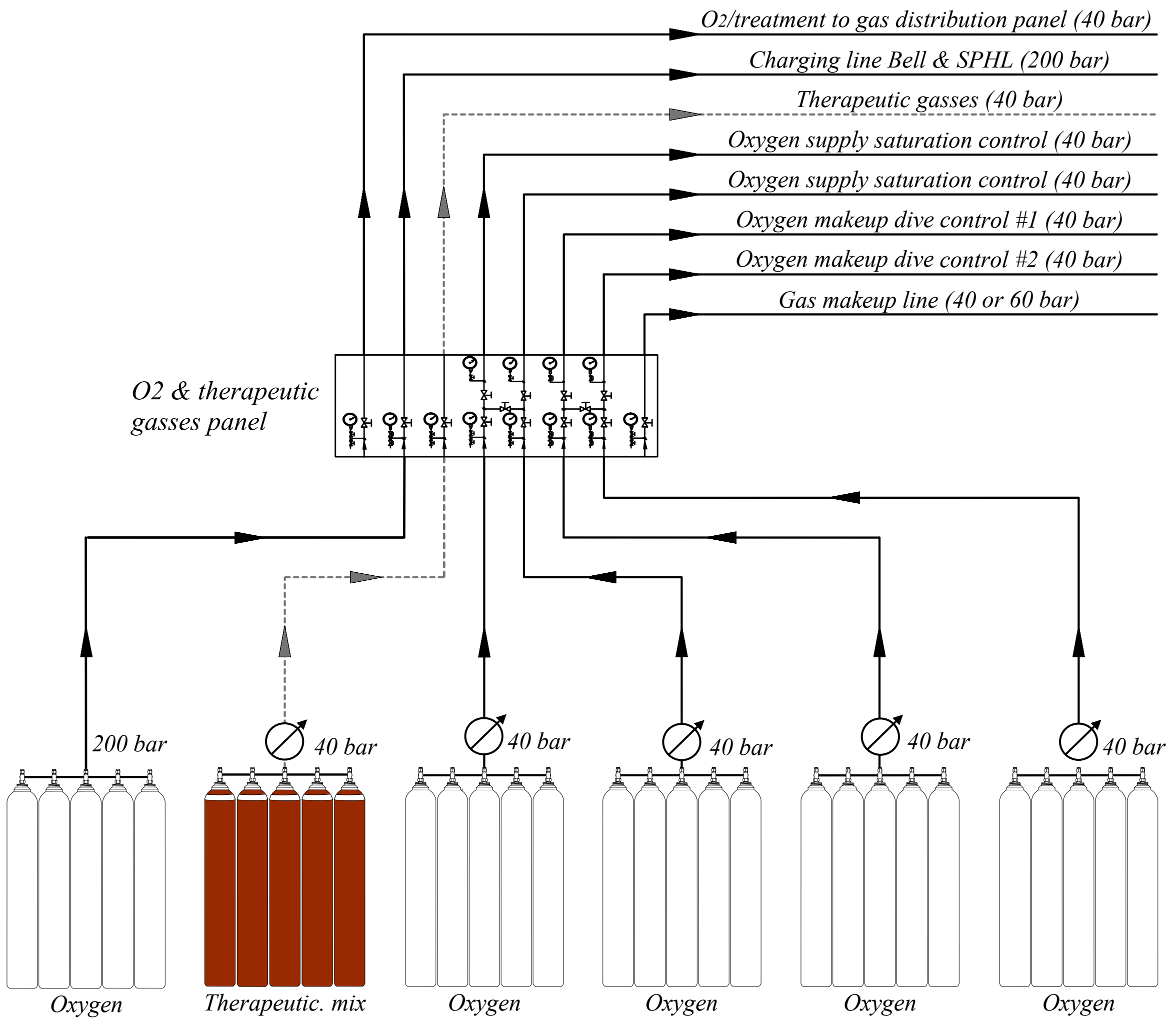


Heliox tubes containers designed by Lexmar (JFD group)

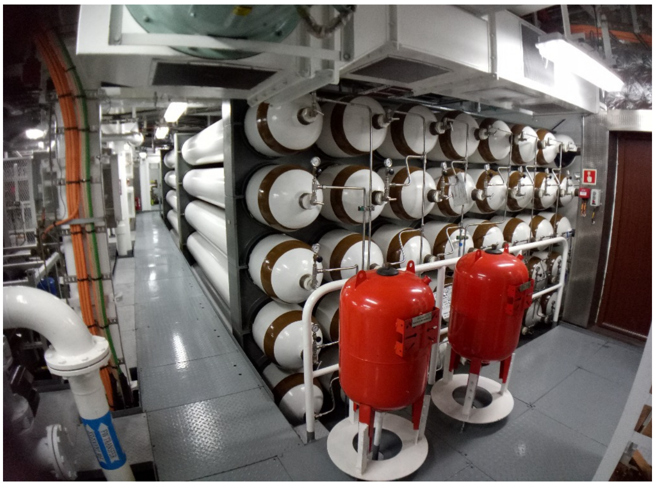


Oxygen super-quads on deck

Oxygen and mixes with more than 25% oxygen must be stored in open and well-ventilated areas that are clear of any fire hazard. Note that regarding this point, Norsok standards consider mixes over 22% O_2 as pure oxygen. For this reason, oxygen and therapeutic blends are usually stored in a protected area of the deck away from potential hazards, and which access can be restricted, so the authorized personnel can work undisturbed and safely, and the gas containers cannot be operated by non-authorized people *(see the photo above)*.
Oxygen and therapeutic gasses are distributed to the relevant parts of the installation through a specific panel usually installed at their proximity in the open area *(see the drawing below)*.
Note that apart for the charging lines of the bell and the Self Propelled Hyperbaric Lifeboats (SPHL) onboard gas reserves, which gas transfer is performed on open deck, the oxygen, and therapeutic mixes must be regulated down at the source (the quad) to a maximum of 40 bar (600 psi) for breathing gas or 60 bar (900 psi) for supplies to gas blenders *(see in the drawing below)*. The rule is that oxygen to be supplied inside a room must be depressurized to 40 bar maximum.

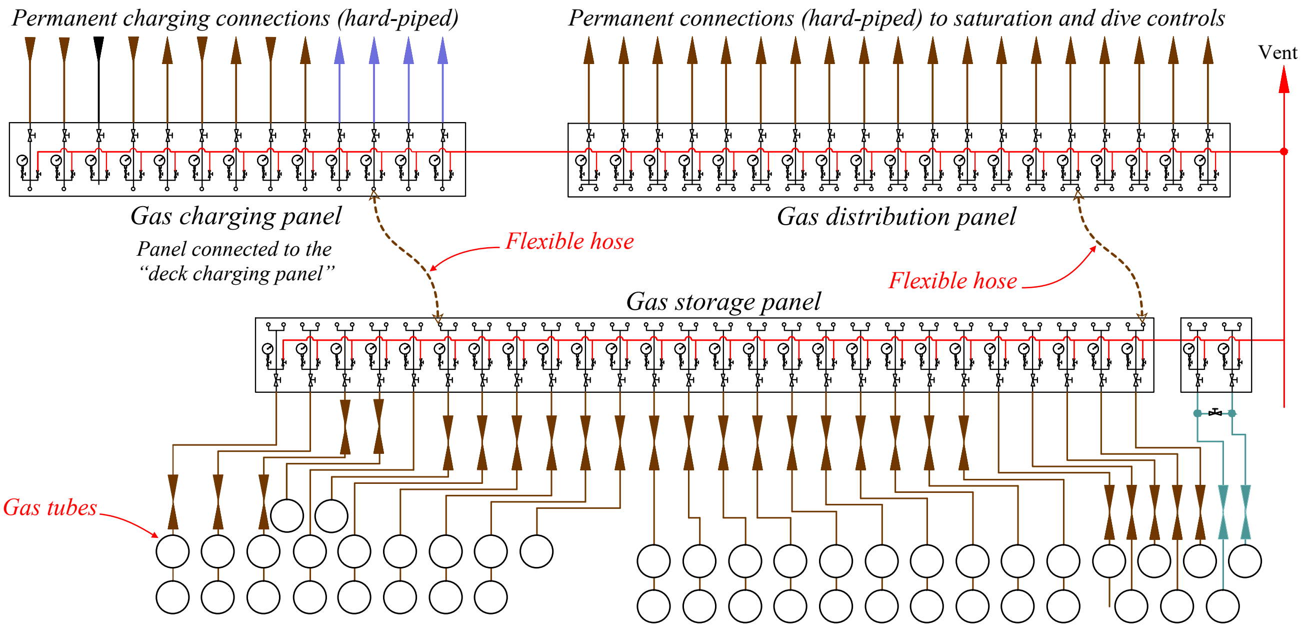


Built-in systems are provided with gas reserves that are usually made of banks of kelly tubes installed in dedicated rooms situated on one of the lower deck to which the gas delivered has to be transferred through connected panels that are accessible on deck. This gas reserve usually is sufficiently important to allow the vessel staying a long time at sea without refilling the banks. As an example, UDS Lichtenstein and Picasso are equipped with 52 heliox tubes and two air tubes 55.9 cm diameter and 11.582 m long. As each tube has a floodable volume of 2.4 m³ and a working pressure of 200 bar, 24960 m³ of heliox and 960 m³ of air can be stored.



Note that IMCA D 024 says: “Any inert gas (helium, nitrogen etc) intended for use as a breathing gas must contain a minimum oxygen content of at least 2% unless special arrangements are in place for the use of pure inert gas”. IMCA also says: “Where bulk HP gas is stored in an enclosed space then an oxygen analyser with high and low alarm must be sited so that any person is warned of an alarm situation before they enter the enclosed space or while they are in the enclosed space. This alarm should be either very audible or very visible. Ideally it will be both”.
As the diving systems taken as an example are designed to dive at 300 m, mixes with less than 2 % oxygen have to be stored. For this reason, analysers with alarms are in place that also connected to the saturation control room and the bridge of the vessel. Also, as most modern Diving Support Vessels (DSV), UDS Lichtenstein and Picasso gas rooms are provided with forced ventilation systems that continuously renew the the atmosphere of the rooms.

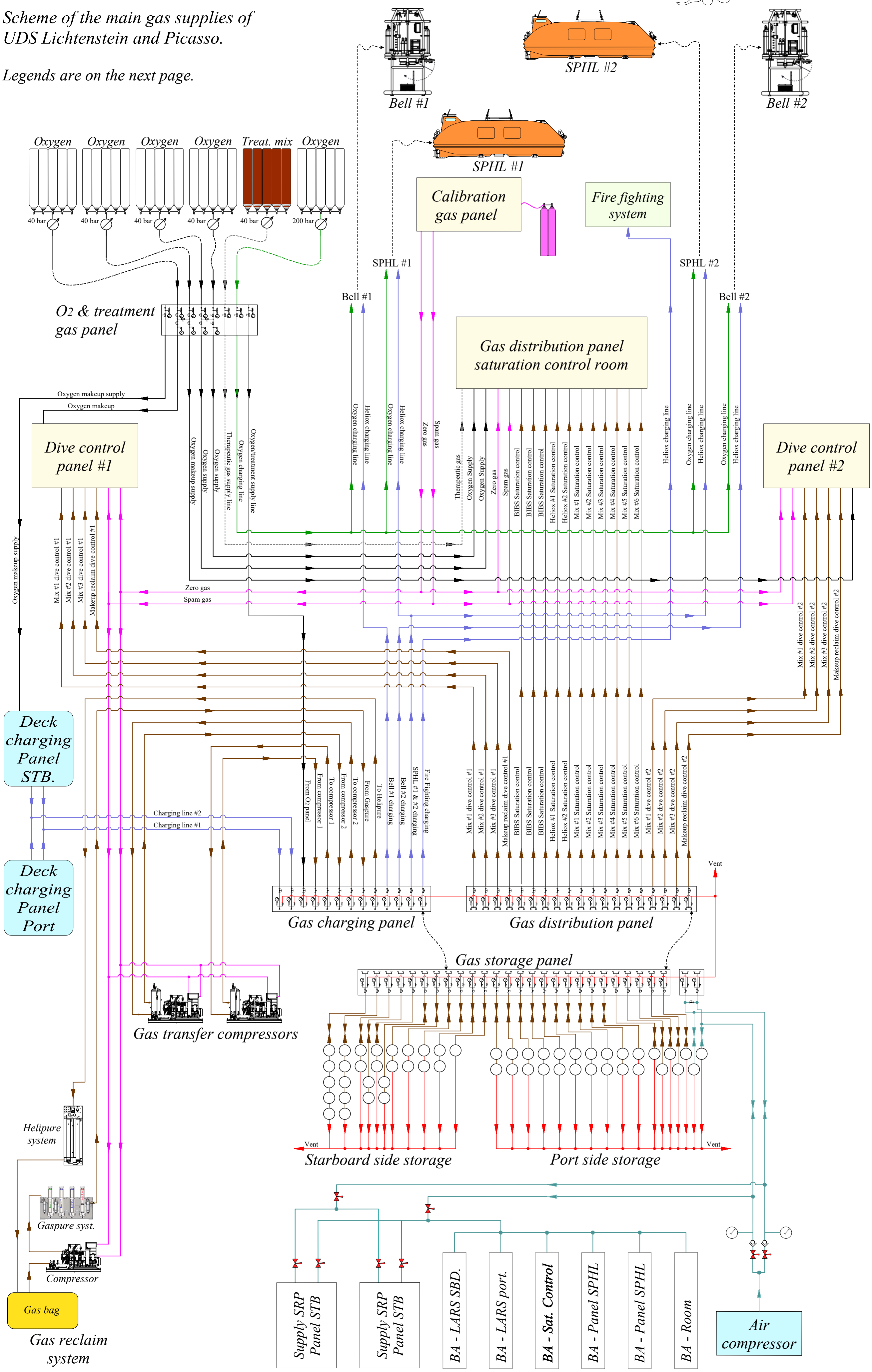
The gas transported through the the connecting panel situated on the main deck, which is often called “deck charging panel” is distributed to the storage tubes through the “Gas charging panel” that is installed at the direct proximity of the tubes and then through the “Gas storage panel” that is connected to each tube.
The “Deck charging panel” and “Gas charging panel” are linked by hard-piping. Flexible hoses are then used to transfer the heliox mix to the selected containers. The reason flexible hoses are used is that these connections are not permanent, and the numerous reservoir to connect would result in a too large and complex gas pipe mesh with rigid pipes.
The “Gas charging panel” is also hard-piped to the reclaim system (Gaspure & Helipure) and the compressors that are used to transfer the gas from one tube to another. In addition, this panel is used to transfer heliox from the reserve to the charging panels of the bells and Self Propelled Hyperbaric Life Boats *(See the photos and the scheme on the next pages)*.
The stored gas is distributed to the saturation control (eleven mixes), dive control #2 (four mixes), and dive control #2 (four mixes) through the “Gas distribution panel”. The connections from this panel to the items to supply are permanent, and metallic pipes are used. As with the “Gas charging panel”, the connections between the “Gas storage panel” and the “Gas distribution panel” are performed with flexible hoses.



Hyperlink Table of contents

Scheme of the main gas supplies of UDS Lichtenstein and Picasso.

Legends are on the next page.



Legends of the scheme on the previous page

Heliox - distribution & recycling — *Oxygen - distribution (LP)* — *Oxygen - charging lines (HP)*

Heliox - charging lines (HP) — *Calibration gasses* — *Air - production & distribution*

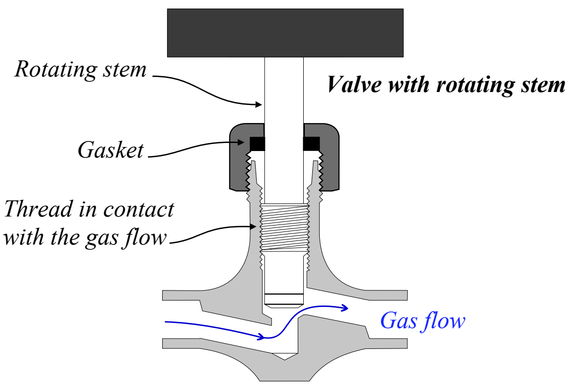
Vent lines stored gasses — *Connecting gas hoses*

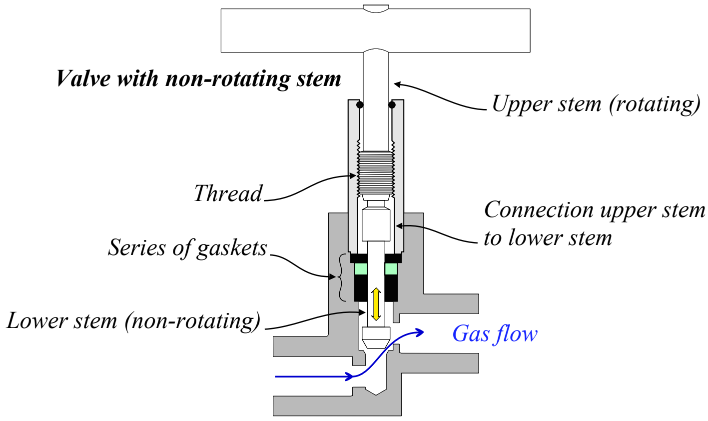
IMCA D 024 says that oxygen lines should be hard piped wherever possible. However, this requirement should apply to the entire pipework of the saturation system.
Heliox is commonly distributed through Stainless steel pipes of ¾ inch (19.05 mm) diameter. However, charging lines and transfer lines are often of ½ inch (12.7 mm) diameter.
Stainless steel is a mix of iron with a minimum of 10.5% of chromium, which is an additive that produces an invisible surface layer of oxide that prevents any further corrosion of the alloy. Varying amounts of carbon, silicon, manganese, nickel, and molybdenum are added to modify the properties of the metal according to usage it is designed for.
Austenitic stainless steels are commonly used in the diving industry. They are non-magnetic alloys with enhanced corrosion and heat resistance compared to other stainless steels. These characteristics are the result of their increased levels of chromium (> 18%) and nickel (> 8%).
Some austenitic stainless steels can be used with oxygen. However, the publication ASTM G128 *"Standard Guide for Control of Hazards and Risks in Oxygen Enriched Systems"* says: *"In regions of high velocity or impingement, such as valves, orifices, branch connections, and other critical areas, copper and nickel-based alloys (brass and alloy 400) are recommended, except for low pressures to 1.4 mPa (14 bar), where selected stainless steels may be used"*.
Besides, IMCA D 012 *"Stainless Steel in Oxygen Systems"* concludes: *"For simplicity and safety, many contractors use 'Tungum' for all O2 systems. 'Tungum' is a non-magnetic bronze copper alloy with non-sparking properties. IMCA endorses this policy as the safest, as well as the most convenient way of proceeding"*.
For the reasons explained in IMCA D 012 and ASTM G128, Tungum is used for the oxygen lines of the diving systems taken as reference in this study, and valves and connectors are usually made of bronze or brass.
Also, in addition to their resistance to oxygen, components made with these alloy have the advantage that their yellow colour differentiates them from other gas lines. Note that pipes of ½ inch diameter are commonly used.

Gas charging panel - Note the oxygen line in yellow metal

Gas storage panel (top) and gas distribution panel (bottom)

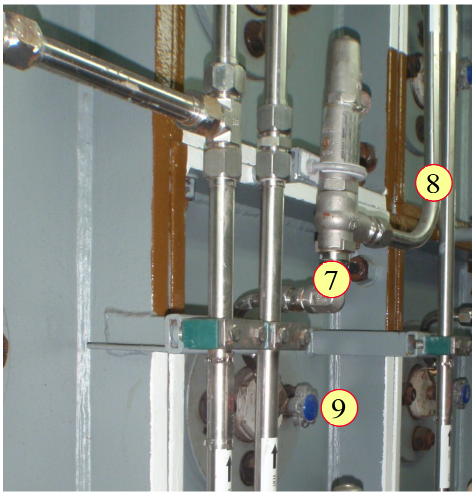
Needle valves are preferred to quarter-turn valves in the panels used for gas transfer and distribution, because they can be opened slowly, which avoids pneumatic impact and adiabatic compression.
For these reasons, and depending on the standard used, such valves are mandatory for pure oxygen and mixes that contain more than 25% (IMCA) or 22% (Norsok) O2. Regarding this point, note that the document ASTM *"Safe use of oxygen systems"* says that parts that require rotation at assembly such as O-rings on threaded shafts can generate particles that may migrate into the flow stream. For this reason, valves with a non-rotating stem where the seat is moving only up and down are more desirable in a high-pressure oxygen system.





In addition to the recommendations above, note that IMCA D 024 says: *"When the oxygen or mix containing over 25% oxygen is regulated down to below 15 bar (225 psi), then quarter turn valves may be used as emergency shut off valves, provided they are clearly marked as such, and lightly secured in the open position during normal operations"*.

Also, the vent lines must be organized to dump outside the room. This is also valid for relief valves. For this reason, appropriate pipework is provided on all gas transfer panels and on the relief valves of the gas banks (see below). Note that the relief valves of gas tubes are often installed at the opposite end the distribution valve is.



1 - Gas inlet #1 distribution panel

2 - Gas inlet #2 distribution panel

3 - Gas outlet distribution panel

4 - Vent line distribution panel (¼")

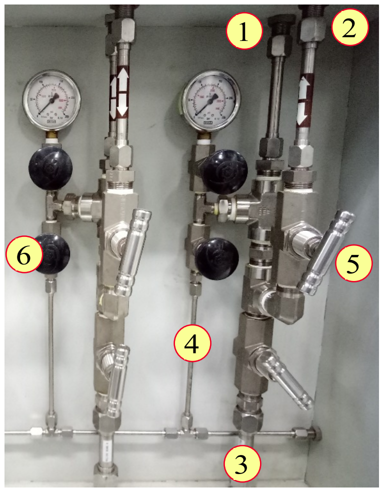
5 - Needle valves inlet & outlet

6 - Needle valve vent line

7 - Relief valve gas tube

8 - Vent line gas tube (1")

9 - Isolation valve gas tube (open)



The flexible gas hoses used to transfer the gasses from and to the storage gas panel must be designed to transfer high pressure "breathing gasses" and fitted with whip-check devices to be attached to solid points *(not the pipes!)*.

- Thermoplastic hoses are usual for the transfer of heliox, air, and calibration gasses. They are commonly made of non-toxic polyester with a reinforcement of aramid fibre braid and an external layer of polyurethane or similar material. However, such hoses are not oxygen compatible.
- ASTM says that Polytetrafluoroethylene (PTFE), which is well-known through the brand name "Teflon", and polychlorotrifluoroethylene (PCTFE) are listed suitable for oxygen service by the Compressed Gas Association (CGA). Polytetrafluoroethylene (PTFE) has one of the highest ignition temperatures for plastics and is considered the best available plastic.
  Nevertheless, particular care must be exercised to ensure that heat of compression ignitions cannot occur. ASTM G63 says that such hoses have been destructed due to too fast compressions. Also, polymers produce toxic gases when they decompose, which can contaminate the breathing systems and may not be detected as some of these ignitions do not affect the surrounding metal and penetrate the system boundary. The risks may be minimized if procedures preclude operator error, and the design incorporates a long, non-ignitable metallic tubing at the downstream end of the flexible hose that should be kept as short as possible, as recommended by IMCA. IMCA also recommends to identify the hoses used to transfer pure oxygen and rich mixes (*> 25 or 22% O_2, depending on the standard used)* so they cannot be confused with other hoses.

The Connections of the flexible hoses to the panels are often standardized, so only a few models of hoses are used. 3/4" and 1/2" JIC connectors are commonly found. However, some companies use different connection sizes or types to avoid connecting inappropriate hoses by mistake. As an example, the oxygen or therapeutic gas connectors can be different so only "oxygen clean" hoses can be used to transfer these gasses.

Valves of cylinders and tubes that belong to the diving system should also be standardized.
The valve connection to the cylinder often depends on the country of origin of the manufacturer. For this reason it must be identified, and corresponding replacement units should be provided in addition to Go and no go gauges to be used to check the condition of the thread.
ISO treads become the most found as these standards are recognized in one hundred and sixty two countries. However, other standards that can be confused with ISO standards may still be used in some countries.
Three parallel threads and two conic threads are recommended by ISO. These threads are designed to cover the full range of existing gas cylinders:

- Parallel thread M18 (used with small cylinders)
- Parallel thread M25 (which is the most used with diving cylinders)
- Parallel thread M30 (Which can be found with large cylinders and gas tubes)
- Taper thread 17E (usually found with small cylinders)
- Taper thread 25E (which is the most used with 50 litres cylinders B-50 and gas tubes)

Parallel and tapered threads require different sealing solutions: "O" rings are used to seal parallel threads. The seal of conical threads is obtained by metal to metal wedging. Nevertheless, sealants are often used to reinforce the seal. When such products are used, they must be compatible with the gas contained in the cylinder.
These valve connection threads are described in detail in:

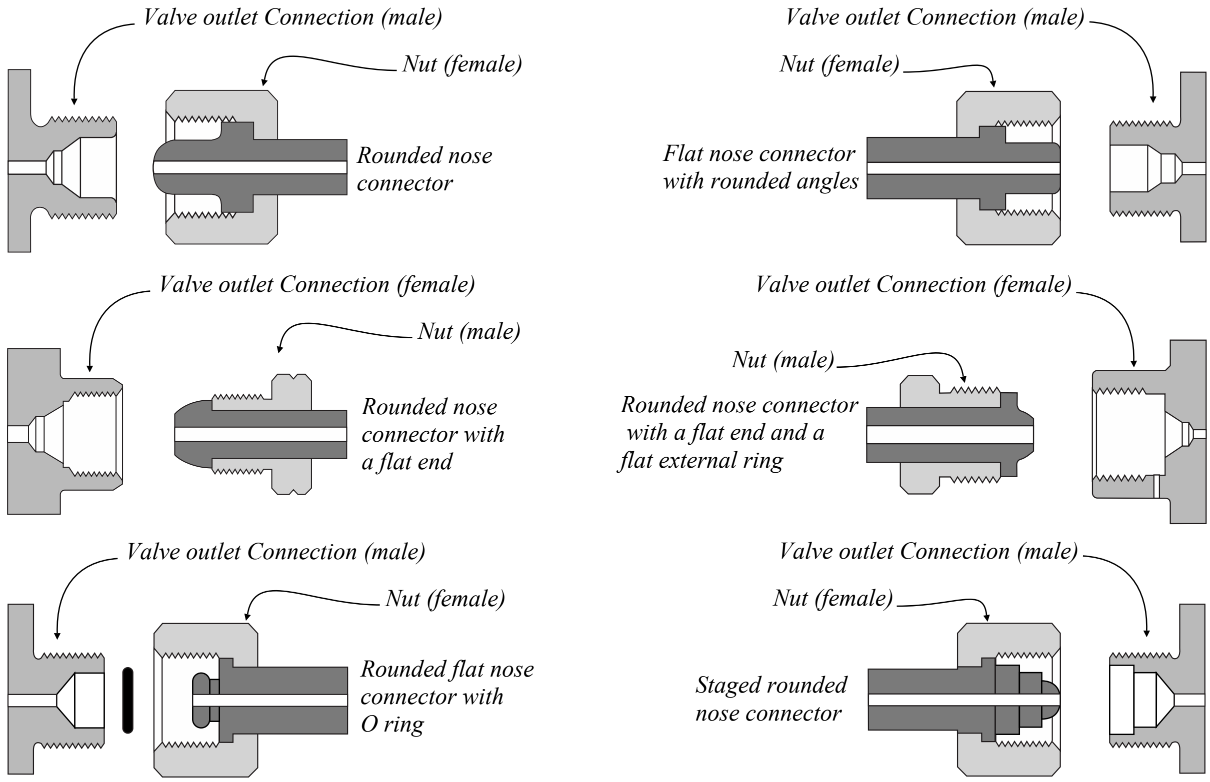
- ISO 15245-1 "*Parallel threads for connection of valves to gas cylinders*",
- ISO 11363 -1 *"17E and 25E taper threads for connection of valves to gas cylinders"*.

The ISO guidelines above are also explained with comparison with European and other international standards in the diving study CCO Ltd #2 *"Organize the maintenance of diving cylinders"* that is free of charge.

Multiple Elements Gas Containers (MEGCs) are usually connected to the saturation system using the same flexible hoses as those used to transfer the gasses between the connecting panels. They are typically connected to the outlet valve of the manifold to which the gas containers are inter-connected. However, this valve may be designed with a different type of fitting as those used onboard, and for this reason, adaptors may have to be installed.
Also, the gas reserves may have to be topped up from gas containers that are not interconnected to a manifold. That can be a problem if the outlet connections of their valves do not correspond to those that are available onboard the diving vessel. Opposite with diving cylinders that are today limited to a few outlet connections, there are infinite models of valve outlet connectors for gas cylinders and tubes, which usually are not compatible with each other, as a lot of countries continue using their national standards. As an example, the list below indicates a few models of cylinders outlet connectors proposed in the catalogs of reputed manufacturers.

Country of origin	***Air connectors***	***Helium connectors***	***Mixed gas connectors***	***Oxygen connectors***
USA	*CGA 590 (206 bar)* *CGA 346 (206 bar)* *CGA 347 (245 bar)* *CGA 702 (>300 bar)*	*CGA 580 (206 bar)* *CGA 677 (206 bar)* *CGA 680 (>300 bar)*	*CGA 590 (HeO2)*	*CGA 540 (206 bar)* *CGA 677 (>300 bar)* *CGA 701 (>300 bar)*
Australia & New Zealand - AS-2473.2	*Type 60* *Type 61 (315 bar)* *Type 62 (425 bar)*	*Type 10 (< 200 bar)* *Type 11 (< 250 bar)*		*Type 10 (< 200 bar)* *Type 17*
France	*Afnor NF D*	*Afnor NF C*		*Afnor NF F*
ISO - 5145	*code #3 (synthetic)* *code #14 (compressed)*	*code #1*	*code #25 (HeO2 < 20% O2)*	*code #2* *code #5*
Germany	*DIN 477 #13*	*DIN 477 #6*	*DIN 477 #14*	*DIN 477 #9*
Italy	*UNI 4410*	*UNI 4412*		*UNI 4406*
United Kingdom	*BS 341 No. 3*	*BS 341 No. 3*		*BS 341 No. 3*
Brazil	*ABNT 218-1*	*ABNT 245-1*	*ABNT 218-1 (>20% O2)* *ABNT 245-1 (<20% O2)*	*ABNT 218-1*

The connectors listed above vary in shapes and sizes, so only the relevant elements can be connected. Some use metal to metal seals, and some others use O rings. The drawings below represent some of the shapes that can be encountered. Note that there are too many designs to be able to show all of them in this chapter.

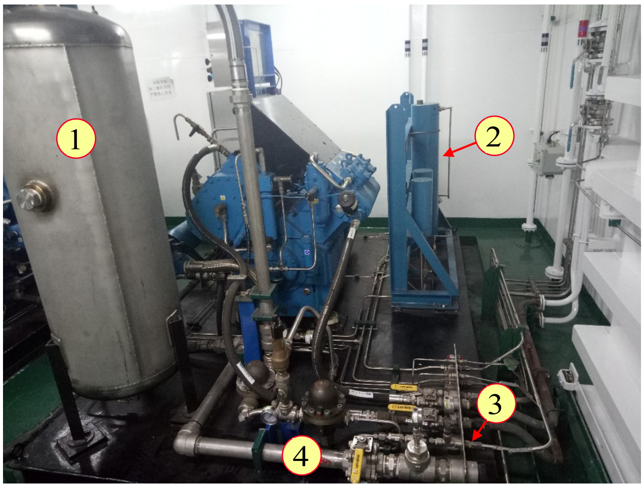


1.2.6.5 - Piston compressors

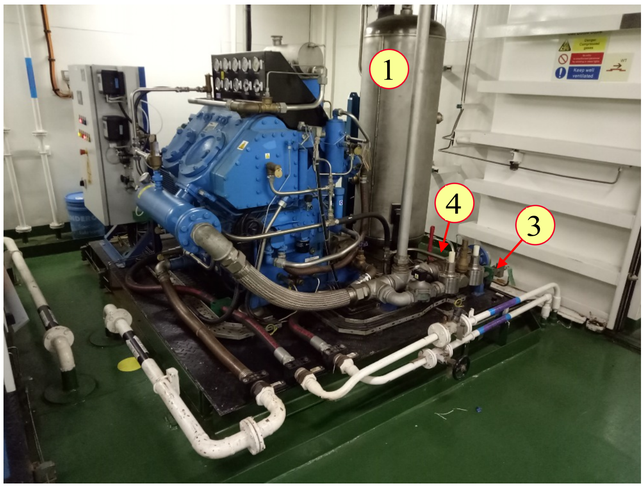
Gasses can be transferred by decantation. However, this procedure that is efficient when the reservoir to fill is empty, cannot be used in case the content of cylinders or tubes to transfer have less pressure than those to top up.
Piston and membrane compressors, also called diaphragm compressors, are used for this purpose. Membrane compressors allow transferring every gas and are described in the next point.

Piston compressors are commonly used with a lot of last generation saturation systems. Thus it is the case with the ensembles installed in UDS Lichtenstein & Picasso that are taken as references for this description.
The advantages of this solution are that only one compressor model is used to perform two functions, which reduces the number of spare parts and consumables to store. Also, these machines are reputed less expensive than membrane compressors. However, their disadvantage is that they are designed for mixes with 21% oxygen maximum. Thus, another system has to be used for the transfer of therapeutic gasses with more than 21% Oxygen.

The pressure of the gas to transfer from the quads or the tubes must be regulated down to the recommended inlet pressure of the compressor, which is usually a pressure close to the atmospheric pressure. In the installation taken as reference, it is done through two regulators that are installed before the compressor inlet to reduce the inlet pressure to 28 bar and then to 1 bar *(see the schemes below)*. Another difference with the installation used with the reclaim system is that a surge tank with a volume of 250 litres is installed before the pulsation damper *(see #1 below)*. This device is a closed reservoir that absorbs sudden rises of pressure and returns the gas stored in it to the inlet hose in case of a brief drop of the supply pressure. Thus, it regulates the gas flow from the regulators to the compressor. Note that a 2nd inlet line that is not fitted with regulators is available. It can be used to compress air or as a backup or an option to compress heliox.
As with the machine use for gas reclaim, the levels of oxygen, carbon monoxide, and carbon dioxide of the inlet and outlet gas are controlled through analysers and sensors. So, the protection systems in place in case of inappropriate gas percentages are similar to those described with the machine used with the reclaim system.
Also, a set that purify and dry the outlet gas designed by Bentley, a company specialized in filtration systems, is installed to ensure that the gas delivered is above EN 12021 standard *(see#2 below)*. This unit is described on the next page.

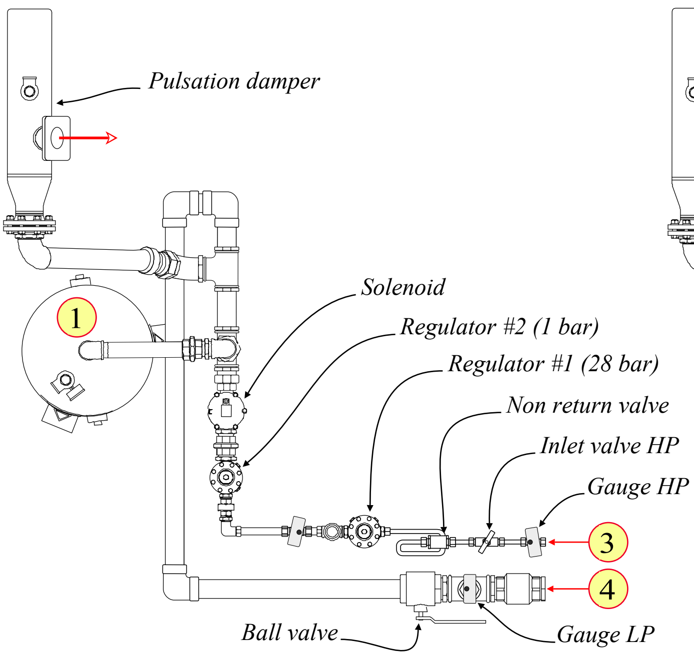


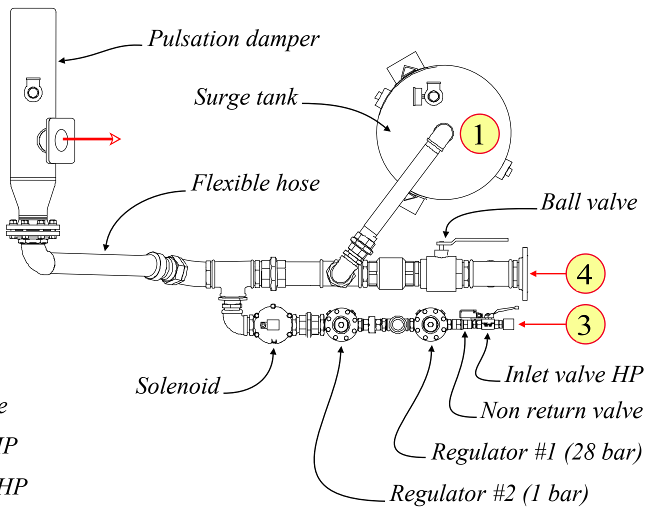
Gas transfer compressor UDS Picasso



Gas transfer compressor UDS Lichtenstein

The gas inlets of the compressors above are composed of the same elements that are arranged differently: See below the plan views of the design onboard Picasso on the left side and of Lichtenstein on the right side.

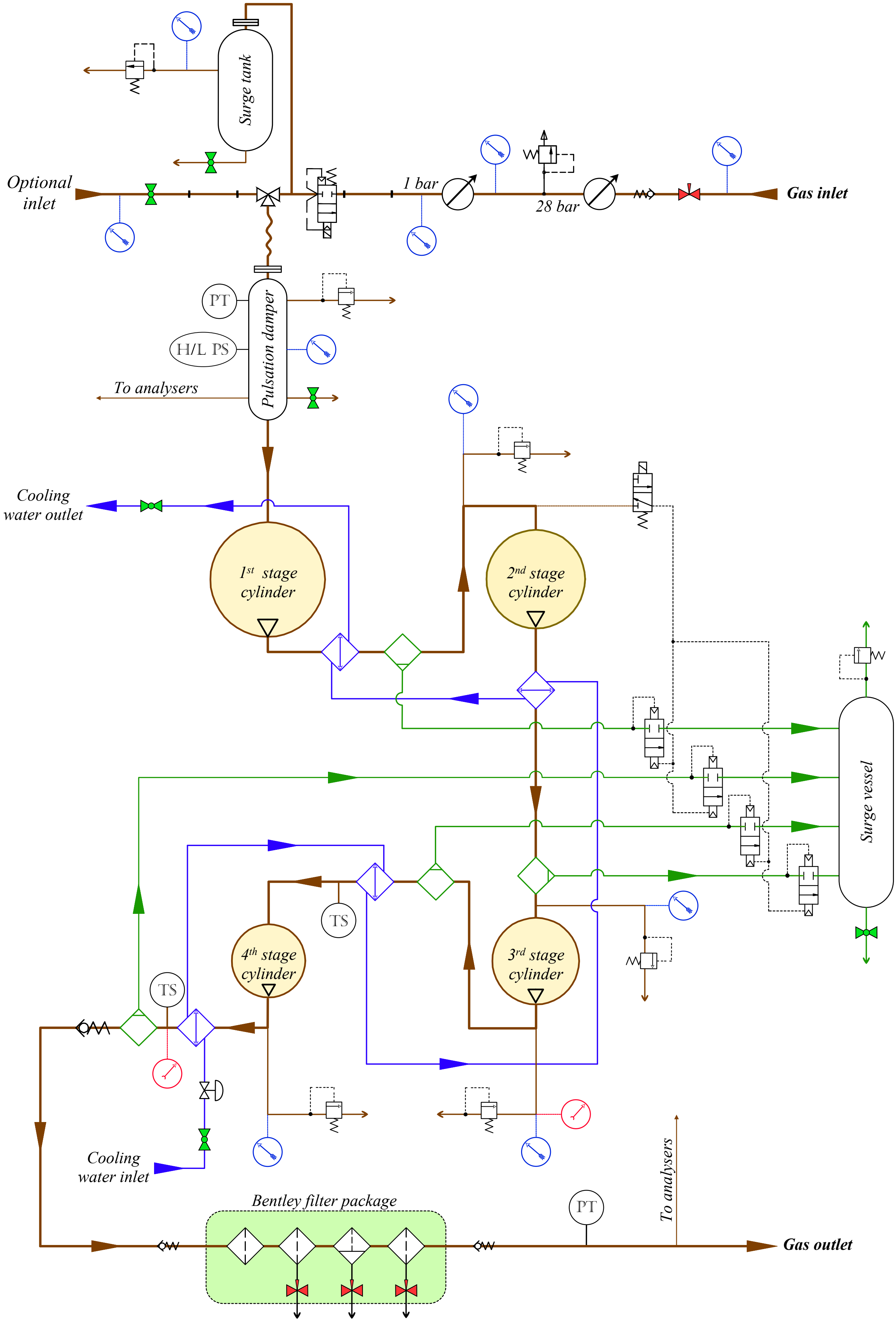


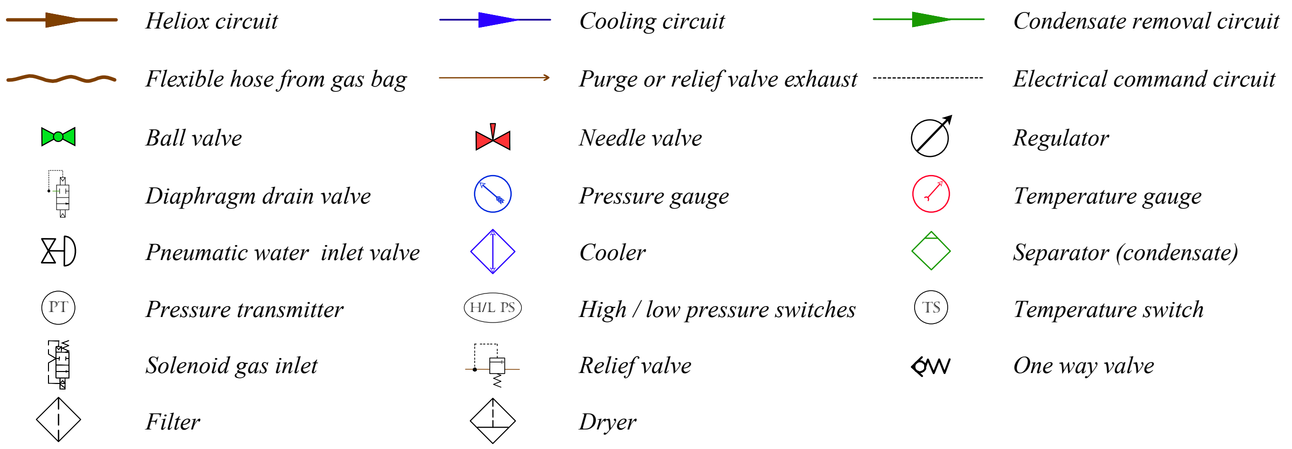


Legends:

#1 - Surge tank | *#2 - Bentley filters & dryer*
#3 - High Pressure inlet | *#4 - Backup or optional inlet*

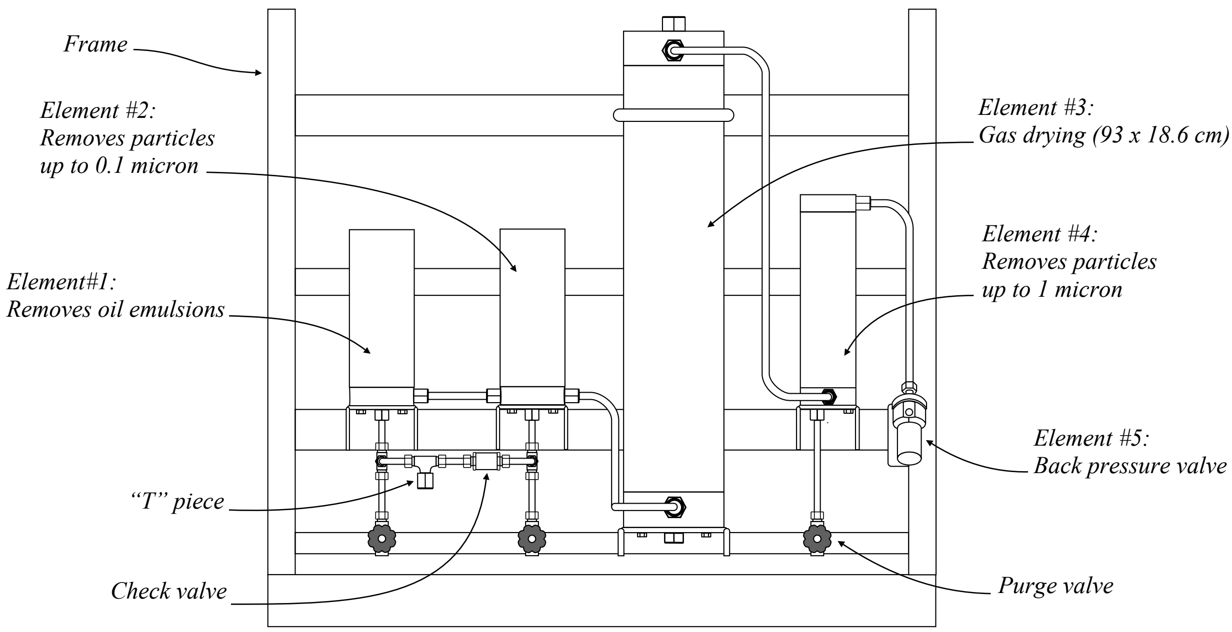
Scheme of the piston compressor described on the previous page. See the legends on the next page.





The Bentley cleanup pack is designed to removes oil vapour to less than 0.05 ppm, with a final particle filtration of less than 1 micron at a flow rate of 110 m³/hr at 207 bar, and dry up the gas to a dew point of compressed gas of -40ºC at atmospheric pressure. It can deliver 110 m³/hr of compressed mix at 350 bar, and is considered a part of the compression system. It is composed of five elements:

- The 1st element is a coalescing filter made from anti static synthetic materials that is rated to 0.1 micron. It removes water and oil emulsions from the compressed gas. The size of this elements is 150 mm long and 50 mm diameter.
- The 2nd elements is made of similar materials as the first element. Its function is the removal of the remaining particles above 0.1 micron.
- The third element is the dryer. It is composed of activated alumina, which is a highly porous form of aluminum oxide (Al_2O_3) that can adsorb gases and liquids without changing its structure and is used as a desiccant for this reason. Besides, note that it is a highly stable compound and highly resistant to corrosion that is also used in the production of ceramics, mechanical seals, bearings, abrasives, grinding wheels, molds, cutting tools, and synthetic gemstones. Another advantage of this material is that it is an excellent electrical insulator
- The fourth element is a dust filter. It consists of an element for the removal of particles up to 1 micron, and of a hopcalite pad, which is a mixture of copper and manganese oxides, that is used to remove the carbon monoxide.
- The fifth element is the back-pressure maintaining valve that is an adjustable relief valve that opens at the minimum pressure setting and above. Its function is to ensure that gas flow does not commence until the set pressure has been reached within 10% of normal working pressure.



1.2.6.6 - Membrane compressors

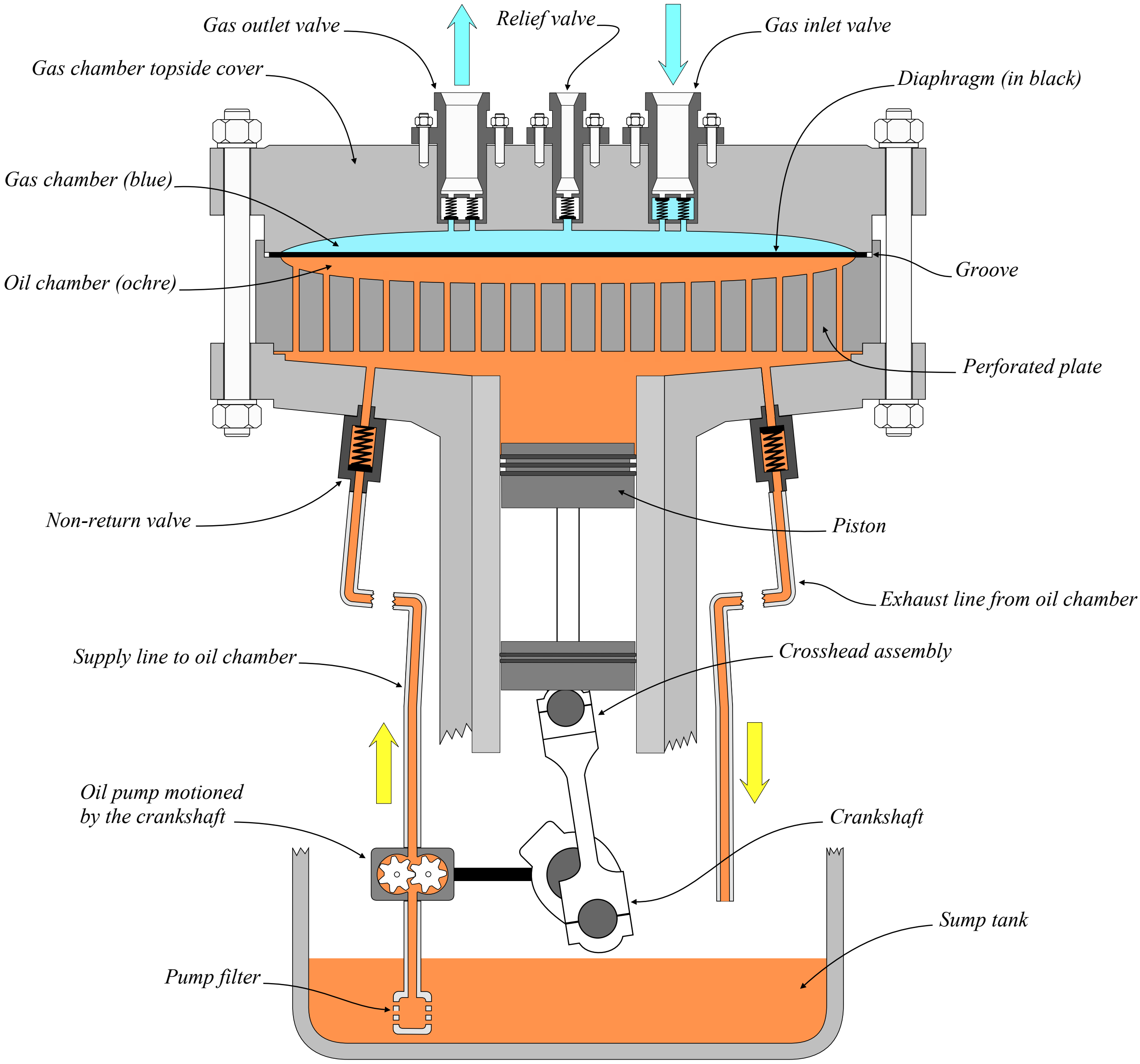
As already said, "membrane compressors", that are also called "diaphragm compressors" and "Corblin", which is the name of the inventor (1916), allow to compress all gasses even though they are oxidizing or flammable. For this reason, they are used for a lot of industrial processes where such gasses must be compressed.
Membrane compressors were used for the gas transfer of all saturation systems in the past, as they were the only machines capable of heliox transfer. However, as a result of technical progress in sealing materials, piston compressors and transfer pumps are today able to transfer such mixes, and a lot of manufacturers propose these devices in replacement of diaphragm compressors for the reasons explained in the previous point. Nevertheless, these machines provide a lot of advantages that must be highlighted, and which are the reasons a lot of companies use them.

The principle of compression consists of a diaphragm, which is composed of three layers of flexible metal plates which separate a double concave chamber in two parts:

- The upper part is filled with the gas to compress that enters it through the inlet valve and is expelled from it through the outlet valve. Also, a relief valve is provided to protect the mechanism from over pressure.
- The lower part is filled with oil that is cyclically compressed by a piston motioned by a crankshaft, which is driven by an electrical motor.

These metal plates, that are sealed at the periphery of the separated chamber, flex against the concave surface of the topside cover when the piston drives oil against them through a perforated plate, which is also concave. They are drawn against the concave surface of the perforated plate when the piston is back to its lower position. As a result, the gas space is reduced when the piston pushes the oil toward the plates, which creates compression, and is then enlarged when the piston is going back, which creates suction. This cycle is repeated every rotation of the crankshaft.
Note that the displacement of the piston nearly equals the movement of the diaphragm, and that the function of the perforated plate is to achieve a uniform pressure load of the oil on the rear surface of the diaphragm plate. Also, the sealing of the metal plates that compose the membrane is reinforced by a metal O ring. As a result of this configuration, the gas compressed is fully isolated from the piston and the oil that moves the diaphragm.

As every piston compressor (or engine), small quantities of oil passes through the sealing rings of the piston to the crankcase. To compensate for this loss of oil volume that could decrease the efficiency of the compression, an oil pump, which is driven by gears motioned by the crankshaft, feeds the oil chamber behind the diaphragm. A non-return valve is installed to protect the pump from back pressure that results from the motion of the piston. Also, because the flow from this pump is calculated to exceed the estimated oil loss, the liquid in excess is removed by an overflow valve that is designed to open when the oil pressure is approximately 10% above the working pressure. The oil in excess is sent back into the sump tank from which it is pumped again to the oil chamber. Note that this oil is also used to lubricate the other parts of the machine.



Manufacturers indicate that the life length of the plates that compose the diaphragm is approximately between 3000 and 5000 hours. However, they may fail before this time, which can result in gas contamination or the machine damaged. For this reason, *IMCA requires that a cracked plate detector which automatically stops the compressor is installed.*

As a result of their design, these compressors cumulate the following advantages:

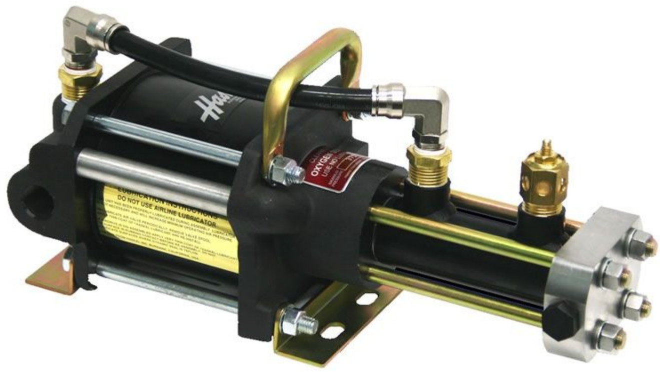
- Their gas chambers are fully sealed towards the outside, so the compressed gas is protected from contamination.
- Linked to above, there are no oil particles in the gas delivered, so the reinforced filtration of piston compressors is not necessary.
- These machines have a reputation of high yield: Some models can compress up to 3000 bar and 225 m³/hr.
- All gas can be compressed. So they can be used to transfer gasses with more than 21% oxygen.
- Their maintenance is reduced, and they are reputed reliable.

Their main inconvenience compared to piston compressors is their price.

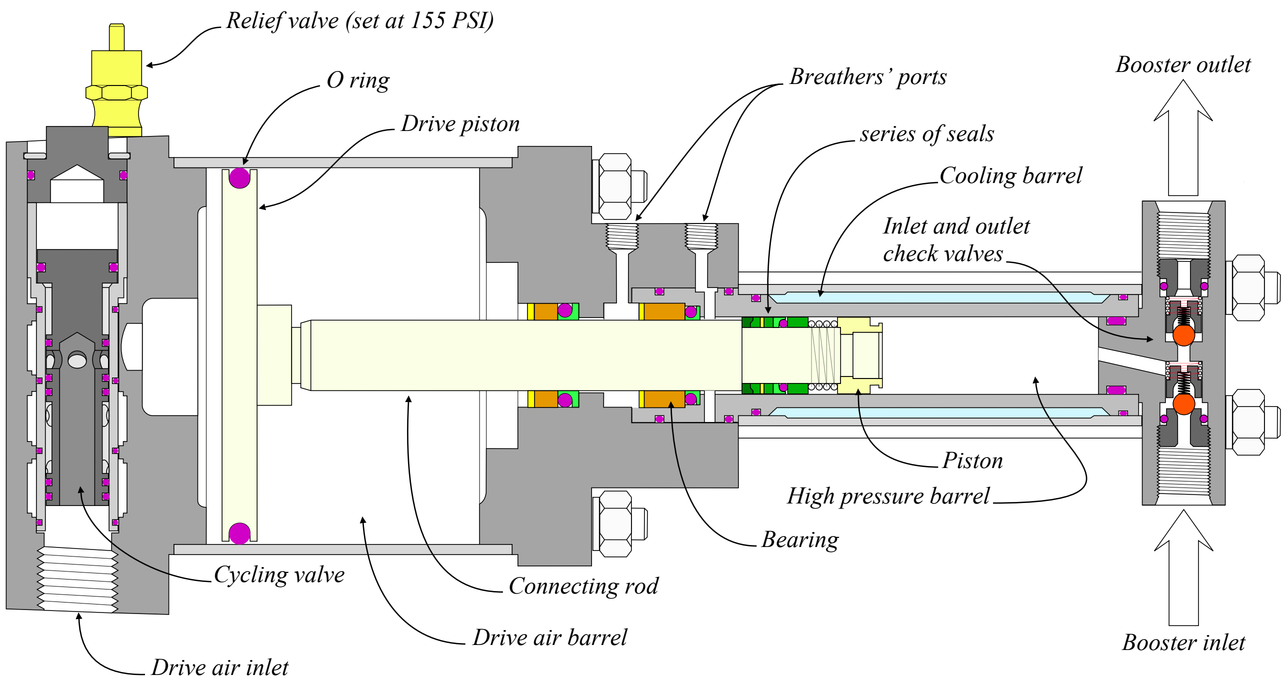
1.2.6.7 - Transfer pumps

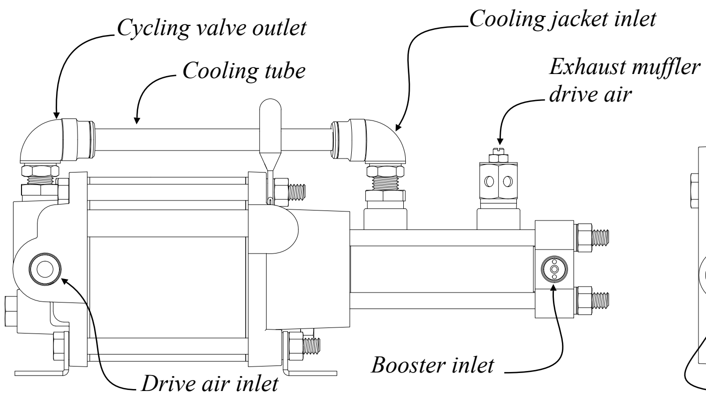
Transfer pumps are machines used in replacement or as a complement of membrane compressors for transferring pure oxygen and therapeutic gasses with an oxygen percentage above 21%.

"Haskel" pumps are the most common gas transfer pumps in the industry. They are suitable to transfer a lot of varieties of gasses, and some models can compress up to 2690 bar. Also, a lot of models are oxygen compatible. Because they are gas boosters, they require a minimum inlet pressure to work, and as a result of the compression ratio, the pressure delivered is proportional to the inlet pressure.

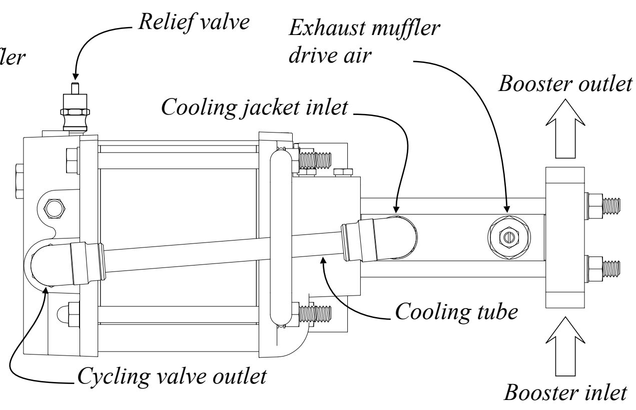


The operating principle of these machines that are powered by compressed air is that a large piston, which is driven by the air provided from a compressor, moves a smaller piston, that is in a separate cylinder, to compress the gas to transfer to the reception gas container.
The small piston that compresses the gas to transfer in the "high pressure barrel" is connected to the drive piston by a rod that links the two units. It is isolated by a series of seals made of materials that are oxygen compatible. The gas inlet and outlet to and from the high-pressure chamber are performed through check valves.
The drive air is regulated by a cycling control valve, pilot valves, and an adjustable exhaust muffler. Also, the manufacturer says that the air drive seals are originally designed to operate within a temperature range of -4°C to 65°C (25°F to 150°F), and that lower temperatures can cause gas leakage while higher temperatures reduce seal life. However, specific seals for harsh conditions can be provided. As recommended by competent organizations, relief valves are installed to protect the machine from over pressurization.
The high-pressure barrel is cooled by the exhausted air from the air drive barrel that is canalised through a jacket surrounding it *(see in the drawings below and on the next page)* with most models, but not all of them.



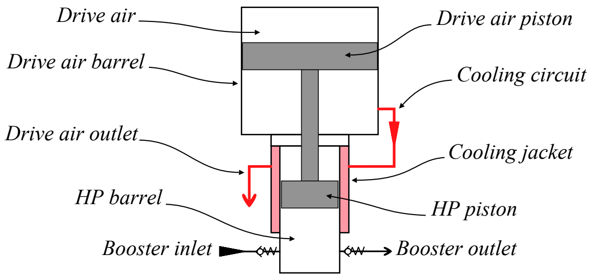


Side view

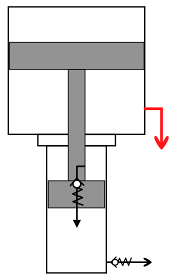


Plan view

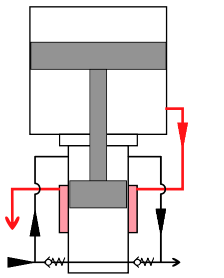
Haskel propose a wide range of machines which various configurations are summarized in the schemes below. Note that the models used in the diving industry are usually limited to 300 - 350 bar.
Also, more than one booster of the same ratio can be linked together to create a multi-stage gas booster, allowing to pump gas at low pressure and compress it to high pressure in only one operation.
The weight of the machines proposed vary from 12 kg to 154 kg. Light machines are often used because they are easy to move and so can be operated in various parts of the deck.



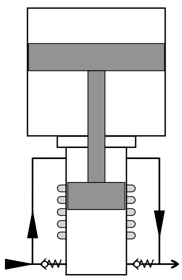
Single stage & single acting with cooling jacket



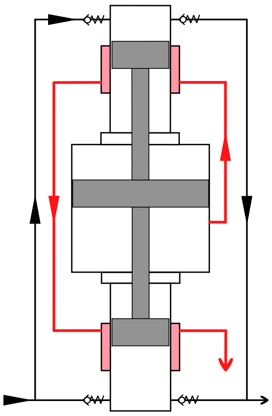
Single stage & single acting Flow through the piston



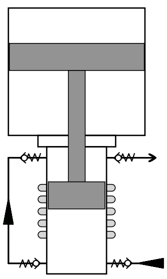
Single stage, double acting with cooling Jacket



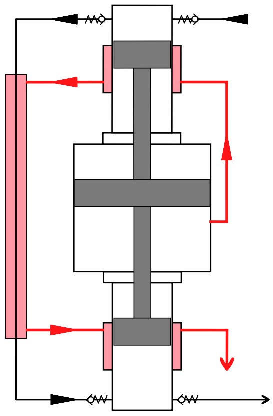
Single stage, double acting with cooling fins



Single stage, double acting, with cooling Jackets



Two Stage with cooling fins



Two Stage with cooling Jackets

Note that these machines are limited to a maximum pressure of the air drive that is usually 10.34 bar (150 PSI). Also, the manufacturer recommends not to exceed 60 cycles per minute during the operations as a higher speed may result in machine damage. The cycles can be controlled by the adjustable exhaust muffler that is in place on the cooling jacket *(see above)*, or by slowly increasing air drive pressure at start up.
Also, the manufacturer recommends that the quality of the drive air conforms at least to class 4 of ISO 8573.1 standards that are explained in the table below, so a filtration is necessary with air from industrial compressors or similar devices.

Class	**Particles**			**Water dew point**	**Oil**
	00.1 to 0.5 micron	**0.5 to 1 micron**	**1 - 5 micron**		
1	≤ 20,000	≤ 400	≤ 10	≤ - 70 °C	0.01 mg/m³
2	≤ 400,000	≤ 6,000	≤ 100	≤ - 40 °C	0.1 mg/m³
3	–	≤ 90,000	≤ 1000	≤ - 20 °C	1 mg/m³
4	–	–	≤ 10,000	≤ +3°C	5 mg/m³

Regarding the quality of drive air, the manufacturer also says that ISO 8573.1 class 1 or 2 may be required for high pressures or heavy-duty applications to avoid freezing and contamination. Note that class 1 or 2 compressed air is dryer and may result that the frequency of re-lubrication of the cycling valve may have to be increased.
In addition to the above, the following recommendations are provided:

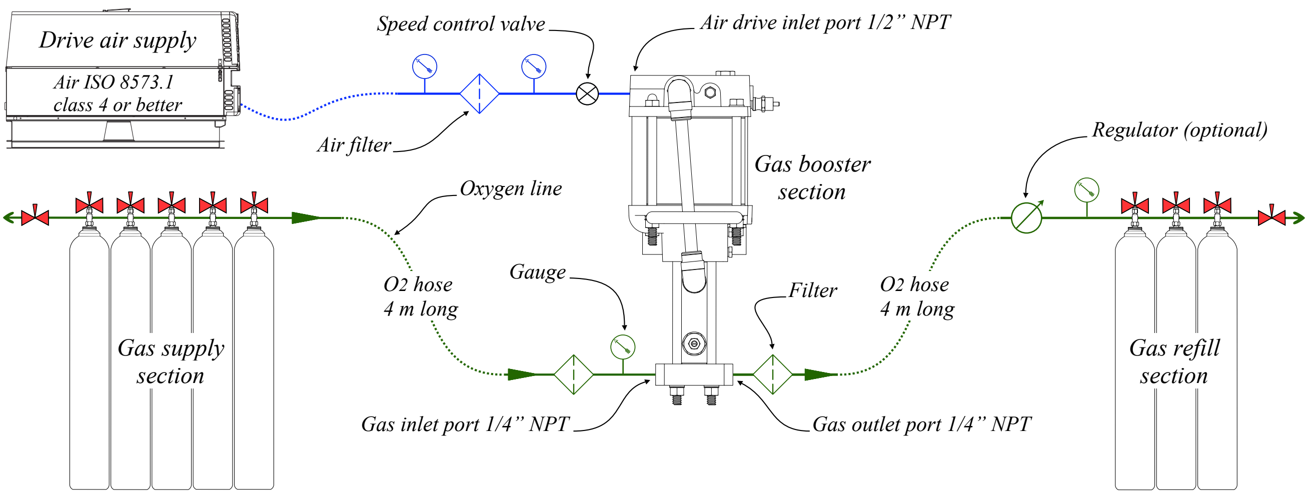
- The operator should ensure that a maximum of water and oil vapour condenses and can be efficiently removed. For this reason, the filters should be installed downstream of coolers and air receivers, and at the point where the temperature of the installation is the lowest. Such an arrangement also reduces the risk of pipe scale contamination downstream of the filters.
- Filters should not be installed downstream of quick opening valves and be protected from possible reverse flow or shocks.
- When existing rigid pipes and flexible hoses are used, the operator should take into account that they can be contaminated and that such contamination is complicated to remove. For this reason, it may be necessary to install additional filtrations downstream of these elements. Also, the lines to and after the filters should be purged before installation and connection. Note that, when it is possible, the most straightforward procedure is to separate the hoses used to supply the machine from those used for other tasks.
- By-pass lines after the filters should be avoided as their isolation valves may leak and contaminate the installation.
- The filters must be installed in a vertical position and in a relevant frame with sufficient room below them to facilitate drainage and element change. Suitable tubing should be in place to canalise the condensate to a collecting tank. Note that gauges should be in place before and after the filter to monitor pressure drop and see when the elements must be changed.
- Gas analyzing of the drive air should be performed at the end of the line to ensure that the air supplied conforms with the quality requested. Drager tubes can be used for this purpose.

Also, Haskel recommends the following precautions to implement to transfer oxygen *(see the scheme below)*:

- Oxygen containers should be at 4 to 4,5 metres from the booster system
- Only needle valves are to be used (No ¼ turn valves)
- The gas booster must be certified and cleaned for oxygen service. Also, procedures must be implemented not to contaminate the machine and the connecting hoses during the installation.
- There must be no valve between the supply cylinders and the booster system, or between the outlet of the booster and fill cylinders
- The valves must be opened gradually
- The maintenance of the transfer pump must be performed by competent persons or in factory

Also, the manufacturer recommends not to exceed a pressure output of 345 bar (5000 PSI) and 50 cycles per minute and that the compression ratios *(maximum output pressure divided by minimum inlet pressure)* are strictly those of the following chart:

Number of stages	***Maximum Compression Ratios***	
	O_2 Inlet < 150 psi (10.34 bar)	***O_2 Inlet of 150 psi (10.34 bar) or higher***
Single Stage	*5 : 1*	*6 : 1*
Two Stages	*25 : 1*	*36 : 1*
Three Stages	*45 : 1*	
For heavy-duty, continuously operating applications, Haskel recommends that the above compression ratios are further reduced, where feasible, with additional staging and/or plenum coolers.		



Oxygen transfer configuration recommended by Haskel (see legends on the next page)

Oxygen line	*Drive air line*	*Drive air hose*
Oxygen hose	*Needle valve*	*Oxygen regulator (optional)*
Oxygen line filter	*Drive air filter*	*Oxygen gauge*
Drive air gauge	*Speed control valve*	*Vent line*

Haskel also gives the following additional recommendations for transferring oxygen:

- Cylinders, manifolds and isolation valves must be closed prior to starting the transfer.
- The 1st valve to open is the one of the supply cylinder (*Gas supply section*)
- The 2nd valve to open is the one the gas cylinder to refill (*Gas refill section).* The operator must then allow pressure to equalize to outlet fill cylinders (7 bar /second pressurisation recommended).
- The pressure of the gas supply should be above the minimum pressure setting.
- The limitation to 50 cycles per minute can be controlled through the pilot switch and the outlet regulator.
- In an emergency situation, the supply valves of the gas supply section must be closed instead of attempting to stop the gas booster.
- At least five minutes of temperature stabilization is necessary at the end of the process. Then, the 1st valve to close is the "air drive speed control valve"
- The 2nd valve to close is the gas supply valve *(Gas supply section)*
- The 3rd valve to close is the gas of the refilled cylinder (*Gas refill section)*

1.2.6.8 - Air compression and surface orientated dive systems

Depending on the design of the saturation system and their safety policy, some companies prefer that the compressed air system that is used to supply the emergency Breathing Apparatus (BA) sets of the dive and saturation controls, Launch And Recovery Systems (LARS), Self Propelled Hyperbaric Lifeboats (SPHL) panels, and scuba replacements, is fully separate from other gasses.
For this reason, this air system can be supplied by a compressor that is designed for this purpose only. It is the case in the scheme of the main gas supplies in point 1.2.6.4. The compressors commonly used are piston compressors that are smaller than the model used for heliox transfer discussed in point 1.2.6.5.

When surface orientated dive systems are installed on the surface support in addition to the saturation system, their gas supplies should be entirely separate from those of the saturation system.

1.2.6.9 - Fire fighting systems

The firefighting systems used are similar to those in place to protect the reclaim and regeneration systems.
Firefighting systems of built-in systems are usually those of the surface support. They are controlled from the bridge with repeaters that are located in the engine control room, dive control room, and saturation control room. Extinguishers are provided in reinforcement.
As the gasses of portable systems are usually stored on deck, the firefighting systems are often portable systems and the systems of the vessel provided to fight a fire that may happen in this area (water lances). The compressors of portable systems are generally installed in containers and are often protected using portable systems only. However fire detectors should be provided. and fixed systems may be in place.

1.2.6.10 - Maintenance

Regarding gas storage and pipework, IMCA recommends the following the planned maintenance:

Items	***Visual external + function test , calibration or for lifting appliances: Load test 1.25 SWL***	***Visual internal + external + leak test at max. Working pressure***	***Internal + external+ leak test 1,5 max. working pressure or for lifting appliances: Load test 1.5 SWL***	***Other***
Cylinders	6 months	2 ½ years		Internal & Ext. examination. + test max working press: 5 years
Welded pressure vessels	6 months	2 ½ years (3;4) + internal & external examination		
Pipework	6 months	2 years		1.5 max. working press: 1st install
Lifting equipment (slings, etc)	6 months		12 months	

Items	Visual external + function test , calibration	Visual internal + external + leak test at max. Working pressure	Internal + external+ leak test 1,5 max. working pressure	Other
Relief valves & bursting discs	6 months	2 ½ years		Bursting discs renewal: 10 years
Analysers	6 months			
Fire fighting portable system	6 months			Manufacturer specifications
Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
Automatic detection	12 months			

Regarding compressors, IMCA recommends the following the planned maintenance:

Items	Visual external + function test , calibration	Visual internal + external + leak test at max. Working pressure	Internal + external+ leak test 1,5 max. working pressure	Other
Fire fighting portable system	6 months			Manufacturer specifications
Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
Automatic detection	12 months			
Cracked plate detectors (membrane compressors)	6 months			3000 - 5000 hours *(See the text below)*
Automatic shut down devices	6 months			
Relief valves	6 months	2 ½ years		
Pipework and fittings	6 months	2 years		1.5 max. working press: 1st install
Air/gas receivers	6 months	2 ½ years OR internal/external inspection		
Electrical testing	6 months			
Function test equipment	6 months			
Delivery and rate of pressure compressors	6 months			
Output purity of compressors	6 months			

Filters should be changed according to the recommendations of the manufacturer.
Note that the maintenance of membrane compressors is similar to the piston compressors , except for the three metal plates that compose the diaphragm that must be inspected and changed according to the recommendation of the manufacturer (between 3000 and 5000 hours).

Regarding the planned maintenance of the Bentley filtration system, the manufacturer recommends the following:

- 100 - 200 hours operation maintenance
  - The desiccant of the element #3 must be changed
- 1000 hours operation maintenance:
  - The coalescing filters of the 1st and 2nd elements must be removed and replaced.
  - The dust element and the hopcalite pad of the 4th element are to be changed
  - The o rings and anti-extrusion backing ring of the filters' heads should be changed.

As the other elements of the dive system, visual inspection and function tests of the element listed on the next page, but not limited to, must be undertaken prior to starting the daily operations.

- Condition of pipework
- Condition of the electrical systems and alarms
- Condition of the filter cartridges
- Oil level of the compressor

Regarding the elements used to transfer oxygen and mixes with more than 25% O_2:

- The items used must be rated "oxygen compatible", plus "cleaned for oxygen service", and identified.
- There is no established rule regarding the frequency of Oxygen cleaning of the elements in service. However, based on their exposure to potential contaminants regular examinations should be performed to decide whether cleaning is necessary. The document EIGA 33/18 that describes the cleaning of equipment for oxygen service, indicates the following methods of investigation *(For safety reasons methods using solvents are not listed)*:
    - Direct visual inspection with white light: The component is observed without magnification under bright white light. This method detects particulate matter greater than 50 µ (0.05 mm) and also, moisture, oils, greases, and other contaminants.
    - Direct visual inspection with ultraviolet (UV) light: Ultraviolet (UV) light, commonly known as black light, causes some oils, greases, detergent residues, and lint and other fibres to fluoresce. However, since not all contaminants fluoresce, UV light inspection is not considered a test for cleanliness. For this reason, this method is only used after performing direct visual inspection using white light and not observing any contamination.
    - Wipe test: This test is used to detect contaminants on visually inaccessible areas as an aid in the previous direct visual inspections. The surface is rubbed lightly with a clean, white, paper or lint-free non-fluorescing cloth that is then visually examined under white light and UV light if no contamination is seen
    - Water break/ink test: The surface of the element to check is wetted with a spray of water that should form a thin layer and remain unbroken for at least 5 seconds. Beading of the water droplets indicates the presence of oil contaminants and that cleaning is required. This test, which allows detecting low contamination levels, is based on the surface tension of a liquid on an oily surface.
    - Odour test: This test is used for medical and food gas systems. If the odour of a solvent is detected then the component or system must be cleaned. Safety precautions must be taken to prevent asphyxiation.
    - Chromatographic, spectrometric, and other detection methods:
        - Chromatography is a method in which the components of a mixture are separated based on their differential interactions using chemical and physical process and is commonly performed in a laboratory.
        - Spectroscopy is the study of the absorption and emission of light and other radiation by matter. It involves the splitting of electromagnetic radiation into its constituent wavelengths, which is done in the same way as a prism splits light into a rainbow of colours. Small amounts of oil or grease contamination can be detected and measured by these methods.
        - Note that the measuring instruments used for these detection methods are expensive, and the technicians using them must be trained.

In addition to these methods, the analysis of gas samples should be done. Also, a lot of companies perform preventive cleaning at regular intervals as the methods indicated above do not allow to check all the inner parts of a system. They are often performed every six months or every year. These inspections and cleanings are recorded in the planned maintenance system of the diving system. These records should indicate the date, the parts or items cleaned, the cleaning fluids used, the procedures followed, the personnel involved, and be signed by the competent person in charge.

ASTM G93 is a guideline that indicates the steps and precautions for efficient cleaning and evaluates several cleaning methods. This document says that mechanical cleaning methods such as abrasive blasting, tumbling, grinding, and wire brushing are aggressive and may damage sealing surfaces, remove protective coatings, and work-harden metals. For these reasons, these methods should be avoided on precisely manufactured devices.

Also, several chemical products are commonly used to clean the inner parts of a gas pipework system. ASTM G93 says that they must be used with precaution, as some can damage metal parts and seals. ASTM G 127 indicates methods to evaluate such cleaners.

Another solution to find an appropriate cleaning agent is to use products that are indicated suitable by recognized diving organizations. As an example, "Biox O2 liquid" is approved for diving systems by the Lloyds Register, and "OCC Oxygen" satisfies the US Navy requirements for diving equipment. Note that other cleaning agents are proposed. However, chlorinated cleaning solvents that have been used during a long period for such operations are no longer considered suitable. Only non-chlorinated cleaning agents should be used, and their formula and effects on the health should be indicated.

Also, despite manufacturers say that their products are safe, precautions should be taken to ensure that the cleaning fluid used does not remain in the system: Common sense says that a product capable of removing greases and other pollutants is not very good for the respiratory system of divers. To ensure that these cleaning agents have been fully removed, a close inspection and gas analysis should be performed after completing the cleaning.

ASTM G93 also says that in-situ cleaning of fully assembled systems and flow cleaning of components is not always effective and is not recommended. The reason is that cleaning using flowing solutions through assembled components may not remove effectively trapped contaminants and that the cleaning solutions may become entrapped in the components. Therefore, it is preferable to disassemble the components of the system if its construction permits it.

- Regarding the storage and handling of the cleaned spare parts, ASTM G93 says that they should not stand unprotected after they have been cleaned and should be protected from contamination in sealed packs and that the long hoses and pipework should be blanked at their ends. Also, the cleaned components should be marked “Cleaned for oxygen service”. ASTM G93 recommends not touching surfaces planned to be in direct oxygen service except with clean gloves or handling devices.
  Besides, the spare parts removed from the service should be protected from contamination and be stored in a protected area.
- IMCA D 031 also says that suspicious components should not be installed on a system carrying gas considered as pure oxygen. Also, equipment received directly from suppliers cannot be considered “cleaned for oxygen service” and should be cleaned according to the procedures indicated above before being used, except if they are provided in sealed packs with the mention “Cleaned for oxygen service”.

1.2.7 - Means for hyperbaric evacuation

1.2.7.1 - Purpose

When the surface support has to be abandoned, the divers in saturation cannot be decompressed quickly enough and need to be evacuated while they are still under pressure. For this reason, IMO, IMCA, and other organizations say that an HRU (Hyperbaric Rescue Unit) which is capable of evacuating the maximum number of divers that the diving system is capable of accommodating, and then maintaining them at the correct pressure with life support for a minimum of 72 hours must be provided. When they are secured in this Hyperbaric Rescue Unit, they are taken to a suitable site at which the decompression can be safely undertaken.
The system provided is usually a floating decompression chamber, that is disconnectable from the system, and is called Hyperbaric Rescue Chamber (HRC), or a self-propelled lifeboat that contains a decompression chamber that is also designed to be disconnected, and is called Self-Propelled Hyperbaric Lifeboat (SPHL).

Hyperbaric Rescue Chamber – HRC

Self-Propelled Hyperbaric Lifeboat – SPHL

IMCA D 052 says that the most practical, and most common, way of meeting the requirements indicated above is to provide a Self-Propelled Hyperbaric Lifeboat (SPHL). Also, NORSOK standards U 100 speak only of SPHL and say that it must be self-propelled. However, a lot of saturation systems designed with Hyperbaric Rescue Chambers are in service, and for this reason, IMCA also says: *"At the time of publication of this document a number of HRUs exist (HRCs) that are not self-propelled, and while the long term intent of the industry is that all HRUs are self-propelled, it is recognised that these units do provide a means of escape for divers in an emergency although the subsequent requirements for life support and recovery may be much more difficult to comply with due to limitations of design and configuration".*
Note that built-in systems, are today all equipped with Self Propelled Hyperbaric Lifeboats.

Besides, there should be a "life support package" (LSP), which is a small Environmental Control Unit (ECU) with adequate reserves of gasses, that can be connected to the Hyperbaric Rescue Unit. It must be designed to provide appropriate external services to support the HRU during the travel to the decompression facility and if necessary until the decompression of the divers is completed. This device is described in the next chapter. However, the necessary fittings to connect it must be provided on the HRU.

1.2.7.2 - Self Propelled Hyperbaric Lifeboat: Lifeboat and its deployment system

As indicated above, "Self-Propelled Hyperbaric Lifeboat" are totally covered life boats designed to accommodate a disconnectable chamber that are launched with davits. For this reason, they must comply with the requirements of The International Convention for the Safety of Life at Sea (SOLAS) and the resolutions emitted by the International Maritime Organization (IMO) regarding life saving appliance (LSA). Also, as "Self-Propelled Hyperbaric Lifeboat" are specifically designed to carry a pressure vessel for human occupancy IMO has published the resolution A.692 "Guidelines and specifications for hyperbaric evacuation systems".

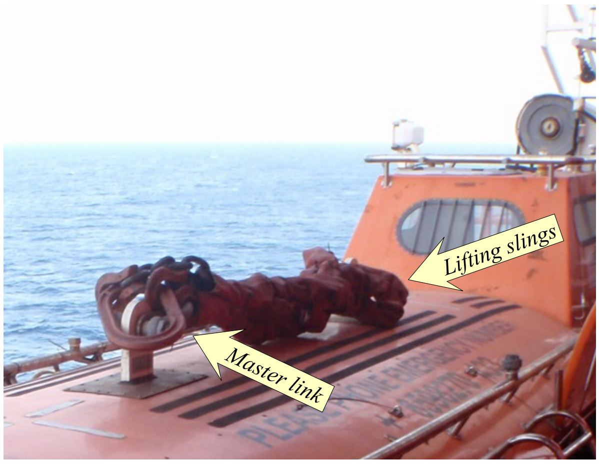
IMO says: The design and construction of the hyperbaric evacuation system should be such that it is suitable for the environmental conditions envisaged, taking into account the horizontal or vertical dynamic snatch load that may be imposed on the system and its lifting points, particularly during evacuation and recovery. They must be designed, constructed and tested in accordance with standards acceptable to the Administration.

- Lifeboats must be of such form and proportions that they have ample stability with a sufficient freeboard when loaded with their full complement of persons and equipment, and are self-righting. Also, their buoyancy and stability should be calculated for the transfer of equipment and rescue personnel on the top of the system when carrying out the recovery from the sea. Of course, their hatches must be designed to be watertight.
- They must be strong enough to be loaded with the full complement of persons and equipment, and be capable of withstanding a lateral impact of at least 3.5 meters per second against the ship's side and a drop into the water from a height of at least 3 meters. The seating arrangement should be strong enough to support a person weighing 100 kg, and the safety belt shall be designed to hold a person with the same mass securely in place when the lifeboat is in a capsized position. Note that their hull is usually made of composite materials.
- SPHL must be provided with one or several towing attachment points. They should be so situated that there is

no likelihood of the hyperbaric evacuation unit being capsized as a result of the direction of the tow line, and be rated at 0.7 x the full laden weight of the HRU. Where towing harnesses are provided they should be lightly clipped or secured to the unit and, so far as is possible, be free from snagging when pulled.

- The self Propelled Hyperbaric lifeboat should be capable of being recovered by a single point lifting arrangement and means must be provided on the unit to permit to hook on or connect the lilting arrangement. This lifting arrangement is usually composed of a master link connected to two lifting points through two slings. When the lifting points are situated in the middle of the boat, a connecting bar and a single sling can be used.

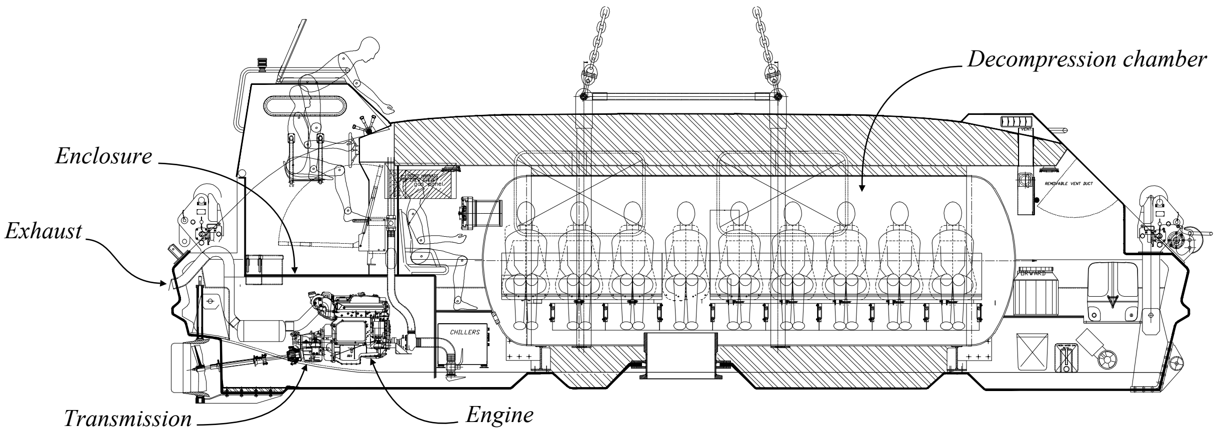
Towing point



Single point lifting arrangement

- The Self Propelled Hyperbaric Lifeboat must be able to sail at least at a speed of 6 knots on a flat sea for a period of not less than 72 h.

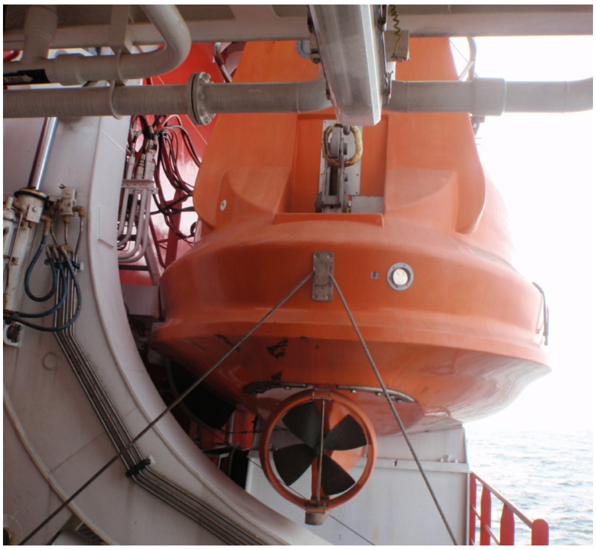
The engine and transmission must be controlled from the helmsman's position. Note that the propeller shafting must be designed so it can be disengaged from the engine.
The engine must be capable of running in any position during capsizing and continue to run after the lifeboat returns to the upright or shall automatically stop on capsizing and be easily restarted after the boat returns to the upright. The design of the fuel and lubricating systems must prevent the loss of fuel and lubricating oil from the engine during a capsize. The design of all engine exhaust pipes, air ducts, and other openings shall be such that water is excluded from the engine when the lifeboat capsizes and re-rights, and of course, during normal operations. Also, the engine must be designed to operate if the lifeboat is flooded up to the center line of its crankshaft. The engine should be designed to start with a manual system or two independent rechargeable energy sources. It must be able to start at an ambient temperature of -15 ºC within 2 min of commencing the start procedure unless a different temperature is judged more suitable. Note that the fuel used must have a flash-point above 43°C. The engine and the transmission are enclosed in a fire retardant casing that protect the people from being in contact with moving and scalding parts. This casing is also designed to reduce the engine noise.
Batteries are kept in a separate watertight enclosure with a gas venting to the external (Usually at the top). IMCA says that a safe fan or other appropriate means of positively venting the compartment should be used.



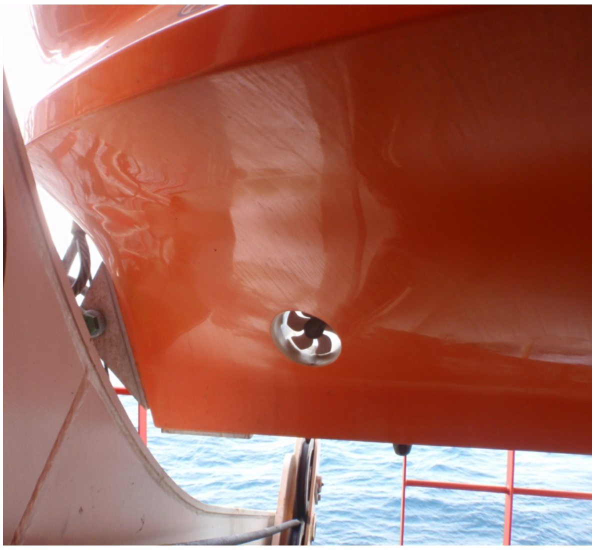
- The electrical systems must be designed to minimize the risk of electrical capacity depletion, fire or explosion, electric shock, the emission of toxic gases, and galvanic action.

Also, the batteries used for the radio must be separate from those used to start the engine and the boat must be provided with means for recharging them when it is at its station or sailing. IMO requires that, when the lifeboat is at its station, it is done through the ship's power supply at a supply voltage not exceeding 50 volts, which can be disconnected at the lifeboat embarkation station, or using a solar battery charger. Of course, it is done through the electrical system of the engine when it is running.
IMO also says that the electrical systems of the engine and accessories must be designed to limit electromagnetic emissions not to interfere with the operation of life-saving radio appliances.
Besides, electrical equipment within the compression chamber should be designed for hyperbaric use, high humidity levels and marine application.

- Lifeboats must be designed with due regard to the safety of persons in the water and the possibility of damage to the propulsion system by floating debris.
  Also, all lifeboats must be provided with a rudder that must be permanently attached to the boat. When the steering system is a wheel or other remote steering mechanism, a tiller able to control the rudder in case of failure of the steering mechanism must be installed or securely stowed near the rudder.
  The rudder and tiller must be so arranged as not to be damaged by the propeller or the operation of the release mechanism of the boat. Note that modern Self Propelled Hyperbaric Lifeboats are equipped with a small bow thruster that increases their steering capacity.



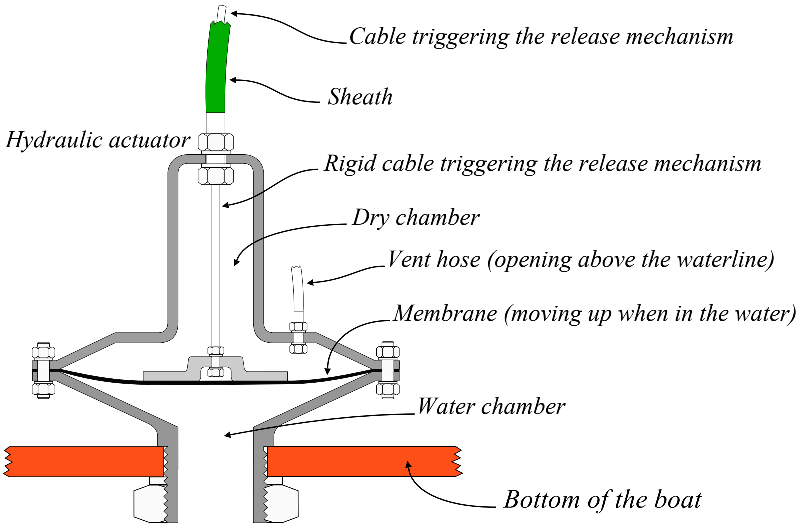
Propeller and rudder



Bow thruster

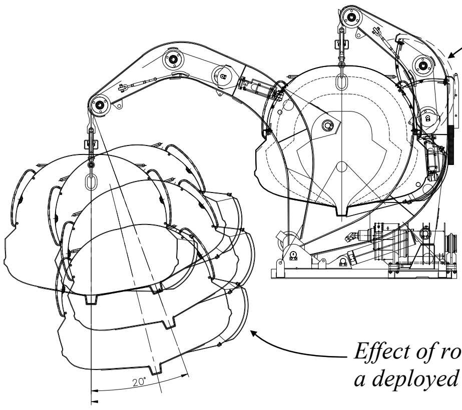
- Self Propelled Hyperbaric Lifeboats are launched using two davits. For this reason, they must be fitted with a mechanism that is designed so that the two cables used to deploy them are released simultaneously.
  IMO says that there should be a normal release capability that will release the lifeboat when it is waterborne or when there is no load on the hooks. This mechanism is often a hydraulic actuator installed at the bottom of the boat that pushes a rigid cable that is linked to the release mechanism: When the lifeboat touches the surface of the sea, the pressure of the water pushes up the membrane or the piston fitted to the rigid cable that triggers the opening of the release system *(see the scheme below)*.

Release system bow (external)

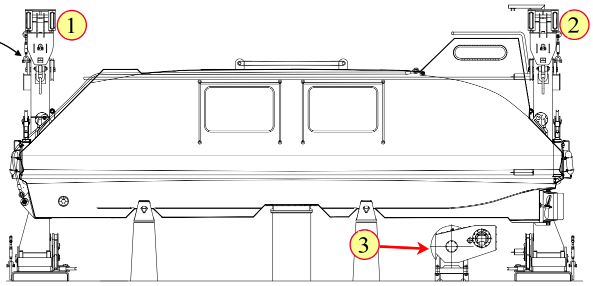


There should be also an on-load release capability which will release the lifeboat with a load on the hooks. This system must be arranged to release the lifeboat under any conditions of loading from no load with the lifeboat waterborne, to a load of 1.1 times the total mass of the lifeboat when loaded with its full complement of persons and equipment. It should be easy to operate.
This release capability must be protected against accidental or premature use. This protection includes a specific mechanism, in addition to a danger sign. To prevent accidental activation during recovery of the boat, the mechanical protection (interlock) should only engage when the release mechanism is wholly and appropriately reset. Also, to prevent a premature on-load release, the on-load operation of the release mechanism should require a deliberate and sustained action of the operator.
The release mechanism must be designed so that crew members in the lifeboat can clearly observe when the release mechanism is appropriately reset and ready for lifting. It should be marked with colours that contrast with its surrounding, and the fixed structural connections of the release mechanism in the lifeboat must be designed with a calculated factor of safety of 6 based on the ultimate strength of the materials used. Clear operating instructions should be provided with the warning notice.

- Regarding the launching system, IMCA says that the unit must have a clear and unobstructed access to the water. Also, IMO A.692 says: *"Consideration should be given to the environmental and operating conditions and the dynamic snatch and impact loadings that may be encountered. Where appropriate, the increased loadings due to water entrainment should be considered. Where the primary means of launching depends on the ship's main power supply, then a secondary and independent launching arrangement should be provided"*.
Brakes must be provided to avoid any falling if the power to the handling system fails. For this reason, they must be able to engage automatically. Also, the brakes must be provided with manual means of release.
Note that the launching may have to be performed from a ship that rolls or have an angle. For this reason, the davits must be arranged to ensure that the boat is sufficiently away from the hull to allow a launching with an angle up to 15º, and that the cables that hold the unit are not entangled. It is the reason they are usually at the extremities. Also, the boat must be lowered perfectly horizontally. Thus the lowering speed of both cables must be the same. The solution commonly used is that the wires are deployed from a single two-section drum.



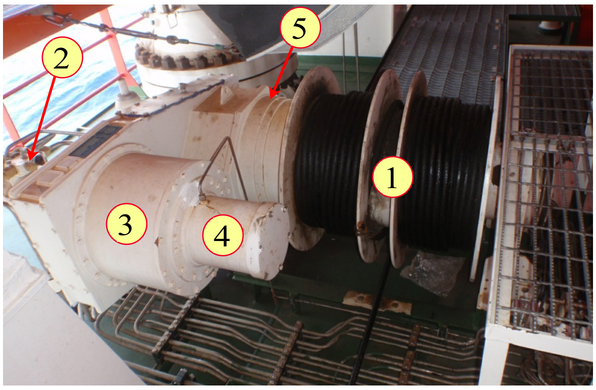
Effect of rolling on a deployed load

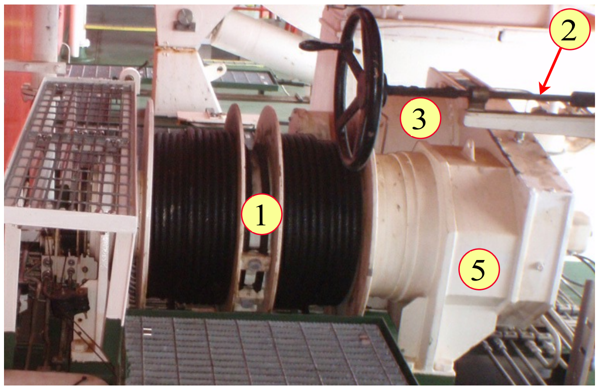


The descent speed of the cables from davits#1 & #2 must be the same, The solution commonly used is to use only one winch (see #3) with a single two-section drum.

The winch of the SPHL described is suitable for launching it to the sea level using gravity. The manufacturer says that this procedure can be controlled from either the winch position or from within the craft through a remote control.
The craft recovery is performed using a hydraulic motor and also controlled from the control unit.
The winch is composed of the following parts:

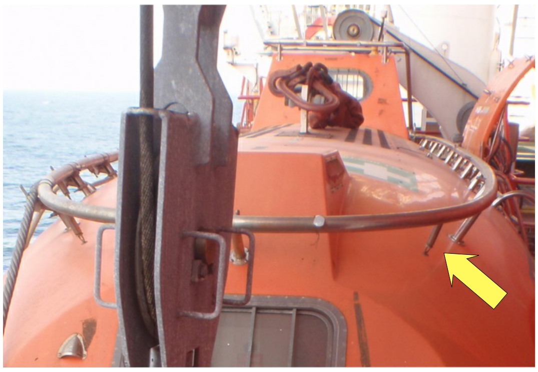
- A wire rope coiling gear (the drum or barrel):
It coils, accommodates, or unwinds the necessary wire rope fall parts. It is equipped with a single two-section drum, the shaft of which is being supported in ball bearings *(see #1 in the photos below).*
- A speed reducer gear with differential unit:
It combines a planetary gear unit and a conventional gear train with a differential unit.
- A safety gear:
It is an automatic governor brake that keeps the rate of the lowering speed within permissible limits during gravity lowering operations *(see #2 in the photos below).*
- A mechanical brake gear with hydraulic relieve mechanism:
It is a spring-operated brake designed to hold the survival craft in any position *(see #3 in the photos below)*. By operating the brake control lever on the power unit the brake is relieved and lowering due to gravity with a speed governed by the safety gear is possible. By releasing the brake control lever the lever returns to the neutral position. Note that #4 in the photos below is the control mechanism.
- A motor power unit with hydraulic brake:
It is an axial piston hydraulic motor driving the gear train through a hydraulic multi-disc brake. This motor allows hoisting the survival craft at the desired speed. The lowering of the boat using this motor is also possible *(see #5 in the photos below).*
- A manual hoisting gear:
It is a hand pump installed on the power unit that can be used to recover the boat if needed.
- A remote control drum:
It is an extra drum that has been placed to store the remote control wire. During the recovery of the survival craft, it might be necessary to check, whether the remote control spools up as appropriate.





- Regarding fire fighting, IMO A.692 says: *"In hyperbaric evacuation units that are designed to float and may be used to transport divers through fires, consideration should be given, where practicable, to providing an external water spray system for cooling purposes"*.

  This water spray system is usually installed at the top of the Self Propelled Hyperbaric Lifeboat *(see the photo on the side)*. Note that the Life-saving appliance (LSA) code says the following:

    - The water for the system must be drawn from the sea by a self-priming motor pump.
    - It must be possible to turn "on" and turn "off" the flow of water over the exterior of the lifeboat.
    - The seawater intake must be arranged to prevent the intake of flammable liquids from the sea surface, and the system must be arranged for flushing with fresh water and allowing a complete drainage.

  In addition to the requirements above, the boat must be designed to protect the crew from the polluted atmosphere they may have to pass through to escape the abandoned ship. For this reason, a self-contained air support system must be arranged that, with all entrances and openings closed, the air in the lifeboat remains safe and breathable, and the engine normally runs for not less than 10 min.
  During this period, the atmospheric pressure inside the lifeboat must never fall below the outside atmospheric pressure nor exceed it by more than 20 hPa. The system must have visual indicators to indicate the pressure of the air supply at all times.
- The Self Propelled Hyperbaric Lifeboat must be discoverable and identifiable at sea. For this reason, a strobe light and a radar reflector must be provided. Also, the hull and the top enclosure must be colored orange and be provided with retro-reflective materials.
  The hull and the top of the enclosure should also be marked with a green panel 1.2 m long and 0.50 m height with the text "Diver rescue" in letters 0.15 m height, and the text "Call rescue services at once - Keep in sight" in letters of 5 cm height. The symbols should be 30 cm height *(see the photos below)*. Also, the following recommendations must be written below each green panel displayed on the side of the boat:
  .1 do not touch any valves or other controls;
  .2 do not try to get occupants out;
  .3 do not connect any gas, air, water or other supplies;
  .4 do not attempt to give food, drinks or medical supplies to the occupants;
  .5 do not open any hatches.

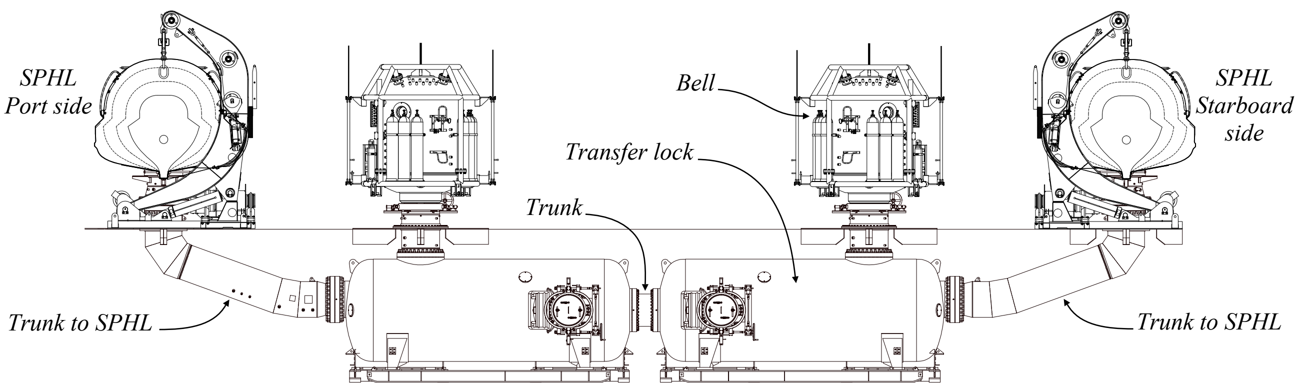
  Also, the name of the ship and port of registry of the ship to which the lifeboat belongs must be marked on each side of the lifeboat's bow in block capitals of the roman alphabet with the number of persons for which the lifeboat is approved. In addition the weight in air of the unit and the safe lifting points must be visible.
- The self Propelled Hyperbaric Lifeboat must be equipped for self sailing and towing:
    - In addition to the design of its fastening point described previously, IMCA says: *"The towing bridle or towing cable needs to be permanently attached to the dedicated tow-point on the HRU and then temporarily secured with frangible links (tie-wraps or similar) to the craft. These frangible links will break away when the towing vessel starts to take the load but will serve to keep the tow-line from fouling or becoming fouled during launch, storage or transit"*. The towline should be stowed in such a way that permits release by the user from a hatch. Also, a lightweight "leader line" fitted to a high visibility buoy should be provided and attached to the towline to transfer it to the rescue vessel.
    - In addition to the towing line already in place, a backup line must be secured at or near the bow of the lifeboat ready for use.

- An illuminated navigation compass must be permanently fitted at the steering position.
- NORSOK standards U100 say that a Global Positioning System (GPS) and relevant charts must be provided. Also, a Global Maritime Distress and Safety System (GMDSS) must be onboard.
- A Very High Frequency (VHF) radio and a satellite phone are required. Note that they must not use the batteries of the engine.
- To signal the boat to other vessels and planes, at least four rocket parachute flares, six hand flares, and two buoyant smoke signals must be onboard. They must be stored in the coxswain cabin.
- Also, a waterproof electric torch suitable for morse signalling together with one spare set of batteries and one spare bulb in a waterproof container must be provided in addition to a daylight signalling mirror with instructions for its use for signalling to ships and aircraft are mandatory
- A whistle or equivalent sound signal should be stored in the coxswain cabin.
- A copy of the life-saving signals prescribed by regulation V/16 must be provided on a waterproof card or in a waterproof container.
- There must be a searchlight with a horizontal and vertical sector of at least 6° and a measured luminous intensity of 2500 cd which can work continuously for not less than 3 h.
- The crew needs to be able to read indicators and documents. For this reason, a manually controlled lamp or source of light must be fitted inside the lifeboat to provide illumination for not less than 12 h/day.
- As necessary, skates and fenders should be provided to prevent damage to the lifeboat during the launch.
- Two boat-hooks and two hatchets must be readily accessible (one unit at each end).
- A buoyant bailer and two buckets must be ready for use.
- A jack-knife should be kept attached onboard.
- Two buoyant rescue quoits attached to not less than 30 m of buoyant line must be readily accessible.
- There must be a sea-anchor of suitable size fitted with a shock-resistant hawser which provides a firm hand grip when wet and is adequate for all sea conditions.
- There should be some tools for intervention on the engine.
- Portable fire-extinguishers suitable for extinguishing oil fires must be in place (one at each end).
- Food should be stored onboard to feed the divers and the crew for at least 72 hours, based on 37 calories/kg + 10 calories/hour effort. Note that military combat rations provide 3200 calories each, and thus are appropriate for this purpose.
- Also, fluid intake must be stored ready for use. It should be based on a consumption of 100 to 1500 ml/ hour per person.
- Three tin openers should be ready for use near the food rations.
- IMO says that one set of fishing tackle should be onboard.
- To prevent the effect of seasickness, anti-seasickness medicine, and vomit bags should be ready for use. There must be sufficient quantities to support the team for at least 72 hours.
- A first-aid Kit for the sailor & surface support personnel (Not to be confused with the DMAC 15 kit that is described in the next point), and a relevant survival manual must be readily accessible.
- Relevant manuals and checklists should be provided to support the team.

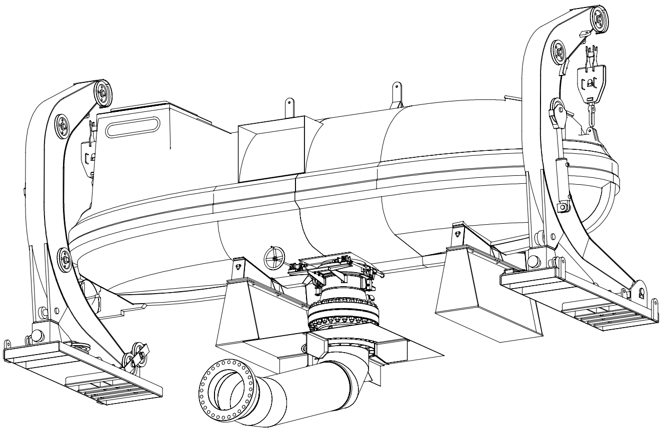
- Fastening points should be provided on the hyperbaric evacuation unit to secure it to the deck of a rescue vessel. Note that relevant cradles should be installed on the rescue vessel and supplied with suitable attachment points.
- Regarding the recovery of the Hyperbaric Rescue unit, IMCA D 051 says that in remote, or unexpected, locations cranes of limited capacity will have to be relied on; therefore it is recommended that when rigged there is a maximum limit of 7.5 metre between the keel of the HRU and the master-link intended to connect to the crane hook. IMCA D 051 also recommends storing the master link so it is reachable from the coxswain cabin.

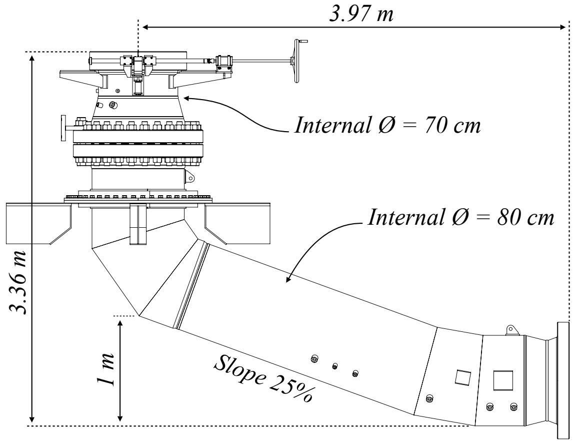
1.2.7.3 - Self Propelled Hyperbaric Lifeboat: Transfer trunk

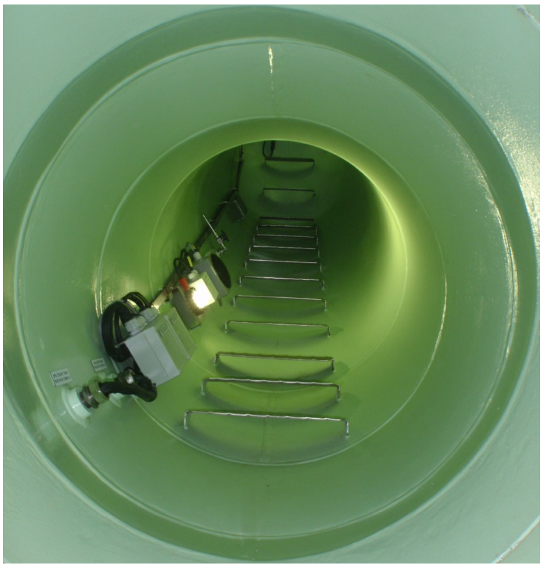
The chamber of the Self Propelled Hyperbaric Lifeboat (SPHL) is connected to the diving system by a disconnectable trunk that is situated at the bottom of the unit and is similar to the model used to connect the bell. The divers access to this connecting trunk through the transfer lock. Note that a lot of built-in systems are equipped with two units, each of them allows evacuating all the divers. Thus, evacuation from the starboard side or the port side is possible. In this case, the transfer locks are interconnected to enable transferring from any chamber to any SPHL *(see below)*.



Note that these connecting trunks must be as short as possible and sufficiently wide to allow for the transfer of an injured diver on a stretcher. It is usually easily done with portable systems, but it is often more complicated with built-in systems as the chambers are in the centre of the ship and the hyperbaric evacuation units on the sides. As a result, longer trunks have to be installed that may create problems to transfer casualties. However, most new saturation ensembles such as those taken as references in this document have been studied to reduce this distance to a minimum (Less than 4 m with the example below), and their internal diameter of approximately 80 cm is sufficiently broad to transfer a person immobilized on a flexible stretcher or a model such as those used for rope access jobs. In this example, the inner diameter is reducing to 70 cm at the flange of the SPHL to comply with the recommendations of IMCA D 051 regarding interfacing with the flange of the Hyperbaric Reception facility.







internal trunk (from transfer lock)

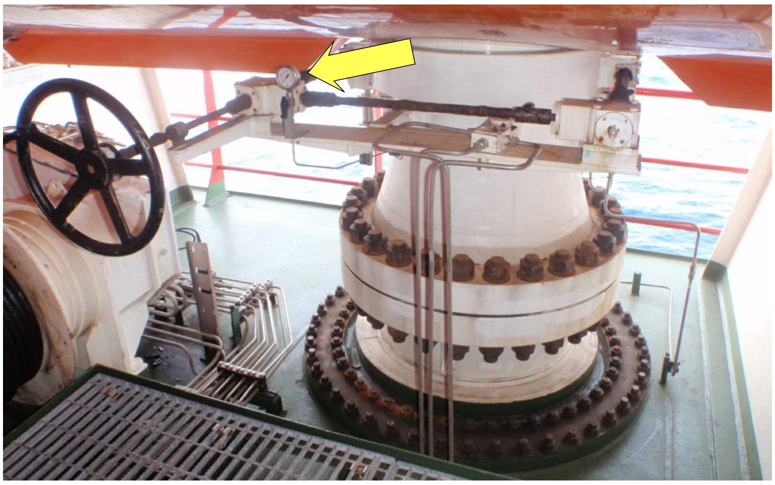
Arrival inside the chamber of the SPHL

IMCA says that the trunk must have been built according to an international standard, and must be certified if it has been constructed after the 1st of July 2014. It must be designed to withstand the maximum depth the saturation system can reach, and be pressure tested for this purpose with all its components such as doors, clamps, valves, etc. Its design standard, serial number, date of manufacture, pressure tests, and other information must be recorded with the other certificates of the saturation system and can be stamped on the unit.
Also, the volume of the trunk must be indicated, and a venting test using a typical heliox mix must be carried out from the maximum depth the system can reach until the surface. During this test, records should be performed at regular and suitable intervals to calculate the time necessary to vent the trunk from any storage depth (It is not necessary to perform a separate test for each storage depth).
Depending on the configuration of the surface support, the trunk may have to pass through areas where it can be exposed to fire or shocks. For this reason, IMCA says that a safety evaluation of the trunking route must be performed and that control measures must be implemented to address the hazards that may be present. Note that the certification body usually performs such an assessment at the installation of the system. However, the crossed rooms must be kept at the original statement of this assessment, and not be reorganized for another purpose.

The trunk must be designed for human occupancy. For this reason the rules applied are those of living chambers:

- Valves or other devices should be fitted externally to hollow penetrators to allow stopping a catastrophic pressure loss. Note that these valves must be in perfect condition. So, easy to operate and free of corrosion. The function of each penetrator and valve must be marked in such a way that confusion is not possible.
- The exhaust orifices must be fitted with guards to protect the divers who may be at their vicinity from suction. These guards must be designed not to injury or disturb the persons transferring through the trunk, and not be damaged during the transfer to and from the hyperbaric rescue unit. Inlets should be fitted with diffusers.

- Doors are in place to isolate the trunk: The door in the entry lock is a classical hinged autoclave door that can be opened from either side: It is fitted with two vent valves and dogs. The door in the chamber of the SPHL is also of autoclave type. However, to allow for easy access inside the chamber, it is installed on rails that enable the diver to slide it to the side. Also, its convex side is in the chamber, and it is secured using a wheel *(see below)*.
- The depth of the trunk is controlled from the saturation control room, and for this reason an electronic sensor or a pipe that links the gauge installed on the control panel is fitted to the trunk.
  Also, IMCA D 024 says that there must be a means of monitoring the depth of the trunking installed at the direct vicinity of the Hyperbaric Rescue Unit *(see in the photo below)*. As every gauge used for human occupancy vessel, its unit marking system must correspond to those used with the diving tables (Metric or Imperial). Note that IMCA D 024 says that dual scale marking is acceptable. A digital gauge may also be used for this purpose. In this case, its display must be large and clear enough to be read in all conditions, and provide a reading with one decimal point. Note that as with the trunk connecting the bell to the system, the primary purpose of this gauge is to inform the operator whether the trunk is under pressure or fully vented.



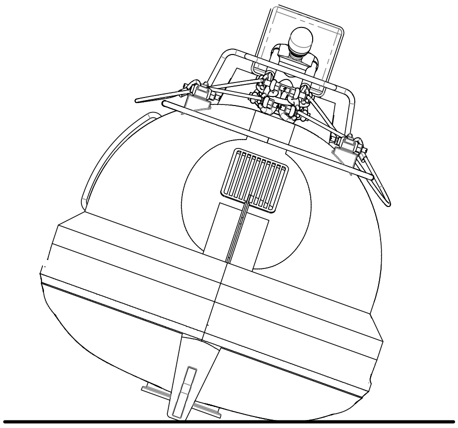
SPHL clamp arrangement with pressure gauge

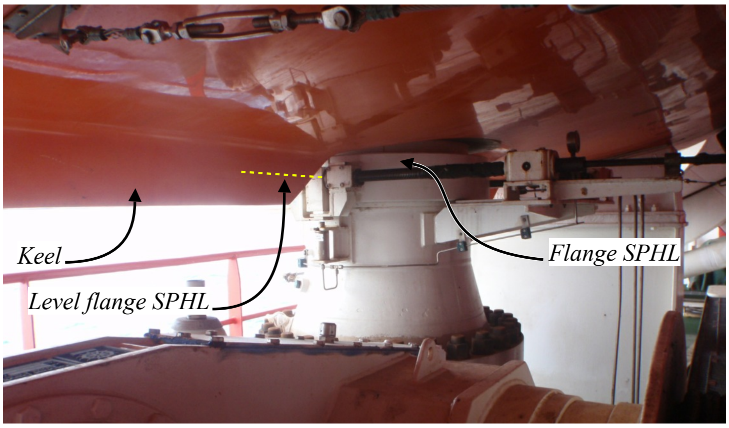
Autoclave door of the SPHL

- In addition to what is said above IMCA D 024 says that viewports may be fitted to the trunk. This point is not common. Nevertheless, in this case, they must conform with the recommendations for viewports and already indicated in point 1.2.2.2 *"Living chambers and their entry lock"*:
  - They must be free of cracks or scratches that could affect pressure integrity.
  - Protections against dropped objects or other damages should be in place.
  - The serial number or other identifying marks must be marked on the outside of each viewport.
  - They must be renewed every 10 years.

The connecting flanges and their clamping system are similar to those used to connect the bell to the dive system (see the photo above). Note that damage to flanges may compromise the mating, and for this reason, they must be adequately protected. Also, the flange of the Self Propelled Hyperbaric Lifeboat (SPHL) must be compatible with the one of the Hyperbaric Reception Facility (HRF) into which the evacuated divers are transferred to complete their decompression. IMO says that if necessary, adapters and clamping arrangements are to be provided.
IMCA D 051 proposes the following guidelines to solve the problems of flange protection and compatibilities:

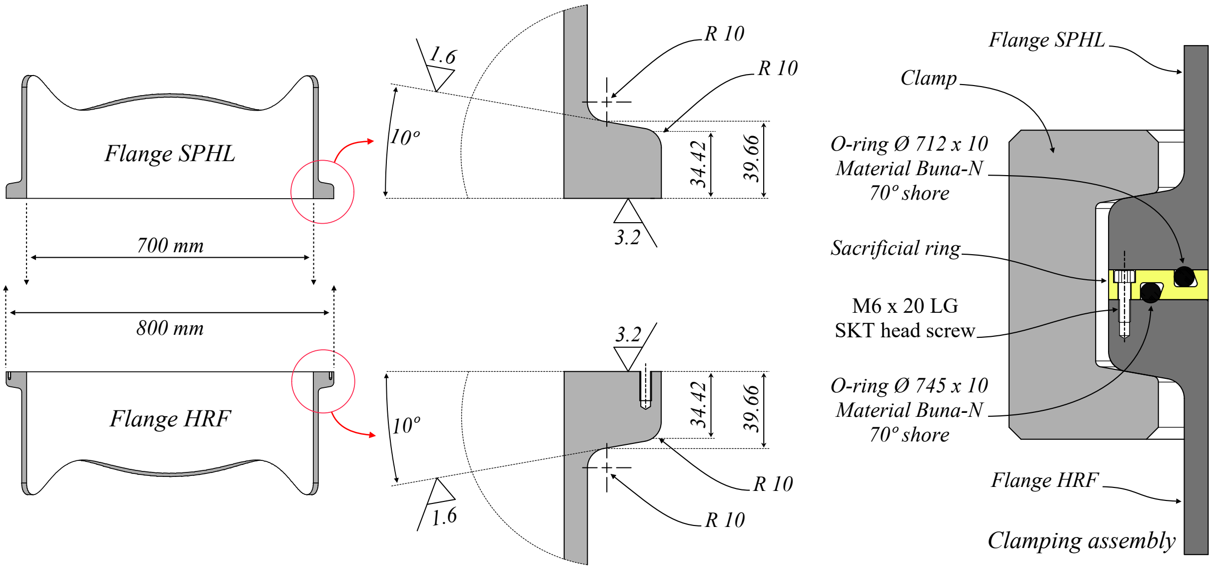
- The Hyperbaric Rescue Unit flange should be protected within the hull of the craft and should not require additional protection. Thus, should the boat be unloaded where cradles, blocks, or sandbags are not available, the flange should remain within the protective envelope provided by the keel and the hull *(see in the IMCA scheme and the photo below)*.



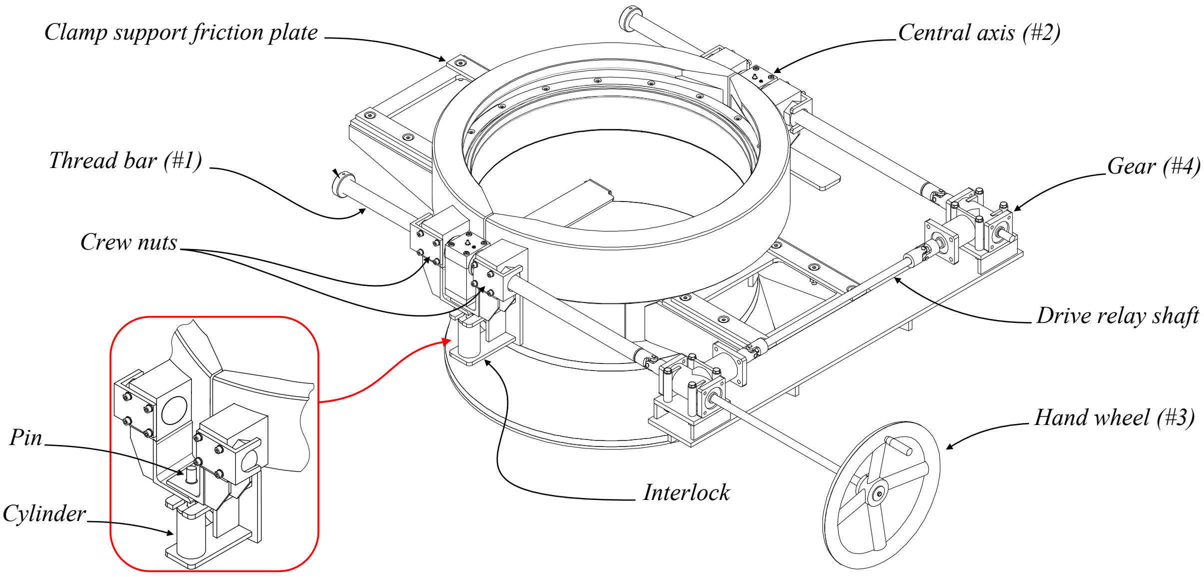


- Regarding the compatibility of flanges, IMCA has published several drawings of an ideal flange that members of the association are invited to adopt *(see next page)*. The idea is to have only one flange profile in the future, and thus avoid mating problems. For this reason, IMCA says that the hyperbaric evacuation systems manufactured after the 1st of July 2014 must meet the common interface standards laid out in IMCA D 051.

The flange promoted by IMCA, which profile views are represented below, has a taper of 10º. IMCA says that it is the optimum compromise for easy clamping and releasing. Note that the flange of the Hyperbaric Reception Facility (HRF) has a sacrificial ring that accommodates the O-rings and can be easily changed if an impact damages it. Because the flange of the Self-propelled Hyperbaric Lifeboat (SPHL) is designed in function of the one of the HRF, the flange of the saturation system must have a similar profile. As indicated before, the internal diameter of the flange is 70 cm.

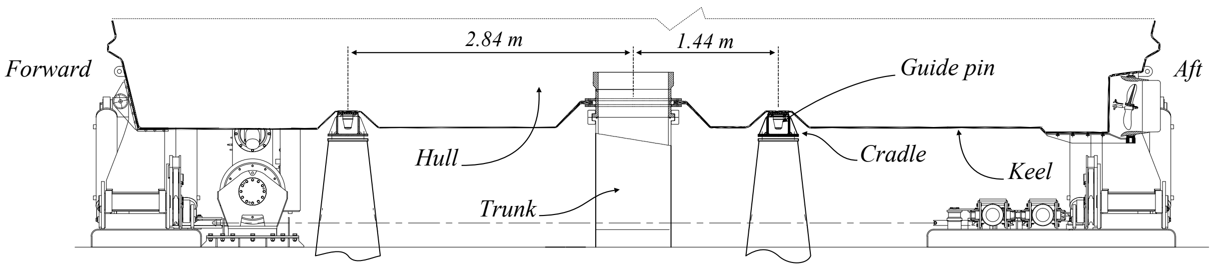


The mechanism of the trunk consists of two half-clamps, with internal profiles in angle with the taper indicated above, that are approached around the flanges by two thread bars (see #1 below) secured on their middle at the central axis of the flanges (see #2) and designed with threads of the opposite direction. As a result, the half-clamps close simultaneously when the bars are rotated in one direction and open when they are rotated in the opposite direction. Note that with the system taken as reference, these thread bars are actuated manually by a hand wheel (see #3), which rotation is transmitted to them through a series of gears(see #4).



An interlock system must be in place to avoid a catastrophic opening of the flange while the trunk is still under pressure. As with the flanges of the bells, it is made of pins installed at the junction of the ½ clamps in the axis of the flanges, that are pushed out of their cylinders by the pressure in the trunk (see #5) through two overlapping holes each one is made in a plate that is part of a half clamp *(see in the drawing above)*. As long as the trunk is under pressure, these pins are outside the cylinder. They retract only when the trunk is fully vented.

- Note that guides are installed on the davit to centralize the flange laterally. Also, the two cradles that hold the boat are organized with guide pins and are always at the same place, so the flange is centralized longitudinally.



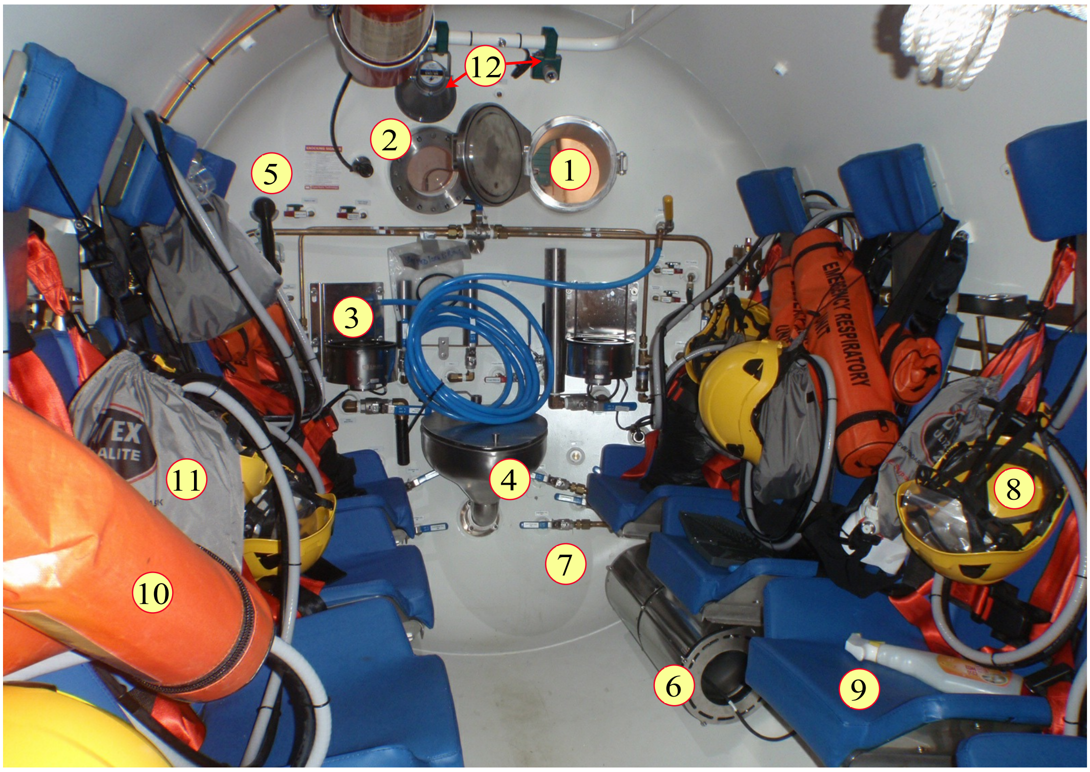
- Means of controls that are not necessary in short trunks must be in place in long or convoluted units such are those that are used with built-in systems.
    - IMCA says that means of communication between divers in the trunk and life support control should be provided: This intercom can be seen on the photo of the internal of the trunk on the previous page.
    - Lights are installed to to allow the personnel under pressure to see clearly the evacuation route and to operate any equipment they are required to use.
    - IMCA says that An assessment should have been carried out as to whether separate analysis of oxygen content is required for the contents of the trunking: We can say that analyser are not necessary in short trunks as they are easily ventilated. However, they must be in place in long trunks.

1.2.7.4 - Self Propelled Hyperbaric Lifeboat: Chamber and its control system

The function of the chamber of the Self Propelled Hyperbaric Lifeboat is accommodating the team in saturation during the evacuation of the surface support. For this reason, it must be designed and built according to a recognized international standard for human occupancy pressure vessels. As a result, its general design is similar to the other chambers of the saturation system, except for some particularities that are linked to its usage.

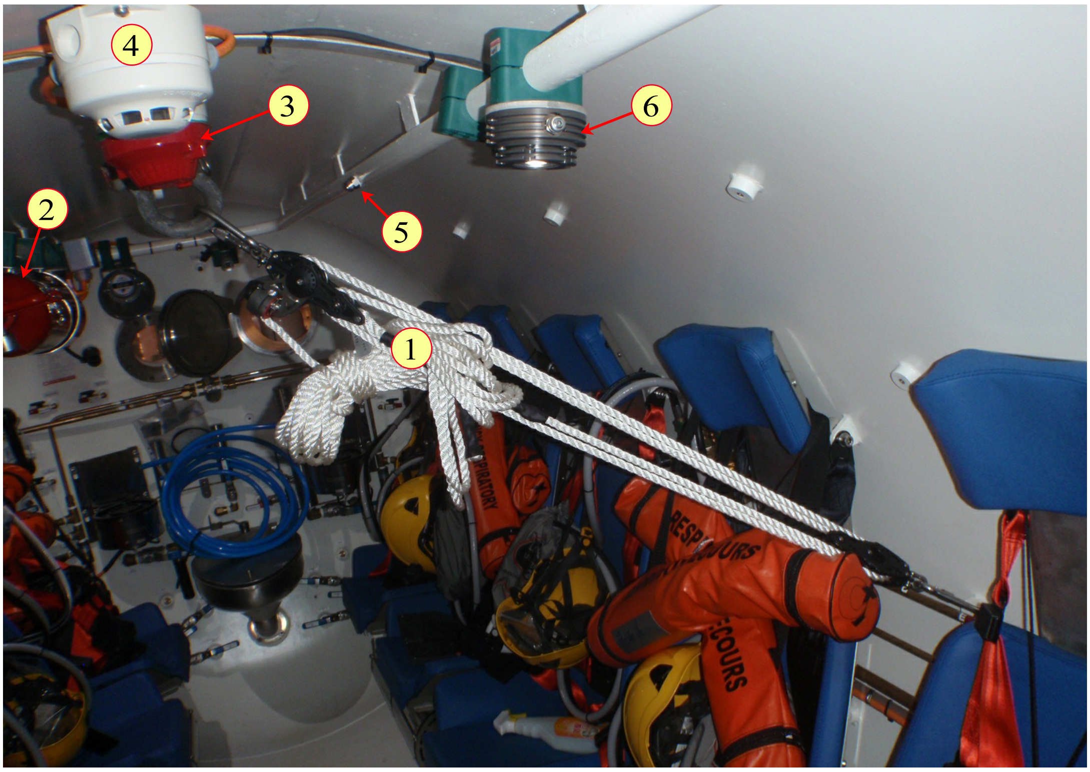
- The following points are to be taken into account:
    - Manufacturers usually provide chambers for 12, 15, 18, or 24 divers.
    - IMCA says that the chamber must be certified if it has been built after the 1st of July 2014.
    - IMCA says that hyperbaric evacuation chambers manufactured after 1 January 2015 should have a minimum internal diameter of 1.75 m (69 inches).
- The volume of the chamber and its medical lock must be indicated. The medical lock should be designed to transfer scrubber cartridges and other voluminous consumables.
- Pressure test are those of other chambers which is described in sheet 25.1 of IMCA D 018 (Visual examination every 6 months, full working pressure every 2½ years, overpressure test every 5 years).
- An identification plate that indicates the name of the manufacturer, the name of the designer, the date and place of manufacture, the design code, the empty weight in air, the volume and dimensions, and the name of the certifying authority must be in place.
- Viewports are usually in place. Their design should be as those used with chambers:
    - Manufactured according to a recognized standard, and tested according to the “American Society of Mechanical Engineers” (ASME) Pressure Vessels for Human Occupancy (PVHO) procedures.
    - Be free of cracks or scratches that could affect their integrity.
    - Be identified (identification mark on the viewport or on the hull adjacent to it)
    - Not be corroded.
    - Be pressure tested (see in the point “maintenance”).
    - Be less that 10 years from the date of fabrication.
- The hull must be in good condition: Its paint must be without severe corrosion. If isolation is in place, it should be clean and without damage. Note that corrosion can quickly start behind damaged isolation material and not be visually detectable.
- Electrical and hollow penetrators must be designed for their purpose and certified by a competent person (IMCA D 018 category 3 or 4). Also, valves or other devices should be fitted to hollow penetrators to allow stopping a catastrophic pressure loss. Note that these valves must be easy to reach and operate and be free of corrosion. The function of each penetrator and valve must be marked in such a way that confusion is not possible. Note that IMCA recommends securing the valves in the position indicated in the checklist (Open or closed) to avoid accidental opening or closure during the launching and that the system used allows to easily operate the valves if needed *(It can be tape, small cable ties, strings, etc.)*.
- Valves carrying oxygen, or mixes containing more than 25% oxygen (22% with Norsok) at a pressure higher than 15 bar must not be quarter turn. Also, these valves and their pipework must be cleaned for oxygen service.
- Regarding the medical and equipment lock, IMCA says: *“A safety interlock system must be fitted to the clamping mechanism securing the lock outer door. This interlock must make it impossible to open the mechanism/door if there is still pressure inside the lock and impossible to obtain a gas tight seal on the lock if the door/mechanism is not properly closed”.*
- Inlets must be fitted with diffusers to protect the occupants of the chamber from excessive noise, and outlets must be fitted with guards to protect the divers from suction.
- There should be one BIBS connection and mask for each diver in the chamber plus one spare. Their exhaust must be organised to dump outside the enclosed parts of the boat.
- Chambers of SPHL are designed with one door at the bottom, that has already been described, and sometimes another door at the forward end of the chamber. Both doors should be designed to be secured when they are closed and should be openable from either side. Equalization valves must be in place and operable from either side. Also, there must be a means to secure the doors opened.
  Note that the mating faces of the doors must be free of corrosion and not damaged by impact. The O-rings must be in perfect condition and lightly covered with silicone grease. As with diving bells, spare seals must be provided inside the chamber.
- A depth gauge or another means of control should be provided inside the chamber.

- Regarding the communications, a hard wired two-way voice system with unscrambler between the saturation control room on the surface support and the divers inside the chamber of the Self Propelled Hyperbaric Lifeboat must be provided. Also, the same type of communication must be provided between the inner chamber and the surface crew in the lifeboat.
  As every chamber, a secondary (back up) communication system that works independently should be in place between the divers inside the chamber and the surface support crew in the lifeboat. the system used is usually a sound powered phone as such device does not need power supply. Tapping code must also be provided.
- Heating and cooling systems should be provided in the chamber to maintain the thermal balance of the divers. They are equipped with fans that circulate the atmosphere of the chamber. These systems must be designed to work at least 72 hours. As with diving bells survival bags for heat retention should be provided for each diver as ultimate support in the case of a breakdown of the heating system.
- Also equipment must be in place to remove the CO_2 and add oxygen. CO_2 removal is usually performed through scrubbers and oxygen is added through a small pipe linked to the onboard oxygen reserves. With the systems of reference, the oxygen is injected at the proximity of one of the scrubber fans (there are two scrubbers). Note that Individual lung powered scrubbers must be provided to each chamber occupant.
- Regarding Environmental Control Unit (ECU), IMCA D 024 says that if fitted, it must meet the following:
  - Have a clear passage for discharge of gas.
  - If an external ECU with large bore piping, be fitted with a non-return valve on the inlet and flow fuse on the exhaust, either internally or externally at the hull penetration. That can be used in place of the protection valves usually in place on hollow penetrators previously indicated.
  - The environmental Control Unit must be capable of providing heating, cooling, CO_2 scrubbing, humidity control.
- IMCA also says that suitable toilets should be provided consistent with the duration the occupants are expected to be in the chamber. Also, if it is a flush type toilet, it must be equipped with interlocks to stop it being flushed while in use. Note that due to the lack of space such device cannot be installed in a separate room. Also, they consume a lot of gas which oblige to reduce the periods of use to a minimum not to affect the gas reserves.
- The seat provided for the divers must offer a minimum comfort and strength: Like those of the surface crew, they must be designed to support a person of 100 kg and be equipped with a safety belt that secures the passenger to it in any position, even in the case of a capsize. Also, they must be fitted with footrests with sufficient room for legs. In addition, a headrest is usually integrated. Also, IMCA says that protective headgear should be provided for the occupants. It is typically a helmet.



1 - Medical lock	*7 - Valves*
2 - viewport	*8 - Helmet*
3 - Fan block scrubber	*9 - Seat and its 4 points safety belt*
4 - Toilet	*10 - Lung powered scrubbers in their housings*
5 - Sound powered phone	*11 - BIBS masks in their grey housings*
6 - Heater/cooler/fan	*12 - Bullhorn & camera*

- Sufficient lighting must be provided inside and outside the chamber to allow operating the valves, read the controls, and read documents.
- Fire fighting systems must be provided. They are usually portable hyperbaric extinguishers of the similar models than those described in point 1.2.2.2.
  Fixed fire fighting systems similar to those described in point 1.2.2.2 may be present with smoke and heat detectors in some chambers (the manufacturers provide them as an option). It is the case of the Self Propelled Hyperbaric Lifeboats of UDS Lichtenstein.
- Equipment for pulling an injured or unconscious diver through the trunk must be present in the bell. It must be designed for the full length of the trunk. Small jaw winches, drum winches or pulley blocks are usually in place for this purpose. The cable should work in the axis of the bottom door. Also a medical kit DMAC D 15 must be available in a protected container.



1 - Pulley blocks unconscious diver recovery | *4 - Smoke detector*

2 - Hyperbaric extinguisher | *5 - Sprinkler (fixed fire fighting system)*

3 - Heat detector | *6 - Low Emitting diodes (LED) light*

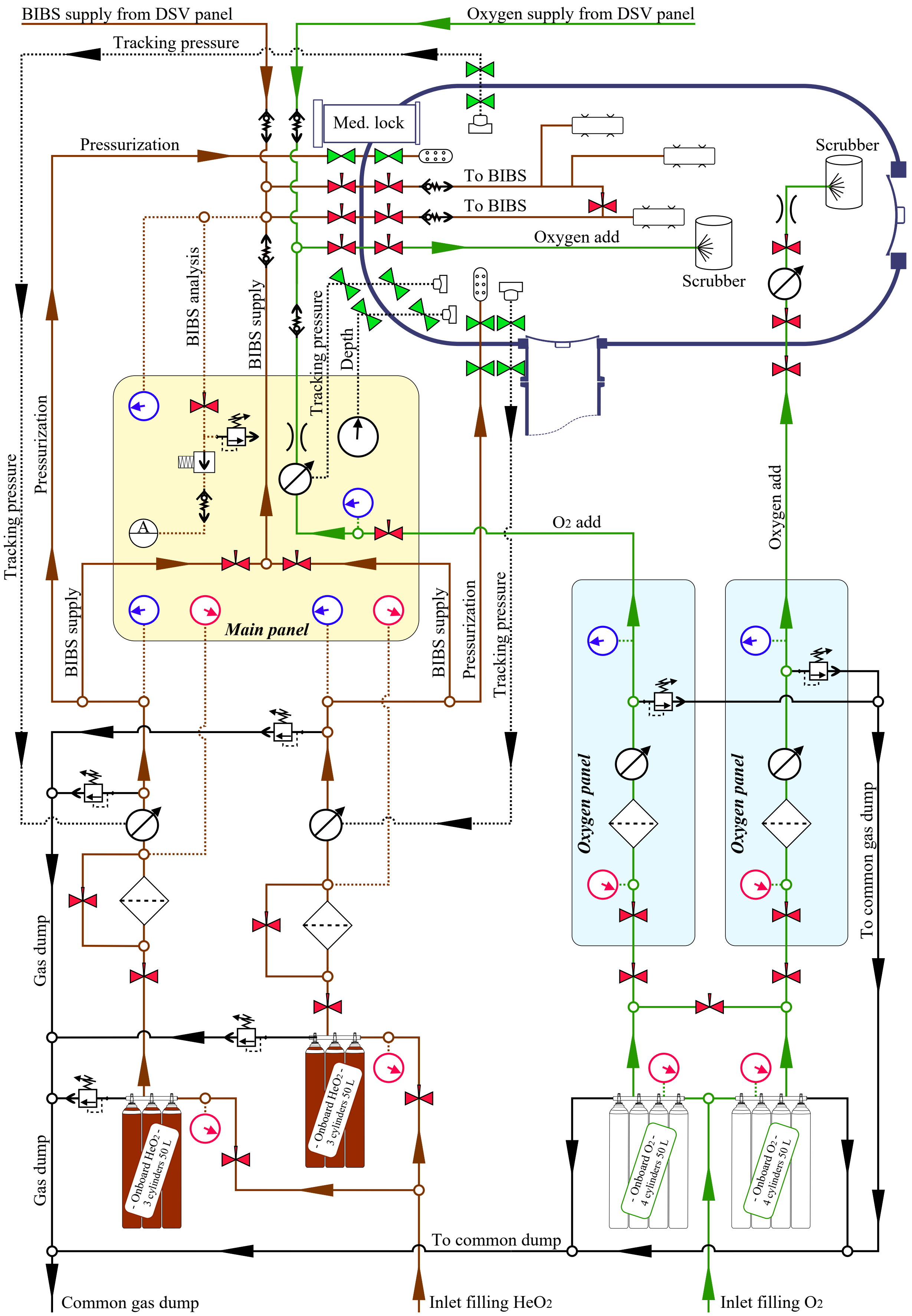
- In addition to the kit DMAC 15, sea sickness tablets, vomit bags, paper towels, waste disposal bags and all necessary operational instructions for equipment within the compression chamber should be available within the chamber.

NORSOK U 100 says that it must be possible to control and monitor the pressure of the chamber from outside and that it must be possible to transfer materials in and out of it. Also, when the chamber is connected to the saturation complex, it must be possible to control and monitor it from the saturation control room.

- Onboard gasses must be provided for this purpose:
  There must be sufficient mix gas to compensate for the use of the food lock and to allow for minor leakage. Due to the reduced place onboard these quantities are limited and installed under the floor around the chamber. As an example, the quantities provided by the manufacturer of the Self Propelled Hyperbaric Lifeboats (SPHL) that are part of the systems taken as references are:
  - 5 x 50 litre - 200 bar (50,000 litres) for a SPHL 12 persons.
  - 6 x 50 litre - 200 bar (60,000 litres) for a SPHL 15 persons.
  - 6 x 50 litre - 200 bar (60,000 litres) for a SPHL 18 persons.
  - 7 x 50 litre - 200 bar (70,000 litres) for a SPHL 24 persons.

  Sufficient oxygen must be provided to allow for metabolic consumption by the maximum number of divers for 72 hours. Note that IMO requires two separate distribution systems. Although the manufacturer calculates for more gas than needed, the place onboard is limited by the size of the supporting boat, and for this reason, the reserves are limited. As an example, the quantities provided by the manufacturer indicated above are as follows:
  - 5 x 50 litre - 200 bar (50,000 litres) for a SPHL 12 persons (planned consumption: 48,000 litres).
  - 6 x 50 litre - 200 bar (60,000 litres) for a SPHL 15 persons (planned consumption: 60,000 litres).
  - 8 x 50 litre - 200 bar (80,000 litres) for a SPHL 18 persons (planned consumption: 72,000 litres).
  - 10 x 50 litre - 200 bar (100,000 litres) for a SPHL 24 persons (planned consumption: 96,000 litres).

The scheme below shows the internal gas reserve and the gas control panels of the SPHLs installed on UDS Lichtenstein, which are designed for 18 divers: 8 bottles 50 litres x 200 bar oxygen + 6 bottles 50 litres x 200 bar heliox mix are provided. Oxygen is supplied through two separate sources and panels. The mix is also supplied from two separate gas banks. Note that the BIBS dump and electrical supplies are not represented.

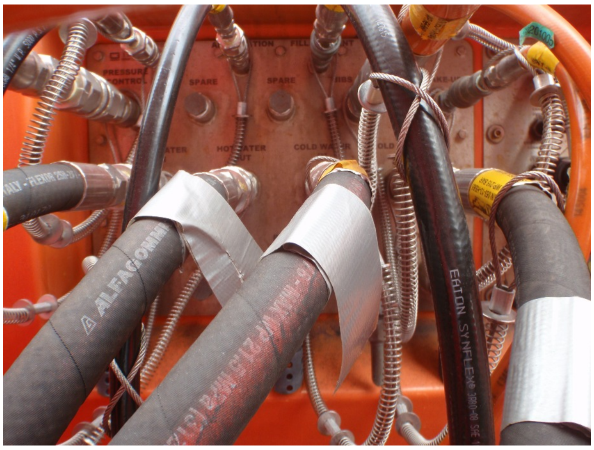


See the legends on the next page

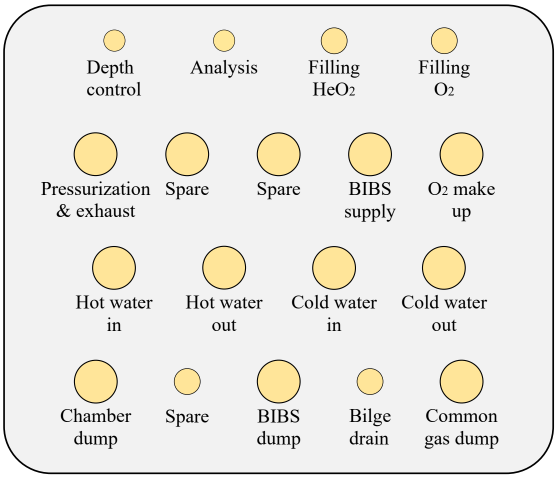
Legends of the schemes on the previous and the next pages

Direction of flux	*Oxygen cylinder*	*Heliox cylinder*
Regulator	*Depth gauge*	*Relief valve*
Silencer	*Low pressure gauge*	*High pressure gauge*
Needle valve	*¼ turn valve*	*Anti suction device*
Diffuser	*Analyser*	*One way valve*
Manifold inlet BIBS	*Flow reducer*	*Filter*
Pipes 1/4" or smaller	*Pipes > 1/4" diameter*	*Flow & pressure reducer*
Anti suction & silencer	*Depth sensor (electronic)*	*Spring loaded valve*
Flow control valve	*Flexible hose*	*Manifold gas cylinders*

- When the chamber is connected to the saturation complex, it is controlled and monitored from the saturation control room through flexible connecting hoses and dedicated supplies and exhaust lines that are represented in the scheme on the next page. Electrical supplies, video, and communications are also connected through a dedicated panel on the external side of the SPHL.



Gas connections with saturation complex

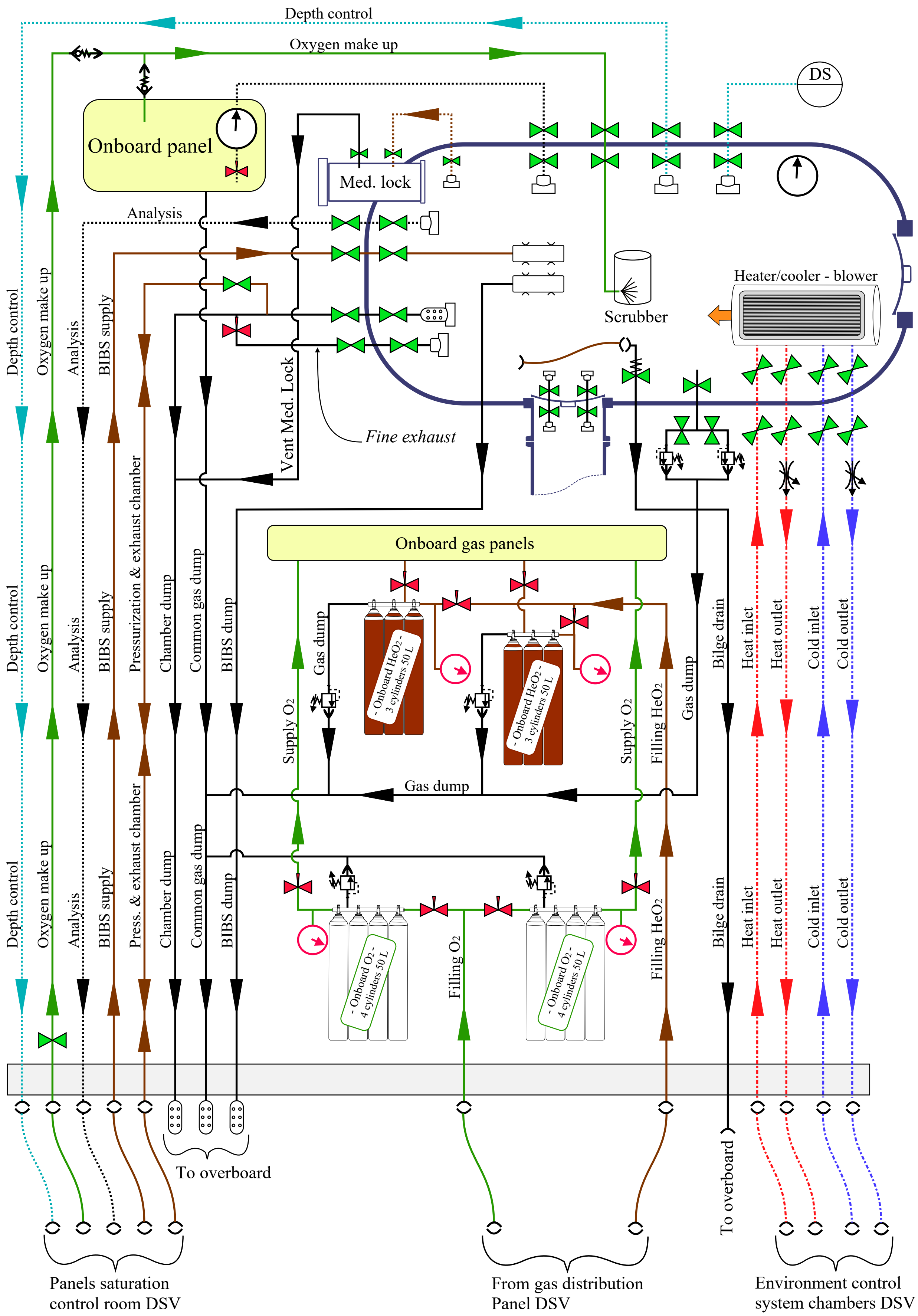


As the Self Propelled Hyperbaric Lifeboat is designed to be quickly launched, the hoses are connected by "snap-tite couplings" (quick connectors.). These connections must be compatible with those of the dedicated Life Support Package (LSP) or the supplies from another LSP. For this reason, NORSOK U100 and IMCA D 051 recommend to use standardized couplings such as those indicated below:

HRC/ SPHL	Description	Life Support Package
4 PIN 8 CONN EO (51F8F-1) or 4 PIN 8 CONN EO (53F8F-1)	Comms	4 PIN 8 CONN EO (51F8M-1)
4 PIN 4 CONN EO (51E4M-1) or 4 PIN 4 CONN EO (53E4M-1)	Power	4 PIN 4 CONN EO (51E4F-1)
SVHN 12-12F	Hot water supply	SVHC 12-12F
SVHC 12-12F	Hot water return	SVHN 12-12F
BVHN 6-6F	Oxygen make up	BVHC 6-6F
SVHN 4-4F	Depth	SVHC 4-4F
SVHN 4-4F	Analyse	SVHC 4-4F
SVHN 12-12F	Blow down	SVHC 12-12F
SVHN 12-12F	Exhaust	SVHC 12-12F
BVHN 12-12F	BIBS supply	BVHC 12-12F

Regarding the designations of the connectors indicated on the previous page:

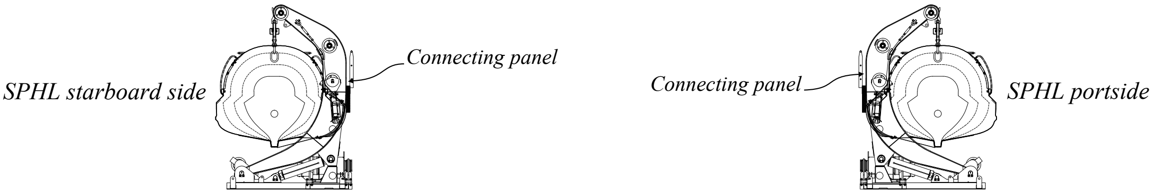
- CONN EO: "Electro Oceanics" - trademark - underwater electrical connector. Also called "Crouse Hinds Underwater Electrical Connectors WATERMATE, EO (alternatively E/O, E-O or E.O.).
- S/BVHN and S/BVHC are “Snap-tite” types couplings.



Notes: Charging panels are used to fill the onboard reserves with oxygen and the relevant heliox mix *(see point 1.2.6.4)*.

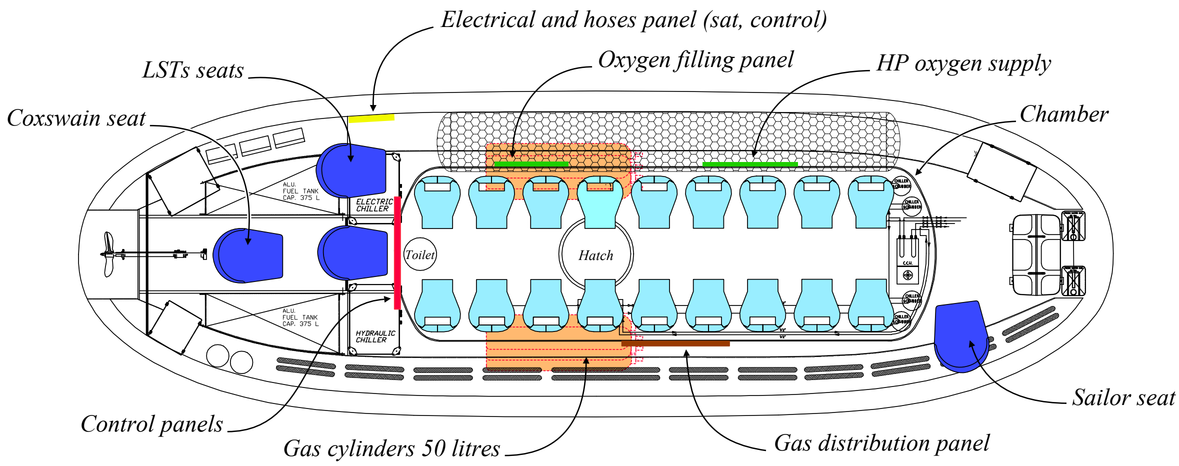
It is recommended install a forced ventilation system to reduce moisture and extreme temperatures into the cockpit area whilst the Self Propelled Hyperbaric Lifeboat is attached to the system *(see IMCA D 051)*.

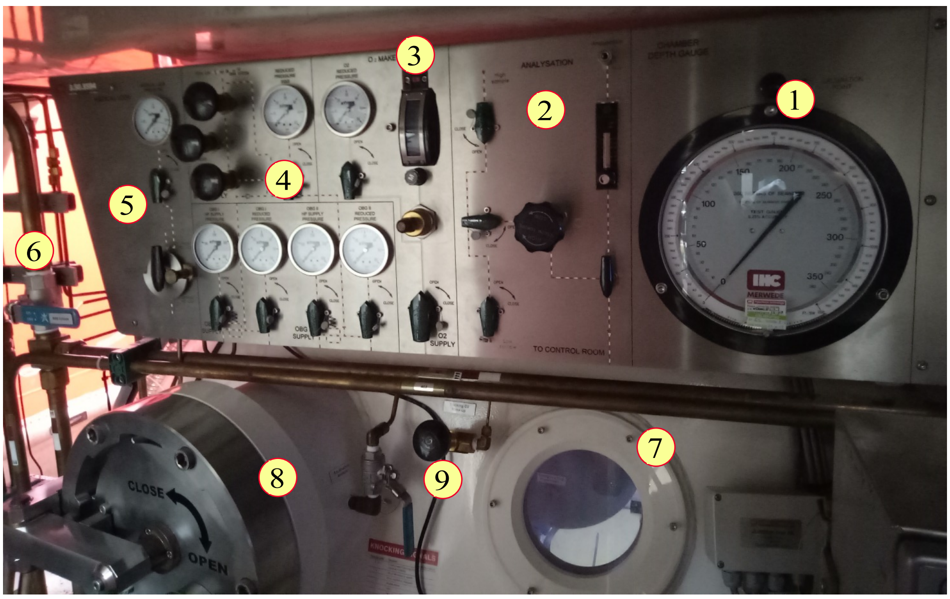
Note that the connecting panel of the Self Propelled Hyperbaric Lifeboat (SPHL) is organized to be deck side of the unit. Thus, a SPHL that is installed on the starboard side of the ship has its connecting panel on its portside and a SPHL installed on the portside of the ship has its connecting panel installed on its starboard side.



As a result SPHLs cannot be installed in another place than the one it is designed for. Note that the position of the connecting panel also results that the position of the gas control panels of the life boat may change accordingly.

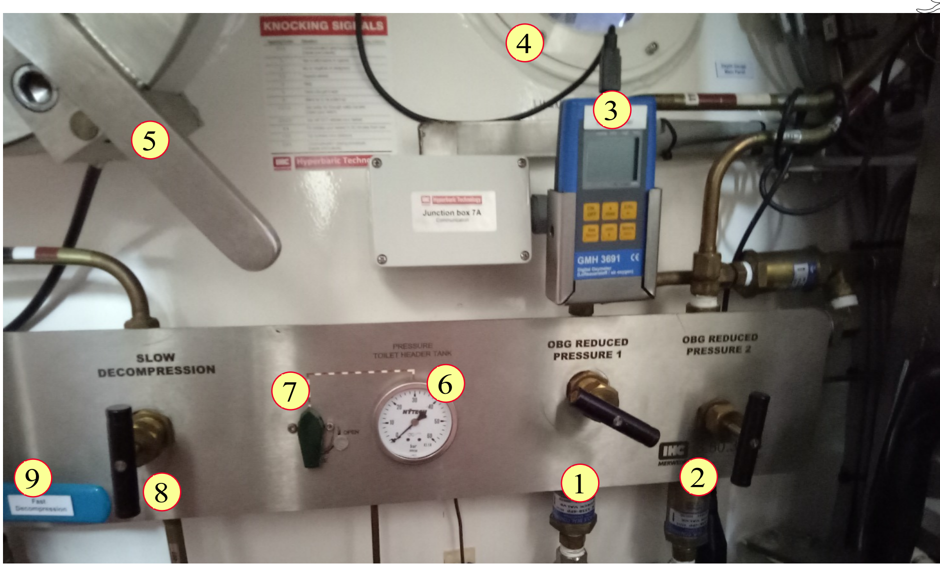
- The main problem of SPHLs is that they must have a reasonable size and weight to be able to be installed on the surface support and be recovered by a crane of fewer than 30 tonnes of Safe Working Load (SWL), as specific units may be difficult to find in some locations.
  As a result of this problem, the engineers are obliged to accommodate a chamber and its environmental control system in a reduced place. As an example, the SPHLs of UDS Lichtenstein that are 10.5 m long for 3.3 m breadth, accommodate a chamber 5,5 m long for 1.75 m internal diameter. For this reason, and as previously described, the reserves of gasses that can be installed onboard are limited. Also, the chamber and gas bottles are heavyweights that must be installed judiciously not to compromise the balance of the lifeboat and keep its navigation properties. Note that, depending on the manufacturer, chambers' weights vary from approximately 3,000 kg to 6500 kg, and the weight of a 50 litres cylinder is around 70 kg. It is one of the reasons they are installed on both sides of the chamber in the lower parts of the vessel. The other reason is that IMO requires that the gas reserves are protected from a fire the boat may have to pass through.
- The control panels *(see the photo below)* are usually installed at the extremity of the chamber, near the coxswain cabin, with the viewport and the medical lock. Due to the reduced space, it often happens that the controls cannot be grouped in only one panel and are disseminated all around the extremity of the chamber with the electrical cabinets. They must be organized such that the Life Support Technician is capable of operating them without having to remove his seat belt.





1 - Depth gauge
2 - Analysis supply
3 - Oxygen make up
4 - BIBS & gas supplies
5 - Medical lock
6 - BIBS exhaust
7 - Viewport
8 - Medical lock
9 - Tracking O2

Topside of the chamber control panel.



1 - Primary supply

2 - Secondary supply

3 - O_2 analyser BIBS

4 - Viewport

5 - Medical lock

6 - Toilet tank pressure

7 - Valve toilet tank

8 - Slow decompression

9 - Fast decompression

Bottom side of the chamber control panel.

Topside electrical cabinet

Bottom side electrical cabinet

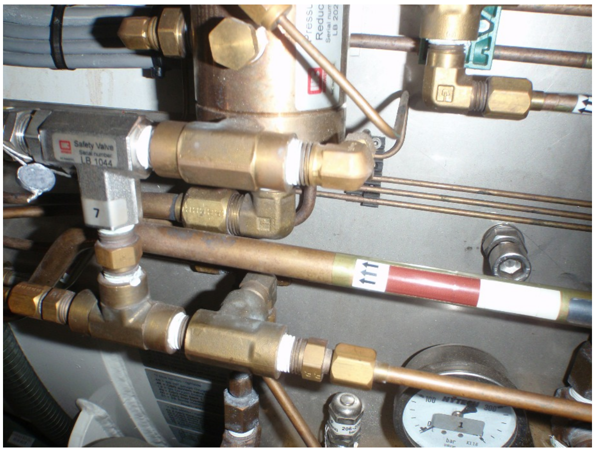
- Control panels must be designed with a minimum controls, and provided with the same protection devices as those provided in the diving and saturation controls.
  - The depth gauge must have a scale appropriate to the duty and operates in the range 25 to 75% of full-scale deflection and operates in the 0 to 25% range during decompression. Its scale divisions are no more than 0.5 msw/2 fsw when used for the final stages of decompression.
    The hyperbaric Rescue Chamber is part of the saturation system, and all the depth gauges in service must use the same unit system.
    The rules for digital gauges are those already indicated previously in this document: Clear enough to be read in all conditions and the display with at lest one decimal.
  - Pressure gauges are smaller than the depth gauges and positioned to show the line pressure of sources coming into the panel and also of any supplies leaving it. They must be organized such that an incorrect reading cannot happen in certain valve positions. Also, they must be designed as the depth gauges except for their smaller scales.
  - Regarding the valves, IMCA rules are that there must be sufficient valves to allow for gas inlet and outlet controls and the make-up of the metabolic oxygen. These valves must be easily operable and not be corroded with their function indicated. Also, if they are used for cross over, IMCA says that they should either be fixed in one position (the handles may be removed to avoid accidental changes) or should indicate very clearly what supply they are connected to.
  - Pipework exhaust must not vent inside the boat. For this reason, chamber dump, gas dump, and BIBS dump are organized accordingly on the connecting panel (see in the scheme on the previous page). Also, IMCA suggests that the onboard gas supplies are regulated to 30 bar. Note that Pressure relief valves and no return valves should be fitted within the chamber controls to protect it from overpressure or an operational mistake.
  - Oxygen must be regulated down to 40 bar or less at the source. Also, the O_2 make-up control panel must be equipped with sufficient valves and a flow indicator installed downstream, so the operator can control the flux delivered into the chamber.
    As it is also the rule, ¼ turn valves must not be used for oxygen. Also, the lines used for carrying this gas must be regularly cleaned for oxygen service.
  - In the SPHL taken as reference an analyser is fitted to the bottom side electrical cabinet *(see the photo above)*. It monitors the following parameters:
    - Chamber pressure

- Oxygen (O_2) percentage
- Partial pressure oxygen
- Carbon dioxide (CO_2) percentage
- Partial pressure carbon dioxide
- Temperature
- Humidity

These data are mandatory. Alarms are also mandatory for oxygen (high & low level) and CO_2 (high). For this reason, a buzzer is installed with a mute command.
A portable analyser, that is packed in a specific case. is available at proximity of the operator and can be connected to the analysis panel in case of a failure of the primary unit. This secondary analyser is also mandatory.
In addition, as the oxygen cylinders and their distribution lines cannot be installed outside the boat for the reasons previously explained, an oxygen analyzer with a high and low alarm should be fitted to detect changes in the oxygen level ambient to the control point as a result of possible gas leaks. Note that pure oxygen is heavier than air, and for this reason, the cell should be installed near the lower parts of the boat.

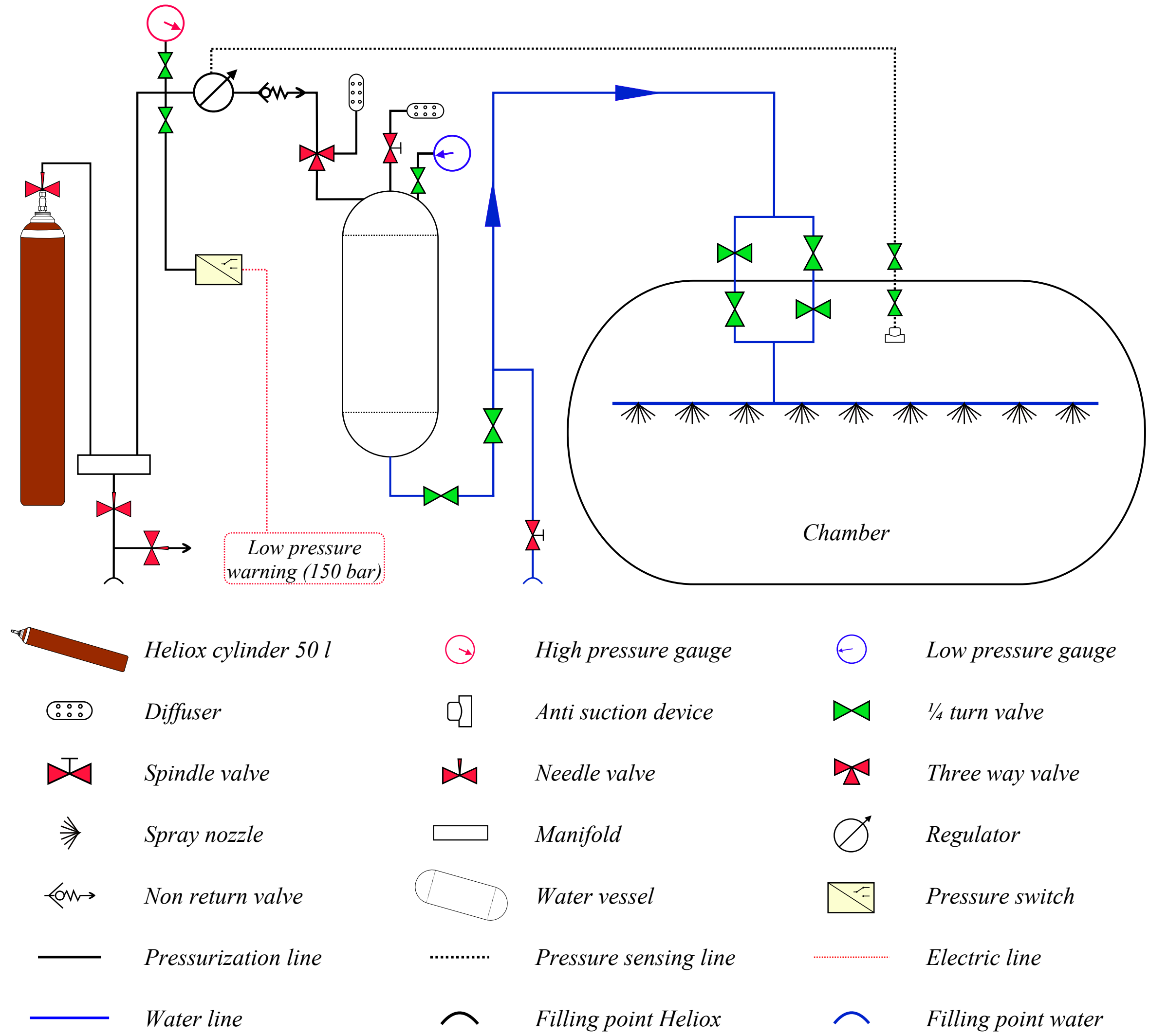
- The necessary level of lighting for the operation of the various panels and the reading of documents is provided through Light Emitting diodes (LED), that offer more light than filament bubbles, on the new units. Also, an emergency lighting system sufficiently powerful to continue the operations must be installed. Note that daylight is provided through viewports of the coxswain cabin.
- The onboard chamber communications provided are usually portable systems such as those used in dive controls. New digital systems such, as an example, those fabricated by fathom, are also available. These systems, that are designed to provide communication to the chamber during rough conditions offer 3 channels expendable to 6 channels that allow the LSS/LST to communicate with the divers inside the SPHL chamber, and also to the launch station prior to the SPHL is being lowered to the water. Note that a secondary means of communication with the divers in the chamber must be ready or use.
Also, note that IMCA says that there must be two-way voice communication between the life support control on the mother vessel and the personnel inside the surface crew compartment of the HRU.
- When the boat is sailing, the condition of the divers can be visually assessed through the viewport that is in front of the Life Surface Technician (LST). The lifeboat manufacturer of the unit taken as a reference says that an optional video system can be used for this purpose.
The video camera inside the chamber is normally used by the LST in the saturation control room when the boat is connected and is mandatory. In addition to this camera, another mandatory video system is installed in the transfer lock to monitor whether divers are entering in the connecting trunk. As a result, the LST can monitor whether a diver entering the trunk arrives in the chamber of the SPHL.
- IMO A.692 says that the chamber must be designed, constructed, and arranged to permit easy inspection, maintenance, cleaning, and, where appropriate, disinfection. IMCA provides similar guidelines. Nevertheless, despite efforts to comply with these rules, the space available in the lifeboat does not allow for immediate access to some elements such as the gas cylinders that are installed in the lower parts of the boat, so under the floor. It is the reason that gas distribution panels are provided on more reachable areas alongside the chamber. Note that it is impossible to stand up in the corridors managed along with the chamber, which obliges to intervene bent or sat. Also, some pipeworks are situated in areas that are not well illuminated, and a portable light is often necessary to intervene.

Access on the side of the chamber


Pipework along the chamber

Fire fighting systems that are suitable for extinguishing oil fires must be present in the cabin. They are commonly portable extinguishers that are installed at both extremities of the boat and are readily accessible.
A breathing system should be provided for the entire crew. Some Self Propelled Hyperbaric Lifeboats are equipped with a built-in breathing system (BIBS). It is the case of the models taken as an example. When it is not the case, portable Breathing Apparatus (BA) sets must be provided.
As indicated previously, some chambers are equipped with a fixed fire fighting system. This system is composed of a reservoir that contains an extinguishing agent, such as water, that is pushed out to the chamber by

heliox under pressure from a bottle 50 litres, and is sprayed in the chamber through several nozzles. The heliox is stored in a cylinder 50 litres / 200 bar. The system is triggered manually by the LST on duty or the divers inside the chamber (see in the scheme below). The commands are organized such that they are readily accessible without been obliged to remove the safety belt. Also, a pressure switch is connected to an alarm that is activated in case of loss of pressure in the cylinder.



1.2.7.5 - Self Propelled Hyperbaric Lifeboat: Access of the crew and technicians

The access of the crew to the Self Propelled hyperbaric lifeboat is performed through a specific secured deck that allows boarding in the unit in a safe and organized manner. This deck must be provided with handrails to prevent falling of personnel to the sea or a lower floor. Also, the gap between the boat and the deck must be reduced for the same reasons. This access is also used for the maintenance and inspection of the inside of the boat.
In addition to handrails, the deck below the boarding level that provides access to the winch, and the clamp must be fitted with gratings or similar protections to prevent the operators from being caught by the cables and pulleys of the winch.

Access hatch to the boat

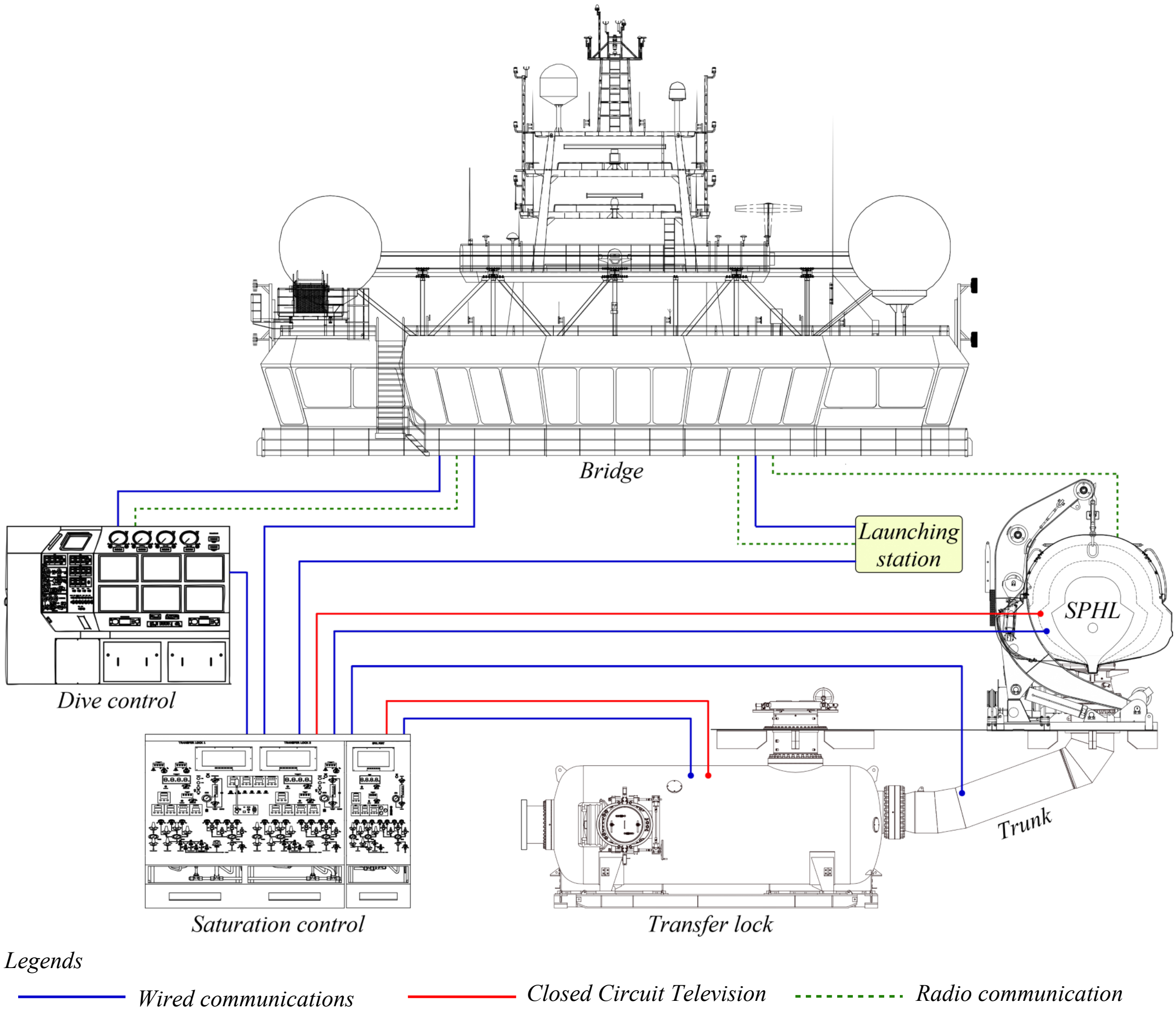
Access to the winch and the clamping system.

1.2.7.6 - Self Propelled Hyperbaric Lifeboat: Summary of the communications to be in place for launching

The primary communications that must be ready for use for the launching of the Self Propelled Hyperbaric Lifeboat have been described throughout the previous points and are summarized below. Note that wired direct communications are not subject to interference and must be installed and used in priority for this reason.
Depending on the company, additional channels may be added. However, an abandon ship procedure with too many people involved in communication may result in confusing information and orders and thus become inefficient. For this reason, it is better to concentrate on some essential relays and make sure that their primary and backup means of communication are present.

- The bridge is the center of commands of the vessel. For this reason, it must be linked to all strategic areas for the abandon ship:
  - Dive control room (wired communications and very high-frequency radio)
  - Saturation control room (wired communications)
  - Launching station (wired communications and radio)
  - Self Propelled Hyperbaric Lifeboat (very high-frequency radio)
- In addition to the bridge, the dive control is linked to the saturation control through wired communications. It can be linked to the launching station through radio and wired communications *(not represented in the scheme)*.
- The Live Support Supervisor (LSS) in the saturation control room is in charge of transferring the divers in saturation to the Self Propelled Hyperbaric Lifeboat. For this reason, in addition to the bridge and the dive control he must have communication with:
  - The living chambers.
  - The transfer lock
  - The trunk
  - The chamber of the SPHL
  - The LST on duty in the SPHL
  - The launching station (transfer under pressure and clamp opening procedures)

  The Closed Circuit Television (CCTV) system that is installed in all chambers and the transfer locks allows monitoring the progression of the divers toward the hyperbaric rescue unit. The camera in the chamber of the SPHL is used to ensure that all the divers are on board and that they can close the hatch. Note that as with the other parts of the saturation system, this camera is also used to monitor people doing maintenance operations inside the chamber. Note that radio communications may be present as a backup.



1.2.7.7 - Self Propelled Hyperbaric Lifeboat: Saturation systems equipped with two units

IMO says that the evacuation system must be designed for the rescue of all divers in the diving system at the maximum operating depth. This evacuation system can be designed with one or several chambers.

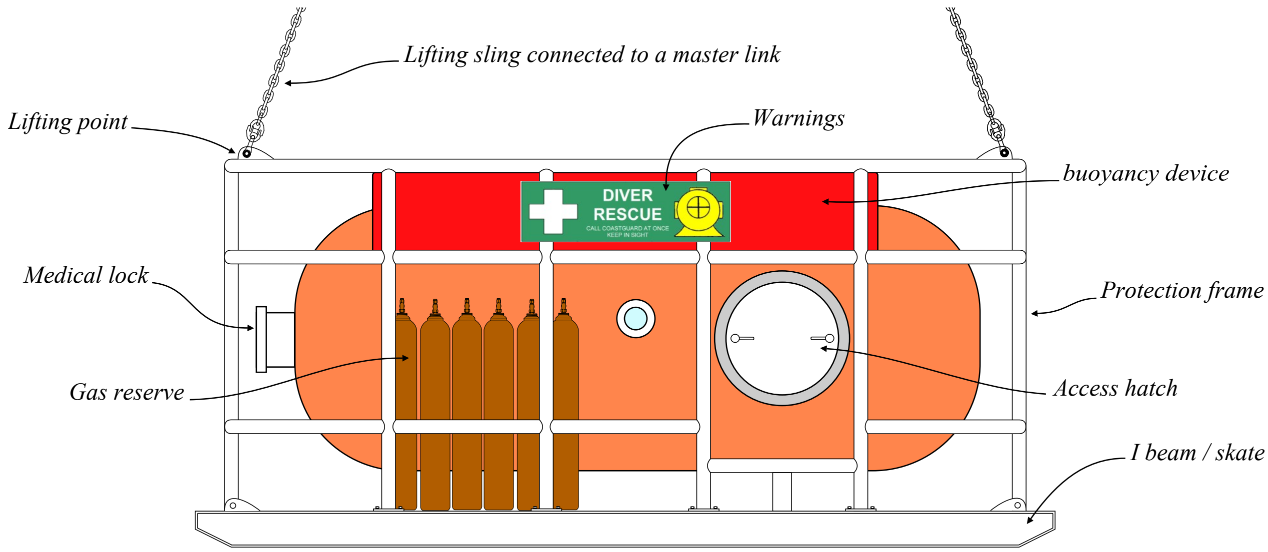
Note that several means of evacuation should be provided in case of operations with diving teams stored at depths that are too far to allow for a reasonable compression time to the deepest storage level to be able to evacuate the divers quickly. As an example, if a team is stored at 100 m and another one at 300 m. 32:20 hours are necessary to compress the divers stored at 100 m to 300 m using the Normam 15 table compression procedure. If the operator does not apply the required stops, the compression time remains at 12:30 hours with a very high risk that the divers who have been compressed will be affected by High-Pressure Nervous Syndrome (HPNS). Also, clients such as IOGP members request that the SPHL is launched in less than 15 minutes. Thus, the compression time of the shallower team must be sufficiently short to allow the divers to evacuate within this given time, which is impossible when the storage depths are too far.

Regarding the numbers of SPHL provided, IMCA D 024 says that when several Hyperbaric Rescue Units are present, the number of persons that can be in the saturation system is equal to the addition of the capacities of the units. However, the inconvenience of such design is that if one unit is damaged, it is not possible to evacuate the entire team present in the saturation complex, or the remaining evacuation chamber is overloaded. For this reason, it is advisable to fabricate saturation systems with two Hyperbaric Rescue Units, each of them can accommodate the entire team in saturation. Note that some client organizations such as IOGP say that when two SPHL are available, each SPHL should provide 100% evacuation capability and redundancy for the saturation diving team *(see IOGP 478)*.
Note that in case the Hyperbaric Rescue Unit of a system equipped with only one unit is lost, the only procedure of evacuation available will be the accelerated decompression procedure explained in DMAC 31. However, this procedure is to be used only when the diving team is dealing with a life or death situation, and should not be considered a "normal" evacuation procedure. This fact should be taken into account when designing the saturation system.

1.2.7.8 - Hyperbaric Rescue Chamber (HRC): Description

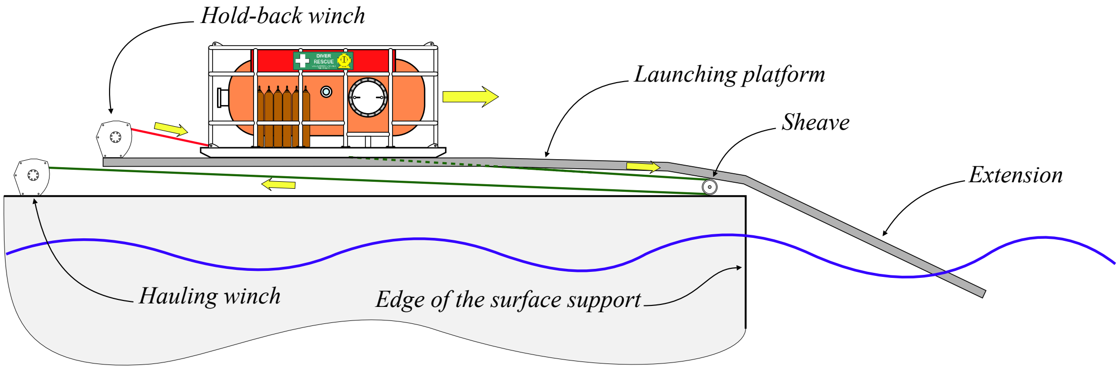
As indicated in point 1.2.7.1, Hyperbaric rescue chambers are floating units usually found with portable systems. Although most manufacturers have ceased to propose them, they have been produced until very recently. For this reason, we can expect to have such evacuation systems for a long time.
The main reasons that such means of hyperbaric rescue remained proposed with portable systems until now are that they are much more straightforward to fabricate and maintain than Self Propelled Hyperbaric Lifeboats. That was considered an advantage with these saturation systems that are used episodically and may have to be stored for sometimes extended periods. Another attractive fact linked to the previous ones is that they are cheaper to fabricate than SPHLs. Despite these convenient points, these means of evacuations, that were the 1st systems provided to the diving industry, offer fewer capacities of rescue than SPHLs because they are not self-propelled and are immersed at 80% when they are in the water, so they cannot be monitored during the transfer like the chambers of SPHLs. For this reason, a small panel is usually installed inside the unit to allow the divers controlling the essential parameters.

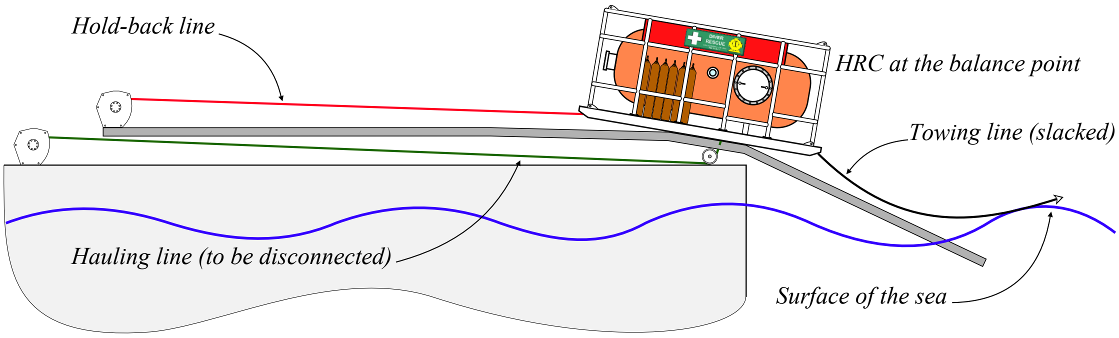
The Hyperbaric rescue chambers are maintained at the surface by their buoyancy and a series of buoys that are installed on the upper parts of a sturdy frame that protects it from shocks. This frame, to which four lifting points are fitted, also protects the connecting panels, reserves of gas, and the medical lock. It is bolted to two I beams interconnected with other beams to form a chassis that can be used as skates to slide the chamber to the sea and eventually recover it through a slope. As it is mandatory, these units are colored orange, and the green warning panel indicating that divers are in saturation, and described in point 1.2.7.2 must be visible on its sides and top.
These chambers must be designed to offer the divers all the functions previously described with chambers of the Self Propelled Hyperbaric lifeboats, except that they are not monitored from the external as long as they are in the water.
Some units are designed such that it may be possible to connect them with the umbilical of the Life Support Package if it is installed on the towing vessel. Still, it is often not possible as many panels are not at the top of the chamber, and there is a risk to damage the lines during the towing, so companies usually prefer not using this option.
Note that the access from the saturation system to such a chamber is often performed by the side.

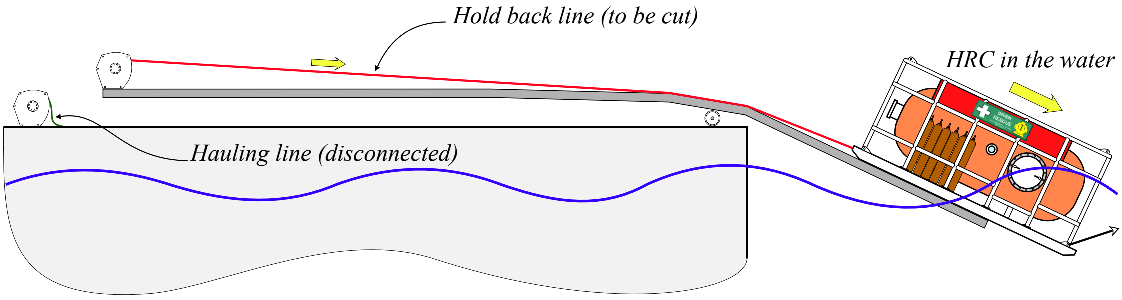


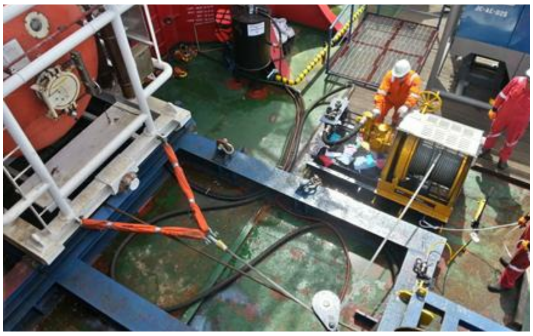
Some Hyperbaric rescue chambers can be launched using davits. However, most models is service use a launching platform, the onboard crane if available, or the "float off" method if none of the previous technic is possible. Launching using the crane is possible only if the weather conditions and the condition of the boat permit it. For this reason, it is often not possible to use it, and procedures using launching platforms are the preferred options. Two methods are commonly used: Controlled slow descent and free fall.

- Controlled descent consists of holding the chamber during its descent until it reaches the water. This method is also called "pull off":
    - The Hyperbaric Rescue Chamber (HRC) is installed on a metallic launching platform that is designed to guide it and allows its skids easy sliding. Several blocking points and the transfer trunk, that must be disconnected before launching, secure it to the saturation system during normal operations.
    - A slope extension is installed overboard to support and guide the HRC until it reaches the water.
    - A dedicated winch is utilized to haul the HRC over the stern or the side of the vessel. The winch wire passes through a sheave that is secured to the chassis of the launching platform at the edge of the surface support and is connected to the dedicated pulling points of the hyperbaric rescue chamber. It is disconnected when the HRC is ready to slide down on the slope extension.
    - To control the descent and avoid potential damage/injury on equipment/personnel due to the impact with the surface of the sea, a hold-back tugger is attached to the HRC.
    - Once cleared to the sea and free of tension the hold back wire is cut with a hydraulic cutter and the rescue boat tow it away. Note that if established the towing line must not be used during the descent.



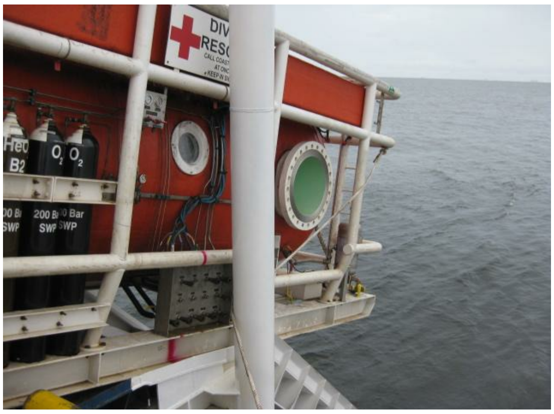




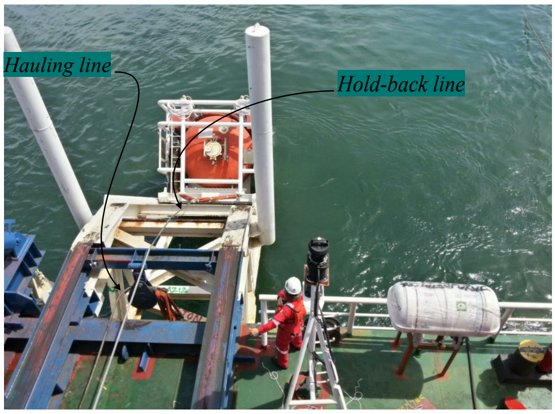

Hold back winch


Hauling winch

Launching platform at the stern of a lay barge

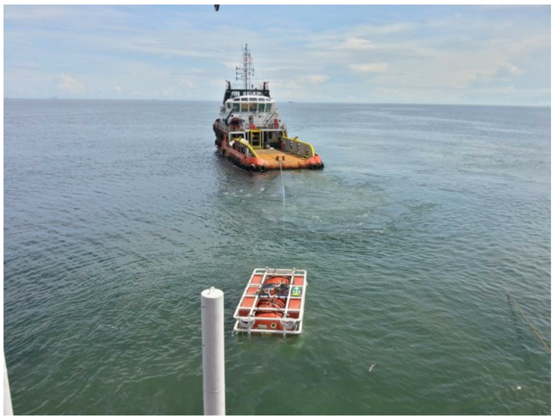


HRC at the balance point



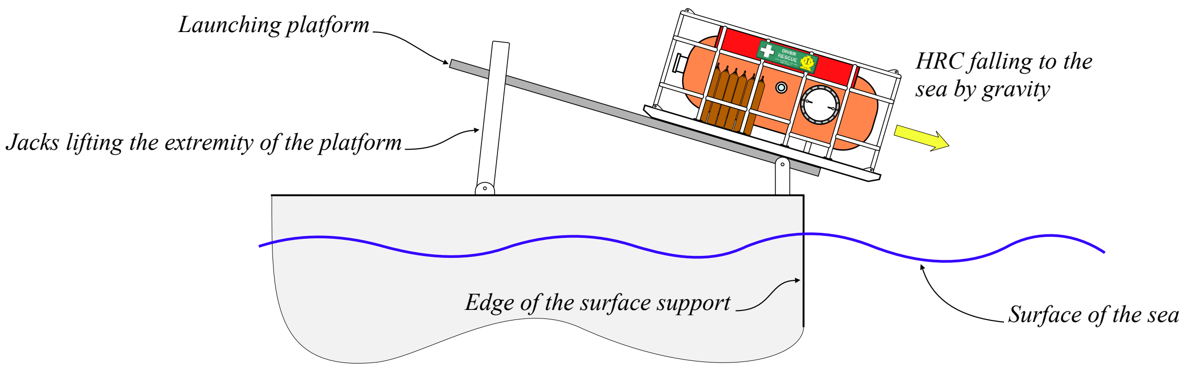
HRC at the end of the launching platform

HRC at the end of the launching platform

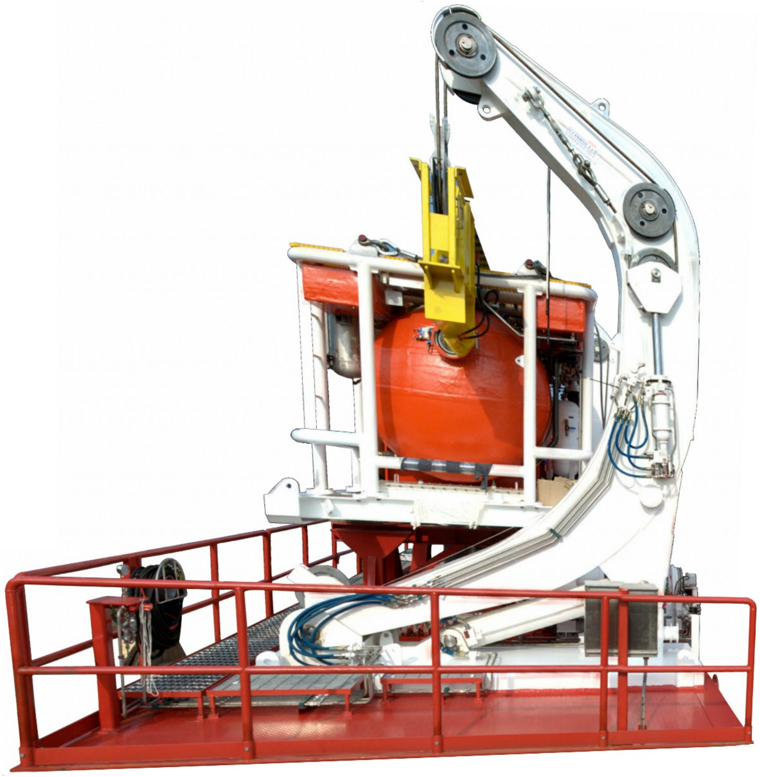


HRC Towed

- The "free fall" procedure consists of dropping, the chamber to the water from the height of the deck where it is stored using a launching platform. Several methods are used that may be based on the one previously explained to move the chamber near the edge of the surface support and then let it fall to the sea. A well-known procedure that is described in the drawing below is based on jacks lifting the extremity of the launching platform opposite to the edge of the surface support to create a slope that allows the HRC to fall to the sea by gravity.



Note that procedures based on a launching platform request a lot of personnel in the case of a controlled descent or can result in a strong impact with the water that may injury the divers and damage the equipment when the chamber is pushed to the water from the height of the deck. For this reason, some manufacturers have designed HRCs with davits that are similar to those implemented with SPHLs. Note that with the model in the photo below that has been built by Lexmar (JFD group), the access to the chamber is made through the bottom of the unit as with Self Propelled Hyperbaric Lifeboats. Such installation that allows lowering the lifeboat in a controlled and soft manner with a minimum crew can be adapted to every model of existing Hyperbaric Rescue Chambers.



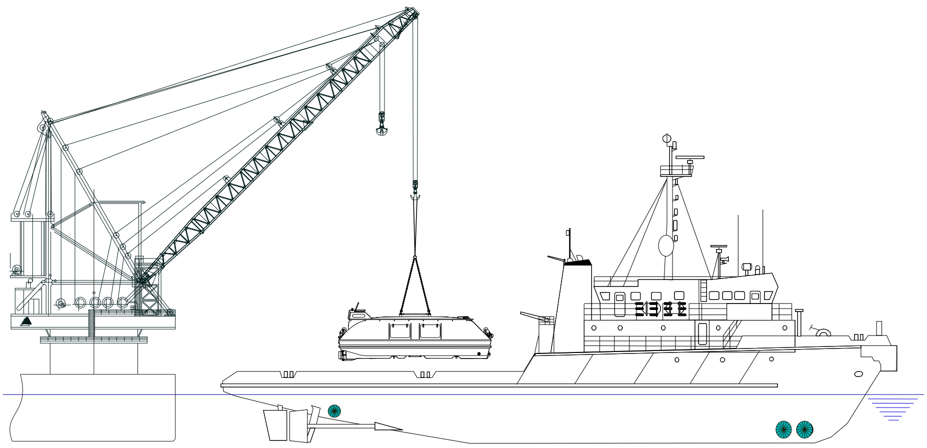
Float off procedure is an ultimate procedure that consists of disconnecting every element that may retain the chamber to the boat to ensure that it will float when the ship sinks. It is to be used only if the progression of the events is too fast to allow for sufficient time to launch the chamber overboard using the planned procedures.

Regarding the connection to the Hyperbaric Reception Facility (HRF), IMCA D 051 does not explain the mating of hyperbaric rescue units (HRU) that are to be connected laterally to saturation systems and hyperbaric reception facilities. Although procedures for approaching and matching are similar to those of SPHLs, it is necessary to ensure that the adjustment of the flanges is perfect. That may oblige to plan for a specific kit for the hyperbaric reception facility that may not be initially designed for lateral mating. This point is explained more in the chapter regarding the Hyperbaric Reception Facilities (HRF).

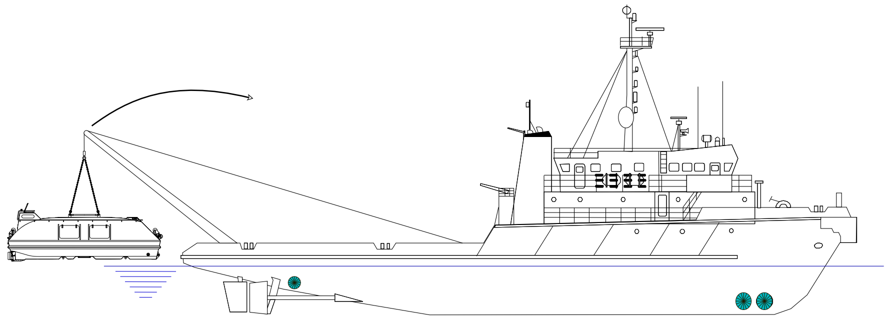
1.2.7.9 - Transfer the Hyperbaric Rescue Unit onboard the rescue vessel

When the Hyperbaric rescue unit is in the water it must be recovered onboard the rescue vessel as soon as possible. Several methods can be use, which those described below are the most common:

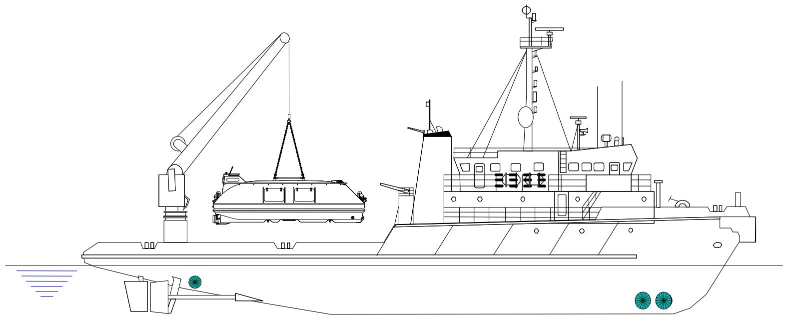
1. Transfer using a crane installed on a platform or a vessel located at the proximity of the worksite:
   The hyperbaric rescue unit sails or is towed toward the crane and is then lifted out of the water and transferred to the deck of the rescue vessel. Note that the transfer may be difficult or impossible with rough weather conditions using this method. Also, the team must synchronize with those of the crane, and time may be lost due to the transiting to the crane before sailing to the decompression facility.



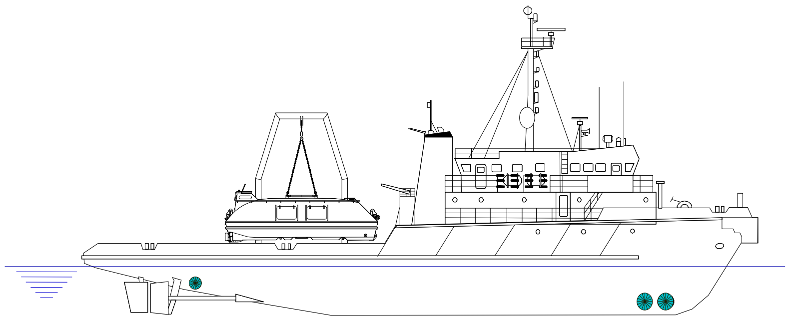
2. Transfer using an “A-frame”, or a slope, installed at the stern of the rescue vessel:
   Ships equipped with an “A-frame” are the most common. The advantage of this system is that the “A-frame” (or the slope) allows to precisely land the HRU to its dedicated place. The inconvenience is that the pickup area is situated at one of the extremities of the boat, which are those that move up and down the most during rough sea conditions. That may result in a complicated recovery. However, some vessels are provided with efficient ballasting systems that can be used to stabilize their stern.



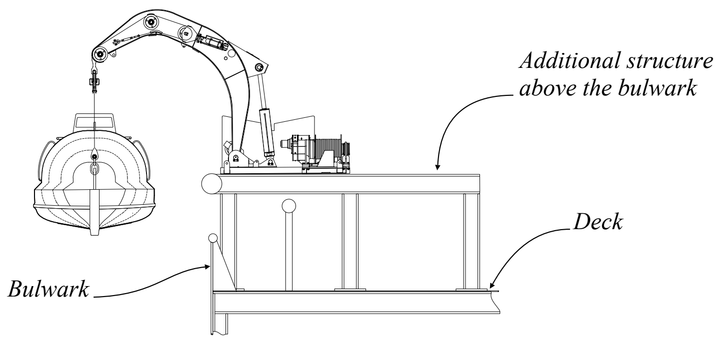
3. An offshore crane installed on the rescue vessel:
   Similarly to those provided with "A-frames", such ships offer the advantage that they can be operated independently from other units. Another advantage of vessels fitted with a crane is that no lifting frame installation is required, which is an advantage in the case of a rented boat. Also, the pickup zone can be situated in the middle of the ship, which is the balance point. Nevertheless, the stability of the load will depend on the position of the crane (at the middle or close to one extremity) and the height of its boom (the higher the boom is, the more significant the movements due to the sea conditions are). As a result, depending on the above, the recovery can be easier or more difficult than with an "A-frame" at the stern.



4. An “A-frame” installed at mid-ship:
   This system combine the advantages of the “A-frame” with those of a pickup area that is situated close to the balance point of the ship. However, a specific frame that takes a lot of space in the middle of the deck has to be installed. Note that with such installation, the HRU is secured on a side of the deck.

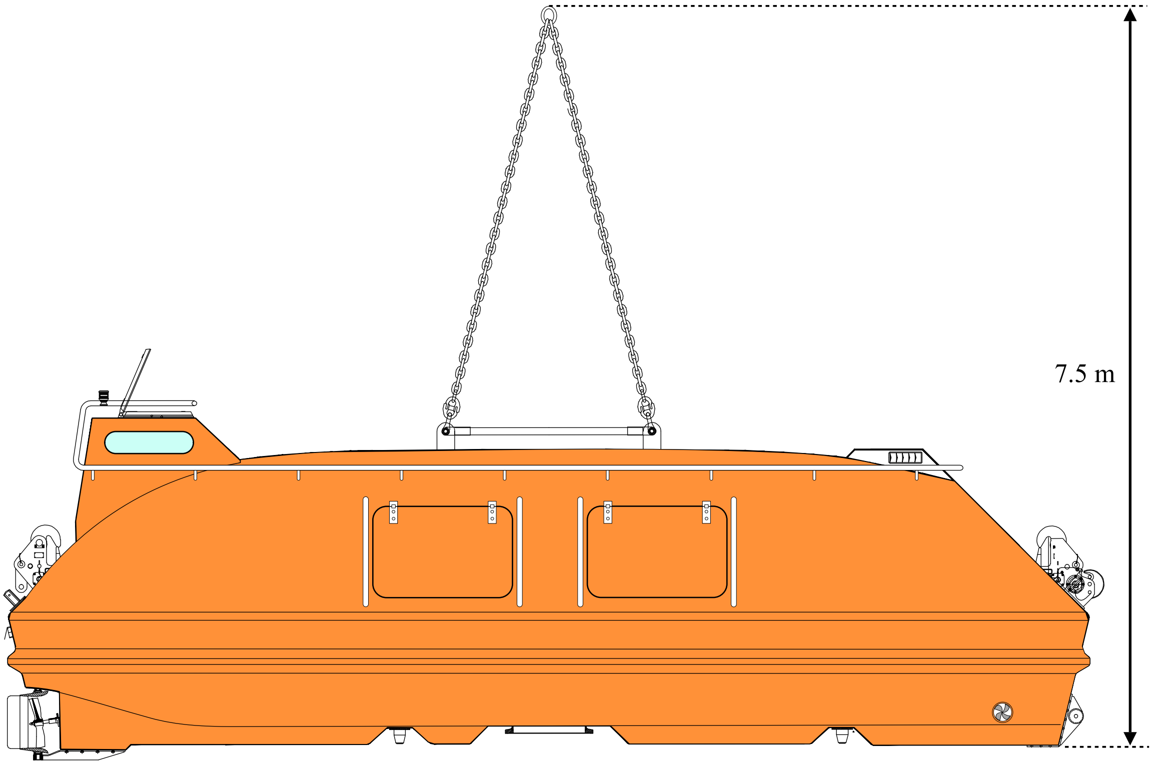


5. Another solution to recover the SPHL from the water is to use davits:
   Davits allow excellent control of the load as they provide two distant lifting points. However, their installation often requires a reinforced structure to pass above the bulwark. Also, the connection of the slings may be complicated by a rough sea. By comparison, the transfer of the lifting rigging connected to the middle of the boat with the extremity near the coxswain cabin is much more comfortable.



1.2.7.10 - Recommended height of the lifting rigging

IMCA says :
The maximum height that can be achieved between the underside of a crane hook and either the deck of the recovery vessel or the quay-side is generally determined by the rating of the crane.
Offshore and within the major ports worldwide cranes, significantly larger than required, are in normal everyday use. In remote, or unexpected, locations cranes of limited capacity will have to be relied on; therefore it is recommended that when rigged there is a maximum limit of 7.5 metres between the keel of the HRU and the crane end master-link.



1.2.7.11 - Maintenance

Hyperbaric Rescue Units must be ready to operate at all times as soon as the divers are compressed in the saturation complex. In case of a technical problem that cannot be immediately solved, the dive must be interrupted, and the divers recovered to the surface. As a precaution, daily inspection of all the critical parts must be carried on and recorded. Also, access to the systems must be restricted to the personnel in charge only.

Regarding the frequencies of inspection, and re-certifications IMCA D 024 says the following:

Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure*	*Other*
Classification certificate				Permanent
Sea fastening design certificates				At mobilisation
Sea fastening installation cert.				At mobilisation
Emergency power testing	6 months			
Compliance Assessment				Permanent
Design				Permanent
Interlock (clamping system)	6 months	2 years	When new	
Communication trunk (+ Batteries)	6 months			
Design trunk				Permanent
Trunk testing	6 months	2 ½ years	5 years	

Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure*	*Other*
Venting test trunk	6 months			Permanent
Valve and pipework trunk	6 months	2 years	When new	
Gauges trunk	6 months			
Viewports	6 months	2 ½ years	5 years	Complete renewal 10 years
Interface panel pipework and valves	6 months	2 years	1st installation	
Interface: Electrical testing	6 months			
HRU floating test				Permanent
HRU Design Standard				Permanent
HRU pressure vessel testing	6 months	2 ½ years	5 years (+ leack test)	
HRU chamber viewports	6 months	2 ½ years	5 years	Complete renewal 10 years
HRU Fire fighting portable systems	6 months			Manufacturer specifications
HRU Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
HRU Automatic fire detection	12 months			
HRU Electrical penetrators Certification				Permanent
HRU Interlock pipework	6 months	2 years		
HRU Electrical testing	6 months			
HRU chamber internal - communication	6 months			
HRU chamber internal BIBS	6 months			
HRU chamber internal portable Firefighting	6 months			Manufacturer specifications
HRU chamber internal fixed Firefighting	Visual: 6 months Test: 12 months			Manufacturer specifications
HRU chamber internal Automatic fire detection	12 months			
HRU chamber internal - Validity medical kit DMAC 15	6 months			
HRU chamber internal - Survival bags	6 months			Checked or back to supplier: 3 years
HRU chamber internal Environmental control unit	6 months			
HRU chamber internal - Pipework and valves	6 months	2 years	1st installation	
HRU chamber internal - gauges	6 months			
HRU chamber internal - electrical	6 months			
HRU without external life support control - Pipework	6 months	2 years		
HRU without external life support control - Electrical	6 months			

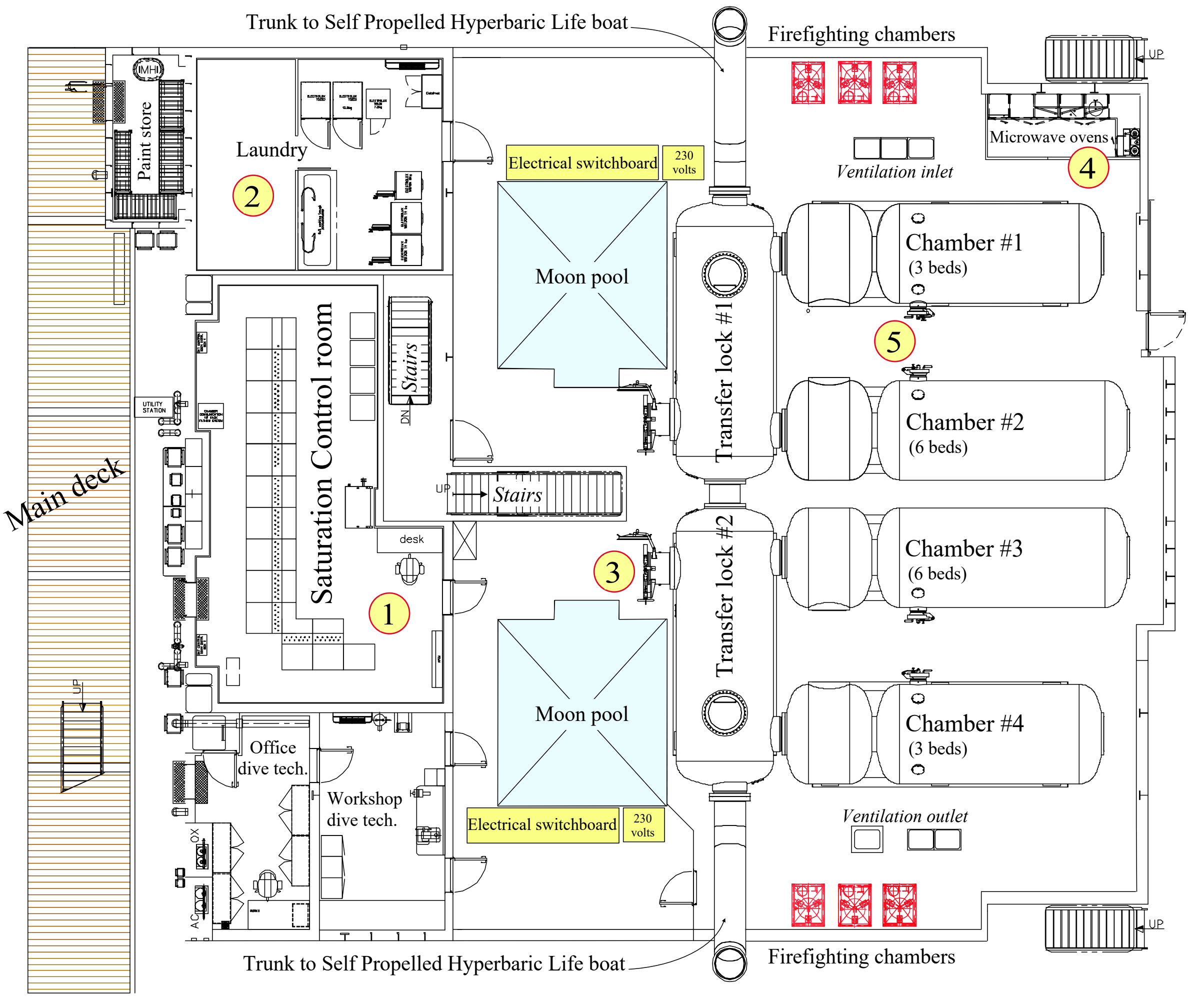
Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure*	*Other*
HRU without external life support control - Comms	6 months			
HRU without external life support control - Gauges	6 months			
HRU without external life support control - Analyser	6 months			
HRU with external life support control - comms	6 months			
HRU with external life support control - comms	6 months			
HRU with external life support control- pipework	6 months	2 ½ years	When new	
HRU with external life support control - electrical	6 months			
HRU with external life support control- Relief valve	6 months	2 ½ years		
HRU with external life support control - Fire fighting portable system	6 months			Manufacturer specifications
HRU with external life support control - Fire fighting portable system	Visual: 6 months Test: 12 months			Manufacturer specifications
HRU with external life support control - Fire detection	12 months			
HRU with external life support control - Fist aid kit	6 months			
HRU with ext. life support control - Analysis + Alarm	6 months			
HRU with external life support control - Cylinders	6 months	2 years	4 years	
HRU with ext. life support control -				
HRU with ext. life support cont. - Radio, GPS, Satellite phone	6 months			
HRU with ext. life support control - Towing test	At mobilization			Before 1st service
HRU with ext. life support control - Mating trial	At mobilization			
HRU Launch and Recovery System (LARS) - Fit for purpose certificate				Permanent
Dedicated launch system: Release Hooks compliance with IMO certificate				Permanent
Dedicated launch system: Launch system testing	Visual: 6 months Function test: 1 year			Falls replacement : 5 years.
Non Dedicated Launch System: Fit for purpose cert				Permanent
Non dedicated launch system: Launch System Testing	Visual : 6 months Function test: 6 months Static 1.25 SWL: months		1 year	Practice deployment: 6 months
Non dedicated launch system: Practice deployment				6 months
Non dedicated launch system: If test above require to replace major components				Evidence that a practice has taken place within the last 5 years

Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure*	*Other*
Non dedicated launch system: If test above require to replace major components				Evidence that a practice has taken place within the last 5 years
LARS - Fire fighting portable system	6 months			Manufacturer specifications
LARS - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
LARS - Fire detection	12 months			
LARS - Communications	6 months			

1.2.8 - Saturation control room

1.2.8.1 - Purpose

The saturation control room is the place from which the Life Support Supervisor (LSS) and the Life Support Technicians (LST) manage the living chambers and the well being and the safety of the divers. For this reason, this room is organized to provide them the necessary information and commands to monitor and control each part of the saturation complex and be in contact with the divers and the key persons involved in the operations at all times. Thus, apart from the elements directly controlled by the diving supervisor (bell, divers' gas reclaim system, and Launch and Recovery System of the bell), all the components of the saturation system are monitored and controlled from this place.
As part of their duties, life support technicians are in charge of transferring food, renew bedding, clean clothes, and perform functions of the saturation complex that cannot be operated remotely. It is the reason the saturation control room *(see #1 in the drawing below)* is usually installed at direct proximity of the chambers and their facilities such as laundry room *(see #2)*, equipment transfer lock *(see #3)*, microwave ovens area *(see #4)*, and food/medical locks (see #5).



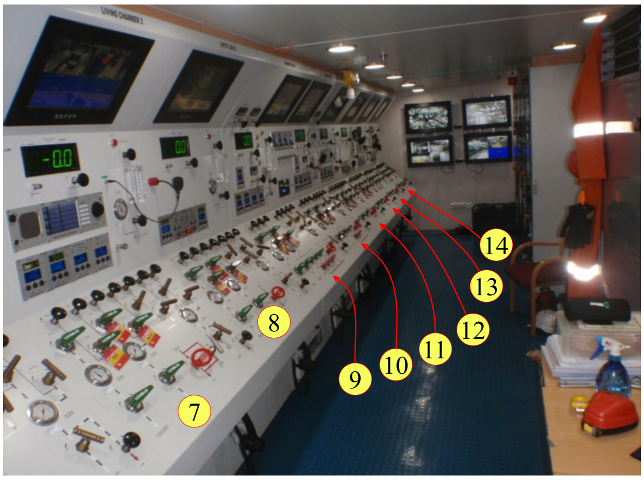
1.2.8.2 - Control panels

Each pressure vessel designed to store, transfer, or evacuate the divers is controlled from the saturation control room through a dedicated panel.
With the systems taken as references, which are designed with two bells and four living chambers, the following panels are provided:

- The gas distribution panel
- Self Propelled Hyperbaric Lifeboat (SPHL) starboard side
- Self Propelled Hyperbaric Lifeboat (SPHL) starboard side
- Gas and Diver Monitoring System (DMS) status screen (Fathom systems)
- Living chamber #1
- Entry lock #1
- Living chamber #2
- Entry lock #2
- Transfer lock #1 with its equipment transfer lock and the trunk to and from the port side bell.
- Transfer lock #2 with its equipment transfer lock and the trunk to and from the starboard side bell.
- Living chamber #3
- Entry lock #3

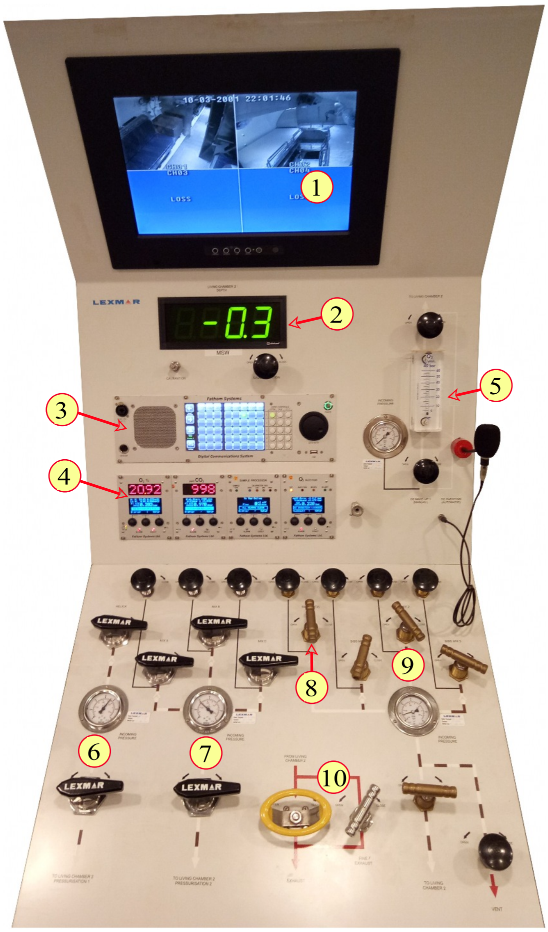
- Living chamber #4
- Entry lock #4

- *1 - Gas distribution panel* - *2 - SPHL Port side*
- *3 - SPHL Starboard side* - *4 - Screen gas & DMS status*
- *5 - Living chamber #1* - *6 - Entry lock chamber #1*



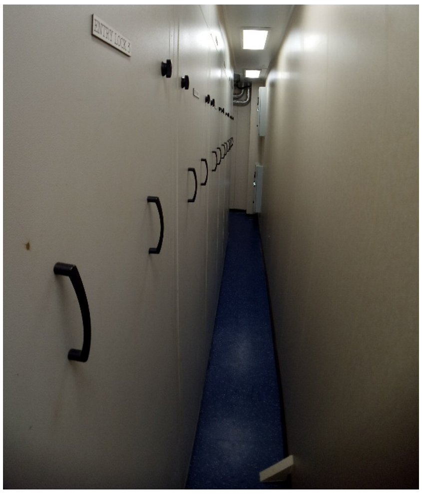
- *7 - Living chamber #2* - *8 - Entry lock chamber #2*
- *9 - Transfer lock #1* - *10 - Transfer lock #2*
- *11 - Living chamber #3* - *12 - Entry lock chamber #3*
- *13 - Living chamber #4* - *14 - Entry lock #4*

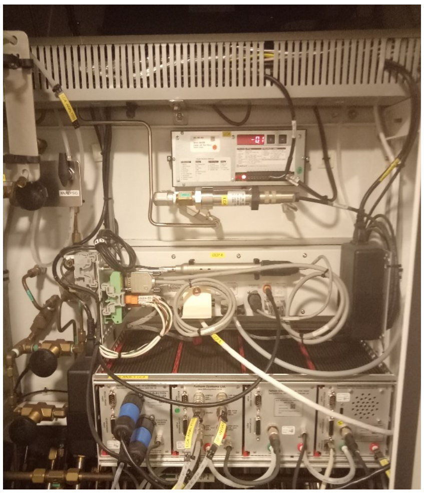
Each panel provides the following functions that are mandatory and may be arranged differently according to the chamber to control and the design promoted by the manufacturer:



- Close circuit television that allows observing the divers at rest. Cameras are described in point 1.2.2.2 of the chapter 1.2.2 “Chambers” *(see #1 in the photo on the side)*
- Depth gauge *(see #2)*:
  The model used with the panels taken as references has a digital display. However, analogic depth gauges are present in many saturation controls. As already discussed, IMCA requires that digital gauges have a display with at least one decimal point that can be read in all conditions. similarly, the scale of analogic gauges must be large enough to be read easily and accurately. Also, gauges should operate in the range 25 to 75% of full scale deflection although they need to operate in the 0 to 25% range during decompression and must have scale divisions of no more than 0.5 msw/2 fsw for the final stages of decompression.
- Two-way unscrambled voice communications *(see #3)*:
  Note that there must be a backup means of communication. It is usually a sound powered phone which is visible under the gas panel. Also, the model presented in the picture allows to establish communication to every chamber.
- Analysis *(see #4)*:
  The models used in the saturation control room of the systems taken as references are those used in the dive control.
- Gas supplies
  - Oxygen make up lines *(see #5)*:
    For living chamber automatic and manual supplies are provided.
  - One heliox mix provided through the pressurization line #1 *(see #6)*.
  - Three heliox mix that can be used to supply the pressurization line #2 *(see #7)*.
  - One therapeutic mix for the BIBS *(see #8)*.
  - Three breathing mixes for the BIBS *(see #9)*.
- Slow & fast exhaust lines *(see #10)*.

The panels are arranged in cabinets that are configured side to side as it is visible in the photos above. This design allows protecting the pipework and electrical devices inside the units, and also the supply lines that are transmitted from one cabinet to another. The inner parts of each cabinet can be accessed from the back which is closed by a specific door.
A corridor is arranged between the backside of the cabinets and the wall of the saturation control room to allow the technicians accessing to the components of the control and gas distribution panels *(see in the pictures on the next page)*.


Corridor for access to the back of cabinets

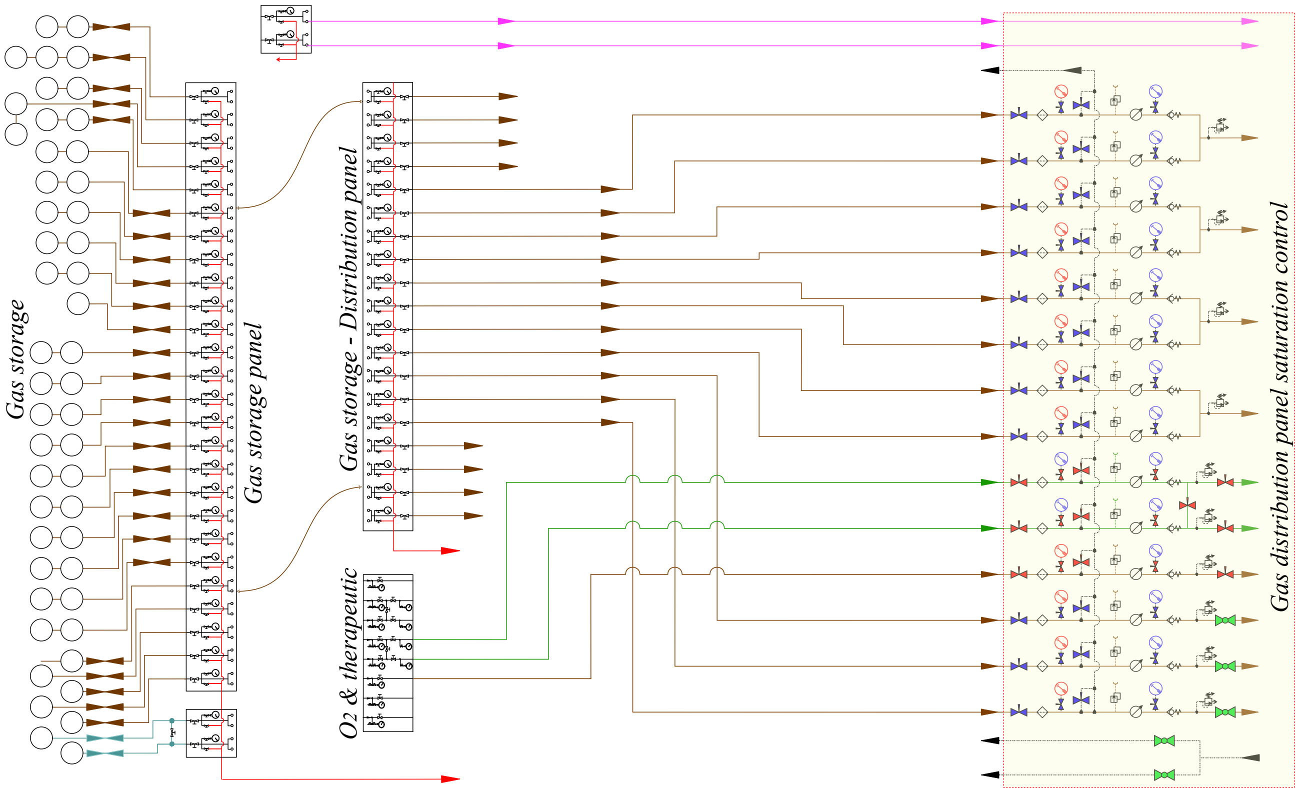

Electronic components inside a cabinet


Pipework inside a cabinet

1.2.8.3 - Gas supplies

- Gas distribution panel:

The control panels are provided with regulated heliox mixes, oxygen, and therapeutic mixes by the "gas distribution panel" *(see #1 in the photo in* point 1.2.8.1*)*. This panel is connected to the "gas storage and distribution system", which is described in point 1.2.6.4, and its supplies must be separate from those of the dive control *(see below)*.

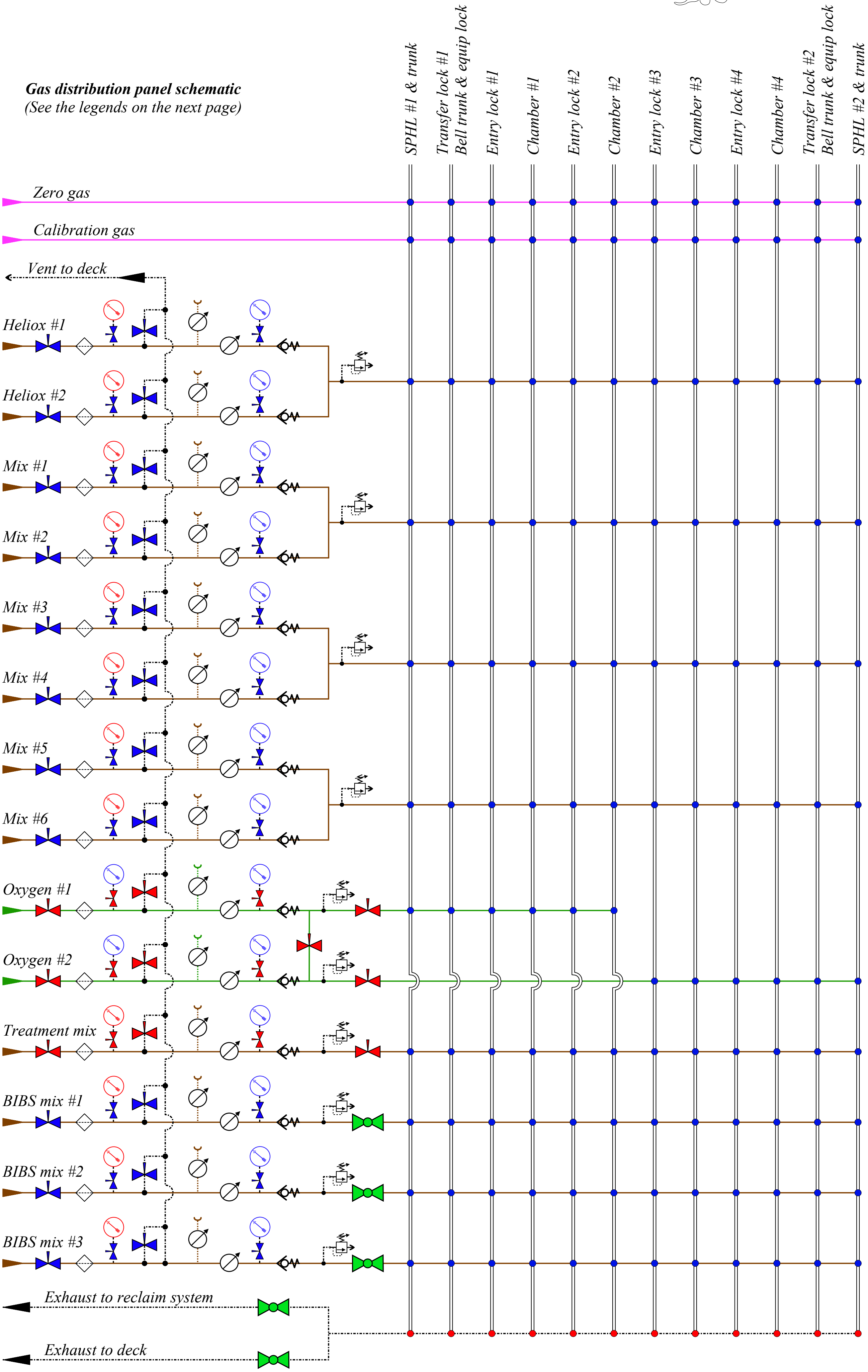


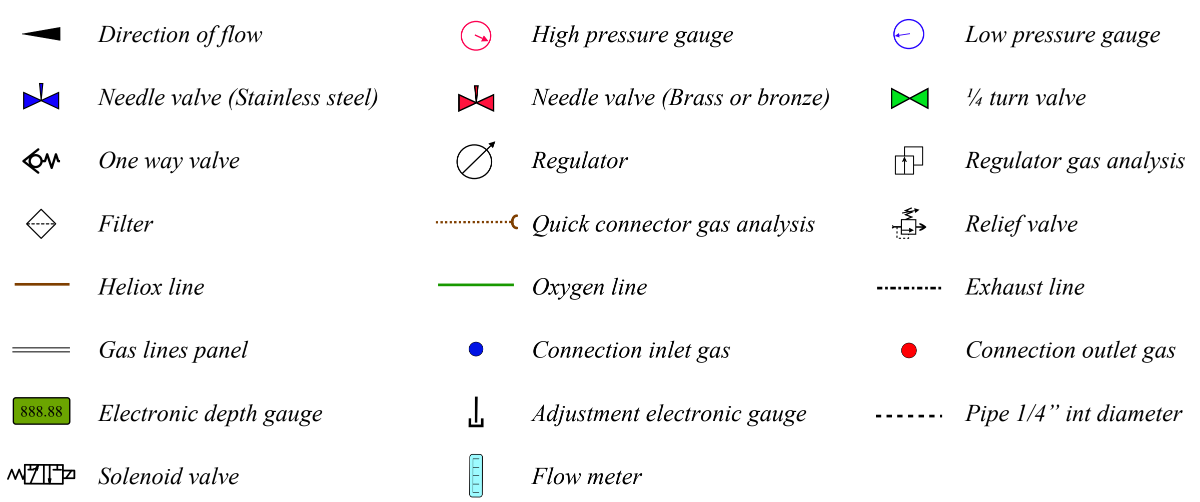
The inlet lines that compose the gas distribution panel are all similar and composed of the following:

- An inlet valve, which is a needle valve, as most mixes are delivered at high pressure.
- A spring-loaded regulator that is designed for the gas delivered and its maximum working pressure. It is protected from impurities by a filter that is installed upstream.
- High and low-pressure gauges that are installed before and after the regulator to show the line pressure of sources coming into the line and also the pressure delivered to the control panel. They are designed according to the IMCA requirements for depth gauges except that they are smaller. Note that there is usually no cross over valves with such panels, so no problem of incorrect reading.
- Relief valves, that are installed to protect the pipework.
- Pipeworks made of tungum, bronze, and brass, to carry oxygen and "rich mixes" (O_2 > 25% or 22% with Norsok standards U100) that are regulated down to 40 bar or less at the source. They must be cleaned for oxygen service. The other lines are usually built with stainless steel.
- Quick connectors 1/4" that are designed to connect analysers. These connectors are optional and not present on some other gas distribution panels. A regulator that is not visible is provided to reduce the pressure of the gas to analyze to an acceptable level.

The scheme on the next page shows the gas lines that compose the gas distribution panel and the units they supply.

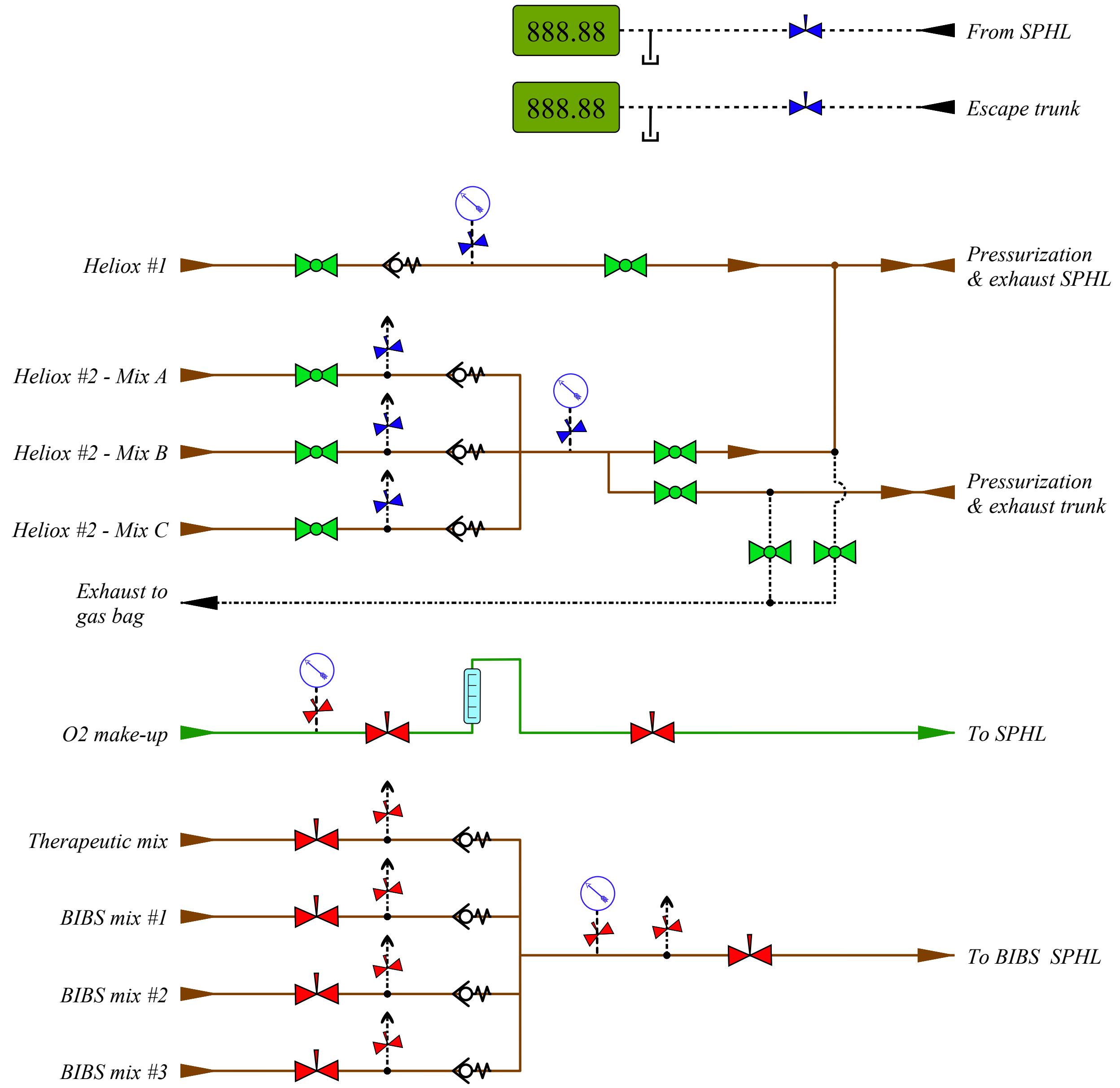
Gas distribution panel schematic
(See the legends on the next page)





- Self Propelled Hyperbaric Lifeboat (SPHL) panel:

With the systems taken as references (UDS Lichtenstein & Picasso), the control panels of the Self Propelled Hyperbaric Lifeboat (SPHL) chambers are situated at the direct proximity of the gas distribution panel *(see #2 & #3 in the photo in* *point 1.2.8.2**)*. These control panels are also used to control the escape trunks to the SPHLs.

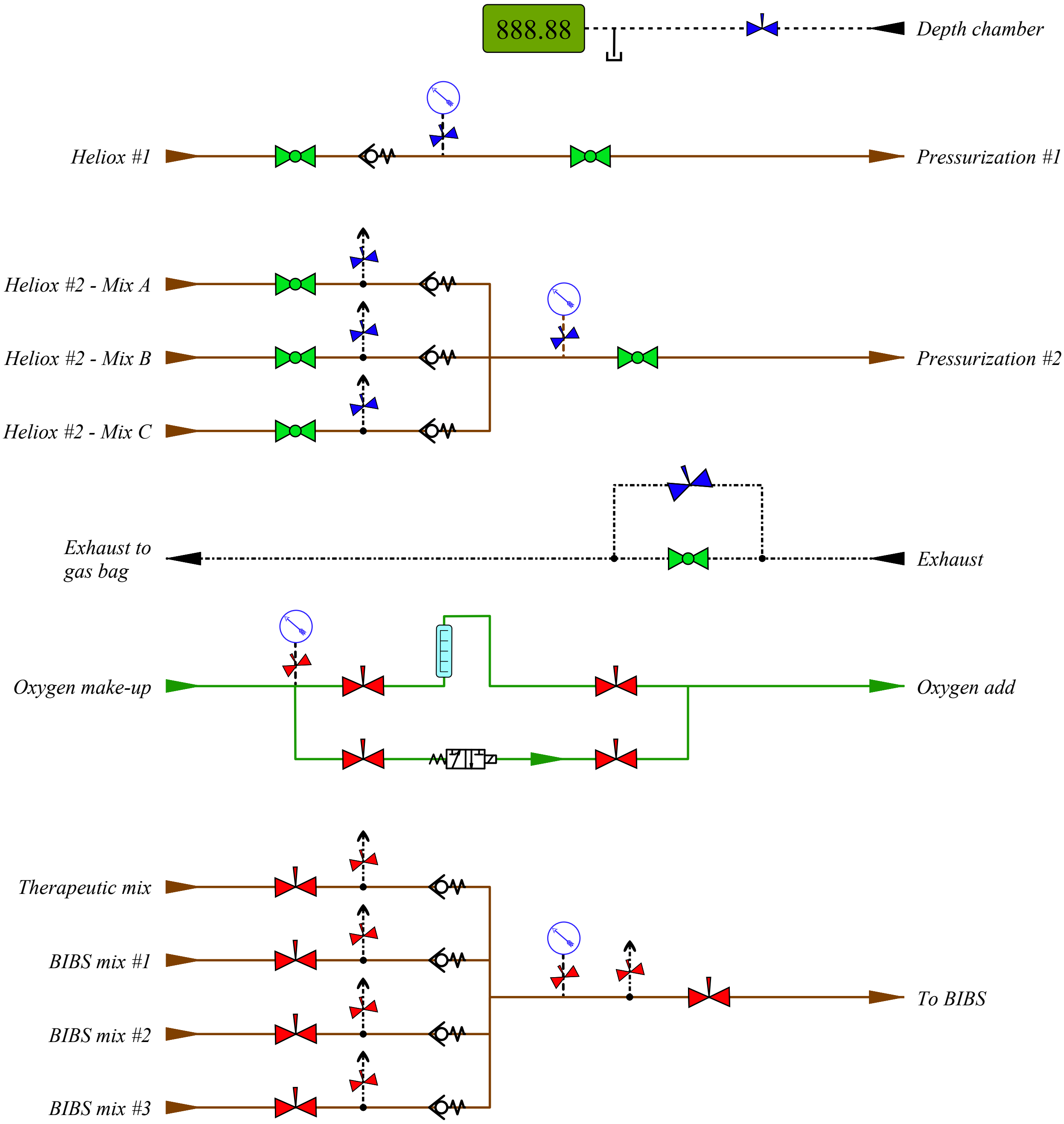


- This panel is designed to manage two devices (SPHL & escape trunk). For this reason an additional depth gauge and controls are provided.
- Pressurization and exhaust are grouped in one line (as with the bell). Each pressurization line has at least two separate gas supplies. Also, gas supply #2 has three sources.

- There is also no “fine decompression” valve of the chamber of the SPHL as it is not planned to perform decompression in it when it is connected to the saturation complex. Thus only one ¼ turn valve is available
- The oxygen make-up of the SPHL is manual only. The reason is that this chamber is an evacuation unit not planned to be used as a living chamber. So the divers will be in it only in case of emergency, or during training and inspection.
- There is one line of therapeutic mix to the BIBS system.
- Three breathing mixes (Not therapeutic) are also available for the BIBS system.

- Living chamber panel

With the systems used as reference the control panels of living chambers #1 & #2 are next to those of the SPHL with the panels of their corresponding entry locks. Thus chamber #1, entry lock #1, chamber #2, and entry lock #2 *(see #5, #6, #7, and #8 in the photo in* *point 1.2.8.2**).*

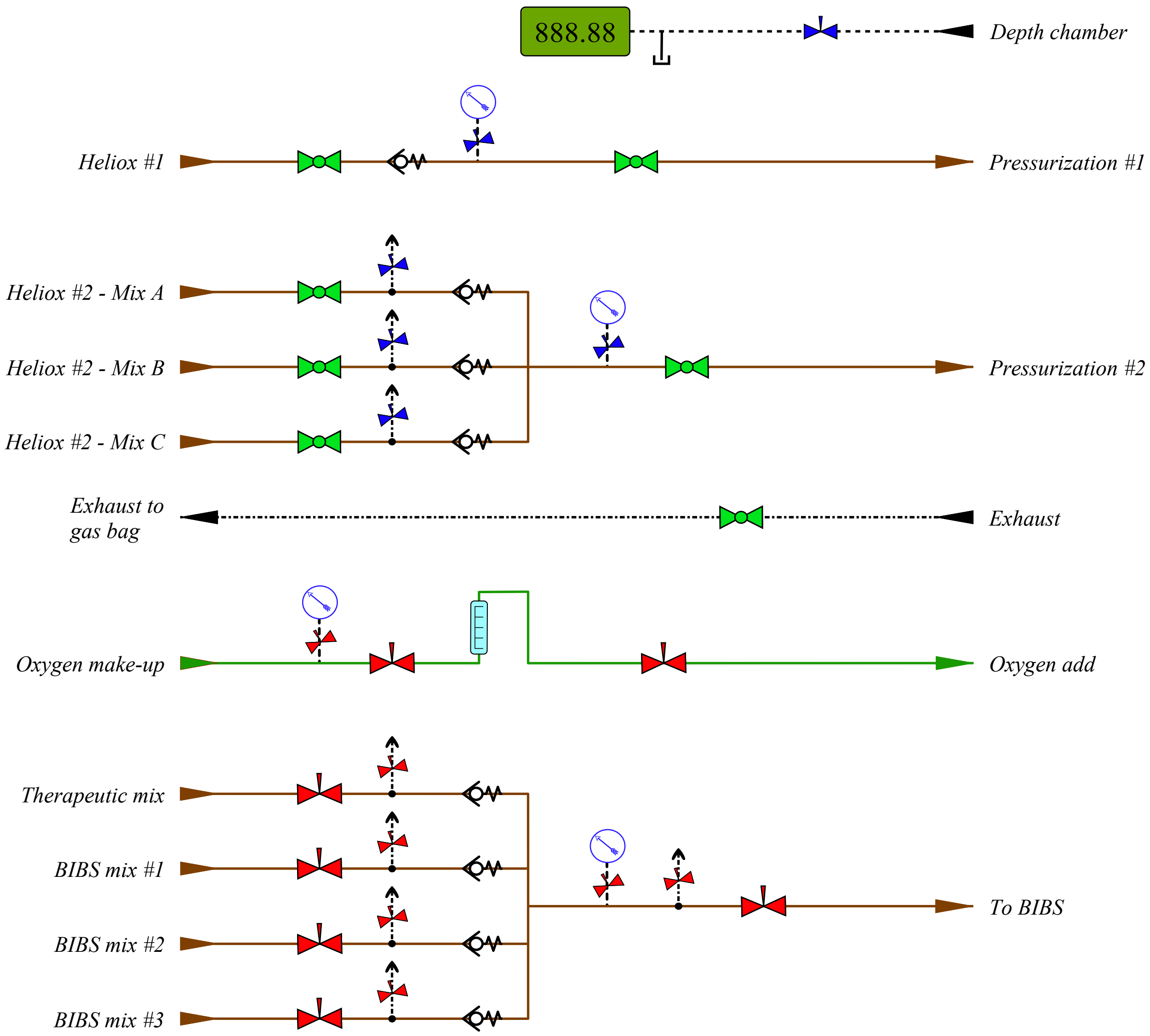


- This panel is designed to manage only one living chamber. It is designed for decompression.
- Pressurization and exhaust lines are separate. There are two pressurization lines with separate gas sources.
- Pressurization line #1 has one gas source and pressurization line #2 has three gas sources.
- Exhaust to the gas bag is designed with a ¼ tun valve that is used for fast recovery and a needle valve that is used for decompression..
- As the chamber is permanently occupied during the operations, the oxygen make-up is manual and automatic. Automatic oxygen add is performed through a solenoid valve. Note that both lines can be fully isolated.
- There is one line of therapeutic mix to the BIBS system.
- Three breathing mixes (Not therapeutic) are also available for the BIBS system.

- Entry lock panel

As indicated, the entry locks' panels are installed aside from the living chambers' panels. This panel is not designed for decompression but provides similar controls as the chamber's panel.

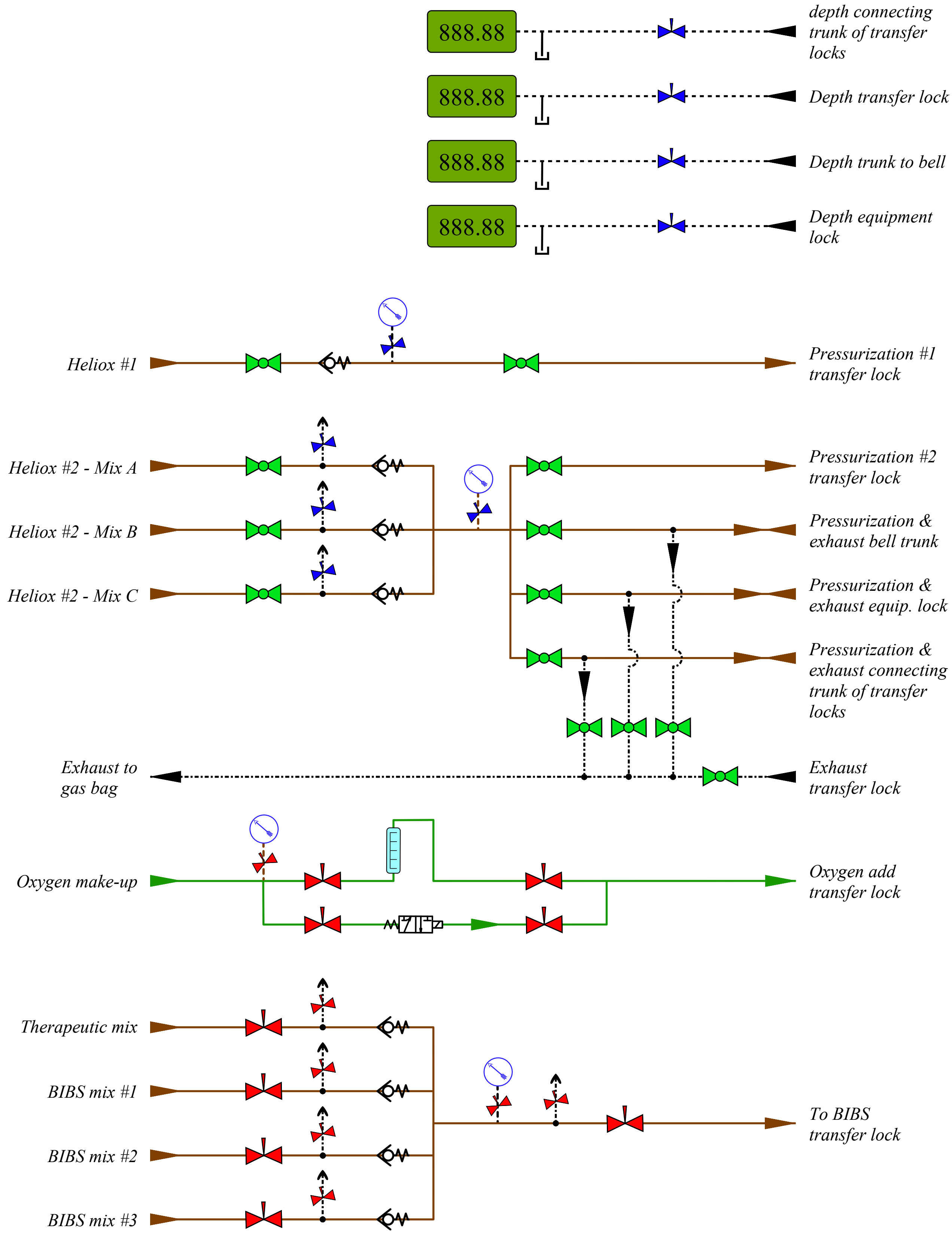
- Pressurization and exhaust lines are separate. There are two pressurization lines with separate gas sources.
- Pressurization line #1 has one gas source and pressurization line #2 has three gas sources.
- Exhaust to the gas bag is designed with a ¼ tun valve that is used for fast recovery . There is no slow decompression valve.
- The entry lock is linked to the chamber by a common Hyperbaric Environment Regeneration System (HERS). For this reason, automatic oxygen make-up is not necessary. However, manual oxygen add is available.
- As with every chamber, there is one line of therapeutic mix to the BIBS system.
- Three breathing mixes (Not therapeutic) are also available for the BIBS system.



- Transfer lock Panel

With the systems taken as references, the entry lock panels are installed between the panel of entry lock #2 and living chamber #3 *(see #9 and #10 in the photo in point 1.2.8.2)*. This panel is designed to manage the connecting trunk of the transfer lock, the transfer lock, the trunk to and from the bell, and the equipment lock. For this reason four depth gauges are provided in addition to additional controls.

- Pressurization and exhaust lines of the entry lock are separate. There are two pressurization lines with separate gas sources. Pressurization line #1 has one gas source and pressurization line #2 has three gas sources.
- Pressurization and exhaust functions of the connecting trunks and the equipment lock are combined in the same pipe. They are supplied by the three gas sources of the pressurization line #2 *(see in the scheme on the next page)*.
- Exhaust to the gas bag is designed with ¼ tun valves. There is no slow decompression valve.
- Oxygen make-up of this lock that is usually frequently used during the diving operations is automatic oxygen and manual. As for the system of the living chambers, these lines can be fully isolated.
- As indicated previously with the other panels, there is one line of therapeutic mix to the BIBS system, and three breathing mixes (Not therapeutic) are available for the BIBS system.



1.2.8.4 - Means for gas analysis

Each breathing gas reservoir should be accompanied by an analysis certificate that describes in detail the gas it contains and the breathing gas standard the analysis refers to. However, a mistake may have been made. For this reason, the gas of each container must be analyzed for conformity by the Life Support Technician in charge before being transferred to the gas storage of the diving system. Also, gasses must be analyzed again before being put in line, and permanently when they are in line. Note that all safety organizations recommend this procedure.

As the mixes used with NORMAM 15 are binary mixes composed of helium and oxygen only, the proportion of these gasses should be checked first. However, the person in charge should also look for pollutants whose maximum proportions are indicated in the standard of gas purity selected. Two categories of analysers are used:

1. Panel analysers are fixed units that are not designed to be transported. They are installed in the saturation and diver control rooms, and on some gas mixing panels.

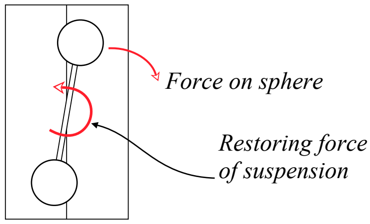
2. Portable analysers are commonly used for the analysis of the content of the gas containers delivered. Some last generation models are very compact and designed to be calibrated with air.

These analysers that can be designed to detect one gas or more, may use one or several systems of detection that are described below. However, note that the industry regularly provides new concepts and products.

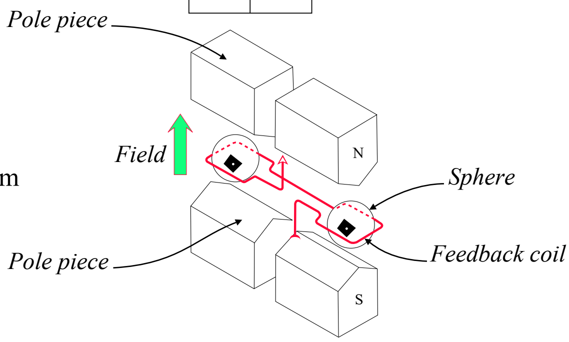
1.2.8.4.1 - Magneto-dynamic (Paramagnetic)

This technology is frequently used with oxygen analysers mounted on panels.
This system is based on the measures of the paramagnetic susceptibility of the sample gas by means of a proven magneto-dynamic type measuring cell.
The paramagnetic susceptibility of oxygen is significantly greater than that of other common gases. This means that oxygen molecules are attracted much more strongly by a magnetic field than are molecules of other gases, most of which are slightly diamagnetic (repelled by a magnetic field).
Magneto-dynamic oxygen analysers are based upon Faraday’s method of determining the magnetic force developed by a strong non-uniform field on a diamagnetic test body suspended in the sample gas.

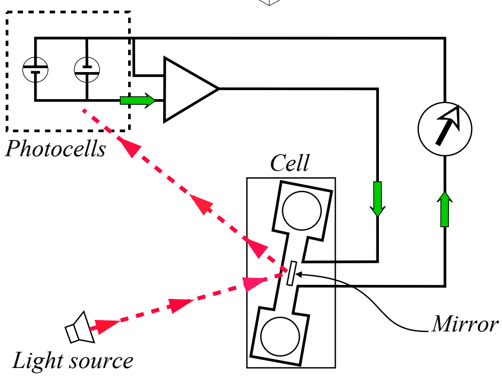
- The test body of all measuring cells oxygen analysers consists of two nitrogen-filled quartz spheres arranged in the form of a dumb-bell.



- A single turn of fine platinum wire (the feedback coil) is secured in place around the dumb-bell. A rugged taut band platinum ribbon suspension, attached to the midpoint of the dumb-bell, positions the dumb-bell in the strong non-uniform magnetic field between the pole pieces of the permanent magnetic structure.

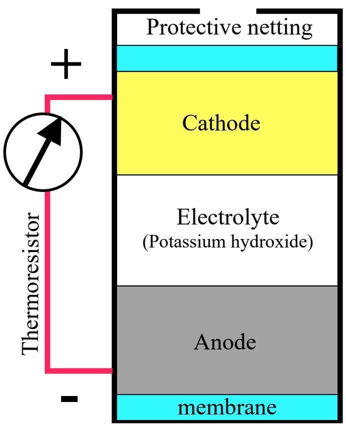


- The angular rotation of the dumb-bell is sensed by a light beam projected onto a mirror attached to the dumb-bell from which it is reflected onto a pair of photocells. The difference in the outputs from these photocells is fed to an amplifier whose output is zero when both photocells are illuminated equally.



1.2.8.4.2 - Fuel cell analysers

Fuel cell analysers are widely used to detect oxygen, because they are robust, lightweight and suitable for remote readings. They are often used with portable or fixed analysers due to these advantages.
The device attached to the gauge allows either a measurement of the partial pressure or a measurement in expanded gas (percentage).



- The O_2 sensor acts as a battery.
- The difference of potentials between anode and cathode is going to be proportional to the quantity of oxygen which will go through a semi-permeable membrane (capillary barrier) and will ionise at the contact with the cathode and will oxidise the anode.
- The lead anode and copper/beryllium cathode are plunged in an electrolyte (a solution of potassium hydroxide).
- A semi-permeable membrane allows the gas to pass through and forbids the electrolyte to follow.
- Between the anode and cathode a thermo-regulator compensates the temperature variations.
- The cell may be fitted inside or outside the analyser with the gas sample flowing over it, or placed in a chamber and connected to the analyser in the control room.

A fuel cell analyser should be calibrated with a zero gas and scale gas, but it must be noticed that a lot of new models can

be calibrated with air (for example : “Analox” O2EII). The calibration with air is based on the fact that fresh air has a proportion 20.9% oxygen. To increase accuracy, the manufacturers provide a humidity compensation chart with each instrument, to show whether to use 20.9% or some slightly lower value when calibrating. Calibration with air can be considered reliable for surface supplied diving, nevertheless the monitoring of saturation diving requires more accuracy, and the use of calibration gas instead of air is recommended.
Also, errors may be caused by condensation on the fuel cell, changes in chamber temperature, changes in the temperature of the wires carrying the signal to the analyser and radio transmissions and other electromagnetic fields.

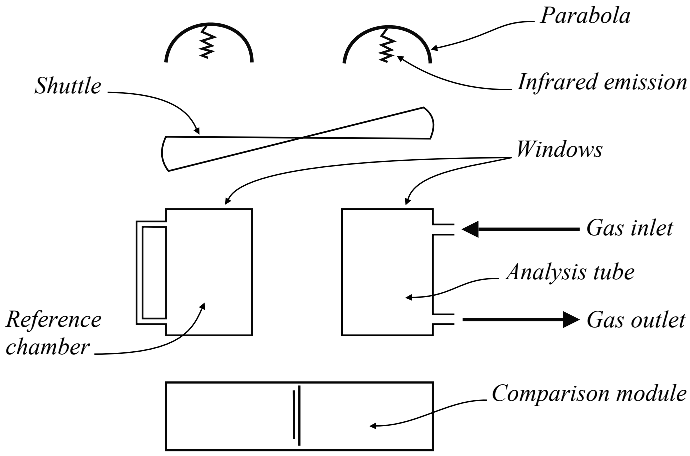
Since the fuel cell is a battery, it will run out, normally in about six months, but depending on the concentration of oxygen in the gas analysed, it will often be less. Erratic reading is an indicator that the cell needs to be changed.

1.2.8.4.3 - Infra-red analysers

This technology is used to detect carbon dioxide
It is also frequently employed for analysers mounted on panels.
It relies on the fact that each gas absorbs specific wavelengths of radiation.

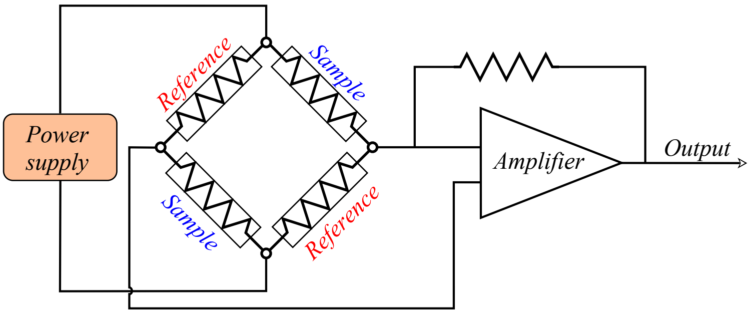
- Equal infra-red beams of the appropriate wavelength are shone onto two cells. One cell contains a reference gas, and the other cell contains the sample gas.
- The sample gas absorbs radiation in proportion to its carbon dioxide content and heats up.
- By comparing the temperature rise with the temperature of the reference cell, the proportion of carbon dioxide can be measured.

Calibration normally requires a zero gas and scale gas



1.2.8.4.4 - Thermal conductivity detectors (also called universal detectors)

This system is found on fixed and portable analysers.
It consists of an electrically heated filament in a temperature-controlled cell. Under normal conditions there is a stable heat flow from the filament to the detector body. When a gas is introduced and the thermal conductivity of the column effluent is reduced, the filament heats up and changes resistance. This resistance change is sensed by an electronic circuit which produces a measurable voltage change.
As for the infrared analysers, thermal analysers comprise two chambers, each with an identical thermal conductivity sensor. The reference chamber is filled with a reference gas, and the other receives the gas to analyse. The difference in thermal conductivity of the reference and gas to be analysed is measured and converted into a concentration value by the electronic circuitry in the instrument.



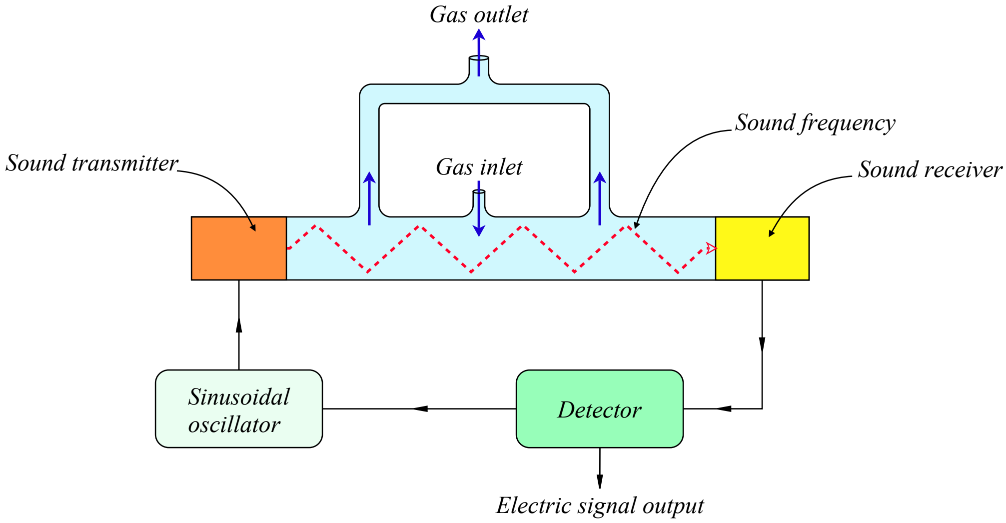
Thermal conductivity is used to detect various gases such as:

- Oxygen
- Helium
- Carbon dioxide
- Carbon monoxide
- Nitrogen
- Hydrogen
- Methane and various hydrocarbons

1.2.8.4.5 - Acoustic Gas Analysis (Also called speed of sound)

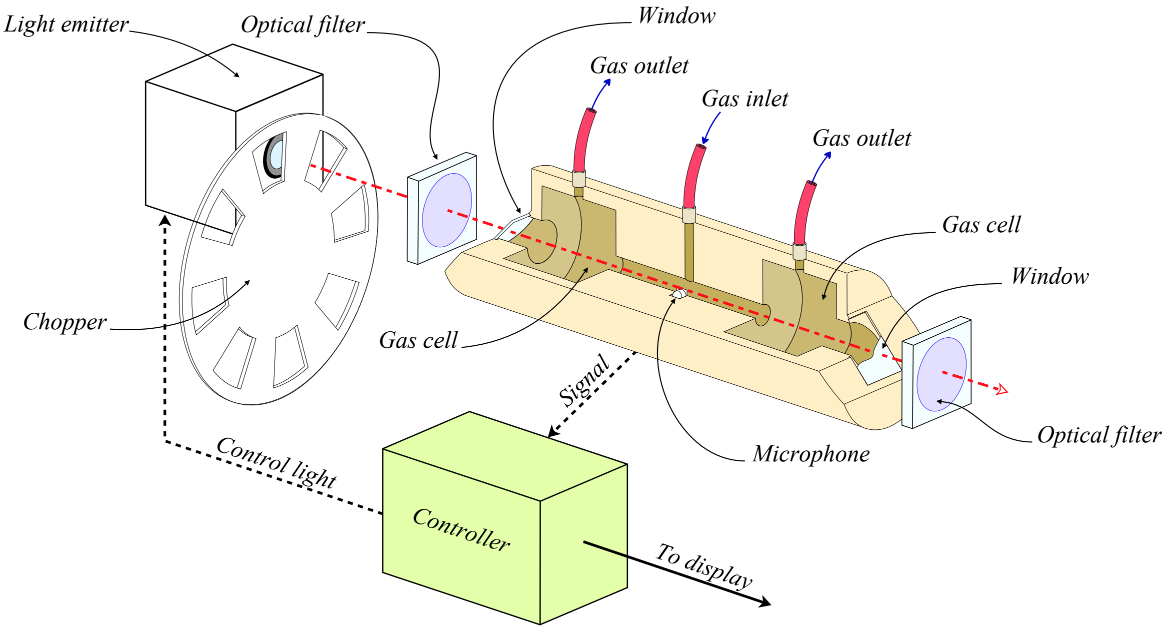
Acoustic Gas Analysing (AGA) is a technology that consists of measuring the speed of sound through a mix to evaluate its components. It is used by scientists in laboratories and adopted by analysers that are used for diving activities. It is the case of the “Analyzer Solo” proposed by Divesoft, which is a portable analyzer that detects oxygen and helium and is offered to advanced sportive divers using trimix blends.

This system that is usually calibrated with air is composed of a small chamber that is filled with the gas to analyze.
A sound at a particular frequency is emitted at one end of this chamber and received by a dedicated sensor at the other end. The speed of the sound depends on the gas the operator is looking for, the temperature of the mix, the humidity of the mix, and the frequency of the sound emitted.
The differences of sound propagation in the sample chamber are recorded by a detector that converts them into an output voltage in proportion with the difference with the calibration sample, which is displayed on a screen and allows evaluating the percentage of gas the operator is looking for.



1.2.8.4.6 - Photo-acoustic gas analysers

Photo-acoustic spectroscopy is the measurement of the effect of absorbed electromagnetic energy (particularly light) on the matter using acoustic detection.
The system consists of a light, commonly an infrared laser, that is used to excite a gaseous molecule that absorbs its electromagnetic radiation. By modulating this radiation source, the temperature changes periodically, giving rise to a periodical pressure change, which can be observed as an audible signal which can be detected with a sensitive microphone. These sounds are converted into electric signals that are sent to the display.



These analysers can detect all the gasses used in the diving industry and their potential pollutants with a very high accuracy. They are currently used for:

- Gas detection in laboratories.
- Monitoring gasses in maritime applications.
- Leak detection in oil and gas industries.
- Detection of toxic gasses and explosives.
- Food Quality Assurance, and others

Portable models are proposed by some manufacturers, as an example NxPAS and SIGAS

1.2.8.4.7 - Chemical sampling tubes (also called colorimetric tubes)

Colorimetric tubes were widely used for carbon dioxide analysis in the diving bell, and even though other systems have replaced them, they should be available in chambers and the dive and saturation control rooms. The range of chemical

sampling tubes is very vast, and for this reason, they are often used to test gas supplies for various contaminants that may be present, such as carbon monoxide, oil, hydrocarbons, and others.
The most widely used chemical sampling tubes are probably those manufactured by Dräger. It is the reason they are commonly described as Dräger tubes. However other manufacturers, as an example SKC, provide similar products.

The system consists of a glass tube that contains a chemical which changes colour in proportion to the amount of the sample gas drawn through the tube. The tubes are usually calibrated in percentage or parts per million, for use on the surface, but actually, measure the partial pressure of the gas.
If a chamber or bell atmosphere is sampled using a tube on the surface, there is no need to make any correction to the reading. However, if the tube is used under pressure, a correction needs to be applied. For a true percentage or parts per million, the scale reading should be divided by the absolute pressure in bars. For a true partial pressure, regardless of depth, the percentage scale reading should be divided by 100 or parts per million scale reading by 1,000,000.
Colourmetric tubes have the advantage of being transportable and easy to operate, nevertheless they are not very precise (15%). Another problem is that they may have limited validity time.

The method for using a tube depends on the manufacturer's instructions. However, the typical procedure is as follows:

- There may be different models of pumps, and the volume of gas drawn through the tube is critical. For this reason, the person in charge of providing such equipment should ensure that the model supplied is correct for the tubes to be used before starting the diving project. The condition of the pump must also be checked.
- The operator ensures he has the correct tube for the gas to be analysed and that it is in-date.
- The operator verify the number of pumps needed, which is normally indicated on the tube.
- The pump should be checked by fitting the unbroken tube into the pump and exhausting the bellows. The pump should not re-inflate. If it does, it is leaking and the reading will be inaccurate.
- When the checks are completed, the operator breaks the ends off the glass tube and fit it into the pump with the arrow pointing towards the pump. The gas is then drawn through the tube.
- The operator exhausts the bellows and allows them to re-fill entirely at their own speed. The chain on the pump must be tight before exhausting the bellows again.
- If the tube shows adequate coloration after one pump, the operator takes a reading from the one pump scale. If not, he carries on for the maximum number of pumps shown.
- If there is no discolouration at all, some tubes can be sealed with the rubber caps provided and re-used up to two more times. Check the manufacturer's instructions.

1.2.8.5 - Last generation analysers designed for chambers' control panels

Analysers used with chambers' control panels are usually of the same model of those used in the dive control. They should provide the operator with a clear and accurate display of the gas concentrations within the chambers and the gas supply lines being monitored. The values are displayed as follows.

- Concentration of a gas: Percentage (%) and part per million(PPM) are commonly used.
- Pressures: Bar and millibar (mbar) are today the most employed units of measure (1 bar = 100000 Pa). However, PSI (pound per square inch) and Atmosphere (atm) are the preferred units in several areas. Note that NORSOK uses kilopascals (KPa) to quantify small pressures (1 KPa = 10 mbar) in some documents. However, this unit is unusual with the analysers commonly found in dive & saturation controls.
- Gas flow rate: Litres per minute (L/min) is the most used unit.
- Depth: Metres of seawater (MSW) becomes the preferred unit. However, feet of seawater (FSW), continue to be used in a lot of countries.
- Time: Hours, minutes and seconds.

The last generation analysers are designed with digital technologies and offer more functions than the previous analogic models. As an example, manufacturers such as Fathom systems, a company based in the United Kingdom, group the analysers in modules that are designed to analyze the O2 and CO2 at the same time and can display some measurements in different units. As an example, oxygen can be shown in percentage and partial pressure at the same time.
Also, these analysers are connected to a computer system through Ethernet link. Note that the "master" is the oxygen analyser displaying results in percentages and that the other analysers of the group act as "slaves" *(In computer networking, master/slave is a model for a communication protocol in which one device or process, known as the master, controls one or more other devices or processes, which are known as slaves)*. In addition the systems of alarms have been reinforced so the diving supervisor is informed more precisely of the problem occurring. As an example, with the analysers taken as reference, the alarms generated by the system can have one of three different states:

I - No Alarm: All parameters are within the acceptable limits / set-points. In this case, the display is green, the Alarm LED is off and there are no spoken warning messages.

II - Active Alarm: It is caused by a parameter moving outside its alarm threshold set-point (or the set-point being changed to put the parameter into an alarm state). As a result, the display flashes between Red and Green, the Alarm LED on the front panel flashes and warning messages are produced every 30 seconds.

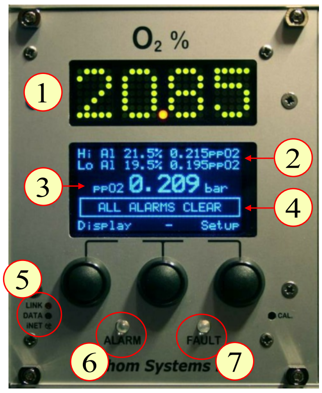
III - Accepted Alarm: An alarm that has occurred has been acknowledged or accepted by the operator (by pressing the appropriate front-panel button). In this case, and provided there are no other active alarms, the display changes to solid red, the alarm LED remains on red (not flashing) and the audible alarm is silenced. This state continues until the parameter returns to a healthy condition or the set-point is modified to be outside an alarm condition.

Note that a second red warning LED that indicates the presence of a fault is on the front panel. This LED flashes and a warning message is generated when there is a system fault present such as follows:

- Incorrect supply voltages
- Failure of sensor sub-systems or components
- Sensors not correctly calibrated
- Missing data communications with external devices / systems
- Internal temperature too high

Also, three additional small LED indicators are on the front panel of the O2 analyser to provide the following information about the telemetry status:

- Link LED indicates when the Ethernet cable is connected to the network.
- Data LED flashes when data is being transmitted or received
- Inet LED flashes when the %O2 master analyser is transmitting data to other modules in the same rack.



#1 Main display (no alarm)

#2 Calibration setup

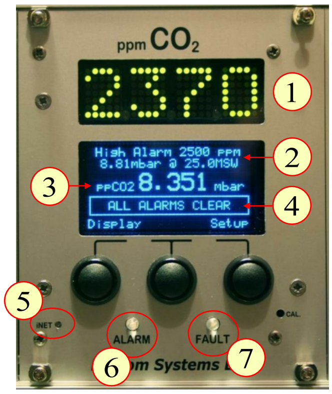
#3 2nd display in Partial Pressure

#4 Alarm display (all clear)

#5 Telemetry status

#6 Alarm LED light

#7 Fault LED light



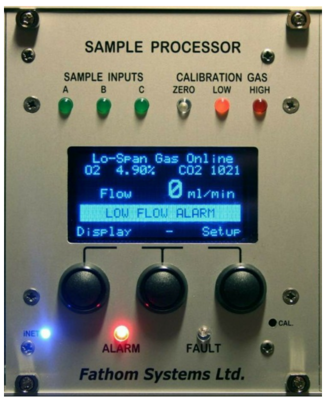
With the new systems described for example, the sample and calibration gases being sent to the CO2 slave and O2 master analysers are managed by the "sample processor", which is a slave module.

With this module, the classical flowmeter that is usually operated manually is replaced by a sensor that measures the mass-flow of gas through the system. The Sample processor automatically calculates the gas density (based on either the known calibration gas oxygen concentration or from the O2 concentration measured by the O2 analyser), and this figure is used to convert the mass-flow measured into a volumetric flow that is displayed on the sample processor displays. The flow rate is normally set between 80 ml/min to 100 ml/min for all gases including calibration gases. Two input versions are proposed by the manufacturer:

A - The single sample version is normally used where the sample to the analyser is not normally changed or 'patched' between different samples. Usually, four quick-connect couplings are available on the rear of the device: One for the zero gas, one for the low span calibration gas, one for the high span calibration gas, and one for the sample to be analysed. However some models have an additional calibration gas (medium).

B - The 3-inputs version allows one of three different samples to be selected by the user, and 'switched' internally by the Sample Processor unit. As a result, six quick-connect couplings are available on the rear of the device: One for the zero gas, one for the low span calibration gas, one for the high span calibration gas, and three for the samples to be analysed.

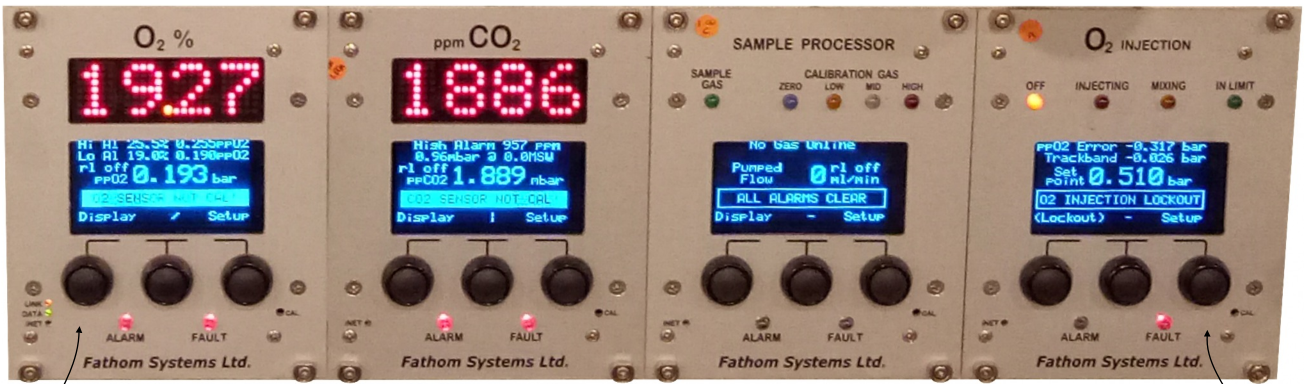
Lights corresponding to the rear inputs are displayed on the front of the device and indicate which gas is monitored by the machine *(see #1 in the photo on the side)*. .
A message is also displayed on the small screen to indicate which operation is ongoing and the flow rate *(see #2)*.
Also, a sample pump is available when there is insufficient pressure from the chambers to allow a suitable sample flow rate at the end of a decompression. However, this pump is normally unnecessary for bell monitoring.
In addition to managing the online gas selection and controlling / measuring gas flow accurately, the sample processor is also able to raise alarms in the event of high or low gas flow conditions, and coordinate an automated calibration process.
Alarms are displayed and processed in the same way as the O2 master analyser *(see #3 & #4 in the photo on the side)*.
The sample processor, and all the analysers can be calibrated using a small screw driver through the hole labelled "CAL" *(see #5)*.



1.2.8.6 - Oxygen injection system

The oxygen injection system in service in the saturation systems of reference is also designed by Fathom. It is based on a controller that is part of the analysing system indicated above. This controller acts as a slave module that allows the Life Support Supervisor (LSS) to set the appropriate partial pressure for the diving operations being carried out, and the unit controls an external O2 injection solenoid valve that adds oxygen to the chamber automatically *(See in the schemes of the previous point)*. This system is an example of the last generation units that is designed as follows:

- Injection decisions are based on the oxygen partial pressure recorded by the analysing system.
- An injection control system allows for efficient and predictable O2 mixing periods. Also, an optional audible warning is given during injection periods. The O2 injection solenoid is powered from an external power supply switched by the internal safety relays inside the oxygen injection controller.
- The injection activity is checked by a separate hyperbaric fuel-cell transducer to ensure that the oxygen is reaching the correct PPO2 in the chamber. The hyperbaric fuel cell used is a standard electrochemical type. This fuel-cell is connected to the controller via a twisted screened pair cable from inside the chamber.
- An independent safety engine microprocessor monitors the primary Injection Controller microprocessor and locks out the Injection function in the event of any malfunction. This hardware, which is called "watchdog", automatically detects software anomalies and reset the processor if any occur, to protect the microprocessor integrity. "Watchdog" is also called Computer Operating Properly (COP) timer.
- The oxygen injection solenoid is controlled by two safety relays in series using forcibly guided contacts.
- A system is provided to lock out the controller in the absence of sufficient and correct sample gas flow, in the event of an analyser fault, in the absence of an O2 or depth signal, and during calibration. As a result, the following conditions must be in place for the oxygen injection being allowed.
    - There must be a valid oxygen partial pressure sample reading from the %O2 Master Analyser. That requires that the paramagnetic sensor signal is calibrated and good and that the system depth signal is present.
    - There must be a valid hyperbaric fuel-cell oxygen partial pressure sensor signal and this sensor must be calibrated correctly.
    - The sample "A" *(on 3-input sample processors)* or the only sample *(for single input sample processors)* must be selected online.
    - There must be a satisfactory gas flow.
    - There must be a correlation between the sample ppO2 reading and the hyperbaric fuel-cell oxygen partial pressure reading, and this must be within the set track band figure.
    - The analyzer cannot be in calibration or have a system fault present.
    - The safety engine microprocessor must be in good condition and must confirm that the state of the main system microprocessor is satisfactory.
- The system automatically changes from PPO2 mode to % O2 mode at a preset depth during the decompression.
- Also, the machine provides diagnostics to inform the LSS of system status.



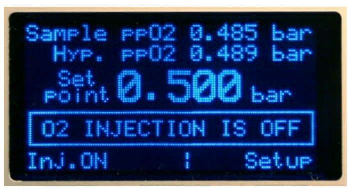
Oxygen analyser (master)

Note that the oxygen injection is installed in place of the slave oxygen analyser of the group of modules used in the dive control.

Oxygen injection (slave)

The panel of the controller is designed with four lights and a multi-function Vacuum Fluorescent Display (VFD) that indicate the operation ongoing and provide a variety of information to the operator. Also, the manufacturer says that the oxygen injection is based on 200-second cycles that are performed and can be monitored as follows:

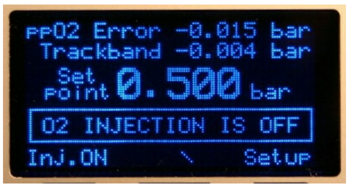
1. Oxygen injection off:
   This mode can be selected by the operator (by turning off the function) or can be the result of an automatic trip that disables the injection for safety reasons. As a result, the controller is idle and does not inject oxygen.
   - The light "off" is illuminated.
   - The display alternates the top two display lines every few seconds. The displayed parameters are as follows:
       - Display 1:



           - "Sample ppO2" is the calculated oxygen partial pressure value converted to partial pressure at the working depth which is displayed in bars.
           - "Hyp. PPO2" is the partial pressure of oxygen measured by the hyperbaric fuel-cell inside the chamber.
       - Display 2:
           - "PPO2 Error" is the difference in partial pressure between the ppO2 set-point and the actual sample ppO2 reading. A negative

error means that the chamber requires O_2 to be injected.

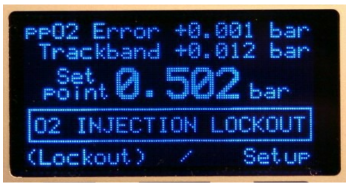
- "Trackband" is the difference between the PPO_2 sample reading and the hyperbaric PPO_2 reading from the fuel-cell. If the system is operating correctly, the hyperbaric fuel-cell PPO_2 reading tracks the calculated sample PPO_2 value. The system will shut down the oxygen injection function if the trackband error exceeds an adjustable threshold.
- "Set Pont" is the current O_2 Injection controller desired set-point. When operating at less than 16 MSW, this value is expressed in $\%O_2$.
- "Status box" shows the current O_2 injection controller operating mode. This box also shows any alarm or error status information.
- "Inj. ON" soft menu button turns the O_2 Injection function on.
- "Setup" soft menu button accesses the setup pages for the controller.



2. Oxygen injection switched on - PPO_2 within the setup limits:
When the injection is switched on, the current ppO_2 is calculated and compared to the desired set-point. If the PPO_2 is within the setup limits no injection takes place, and the system repeatedly calculates the injection parameters but no O_2 is added until the oxygen level falls below the injection threshold.
   - The light "In limit" is illuminated to indicate that the concentration of oxygen inside the chamber is within the tolerance band previously setup.
   - The "status box" in the display Indicates "O_2 is in limit".

3. Oxygen injection switched on - PPO_2 below the setup limits - Controller calculating the needs:
As indicated above, the system permanently monitors the PPO_2 in the chamber. If the actual PPO_2 value is below the threshold and requiring O_2 make-up, the duration in seconds for injection is calculated and the 200 second cycle is started.
The duration of the injection period is based on the magnitude of the concentration to return within the setup values: The further below the desired set-point the actual chamber reading is, the longer the time of injection of oxygen.
   - The "status box" in the display indicates "Calculating".

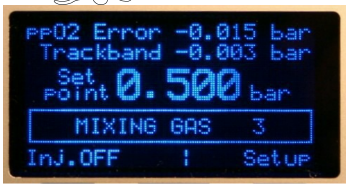
4. Oxygen injection switched on - PPO_2 below the setup limits - Controller checking for safety:
Before injecting, the machine performs safety checks to ensure that it is safe to allow for injection.
If all the conditions are in place for injection, the process can start.
If a critical condition is not met, the oxygen "injection controller" is locked out to prevent unsafe injection of O_2 into the chamber. In this case, the injection cannot start until the problem detected is resolved.
   - The "status box" in the display goes to the next step (injection) if the controller allows for it.
   - The "status box" in the display indicates "O_2 injection lockout" if a critical condition is not met *(see on the side)*. The error is also detailed in the menu. The light "fault" is illuminated.



5. Oxygen injection switched on - PPO_2 below the setup limits - Injecting oxygen:
When the safety checks are completed, and if it is safe for injection, the internal relays are energized, so the oxygen solenoid valve is opened for a duration that is based on the calculation made in step #3 above. This duration can range from 1 second up to a maximum of 100 seconds.
   - The light "injecting" is illuminated during this period.
   - The "status box" in the display indicates "O_2 injection lockout".

6. Oxygen injection switched on - PPO_2 below the setup limits - Mixing period:
At the end of the injection time, the oxygen solenoid valve is closed for the mixing period where the injected oxygen mixes and disperses inside the chamber. For this reason,no further injection takes place until it has expired. This period takes the remaining time in the 200-second injection cycle.

- The light “mixing” is illumined during this time.
- The “status box” in the display indicates “Mixing gas” *(see on the side)*.



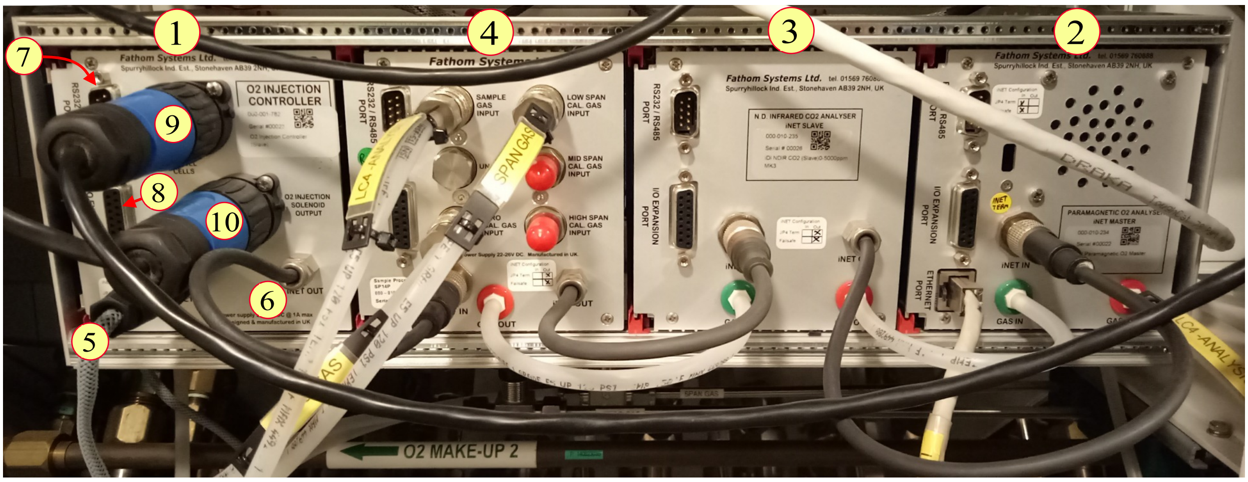
7. Oxygen injection switched on - Continuation of the oxygen injection process after mixing:
   When the mixing is completed, the current PPO2 is calculated and compared to the desired set-point. So the process of oxygen injection starts again from point #2.

The multi-function Vacuum Fluorescent Display (VFD) that provides messages and information is also used to check or set-up the system operating parameters. The operator can access them through the following menus using the three buttons under the display screen:

- Oxygen partial pressure to %O2 changeover point:
  For depths deeper than the “percent threshold”, which is set up at 16 MSW by default, the desired injection set-point is specified in ppO2. When the chamber depth reaches the “percent threshold” during decompression, the system automatically switches to maintaining the surface equivalent percentage set-point that has been configured. This “percent threshold” can be modified.
- Fuel cell calibration:
  Fuel cells must be periodically re-calibrated. As it is not possible to enter the chambers to do it when they are at depth, the controller offers two calibration modes:
  A full two-points calibration that requires a zero gas to be applied to the fuel-cell, and a span only calibration mode. where the electrical zero-point is forced by electrically shorting out the input to the controller’s fuel-cell instrumentation amplifier. When the calibration mode is selected, the machine perform the operations automatically.
- Trackband adjustment:
  The User can adjust how close the oxygen partial pressure sample and hyperbaric PPO2 from the fuel-cell can be before a “track band error” is generated. The required value depends on two-man factors:
  1. The quality/efficiency of the gas mixing within the chamber.
  2. The Sample line response time from the chamber.

  The manufacturer says that this value should be determined experimentally for each chamber by looking at the differences between the partial pressure of the oxygen sample and the hyperbaric PPO2 when the injection is activated. Once these figures are established, the track band figure should be set to a value slightly larger than the most significant difference observed. The manufacturer recommends a figure between 30 mbar and 60 mbar as a starting point.
- Safety Engine Status Displays
  The safety engine status can be displayed to ensure that it works correctly.
  The safety engine has its own Electrically Erasable Programmable Read-Only Memory (EEPROM) that stores its serial number that must match with the serial number of the main processor; otherwise, the controller is locked out. These serial numbers, which are bound together when the controller is manufactured, can be checked through this menu.
- Resetting to factory default settings:
  The controller settings can be restored to factory defaults if required. As with any computer, this action results that all calibration and setup data are lost. For this reason, that is usually carried out if there is a system fault that cannot be rectified, or to follow advice from the manufacturer.
- Resetting Controller
  The oxygen injection controller can be reset rather than powering down the entire rack if required.

Connectors fitted to the oxygen injection controller are accessible at the rear of the unit. They are visible on the photo below *(see #1)* with the master module, which is the oxygen analyser *(see #2)*, and the CO2 analyzer *(see #3)* and sample processor module *(see #4)* that, similarly to the O2 controller, are slave modules.



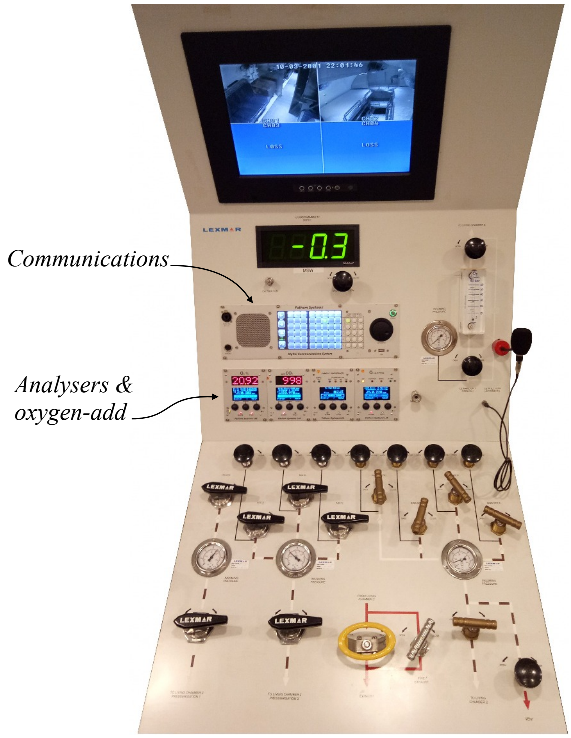
- The “iNET in” connector *(see #5 in the photo on the previous page)* is used to connect the 24 volts DC power to the injection controller module. It is an industry standard “5-pole M12 male panel-mounting type” similar to the one of the oxygen analyzer master module *(see point 1.2.8.5)*. As the oxygen injection controller occupies the furthest slot from the master module in the installation rack, the iNET input comes directly from the 24 volts power supply module.
- The “iNET out” connector *(see #6 in the photo on the previous page)* connects the 24 volts DC power to the next module in the installation rack (usually the “sample Processor module”). An industry standard “5-pole M12 female cable mounted type” is used as with the other modules in the installation rack.
- A RS232 / RS485 port *(see #7 in the photo on the previous page)* is in place , but the manufacturer says that it is unused on this module.
  Recommended Standard 232 (RS-232) refers to a standard for serial communication transmission of data which defines the signals connecting between a Data Terminal Equipment (DTE) such as a computer terminal, and a data circuit-terminating equipment or Data Communication Equipment (DCE) such as modems, printers, computer mice, data storage, uninterruptible power supplies, and other peripheral devices. RS232 serial link is found on any desktop.
- An Input/Output expansion port (I/O expansion port) is also in place *(see #8 in the photo on the previous page)*. This port is a computer socket that connects the central processing unit (CPU), also called a central processor or main processor, to a peripheral device via a hardware interface or to the network via a network interface. Only the pins #14 and #15 are used for transistor ground and reference with this unit.
- The Oxygen fuel cell connector *(see #9 in the photo on the previous page)* is a “7-pin Amphenol C16-1 male bulkhead connector”. It is a circular waterproof connector that is fabricated by Amphenol, a reputed brand for such devices. Such connectors are used for measuring and controlling applications, as well as for power supply. Only a few pins of this connector are used to connect the injection controller module to the fuel cell in the chamber.
- The O2 injection solenoid output *(see #10 in the photo on the previous page)* is a “4-pin Amphenol C16-1 male bulkhead connector” which characteristics are similar to those described above, except that there are only four pins that are used to connect the injection controller module to the solenoid valve.

Note that a lot of saturation complexes are not equipped with this last generation automatic oxygen add system. In this case, the oxygen can be proportioned through a solenoid valve which frequencies of opening and closure can be manually adjusted according to the needs (but there is no module to calculate the actual dosage), or through an injection orifice from which the oxygen proportion can be modified by playing on the supply pressure of the regulator to increase or decrease the flow of gas delivered. These systems are less precise than the one presented above.
Note that when an automatic oxygen add system is installed a separate manual oxygen add must be present as a backup. Also the automatic system must be designed so it cannot fail in on position and flood the chamber with O_2. Also, manual oxygen make up systems must have a flow indicator on the downstream side of the make-up line to indicate that oxygen is flowing into the chamber. It is the case with the diving systems taken as references *(see in the previous schemes)*.

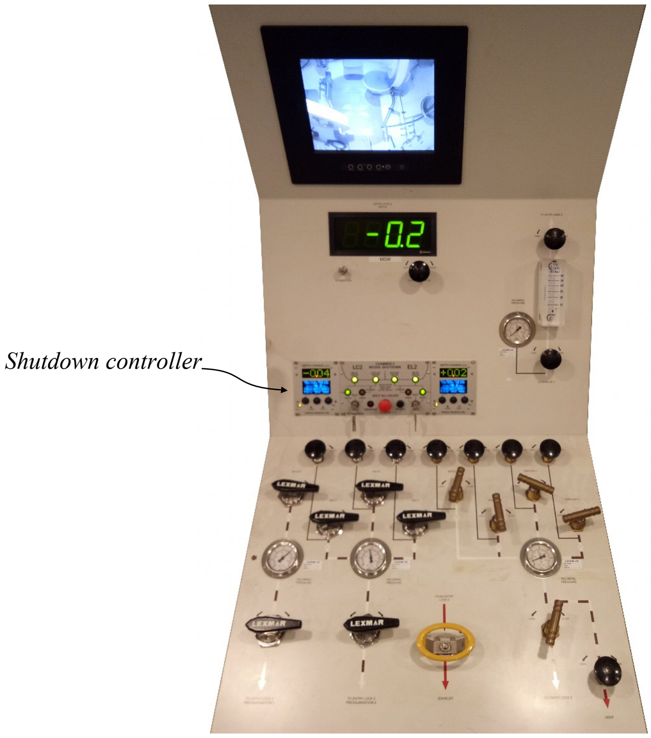
1.2.8.7 - Regeneration shutdown controller

This system is also present in the saturation controls of the system taken as references but not with all systems. However, we can expect that most last generation systems will adopt it in the future.
In point 1.2.2.1 of the chapter “Chambers”, it is said that IMCA recommends that large pipes such as those used for the Hyperbaric Environment Regeneration System (HERS) are fitted with a “non-return valve” for inlet and a “flow fuse” for exhaust at the hull penetration respectively. Also, in point 1.2.4.1 of the chapter “Hyperbaric Environment Regeneration System (HERS)”, it is said that such devices, that are mechanical systems where spring actuated valves are maintained open by the pressure in the pipe, can be replaced by pneumatic actuated valves that are designed to close automatically if a rapid drop of pressure is sensed in the pipework.
The regeneration shutdown controller is an active system that is designed to control these pneumatically actuated valves. The advantage of such a system is its ability to close the valves promptly and independently of chamber depth or gas flowrate.
As it is the case with the systems used as an example in this document, it is usual that a single Hyperbaric Environment Regeneration System (HERS), so a blower and its associated scrubbers, supply both the living chamber and its entry lock *(see the scheme in point 1.2.4.1)*. However, as indicated above and in the description of chambers and the Hyperbaric Environment Regeneration System, each large inlet or outlet port must be fitted with a shutdown valve at the hull penetration. Also, as it is the rule with hollow penetrators, there must be a backup system with a manual override available in case of an equipment fault.
For these reasons, the system is designed with a digital depth transducer that is installed in the entry lock and another one in the living chamber. Each of them transmits the data it collects to its dedicated "depth monitor". These two "depth monitors" are connected to a "shutdown controller module" that combines their depth readings to close the pneumatically actuated valves of the affected chamber in case of a sudden pressure drop. Note that this module provides the status of the valves, and manages the power supplies. Also, it gives the possibility to override the automatic shutdown control and provide a common blower shutdown circuit with a manual emergency stop.
As the system is designed to operate faster than mechanical ones, whatever is the storage depth, the transducers and the "shutdown controller module" that calculate the rate of change of depth of each chamber must be of very high accuracy and reliability. In addition to initiating the shutdown, this high accuracy allows the shutdown controller to evaluate whether the chambers are compressing or decompressing.

The "shutdown controller" and its two associated "depth monitors" are housed in a rack 19" long, which is installed on the control panel of the entry lock of the systems Lexmar (JFD group) taken as reference. Note that this rack takes the place of the analysers and the oxygen-add system. The reason is that a single gas analyzer is used to scan the entry lock and SPHL trunk gas parameters, and that the system automatically scans each of the inputs in turn every 2 minutes. The digital communications module is used for both the living chamber and the entry lock. *(See in the photos below)*. Note that, some other systems provide both analysers and "shutdown controller" on the entry lock panel.

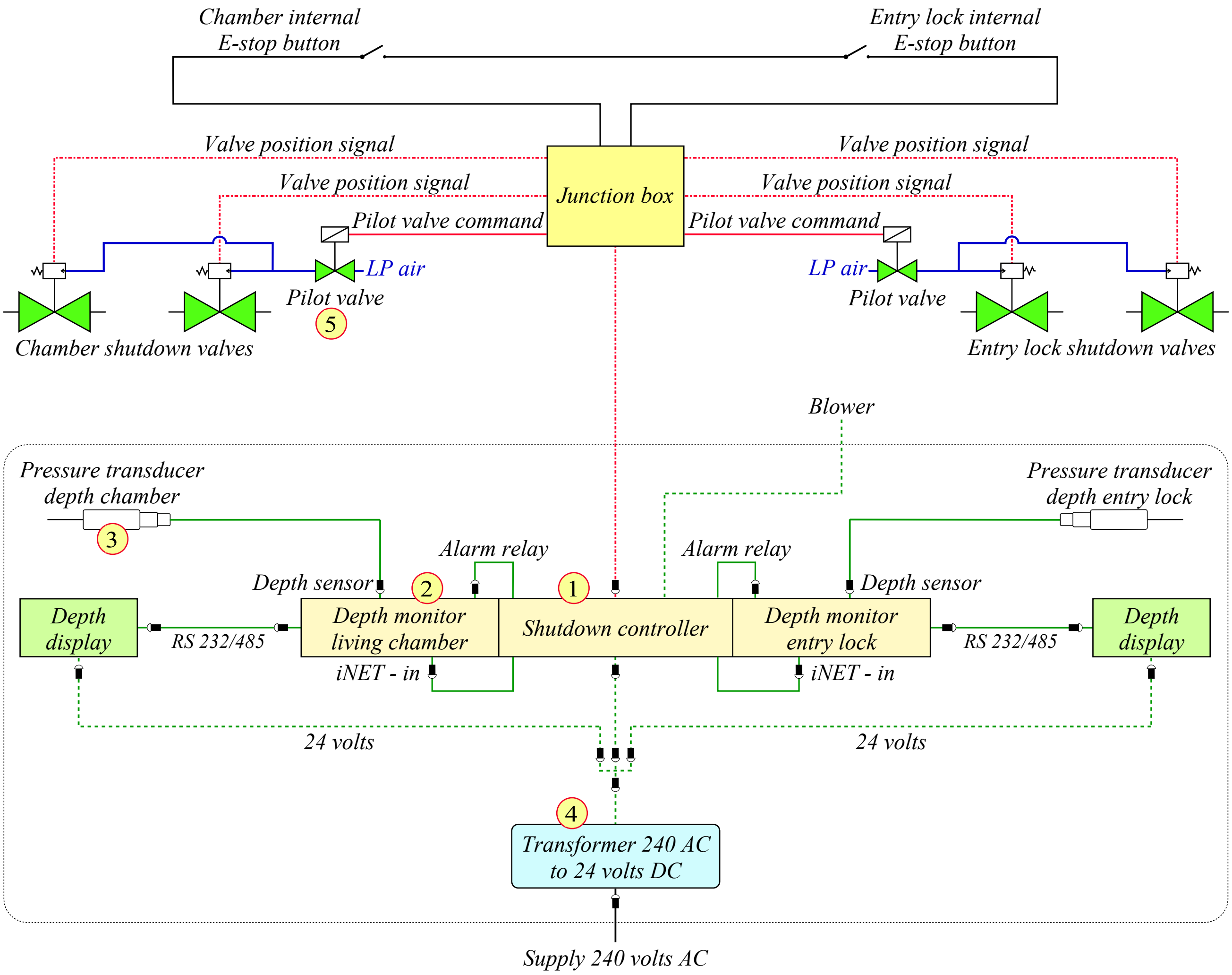


Living chamber panel

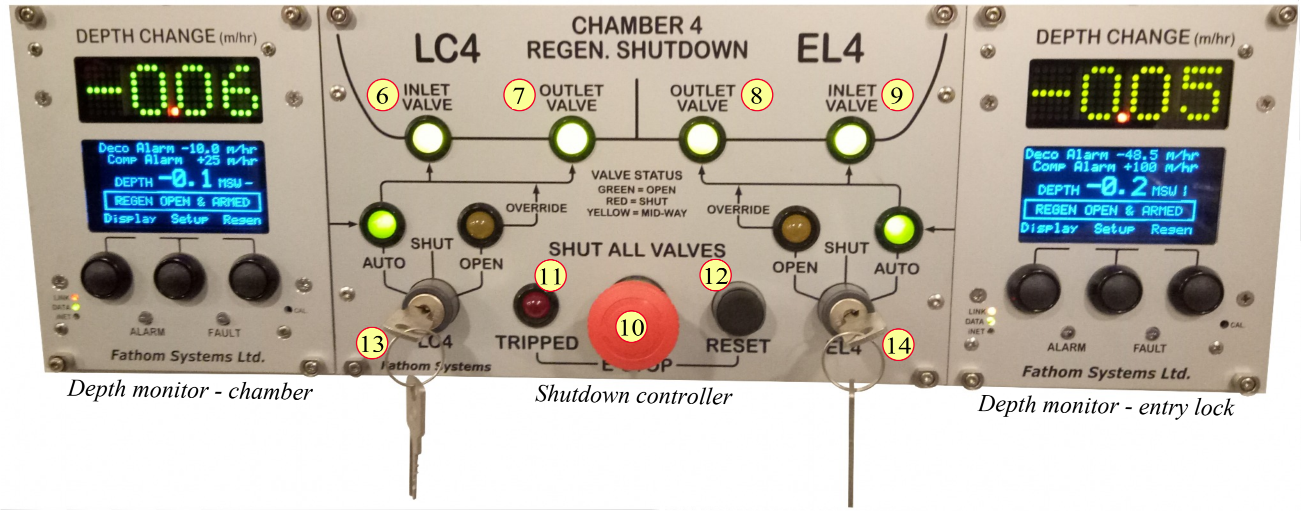


Entry lock panel

The scheme below shows how the system is organized *(See the explanations on the next page):*



The "shutdown controller" *(see #1 in the scheme)* manages the signals from the depth monitor *(see #2)* of the living chamber, and the depth monitor of the entry Lock. The signals for these two monitors come from the pressure transducers *(see #3)*. A common 24 volts supply *(see #4)* is used to power the shutdown controller and its two associated depth monitors .
The actuated valve is controlled by a solenoid, which must be energized to maintain the valve in the open position . This function is usually provided using a piloted valve *(see #5)* where a Low Pressure (LP) air supply provides the power to open the shut-in valve against its fail-to-close springs. The "shutdown controller" system gives a volt-free contact output for each valve pair, and external wiring or control gear should be used to implement the necessary switching of the shutdown valve solenoids. Note that "volt free contacts", also called "volt free switches", are mechanical contacts with no electrical connection to any other part of the equipment the contacts being open and closed mechanically by a solenoid or other device.
To have the "shutdown controller" providing visual status indications of the positions of the valves, each unit is equipped with electrical limit switches that provide a feedback signal to the controller which front panel is designed as follows:



Depth monitor - chamber *Shutdown controller* *Depth monitor - entry lock*

There are four lamps which indicate the actual position of the inlet shutdown valves *(see #6 & #9)*, and outlet shutdown valves *(see #7 & #8)*. These indicators are tri-colour to show the three possible valve positions as follows:

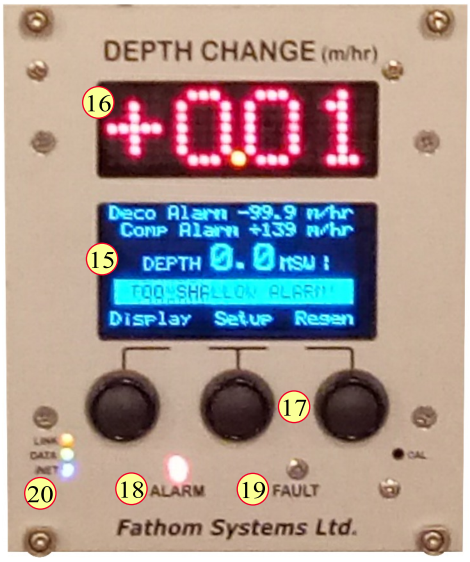
- Green indicates that the valve is open.
- Red indicates that the valve is shut.
- Yellow means that the valve is between open and closed (mid opened).

Note that the valve position status indication is completely independent of the actual commanded position or status of the Depth Monitor outputs as the position is sensed at the valves. As a result, in addition to providing a clear status of the valves, these indicators help identify a valve that is not operating correctly.
An emergency stop pushbutton is provided *(see #10)*. This command allows closing the valves if the operator detects a fault or a leak before the automated depth monitor has activated. Also, the shutdown controller system provides an isolated barrier protected “E-stop” circuit which is designed to limit the energy available to external or chamber mounted emergency stop pushbutton switches. Limiting the energy to ATEX requirements allows switching inside the inner area of the chamber complex. Note that The term ATEX is used for the European Union's (EU) 94/9/EC directive addressing equipment and instrumentation intended for use in potentially explosive atmospheres.
The E-Stop loop circuit use "normally closed" contact switches at each location and form a series-connected electrical "loop" around the system. This loop is broken when a switch is operated, in turn activating the chamber shutdown. In this case, an indication is displayed on the Shutdown Controller front panel "tripped" red indicator *(see #11)*. The system can be reset by pressing the "reset button" *(see #12)* on the front panel.
Two key-switches are provided, one for the living chamber and one for the entry lock *(See #13 for the living chamber and #14 for the Entry Lock)*. They allow for the three following positions:

- Auto:
  With this mode, the depth monitor continually monitors the depth, the rate of pressure change when changing the depth, and the state of the valves. A green indicator lamp is illuminated. The rate at which the depth monitor will trigger a shutdown is to be set accordingly for each depth range.
- Shut:
  When the key is on this mode, the valves are maintained in their “shut state” regardless of the depth monitor output.
- Open:
  When the key-switch is selected to the ‘”open position”, there is no automatic function to close the valves from the “depth monitor” signal and therefore the chamber and its occupants are not protected from mechanical damage or fractured pipework. For this reason, this position is selected only for maintenance or exceptional circumstances where the risk of unprotected operations has been assessed and accepted.
  This position, is indicated by a yellow warning lamp.
  The manufacturer says that if the chamber is manually surfaced without overriding the shutdown controller, it is possible to cause a shut-in and result in a pressure differential between the chamber and the environmental

control unit (ECU) pipework. For this reason, the operator must ensure that the pipework pressure is checked before any maintenance work is carried out.

The "depth monitors" that are installed on both sides of the "shutdown controller" are equipped with display modules:



- The depth reading is displayed on the "vacuum fluorescent display" together with various other status information *(see #15 in the photo)*. Note that the computer calculates the rate of change of depth over 1 minute, 5 minutes, 15 minutes and 1 hour, and that these rates are provided on the vacuum fluorescent display.
- The one-hour rate of change of depth is also indicated on the depth change screen that is above the "vacuum fluorescent display" *(see #16)*. This small display, that is green for a normal status and red in case of an alarm *(see in the photo)*, indicates a positive value (+XXX m/hr) for increasing depth (compression), and a negative value (-XXX m/hr) for decreasing depth (decompression).
  Due to the large range of depth change required between blowdown and decompression, and for greater accuracy, the decimal point moves according to the value being displayed.
- As the other modules made by Fathom, three buttons that are below the "vacuum fluorescent display" are to be used to access the setup menus *(see #17)*. Also, alarm *(see #18)*, fault *(see #19)*, and data communication *(#20)* lights are present

The manufacturer says that there are three alarm conditions:

- No alarm, means that the parameters are within limits previously setup. The depth change screen is green and there is no visible and audible warning.
- An active alarm occurs when a parameter moves outside one of the setup limits.
  In addition to the depth change display in red, the red light "alarm" on the front panel *(see #18)* flashes red. Also, a spoken alert is generated that announces the location and the nature of the problem. This audible alarm is amplified and played via a loudspeaker mounted on the rear panel of the module. The audio volume is adjustable via the front panel controls of the "depth Monitor". Note that in the case that the depth value exceeds the largest number that can be shown on display, so +999 m/hr for compressing, and -999 m/hr for decompressing, the display indicates an "overflow condition", either positive or negative by displaying "+ OVF" or "- OVF" on the depth change screen (see #16 above).
- Accepted alarm is a warning that has been acknowledged or accepted by the operator by pressing the appropriate front-panel button.
  After being accepted, provided there is no other active alarm, the depth change display is red, the alarm light on the panel remains red but ceases to flash, and the audible alarm is silenced. This condition continues until either the set-point is changed to put the monitored parameter outside an alarm condition or the parameter returns within limits previously setup.

The presence of malfunction is indicated by the fault light (see #19 above) that flashes, and a warning message such as those below is generated on the "vacuum fluorescent display".

- Missing or incorrect data communications with the depth transducer.
- Internal voltage supply below or above the correct levels.
- Internal temperature too high.

The setting up of the machine is performed as for the analysers and the oxygen add system from the manufacturer previously discussed. The following elements can be adjusted through the menu:

- Decompression alarm and compression alarm.
- Regeneration valve flow-fuse set point.
- Minimum and maximum depth alarms.
- Working depth and alarm window.

The regeneration valve automatic shutdown function can be checked on the "vacuum fluorescent display" through the dedicated menu. Three possible states are displayed:

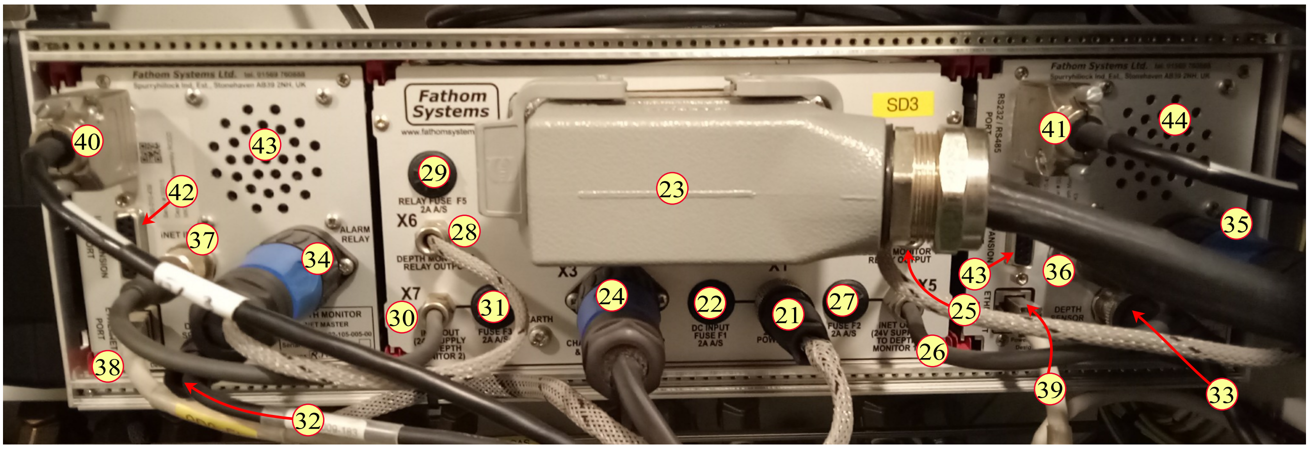
- "Auto armed open mode":
  It is the normal operating mode where the regeneration valve is open, but is the decompression rate change is continually monitored and compared this to the flow-fuse trip set-point. The depth change screen display is green and the condition of the valve is indicated on the "vacuum fluorescent display" *(see in the photo on the side)*.

- “Auto tripped shut mode”:
  If the rate of decompression exceeds the flow-fuse set-point, the depth monitor generates a "flow-fuse tripped alarm" and commands the regeneration valve relay to the de-energized state. At this point, an audible alarm is generated, the alarm light flashes, and the status box indicates the alarm condition *(see in the photo on the side)*.
  The “auto armed open mode” also trips automatically to the “auto tripped shut mode” if there are any of the following conditions:
    - Loss of communications with the depth transducer.
    - Loss of communications with the safety engine.
    - Other system fault.
    - System reset / watchdog timeout.
    - The operator has de-selected the "auto armed open mode".

  After the flow-fuse trip alarm has occurred the control screen indicates that the status of the regeneration isolation valve is closed.

- “Manual held shut mode”
  The manufacturer says that is mode this selected by the operator either after a flow-fuse trip, or if he wishes to close the regeneration valve manually for some operational reason.
  The manufacturer also says that this mode is safe from the perspective of pressure containment, but obviously, there is no chamber gas processing being carried out by the regeneration system. This mode would therefore not normally be maintained for extended periods when divers are in the chamber.
  To exit this mode, the operator must put the depth monitor into the "auto armed open mode" to reset and arm the “Flow-Fuse” alarm through the proper menu. If the rate of change of decompression is less than the flow-fuse trip value, and the safety engine and all other systems are working correctly, the depth monitor re-arms the Flow- Fuse alarm. If, however, there is still an alarm condition prevailing, the system automatically re-trips the Flow-Fuse.

The rear panel of the “shutdown controller” contains all the connections to the two “depth monitors” and to the chamber control system components.



- X1 Connector *(24 volts DC power in)*
  This 5-poles M12 male connector is used to connect the 24 volts direct current (DC)/ 2 amperes power supply to the “shutdown controller unit” *(see #21 in the photo above)*. It also supplies the two associated “depth monitors” *(see on each side)* and is protected by a relevant local fuse *(see #22)*. It must be supplied by an uninterruptible power supply (UPS).
- X2 Connector *(E-stop loop, valve position limit switches & valve solenoids)*
  This connector is a Harting 16-pole ‘HAN’ series industrial connector (Female on the Shutdown Controller) that is kept in position using a robust double-latch system *(see #23)*. The function of this connector is to connect to the external E-Stop switch loop, the shutdown valve position limit switches, and the 24 volts DC shutdown valve solenoid valves.
- X3 Connector *(E-Stop and blower control)*
  This connector is an Amphenol C16 7-pole type, with a male connector fitted to the "shutdown controller" *(see #24)*. It is used to provide a blower shutdown function, and to provide an additional connection to the E-Stop loop.
- X4 Connector *(Depth monitor #1 relay output)*
  It is the input to the "shutdown controller" from the living chamber depth monitor shutdown solenoid valve output *(see #25)*. This connector is pre-installed through a cable-gland into the "shutdown controller" and is usually pre-connected to the associated "depth monitor module". The relay fuse F4, which is not visible in the photo, is installed above this connector.
- X5 Connector *(24 volts ‘output to “depth monitor” #1)*
  This 5-pole M12 connector provides the 24 volts DC power to "depth monitor" #1, which is the one used for the

living chamber *(see #26)*. This supply comes from the "shutdown controller" 24 volts DC Input supply and is protected by a 2A fuse with anti-surge *(see #27)*. This connector is also pre-installed through a cable-gland into the "shutdown controller" and is usually pre-connected to the associated "depth monitor module".

- X6 Connector *(depth monitor #2 relay output)*
  It is the input to the “shutdown controller” from the entry lock “depth monitor” shutdown solenoid valve output *(see #28)*. As the previous elements, this connector is pre-installed through a cable-gland into the "shutdown controller" and is usually pre-connected to the associated "depth monitor module". The relay fuse F4 *(see #29)*, is installed above this connector,
- X7 Connector *(24 volts output to “depth monitor” #2)*
  This 5-pole M12 connector provides the 24 volts DC power to "depth monitor #2, which is the one used for the entry lock. *(see #30)*. This supply comes from the "shutdown controller" 24 volts DC input supply and is protected by a 2A fuse with anti-surge *(see #31)*. As the previous elements, this connector is pre-installed through a cable-gland into the "shutdown controller" and is usually pre-connected to the associated "depth monitor module".
- Depth sensor connector of the “depth monitor”
  This connection transmits the data from the pressure transducer in the chamber or the entry lock *(see #3 in the scheme, and #32 & #33 in the photo on the previous page).*
- Alarm relays of the “depth monitors”
  These connectors link to the connector X4, and the connector X6 (*see in the scheme, and #34 & #35 in the photo on the previous page).*
- INET-in of the “depth monitors”
  These connectors link to the connector X5, and the connector X7 (*see in the scheme, and #36 & #37 in the photo on the previous page).*
- Ethernet ports of the “depth monitors” *(see #38 & #39 in the photo on the previous page).*
- RS232 / RS485 port to the depth display *(see in the scheme, and #40 & #41 in the photo on the previous page).*
- Input/Output expansion port (I/O expansion port)
  This port is a computer socket that connects the central processing unit (CPU), also called a central processor or main processor, to a peripheral device via a hardware interface or to the network via a network interface *(see #42 & #43 in the photo on the previous page).*
- Loudspeakers audible and voice alarms *(see #44 & #45 in the photo on the previous page).*

1.2.8.8 - Communications and transmission of data

The saturation control room is the place where the Life Support Supervisor (LSS) and the Life Support Technicians (LST) ensure that all the conditions for the well being of the divers at rest and, if needed, their emergency evacuation from the saturation complex, are provided. Also, daily support and maintenance activities must be monitored at all times. For these reasons, there must be communications to strategic points of the diving system and surface support.

The means of communications to the divers in chambers are usually the same as those provided for the bell and described in document #4. So, the verbal and visual means of communications with the inside of the saturation systems taken as references can be listed as follows:

No	***Description***	***Requirements IMCA***	***Requirements from clients and other organizations***	***Additional information***
1	Two way unscrambled voice communications Chamber #1	Mandatory	Mandatory	There should be four wires into the communication cable to allow the installation of duplex communications that enable all parties connected to talk and listen at the same time.
2	Two way unscrambled voice communications entry lock #1	Mandatory	Mandatory	With the systems taken as reference, the digital module used is shared with the living chamber.
3	Sound powered phone chamber #1 (backup communications)	Mandatory	Mandatory	Not unscrambled
3	Sound powered phone entry lock #1 (backup communications)	Mandatory	Mandatory	Not unscrambled
5	Video camera chamber #1 (2 units are installed: One of them provides a view of the sleeping area and the other one a view of the table & medical lock area)	Mandatory	Mandatory	According to NORSOK U100, all chamber compartments, bells, habitats and winch drums when necessary, shall be equipped with video monitoring system, enabling the surface support crew to visually monitor the occupants and operations.
6	Video cameras entry lock #1	Mandatory	Mandatory	Refer to point #5 in this list

No	Description	Requirements IMCA	Requirements from clients and other organizations	Additional information
7	Two way unscrambled voice communications Chamber #2	Mandatory	Mandatory	Refer to point #1 in this list
8	Two way unscrambled voice communications entry lock #2	Mandatory	Mandatory	.Refer to point #2 in this list
9	Sound powered phone chamber #2 (backup communications)	Mandatory	Mandatory	Not unscrambled
10	Sound powered phone entry lock #2 (backup communications)	Mandatory	Mandatory	Not unscrambled
11	Video camera chamber #2 (2 units)	Mandatory	Mandatory	Refer to point #5
12	Video cameras entry lock #2	Mandatory	Mandatory	Refer to point #5 in this list
13	Two way unscrambled voice communications Chamber #3	Mandatory	Mandatory	Refer to point #1 in this list
14	Two way unscrambled voice communications entry lock #3	Mandatory	Mandatory	.Refer to point #2 in this list
15	Sound powered phone chamber #3 (backup communications)	Mandatory	Mandatory	Not unscrambled
16	Sound powered phone entry lock #3 (backup communications)	Mandatory	Mandatory	Not unscrambled
17	Video camera chamber #3 (2 units)	Mandatory	Mandatory	Refer to point #5 in this list
18	Video cameras entry lock #3	Mandatory	Mandatory	Refer to point #5 in this list
19	Two way unscrambled voice communications Chamber #4	Mandatory	Mandatory	Refer to point #1 in this list
20	Two way unscrambled voice communications entry lock #4	Mandatory	Mandatory	.Refer to point #2 in this list
21	Sound powered phone chamber #4 (backup communications)	Mandatory	Mandatory	Not unscrambled
22	Sound powered phone entry lock #4 (backup communications)	Mandatory	Mandatory	Not unscrambled
23	Video camera chamber #4 (2 units)	Mandatory	Mandatory	Refer to point #5 in this list
24	Video cameras entry lock #4	Mandatory	Mandatory	Refer to point #5 in this list
25	Two way unscrambled voice communications Transfer lock #1	Mandatory	Mandatory	Refer to point #1 in this list
26	Sound powered phone transfer lock #1 (backup communications)	Mandatory	Mandatory	
27	Video camera Transfer lock #1 (2 units)	Mandatory	Mandatory	Refer to point #5 in this list One unit looks at the trunk to transfer lock #2, & one unit looks at the trunk to SPHL #1.
28	Two way unscrambled voice communications Transfer lock #2	Mandatory	Mandatory	Refer to point #1 in this list
29	Sound powered phone transfer lock #2	Mandatory	Mandatory	Not unscrambled
30	Video camera Transfer lock #2 (2 units)	Mandatory	Mandatory	Refer to point #5 in this list One unit looks at the trunk to transfer lock #1, & one unit looks at the trunk to SPHL #2.
31	Unscrambled voice communications trunk from transfer lock #1 to SPHL #1	Mandatory	Mandatory	Refer to point #1 in this list
32	Two way unscrambled voice communications SPHL #1	Mandatory	Mandatory	Refer to point #1 in this list

No	Description	Requirements IMCA	Requirements from clients and other organizations	Additional information
33	Sound powered phone SPHL #1	Mandatory	Mandatory	Not unscrambled
34	Video camera SPHL #1	Mandatory	Mandatory	Refer to point #5 in this list
35	Unscrambled voice communications of trunk from transfer lock #2 to SPHL #2	Mandatory	Mandatory	Refer to point #1 in this list
36	Two way unscrambled voice communications SPHL #2	Mandatory	Mandatory	Refer to point #1 in this list
37	Sound powered phone SPHL #2	Mandatory	Mandatory	Not unscrambled
38	Video camera SPHL #2	Mandatory	Mandatory	Refer to point #5 in this list
25	Diver Monitoring System	Not indicated	Optional outside Norwegian waters / Mandatory with NORSOK and some clients	NORSOK says: *"A diver monitoring system shall be provided for each diver"*
26	Divers' exposure data recording	Not indicated		NORSOK says that the diving contractor must have a system for recording the divers exposure data

Note that the unscrambled verbal communication systems in use with the systems taken as references (UDS Lichtenstein & Picasso) is the digital Fathom communicator for divers.

Communications and surveillance for the intervention of Life support technicians on chambers and other parts of the system can be listed as follows:

No	Description	Requirements IMCA	Requirements from clients and other organizations	Additional information
1	Intercom external equipment lock of transfer lock #1	Mandatory	Mandatory	
2	Video camera External equipment lock of transfer lock #1	Mandatory	Optional or mandatory	NORSOK U100 says that all chamber compartments, bells, habitats and winch drums when necessary, must be equipped with video monitoring system.
3	Intercom external equipment lock of transfer lock #2	Mandatory	Mandatory	
4	Video camera External equipment lock - transfer lock #2	Optional	Optional or mandatory	See point #40 in this list
5	Intercom External medical lock chamber #1	Mandatory	Mandatory	
6	Video camera External medical lock chamber #1	Optional	Optional or mandatory	See point #40 this list
7	Intercom External medical lock chamber #1	Mandatory	Mandatory	
8	Video camera External medical lock chamber #1	Optional	Optional or mandatory	See point #40 in this list
9	Intercom External medical lock chamber #2	Mandatory	Mandatory	
10	Video camera External medical lock chamber #2	Optional	Optional or mandatory	See point #40 in this list
11	Intercom External medical lock chamber #3	Mandatory	Mandatory	
12	Video camera External medical lock chamber #3	Optional	Optional or mandatory	See point #40 in this list
13	Intercom External medical lock chamber #4	Mandatory	Mandatory	

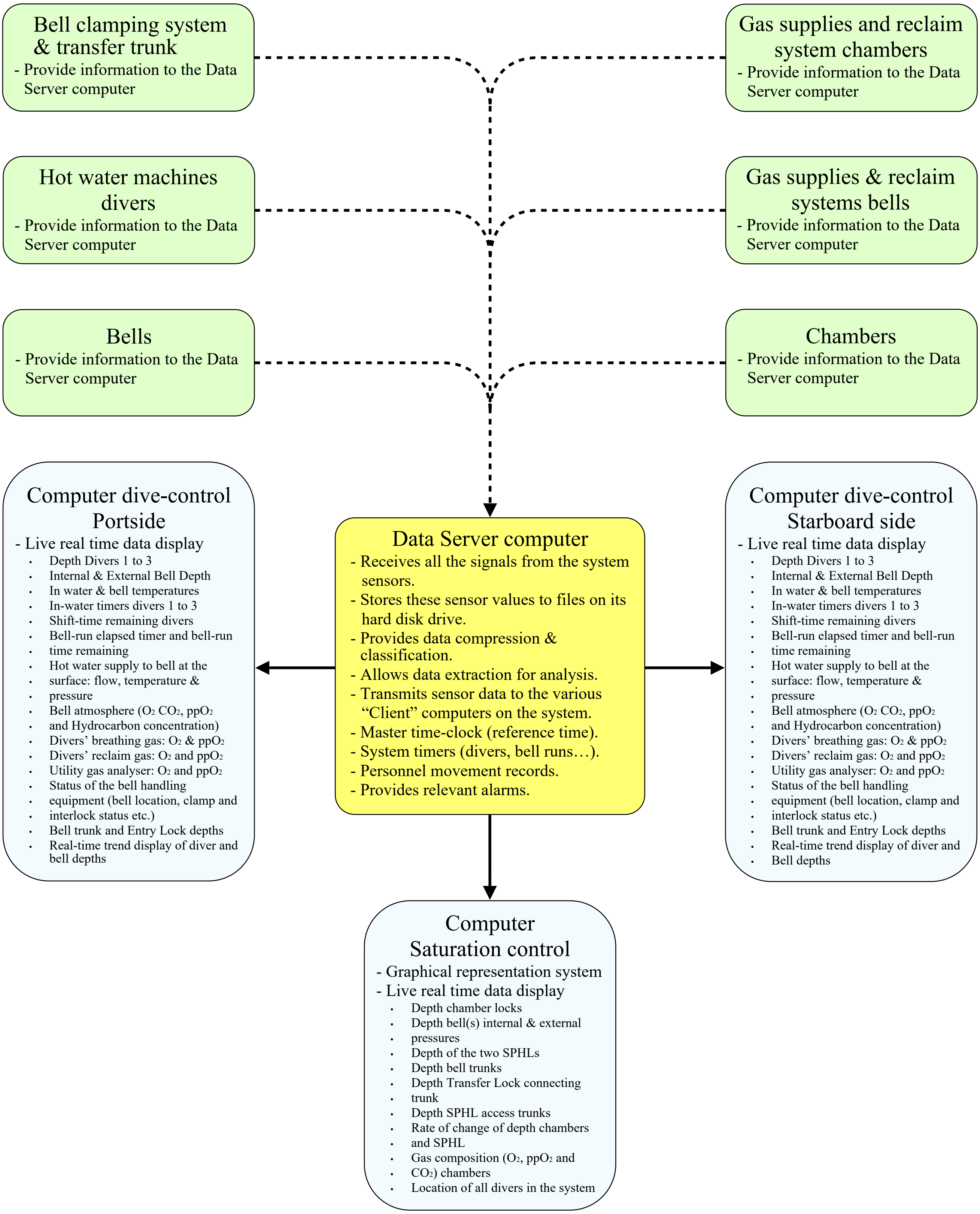
No	Description	Requirements IMCA	Requirements from clients and other organizations	Additional information
14	Video camera External medical lock chamber #4	Optional	Optional or mandatory	See point #40 in this list
15	Intercom Launching station SPHL #1	Mandatory	Mandatory	
16	Video camera Launching station SPHL #1	Optional	Optional or mandatory	See point #40 in this list
17	Intercom Launching station SPHL #2	Mandatory	Mandatory	Refer to point #1 in this list
18	Video camera Launching station SPHL #2	Optional	Optional or mandatory	See point 39 in this list
19	Intercom Gas storage area	Optional	Not indicated	Such equipment should be in place
20	Video camera gas storage area	Not indicated	Not indicated	Such equipment should be in place
21	Intercom Compressor room	Optional	Not indicated	Such equipment should be in place
22	Video camera Compressor room	Not indicated	Not indicated	Such equipment should be in place
23	Intercom / phone Gas reclaim area	Optional	Not indicated	Such equipment should be in place
24	Video camera gas reclaim area	Not indicated	Not indicated	Such equipment should be in place
25	Intercom / phone Diver laundry	Optional	Not indicated	Such equipment should be in place
25	Intercom / phone Diver ultrasound ovens	Optional	Not indicated	Such equipment should be in place

The means of communications to the other parts of the surface support can be listed as follows:

No	Description	Requirements IMCA	Requirements from clients and other organizations	Additional information
1	Hard wired communications to and from the bridge	Mandatory	Mandatory	The primary link must be hard wire, immediately available and unable to be interrupted.
2	Secondary communications to and from the bridge	Not indicated	Optional	The secondary link should be hard wired (phone)
3	Hard wired communications to and from the dive control room (Intercom)	Mandatory	Mandatory with most clients and contractors	There should be a permanent and clear connection between the the diving supervisor and the Life Support Technician (LST) on duty. Hard wired communications have the advantage to be dedicated and not interrupted.
4	Secondary communications to and from the dive control room	Not indicated	Mandatory with most clients and contractors	Such communications should be hard wired
5	Hard wired communications to and from Offshore Installation Manager.	Not indicated (It can be the phone)	Mandatory with most clients and contractors	See #1 above
6	Secondary communications to and from Offshore Installation Manager (OIM)	Not indicated	Optional	The secondary link can be hard wired, or if possible, a dedicated radio channel.
7	Phone communications to the diving medical specialist (doctor)	Not indicated	Mandatory with most clients	Norsok U 100 says that first aiders must have suitable priority telecommunication with the diving doctor, or any other competent personnel, and that tele-medicine, and monitoring equipment must be in place
8	Tele-medicine / Data transmission system	Not indicated	Mandatory with Norsok and some clients	

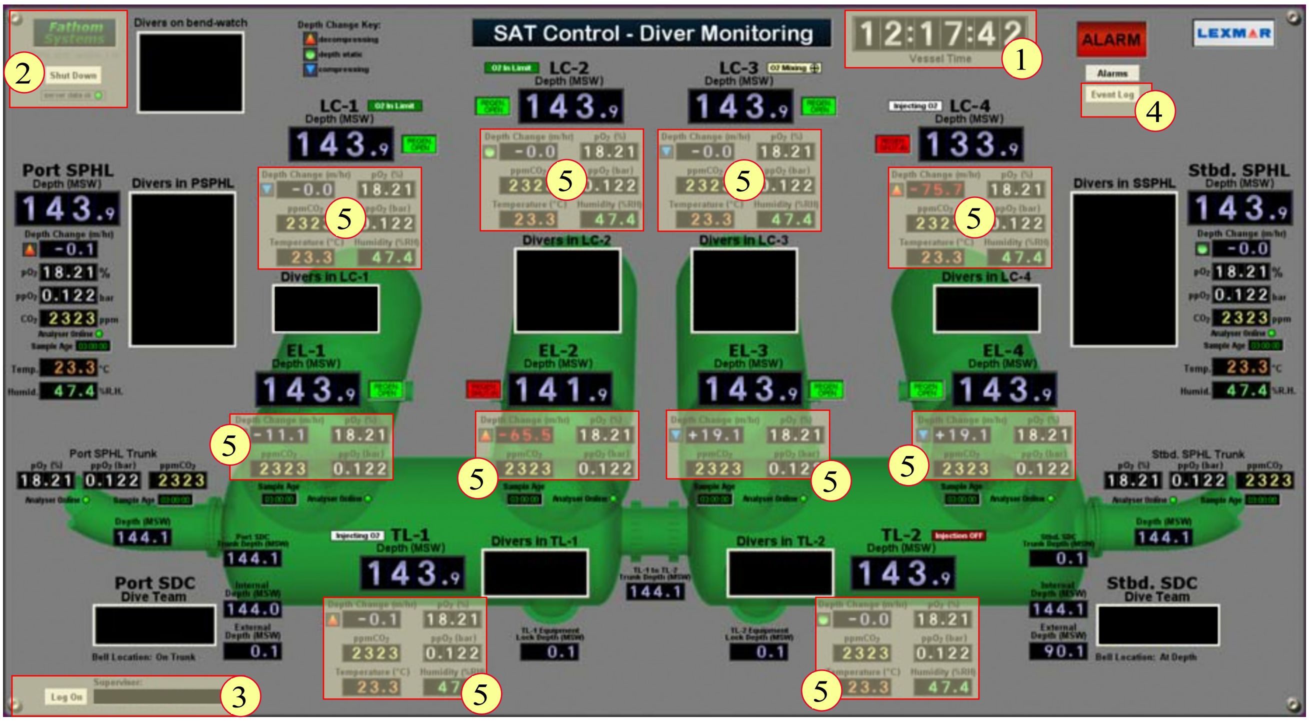
1.2.8.9 - Diver Monitoring System (DMS)

The Diving Monitoring System in place in the saturation control room is the complement of the one in place in the dive control, to which it is linked as shown in the scheme below.
The Diver Monitoring System (DMS) comprises networked computers that communicate with bespoke hardware devices that acquire data from sensors fitted to various parts of the dive system. These sensors measure parameters such as depths, temperatures, gas compositions, hot water flow, humidity, etc. The primary function of the system is to measure these physical parameters and store the values on a computer disk file for archiving and subsequent analysis. In addition to recording the sensor values, there are a number of computers that provide operators with real-time graphical displays of the sensor values to assist in the management of diving operations.



A client computer, which is equipped with a 27" flat-panel touch-screen display, provides a real-time display of all the system parameters related to life support operations. With the systems taken as references *(UDS Lichtenstein & Picasso)*, this display, which is also used to provide the gasses status, is in the corner of the cabinet between SPHL #2 panel and living chamber #1 panel. However, depending on the configuration of the room, it can be installed anywhere in it.

Note that, similarly to the diving supervisor, the LSS must log his name in the system when starting his shift. During normal operations, his main interactions with the software are the adjustment of alarms settings and the displacements of the divers inside the system. The presentation of the data collected is also similar to those of the display in the saturation control. To improve the reading of the data provided, a scheme that represents the saturation chambers and their connecting trunks is displayed with the names of the divers stored in each unit and the environmental control values applied to them. Note that due to lack of space, the SPHLs are not represented. However, their data are indicated on each side of the screen *(see in the snapshot below)*.



1) - Vessel time display *(see #1 above):*
This function shows the time on the bridge of the vessel which is the reference for all vessel operations. The vessel time is synchronized to the real-time server clock of the Diver Monitoring System. If for some reasons, the server is unavailable, this display can be used as reference time. However, it is not synchronized, and for this reason, it is displayed with red numbers.

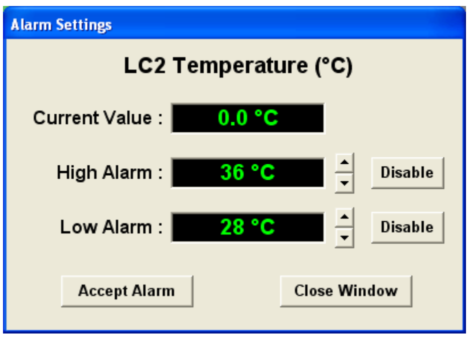
2) - Shutdown button, server indicator & version information *(see #2 above):*
It allows the Life Support Supervisor (LSS) to shut down the saturation control client display software. The LSS can also see the details of the software revision status of the application by clicking on the “Fathom Systems” logo that is the link to open the window that shows the software details.

3) - Life Support Supervisor (LSS) identification (name and ID number) & Login button *(see #3 above)*:
This window displays the name and identification number of the Life Support Supervisor on duty who enters the system by clicking the button “log on” to open the list of supervisors from which he selects his name. If he has not worked on the system before, he must first enter his details and password using the ‘Personnel Database editor’.

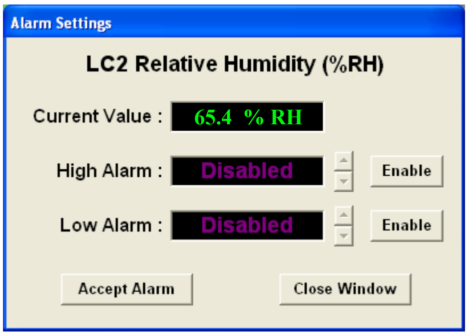
4) - Events display *(see #4 above)*:
This window provides diagnostics and status information about the software. Alarms that are generated are also described in it. Over time, this list of status messages builds-up, and the previous messages can be accessed by the vertical scrollbar at the right-hand side of the window.

5) - Chamber Parameter displays *(see #5 above)*:
There are digital readouts for each of the chamber compartments in the system, colour-coded and displaying the following environmental control parameters:

5.1 - The temperature (ºC) *(Living Chambers, Transfer Locks and SPHLs only)*
This window shows the data transmitted by the internal temperature sensor which is is combined with the humidity sensor and is fitted inside the chamber. High and low alarms can be set for each temperature signal by clicking on the digital display that opens the following alarms configuration window:



5.2 - Humidity (%R.H.) *(Living Chambers, Transfer Locks and SPHLs only)*
This display shows the data from the combined humidity & temperature sensor and is fitted inside the chamber. High and low alarms can be set by clicking on the digital display that opens the alarms configuration window below:

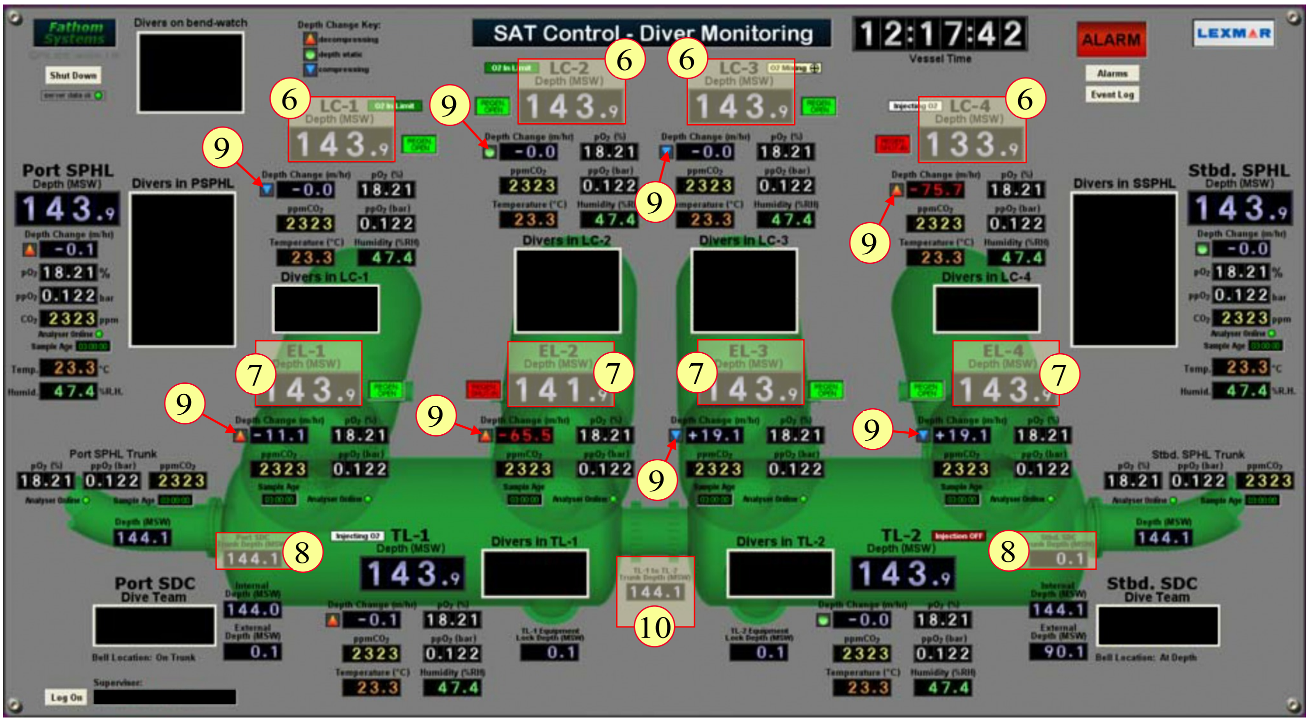


5.3 - Oxygen (O2) percentage
The value displayed is taken from the oxygen analyser. High and low alarms can be set by clicking on the digital display that opens the alarms configuration window that is similar to those explained above.

5.4 - Oxygen partial pressure
The value displayed is also taken from the oxygen analyser. High and low alarms can be set by clicking on the digital display that opens the alarms configuration window that is similar to those described previously.

5.5 - Carbon dioxide (CO2) parts per million
The value displayed is taken from the CO2 analyser. High and low alarms can be set by clicking on the digital display that opens the alarms configuration window that is similar to those described previously.

Note that to suit the operational requirements the system can 'patch' the gas analyzer used for the entry locks. When this activity is carried out, the analyzer informs the diver monitoring system of the current online gas.



6) - Living chamber depth displays *(see #6 above)*:
These displays are generated from the signals from the digital depth transducers connected to the depth monitors. The rate of change of depth is calculated for each of these digital transducer signals within the depth monitor.

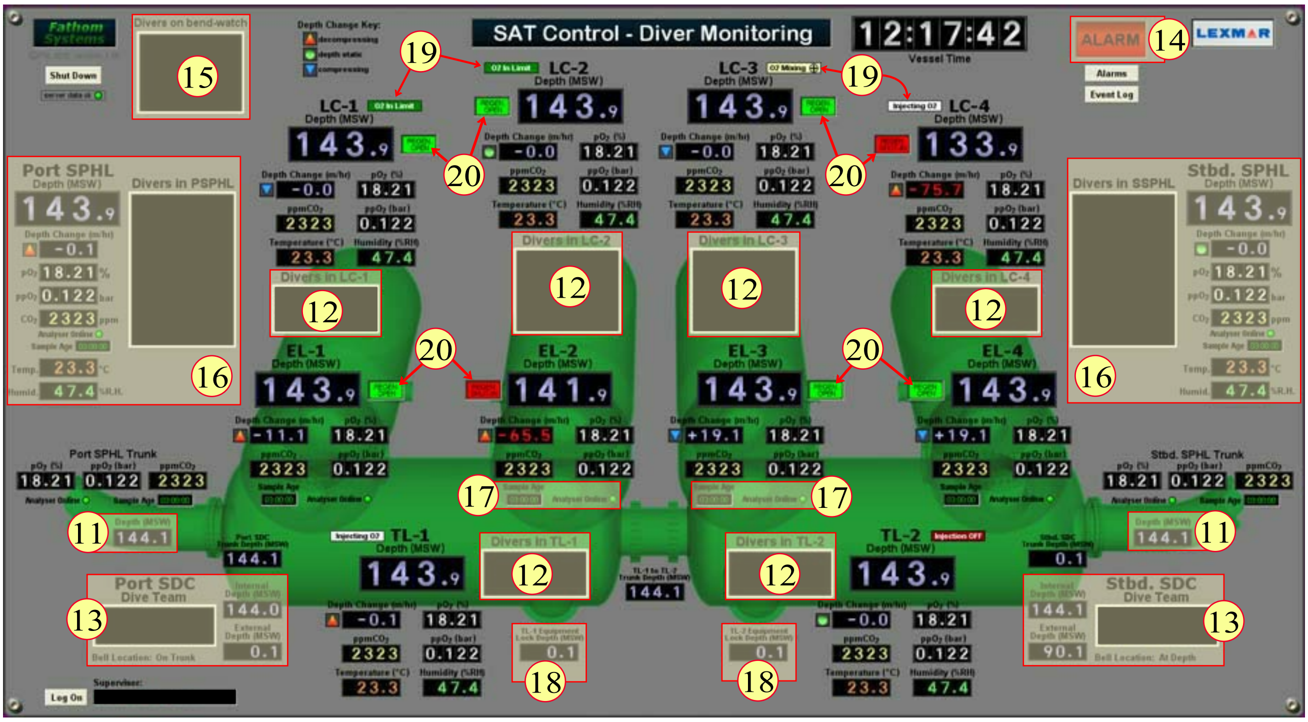
7) - Entry locks displays *(see #7 above)*:
These displays are also generated from the signals from the digital depth transducers connected to the depth monitors. The rate of change of depth is calculated for each of these digital transducer signals within the depth monitor.

8) - Bell mating trunk depth displays: *(see #8 above)*:
This display is generated from the signal from the analog depth transducer located in the trunk gauge line. There is no alarm for this display.

9) - Compression / decompression indicator *(see #9 above)*:
These dynamic indicator inputs, which are adjacent to the depth change displays, show whether the chamber locks depths are getting deeper (compressing), shallower (decompressing), or are static. Their data are taken from the calculated rate of change of depth values. Relevant legends explained at the top of the panel.

10) - Transfer lock #1- transfer lock #2 interconnecting trunk depth display *(see #10 above)*:

The data transmitted are those from depth transducers that are mounted on the pipework attached to the trunk gauge line. The alarm configuration window can be opened by clicking on the display.



11) - SPHL Access Trunk Depth displays *(see #11 above)*:
These displays transmit the signals from the depth transducers mounted behind the trunk gauge in the main saturation control panel. The operator can set and adjust high and low depth alarms by clicking on this display.

12) - Diver Location Window - chamber *(see #12 above)*:
Such windows show the names of the divers in the chamber they are stored. When the divers move around the system, their new location can be updated by selecting their name and right-clicking or double-clicking the mouse to pops up a context menu or access the personnel database.

13) - Bell Depth, location & Dive Team displays *(see #13 above)*:
These displays show the current bell internal and external depth values expressed in MSW. Also, the divers in the bell are identified as D1, D2 and D3 in the relevant window. The bell location is also displayed to inform the LSS whether it is at depth, transferred, or on the trunk.
Note that alarms are not provided as the bell is under the responsibility of the diving supervisor.

14) - Alarm indicator *(see #14 above)*:
This display is grey when all alarm parameters are within the preset limits. It is illuminated red and flashes when one (or more) parameter is outside the limits or is faulty, and until the Life Surface Supervisor accepts the alarm. The nature of the alarm is listed in the system status display window "event log" that provides diagnostics and status information about the software and is previously described in point 4. To accept the alarm, the operator clicks on the display to open the relevant window. However, this windows does not provide any description of the alarm, and for this reason, it is indicated *"Are you sure you know which alarm you are accepting? Click 'yes' to accept, 'no' to check first"*.

15) - Diver on bendwatch *(see #15 above)*:
This display indicates the divers under bendwatch supervision. Divers can be moved from the chambers to the bendwatch list by selecting their name from any chamber list-box, and right clicking or double-clicking the mouse to open the relevant menu.

16) - SPHL Parameters and divers *(see #16 above)*:
Each SPHL has a set of displays, similar to the chambers providing displays of depth, rate of change of depth, percentage O_2, CO_2 in parts per million, partial pressure O_2, temperature, and relative humidity. Also, the 'diver location window' is used to list the divers in the SPHL. Transfer of names to this list is performed as indicated before.

17) - Scanning Analyser Status *(see #17 above)*:
A single gas analyzer (%O2 and CO2 parts per million) is used to scan the entry lock and SPHL trunk gas parameters. The scan cycle is typically 2 minutes, and the system automatically scans each of the inputs in turn. For this reason, there is a display that shows when a particular analyzer is online, and the age of the sample in hours, minutes, and seconds since the last time the analyzer was online. Note that the sample is deemed invalid passed 3 hours, so the display is blanked after this time.

18) - Equipment lock depth *(see #18 above)*:
They provide data from the digital depth sensors of the equipment locks.

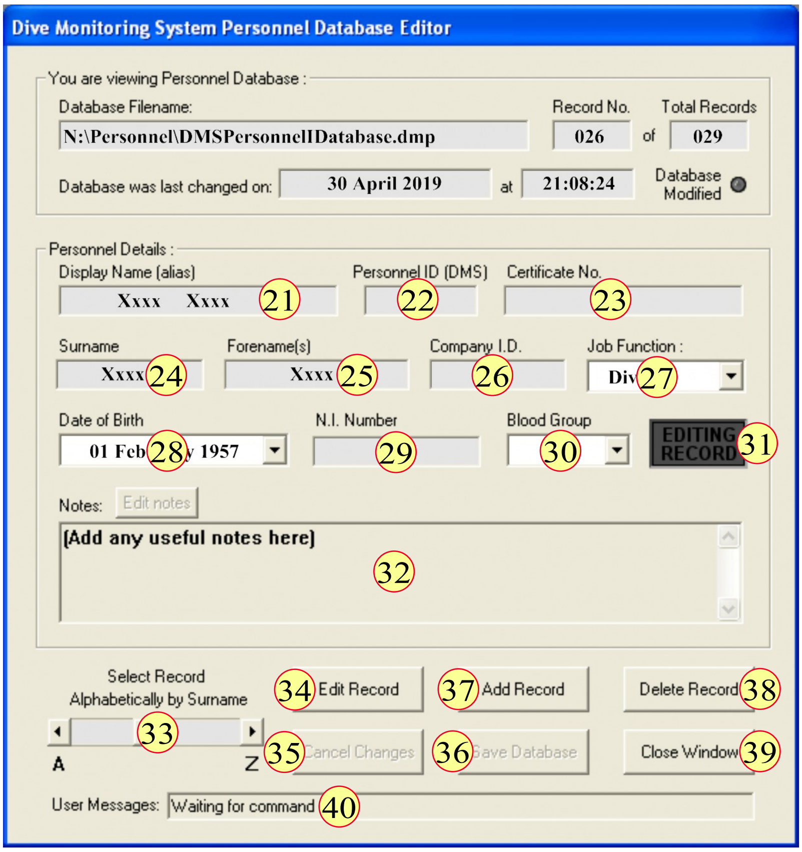
19) - O_2 Injection Status *(see #19 above)*:
This display indicates the data from the oxygen injection modules explained in point 1.2.8.6.

20) - Shutdown Controller Status *(see #20 in the scheme on the previous page)*:
These displays show the condition of the regenerations valves as explained in point 1.2.8.6.

Record the names and identification numbers of the divers in the saturation complex in addition to those of the diving supervisors and Life Surface Technicians is a task that is usually made by the senior Life Support Supervisor.
With the system Fathom in use with the saturation complexes taken as examples, this database is located a hard disk in the data server computer, and its partition letter is "N". So it is stored in the following directory on the server: "N:\Personnel\LXn DMS Personnel.dmp", where LXn is LX1, LX2, etc., depending on the identification number of the diving system. It can be accessed through the menus of the display in the saturation control room.
As this database must indicate the name of the people and their function, every person is given an identification number in the range of 001 to 999 that is prefixed with a digit that represents his/her function and allows the system to separate the divers from the supervisors and the life support personnel as in the example below:

Job function	*Prefix*	*Identification number (example)*	*System identification number (example)*
Diver	*1*	*xxx*	*1xxx*
Diver medic	*2*	*xxx*	*2xxx*
Diving supervisor	*3*	*xxx*	*3xxx*
LSS / LST	*4*	*xxx*	*4xxx*

To add people to the database, the LSS must use the personnel database editor. He can access it by clicking one of the diver list boxes (see #12) on the screen of the terminal and select the option "'Personnel Database Editor" or "Show selected Diver's Information" in the menu to open the relevant window that looks like the one below.



When the window is opened, the operator can add or modify the following personnel details:

21) - Display name (alias) *(see # 21 above)*:
It is the name that will be displayed in the relevant boxes and on the display screens in the dive and saturation control rooms.

22) - Personnel ID (DMS) *(see # 22 above)*:
This number that is automatically generated by the system, so it cannot be edited, is the unique personnel identification number for the displayed person. It includes the prefix digit that indicates the person's job function.

23) - Certificate No. *(see # 23 above)*:
This optional field that can be used to record a certificate number (as an example the reference of the diving certificate) for the displayed person.

24) - Surname *(see # 24 above)*:
Also called 'family name'. This field must be edited.

25) - Forename(s) *(see # 25 above)*:
Also called 'given name'. This field must be edited.

26) - Company ID *(see #26 in the scheme on the previous page)*:
This field can be used to indicate a separate identification number. This information is optional

27) - Job function *(see #27 in the scheme on the previous page)*:
This drop-down combo box is used to specify one of the four the job function explained above, so, diver, diver medic, diving supervisor , and LSS/LST. An entry in this combo box is required and can be changed.

28) - Date of birth *(see #28 in the scheme on the previous page)*:
This drop-down date entry box is used to specify the person's date of birth. An entry in this area is required.

29) - NI number *(see #29 in the scheme on the previous page)*:
National insurance registration number. It is an optional information.

30) - Blood group *(see #30 in the scheme on the previous page):*
All possible combinations of blood group and rhesus factor are available. The manufacturer says that the 'Unknown' option can be selected if this information is missing. However, people should not be authorized to work as long as their blood group is not documented.

31) - Editing record *(see #31 in the scheme on the previous page):*
This panel illuminates green when the displayed database record is being edited

32) - Notes *(see #32 in the scheme on the previous page):*
This area allows free text entry about the person. This box can be left blank.

33) - Record selection scrollbar *(see #33 in the scheme on the previous page):*
This horizontal scrollbar control is used to search through the database alphabetically to find a particular person.

34) - Edit record button *(see #34 in the scheme on the previous page):*
The editable fields on the window can only be changed after clicking this button. After this button is clicked, the "Editing Record" indicator panel illuminates, and the "Cancel Changes" and "Save Database" control buttons are enabled. When editing the database, only one record can be edited at a time between saves.

35) - Cancel Changes button *(see #35 in the scheme on the previous page):*
This button is enabled only during an editing session. The changes that have been made since the database was last saved will be deleted, and the window will return to the "non-editing" mode if it is clicked.

36) - Save Database button *(see #36 in the scheme on the previous page):*
This button is enabled only during an editing session, and the records are saved to the database on the server when it is clicked. This function automatically creates a backup file of the entire personnel prior to this save action. When the files have been saved, the window returns to the "non-editing" viewing mode.
Note that when the change is made the application sends a message to the server to automatically re-load the personnel database from the server hard-disk so all personnel database changes are propagated throughout the system automatically.

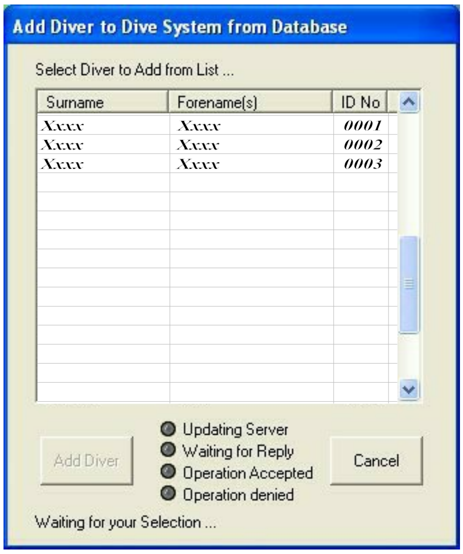
37) - Add Record button *(see #37 in the scheme on the previous page):*
When clicked, this button appends a new record to the end of the database, initially populated with blank fields, ready for editing. The editing mode is automatically started, and the LSS is free to type in the details of the person he is adding to the database. The record number (and therefore the DMS I.D. number) are automatically generated, and the total number of records in the database is incremented by 1.

38) - Delete Record button *(see #38 in the scheme on the previous page):*
When clicked, this button deletes the displayed record from the database. Once deleted, a record cannot be used again.

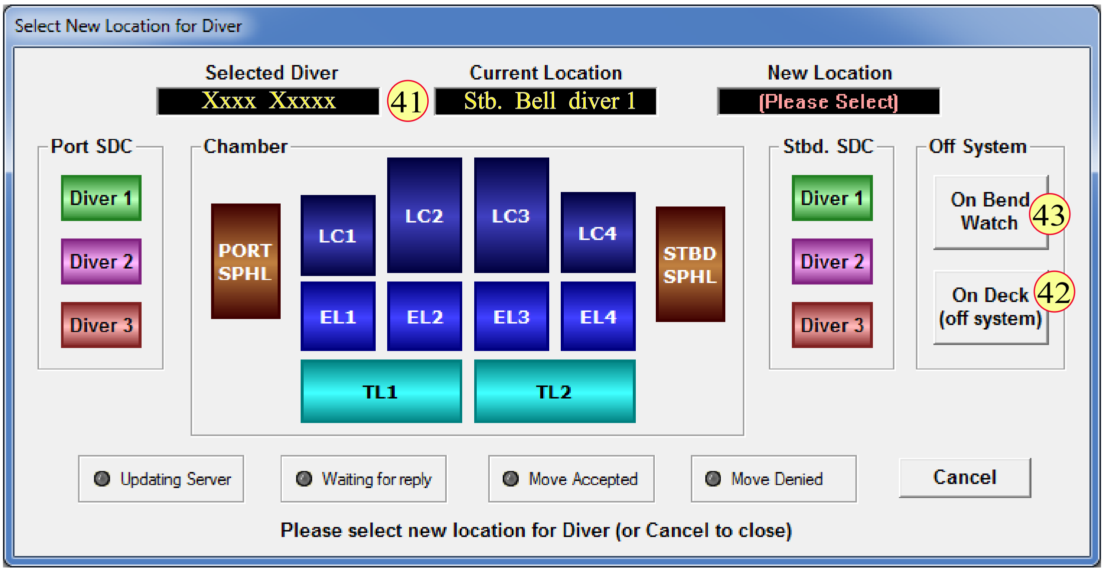
39) - Close Window button *(see #39 in the scheme on the previous page):*
When clicked, this button finishes the database editing session and closes the database editor window. It cannot be clicked during the editing.

40) - User messages *(see #40 in the scheme on the previous page):*
This single line of text provides messages from the system.

When the personnel has been registered into the database, the LSS can add them to the system. To do it, he must select the "diver location window" of the living chamber into which they are stored *(see #12 above)*. Note that if a diver has to be transferred in another part of the system, he must be logged in the living chamber at first, and then moved to the planned place.
Right-clicking on the relevant window opens the same menu from which the personnel database editor can be accessed.
To access the window that allows transferring personnel in the dive system, the operator must click the option "add new diver from the database" that opens the window displayed on the side. Using the slider, the operator selects the name of the person to transfer into the saturation complex and then click the tile "add diver". As a result, a message is passed to the data server requesting to move the selected diver to the system. When the computer accepts the request, the name of the diver automatically appears in the location window of the chamber in which he is stored. The status lights "updating server", "waiting to reply", "Operation accepted", and "operation denied" inform the operator of the response of the computer
This operation is to be renewed for each diver to transfer.

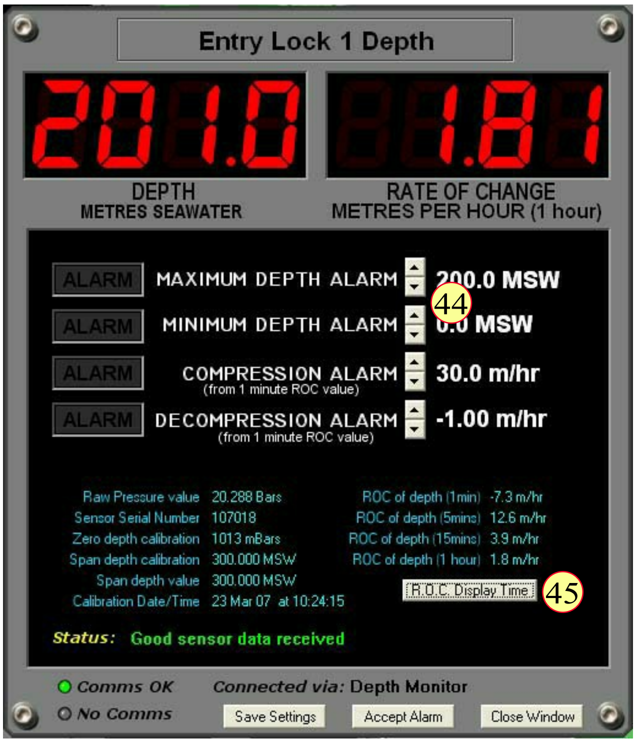


To move a divers from the chamber he is stored to another part of the system, the Life Support Supervisor right clicks or double clicks his name in the "diver location window" *(#12)* of the living chamber. In the menu that is opened, he selects the option "move Diver". As a result, a window similar to the one displayed below appears that shows the name of the diver selected and his current location *(see #41)*.



The LSS then clicks the button that indicates the place where the diver is to be transferred. As a result, a message is sent to the server across the network to request the move, the status of which is displayed with the indicators along the bottom of this window. If the message is accepted, the windows closes automatically and the name of the diver is transferred to his new location.
Note that the LSS must indicate the function of the divers (D1, D2, D3) when they are transferred to the bell. Also, as indicated above, the divers cannot be transferred directly from the external of the system to the bell and must be logged in their chamber first.
At the end of the diving operations, the LSS can transfer the divers off the system *(see #42)*. It can do it using the previous procedure and then log them in "bendwatch" *(see #43)* for the duration of the process. Note that as for the transfer into the saturation complex the divers cannot be directly transferred from the bell to deck or bendwatch.

The system provides a menu to adjust the status display of the depth sensors and set their alarms *(see #6 in the scheme on the previous page)*. To access it, the operator clicks the depth display on the screen. As a result, a window similar to the picture below where the parameters selected are displayed appears.



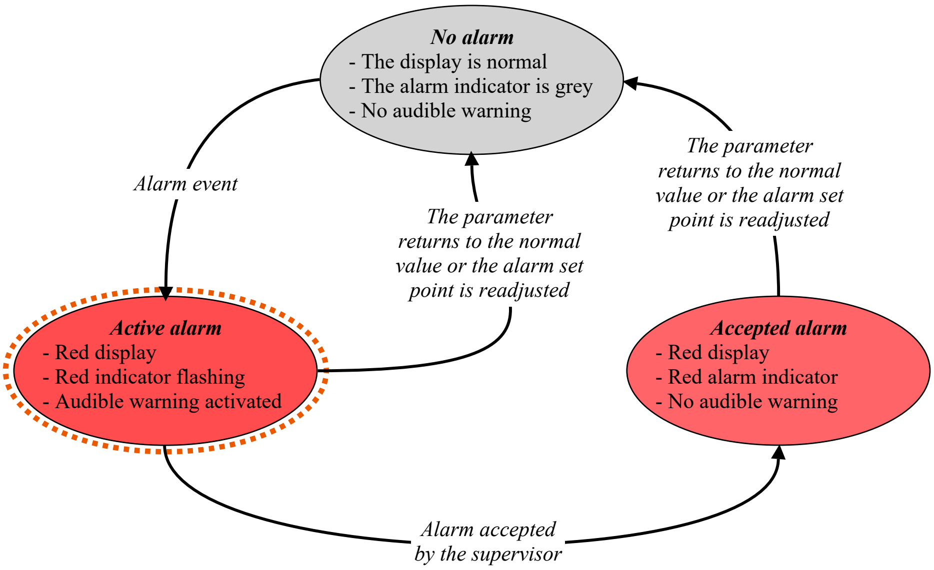
The alarms can be adjusted to the desired values using the sliders *(see #44 above)*. When the setup is completed but not saved, the text colour changes from white to yellow until the operator clicks the title "Save settings"
The LSS can select the time base periods of rate of change of depth by clicking the tile "ROC Display time" *(see #45)* repeatedly to select one of the four time scale values of 1, 5, 15, 60 minutes proposed by the software.
Note that the machine calculate the rate of change of depth by subtracting the current depth from the stored depth at the

point of the time base and expressing this as a rate of change in MSW per hour. As already explained in point 1.2.8.7, negative values mean that the chamber is decompressing and positive ones that it is compressing.
The contractor says that the 1 minute or 5-minute values should be used when setting up decompression bleed-off rates and that the longer time base values are of more use when looking at the overall decompression profile.

The ways that alarms are indicated on the terminal of the saturation control room are similar to those of the dive control terminal, that are explained in Book #3:

- The digits of the element affected turning red
- The alarm indicator is illuminated red and flashing *(see #14 in the drawing of the monitoring screen)*.
- An audible warning is generated every 10 seconds
- A description of the problem published in the status box *(see #4 in the illustration of the monitoring screen)*.
- When a system error or fault alarm is generated, the display changes to a row of red dashes.

The alarm must be accepted by the supervisor to stop the indicator from flashing and the audible warning from being repeated. For this , the LSS must click on the display of the parameter in alarm state to open the relevant menu.
Once accepted, the alarm indicator remains illuminated red and the digital parameter display remains red also until the alarm returns to a condition that does not exceed the alarm set point(s). When the alarm returns within the setpoint(s), the display returns to its normal display colour and the alarm indicator returns to grey.



Note that it may happen that the data server is unavailable. In this case, the machine emits a window that indicates that the server is off line. If a function is selected that requires interaction with the server, a message is presented to inform the operator that the service is disabled.
The LSS cannot solve problems of server unavailable or system errors. for this reason, a quick intervention by the system technician is necessary.

The saturation control client application can be quitted at any time by clicking on the "shut down" button *(see #2 in the previous scheme)* and confirm the action through the menu that is opened (as for every computer or cell phone). Note that data are still logged by the server when the application is shut down.
To restart the application, the supervisor simply double clicks on the desktop icon.

1.2.8.10 - Protection from gas accumulation in the room

The saturation control is supplied with oxygen, therapeutic mixes, and also low oxygen percentage mixes. To avoid these gasses from accumulating in the room, the exhausts must be designed to vent them to the gas bag of the reclaim system or a safe open area overboard. So these gases are recovered or dumped in the wind. Note that venting is also very noisy and for this reason the orifices must be far from areas where activities are carried out.
Also, undetected leaks may happen that build a flammable atmosphere or a poor oxygen percentage atmosphere in the control room. For this reason IMCA D 024 says that an oxygen analyser with audible and visible high and low alarm must be sited in any enclosed life support control to warn the occupants of any rise or fall of oxygen levels outside pre-set parameters due to gas leakage in to the area.
Such analysers are specifically designed for this purpose and must not be confused with those used to monitor the atmosphere of the chambers. Their concept may be based on those previously described in points 1.2.8.4 & 1.2.8.5, which may be fitted with a fan that creates a regulated gas flow through the sensor to adapt them to this function.
However, a lot of systems are using electrochemical cells similar to those used with personal oxygen analysers that are designed to work with a very reduced gas flow.
Manufacturers recommend installing the air intake of oxygen detection devices approximately 1 metre off the floor of the room. The reason is that when it is not yet mixed with the atmosphere of the room, oxygen is heavier than air and tends to concentrate on the lowest parts of the room.
Note that low oxygen concentration heliox mixes are lighter than air and will concentrate within the top parts of the room.

1.2.8.11 - Fire fighting

IMCA D 024 says that suitable firefighting arrangements must be available. It may be by means of permanent ship or platform provided equipment or by means of portable extinguishers etc. It should be capable of dealing with any type or size of foreseeable fire hazard".
IMCA D 024 also says: *"Whether fixed or portable the fire fighting system should be in accordance with manufacturer's specification and fit for the purpose it will be used for"*.
Also, NORSOK standard U100 says that facilities for human-crewed underwater operations must have fire detection and firefighting equipment covering the entire plant both internally and externally and that the material must have adequate capacity to put out fires that might occur. Classification societies confirm this requirement.
In addition to the above, in chapter II-2 of SOLAS (*International Convention for the Safety of Life at Sea*), it is said that a vessel must be equipped with fire detection and firefighting systems. As a result, all built-in saturation systems are protected with the detection and firefighting system of the boat. In addition to portable extinguishers, this system is composed of smoke, heat, and flame detectors, and a water mist system that is fed by two fire pumps 140 m3/h each is installed in the dive control. The operating panel, control unit, and power supply of this system are contained in a central cabinet on the bridge.
However, some transportable saturation systems are not equipped with fixed firefighting installations, and in this case, portable systems have to be provided. Also, as said above, built-in control rooms are equipped with hand-carried systems in addition to the firefighting system of the boat. The following extinguishing agents can be used:

- Water:
  Water is used to cool and protect from heat or flame impingement. Water properly applied (in the form of fog or spray and in sufficient quantity, generally estimated at 10 litres per m 2) can absorb the heat and prevent damage (throwing streams 20 litres per m²). Water does its most effective job of cooling when it is converted into steam.
  Available water should be used to cool the most critical areas of the fire engulfed equipment and the equipment in the radiation zone.
  Water may be used in two principal forms: Spray or fog and straight streams. Each has its particular advantages, disadvantages, and scope of application.
  In general, the straight stream has the greatest range of driving force, the wide angle spray (fog) has short range and affords the maximum protection for the fire fighter; and some in between position, which combines the two, will in most cases be the most desirable. The objective is to get the water in the right form and on the place where it will have the most effect as a cooling or extinguishing agent.
- Foam:
  Fire extinction is normally achieved by the use of fresh or salt water, because of its good cooling characteristics. However, with oil, which has a lower specific gravity than that of water, effective extinction can best be achieved by smothering the burning fuel with foam, thus cutting off the oxygen feeding the fire.
  - Mechanical air foam is a mixture of water under pressure, foam concentrate and air combined in set proportions to provide stabile foam.
  - Foam concentrate is a liquid foam making chemical that will normally be one of two types:
    - Protein Concentrate — manufactured from natural or organic products.
    - Synthetic Concentrate — manufactured from detergent based material

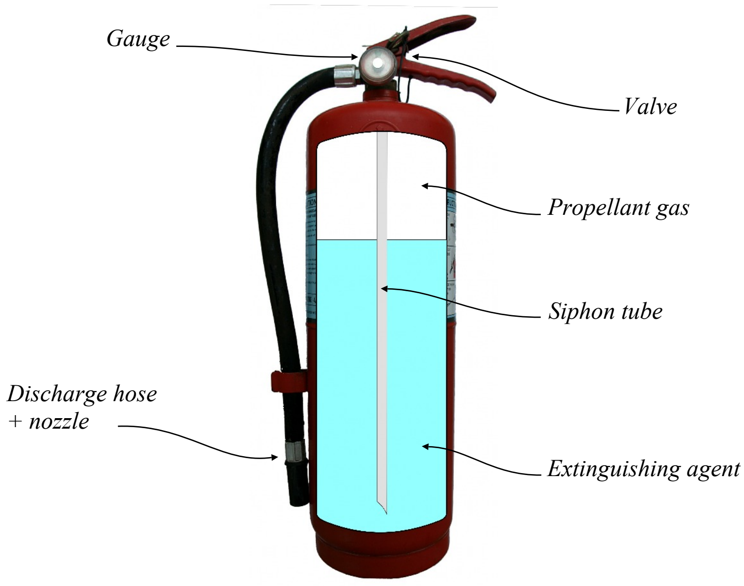
  Foam is not generally used in the dive control room as items filled with oil are usually not present in it. However, depending on the design of the saturation system, such extinguishing agents may be present outside the room and at its direct vicinity.
- Carbon dioxide (CO_2):
  Carbon dioxide dilutes the air surrounding the fire until the oxygen content is too low to support combustion. It has a very limited cooling effect and does not conduct electricity. Also, carbon dioxide does not support combustion in ordinary material. However, it reacts with magnesium and other metals.
  As a result of its characteristics, CO_2 is considered a "clean extinguishing agent" by fire combat specialists who recommend it for the protection of computer server rooms as it can be used to combat electrical fires while preserving the delicate electrical and electronic equipment.
- Halon:
  Halon is made up of carbon and one or more of the following elements: Fluorine; Chlorine; Bromine; or Iodine. Two halons are used in fire fighting:
  - BTM (Bromo Trifluoro Methane) known as HALON 1301 is stored as a liquid under pressure. When released in the protected area it vaporises to an odourless, colourless gas and is propelled to the fire by the storage pressure. Halon 1301 does not conduct electricity.
  - BCF (Bromo Chlorodifluormethane) known as HALON 1211 is also colourless but has a faint sweet smell. Halon 1211 is stored as a liquid and pressurised by a nitrogen gas. Pressurisation is necessary since the vapour pressure of Halon 1211 is too low to convey it properly to the fire area. Halon 1211 does not conduct electricity.

  For the same reasons as Carbon dioxide, Halon is considered a "clean extinguishing agent" by fire combat specialists and recommended to combat electrical fires.
- Dry Chemical Powders:
  They are considered multipurpose extinguishing agents. Dry chemicals may be used in fixed systems or portable extinguishers. They extinguish a fire by shielding radiant heat and to the greatest extent by breaking the

combustion chain. Class D dry powder is the only extinguishing media, which will successfully extinguish metal type fires. However, note that powders are generally limited to electric fires below 1000 volts. Also, this extinguishing agent is not considered a “clean extinguishing agent” and is very corrosive. Note that the manufacturer proposes several types of dry chemical extinguishing agents.

Extinguishers are the most common portable fire extinguishing devices in dive controls. The reason is that they are easy to use and can be stored near the strategic points without the need for a specific installation.
Note that there are two main types of extinguishers:

- “Stored-pressure extinguishers” contain the extinguishing agent at the bottom, and the rest of the vessel is filled with a propellant gas which is usually nitrogen. The propellant gas at a pressure between 12 and 17 bar, and this operation is usually performed in the factory. A gauge is installed on the device to ensure that the gas pressure in the reservoir is still adequate. The advantage of this design is that it is very simple with a minimum of parts. Its main disadvantage is that it cannot be opened on site and must be returned to the factory or a specialist for this operation



- “Cartridge-operated extinguishers” have the fire extinguishing agent not stored under pressure and the propellant gas that is in a separate small sealed cartridge. Depending on the design, this cartridge is operated by a specific mechanism triggered by the valve that pushes a plunger or by pressing a dedicated built-in squeeze lever. The advantage of such a system is that the extinguishers can be opened on-site as the reservoir is not under pressure. Their disadvantage is that their mechanism is slightly more complicated.

Note that IMCA says that portable systems must have an external visual examination and check that any indicating device reads within the acceptable range at least every six months.
Also, nozzles, valves, pipework, and other elements of fixed systems must be visually examined every six months.
Besides, the system must be function tested or have a simulated test using air or gas as the test medium every year.
IMCA also recommends that automatic detection and activation systems are tested at least every 12 months.

Note that fire detectors are installed on the majority of portable systems and are mandatory in many countries.

Regarding integrated system in modern ships, the “central control station” that is in the bridge centralizes the following functions:

- Fixed fire detection and alarm systems.
- Automatic sprinklers, fire detection and alarm systems.
- Fire door indicator panels.
- Fire doors closures.
- Watertight door indicator panels.
- Watertight door closures.
- Ventilation fans.
- General/fire alarms.
- Communication systems including telephones and microphones to public address systems.

As a result, in case of a fire in the saturation control room, gas storage room, chamber area, and around the SPHL, the fire and smoke detectors activate a fire alarm to inform the “central control station” that the compartment is on fire. Hence, the firefighting systems are automatically or manually activated with the audible alarm. Nevertheless, on a lot of vessels, the sprinklers and alarms that are in place to protect the parts of the system that are controlled from the saturation control room are relayed and can be remotely released in it. Note that the “central control station” is the master station and has control over the saturation control.

The internal firefighting system of the saturation complex is organized so that manual activation/deactivation controls are located at the operator’s console in the saturation control room. These controls must be designed to prevent unintended activation. For this reason they are grouped in a specific cabinet.

1.2.8.12 - Emergency breathing apparatus

IMCA D 024 says that emergency breathing apparatus fitted with communications must be available for the supervisor so that he may perform his duties in a smoky or polluted atmosphere.

The breathing apparatus must also allow the supervisor and the Launch and Recovery System (LARS) operator to escape with the rest of the team when they have completed their duty. For this reason, the breathing apparatus must be fitted with a bottle that allows doing it.
Also, new models enable connecting to a gas reserve without using the bailout bottle during the time the people finish the ongoing diving operation. As an example, Drager, a well-known manufacturer, proposes an “Automatic Switch Over Valve” that is designed for this purpose and connects automatically from the external supply to the bailout if this supply fails *(see below)*.

Automatic Switch Over Valve

Note that the breathing apparatus must never be connected to a compressor as the air intake may be in a polluted area. For this reason, the air provided must be from a gas reservoir only.
In addition to the emergency breathing apparatus, several escape sets should be provided to allow the not essential personnel present in the dive control to escape. These items are composed of a small bottle and a hood or a breathing mask and do not allow any other activities than moving to the muster station.

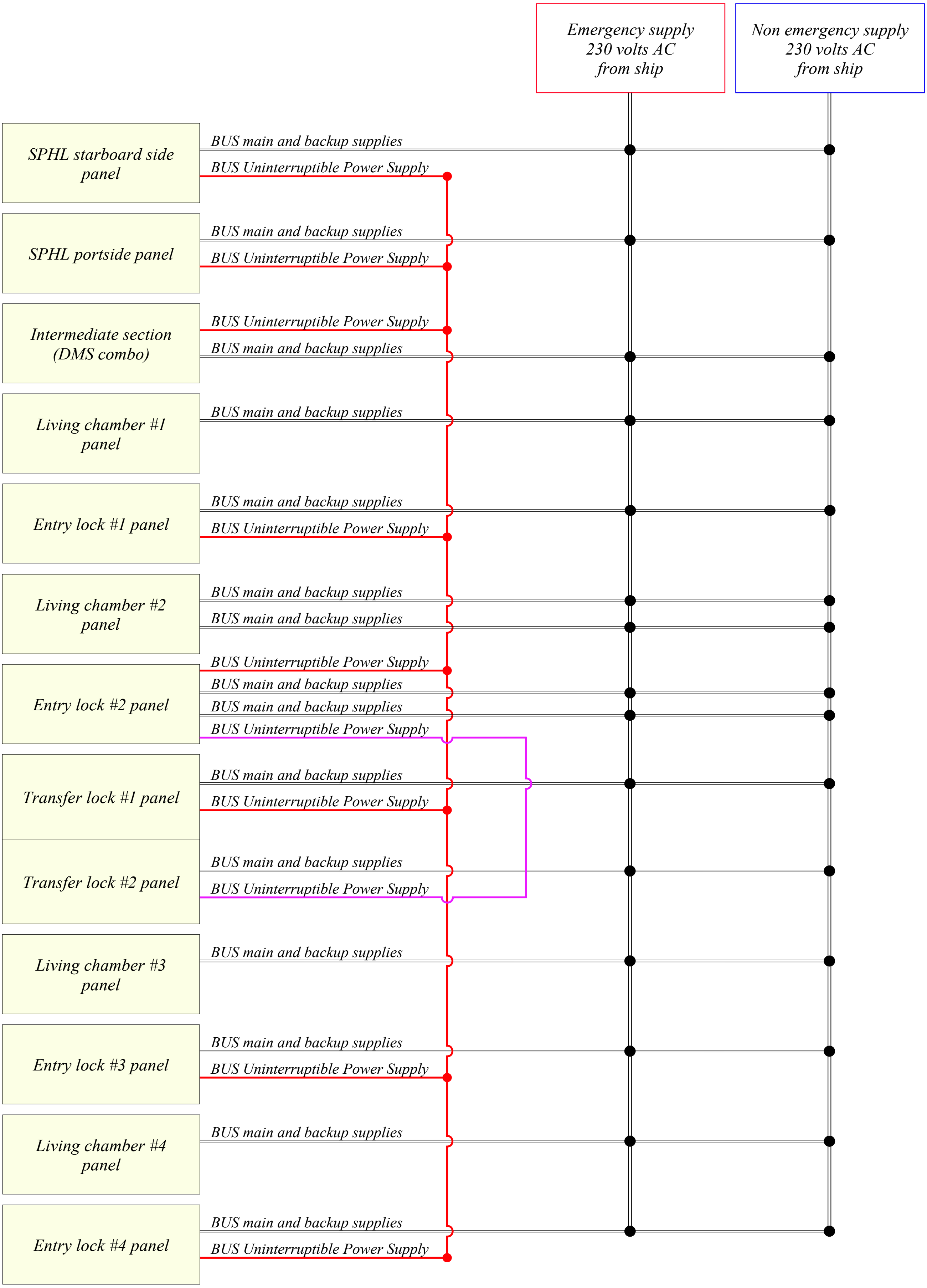
MCA D 024 says that Emergency breathing apparatus (and escape sets) should be function tested (including voice communications) at least every six months and at the same time their cylinder is fully charged. Also, the bottle should be tested for leaks at its maximum working pressure of and externally examined every two and a half years. The same inspection increased with an internal examination has to be performed every five years.

1.2.8.13 - Electrical supplies

The saturation control room is the place from which the parameters and also the electrical supplies of the chambers are controlled. As for the dive control, it is supplied with 230 volts alternating current (AC) and 24 volts direct current (DC). Some elements are also supplied with 12 volts DC.
This current is provided by the main and back up electrical supplies. On ships, the main supply is provided by the main generators and the backup supply is provided by the emergency generator that is designed to work even though the lower parts of the vessel are flooded. The electricity from these generators is controlled and regulated down through switchboards and supply transformers. Note that a lot of vessels, are equipped with harbor generators that provide the main electrical supply when they are in port.

Uninterruptible Power Supply (UPS) systems should be provided to complement the primary and backup supplies. UPS units filter small utility line fluctuation and isolate electrical equipment from large surges by internally disconnecting from utility line power and supplying continuous power from their internal battery until power returns to a safe level or the battery is fully discharged. Their operational duration when the regular electric supplies fail is not indicated in IMCA. However, note that IMCA says that the UPS in the dive control must be designed to operate during at least 30 minutes.
With the saturation systems taken as reference, three UPS provide backup power supply to all the essential services of the saturation control panels. Two of them are dedicated to all chamber gas analysers, and one unit is dedicated to the Diver Monitoring System. Besides, a UPS is provided in each cabinet that controls the electrical supplies to the chambers and fire fighting system.

The scheme below represents the power supplies of the control panels of the systems taken as references. Note that each connection is protected by a relevant breaker.
Note that apart from those equipped with "regeneration shutdown controllers", the control panels are not used to control the electrical supplies of the chambers. These controls are performed through the electrical cabinets that are in the same room but separate from the control panels *(see on the next page)*.



Note: In a power system, a "BUS" is defined as the vertical line at which the several components of the power system (generators, switchboards, transformers, etc.) are connected.

Hyperlink Table of contents

As indicated previously, the electric controls of the chambers are performed through separate electrical cabinets. It is also the case of the firefighting alarms and commands, the DMS server, and the Environmental Control system. Each rack is supplied with current 230 volts AC by a main and a backup source and provided with one or two Power Supply Units (PSU) that convert this current to 24 or 12 volts DC. The drawing below lists the elements of each cabinet.

230 volts AC (BUS - L1N1)

Electrical cabinet #1

- *DMS server PC*
- *Colour quad process #1*
- *Colour quad process #2*
- *Colour quad process #3*
- *Colour quad process #4*
- *PSU #1*
- *24 volts DC (BUS - A)*
  - *Alarm annunciator #1*
  - *Cold water valves*
  - *Hot water valves*
  - *ECU (PLC)*
  - *HECS interfaces*

230 volts AC (BUS - L2N2)

Electrical cabinet #2

- *Colour quad process #5*
- *Colour quad process #6*
- *Video splitter Amplifier*
- *PSU #2*
- *24 volts DC (BUS - B)*
  - TL1: *Overhead lights*, *Scrubber*, *Air handling unit*, *Med. Bunk light*
  - TL2: *Overhead lights*, *Scrubber*, *Air handling unit*, *Cameras*
  - LC1: *Overhead lights*, *Scrubber*, *Circulating fan*
  - *IPS living chamber #1*
  - LC2: *Overhead lights*, *Scrubber*, *Circulating fan*, *Cameras*, *Air handling unit*, *Bunk lights (6)*
  - *IPS living chamber #2*
  - LC3: *Overhead lights*, *Circulating fan*, *Scrubber*
  - *IPS living chamber #3*
  - LC4: *Overhead lights*, *Scrubber*, *Circulating fan*, *Cameras*, *Air handling unit*, *Bunk lights (3)*
  - *IPS living chamber #4*
  - EL1: *Overhead lights*, *Scrubber*
  - *IPS entry lock #1*
  - EL2: *Overhead lights*, *Scrubber*
  - *IPS entry lock #2*
  - EL3: *Overhead lights*, *Scrubber*
  - *IPS entry lock #3*
  - EL4: *Overhead lights*, *Scrubber*
  - *IPS entry lock #4*
  - SPHL #1: *Light*, *Camera*
  - *Light trunk SPHL #2*
  - *Alarm annunciator #2*

230 volts AC (BUS - L3N3)

Electrical cabinet #3

- *Colour quad process #7*
- *Colour quad process #8*
- *SPHL #1 camera PSU*
- *SPHL #2 camera PSU*
- *PSU #3*
- *24 volts DC (BUS - C)*
  - TL1: *Overhead lights*, *Scrubber*, *Air handling unit*, *Cameras*
  - TL2: *Overhead lights*, *Scrubber*, *Air handling unit*, *Med. Bunk light*
  - LC1: *Overhead lights*, *Scrubber*, *Circulating fan*, *Cameras*, *Air handling unit*, *Bunk lights (3)*
  - *IPS living chamber #1*
  - LC2: *Overhead lights*, *Scrubber*, *Circulating fan*
  - *IPS living chamber #2*
  - LC3: *Overhead lights*, *Scrubber*, *Circulating fan*, *Cameras*, *Air handling unit*, *Bunk lights (6)*
  - *IPS living chamber #3*
  - LC4: *Overhead lights*, *Circulating fan*, *Scrubber*
  - *IPS living chamber #4*
  - EL1: *Overhead light*, *Camera*
  - *IPS entry lock #1*
  - EL2: *Overhead light*, *Camera*
  - *IPS entry lock #2*
  - EL3: *Overhead light*, *Camera*
  - *IPS entry lock #3*
  - EL4: *Overhead light*, *Camera*
  - *IPS entry lock #4*
  - *Light trunk SPHL #1*
  - SPHL #2: *Light*, *Camera*
  - *Alarm annunciator #3*

230 volts AC (BUS - L4N4)

Electrical cabinet #4

- *Colour quad process #9*
- *Colour quad process #10*
- *Colour quad process #11*
- *Colour quad process #12*
- *PSU #5*
- *PSU #4*
- *12 volts DC (BUS - D)*
- *24 volts DC (BUS - E)*
  - *Fire detector TL1*
  - *Fire detector TL2*
  - *Fire detector LC1*
  - *Fire detector LC2*
  - *Fire detector LC3*
  - *Fire detector LC4*
  - *Fire detector EL1*
  - *Fire detector EL2*
  - *Fire detector EL3*
  - *Fire detector EL4*
- *Fire fighting system*
  - *Deluge TL1*: *Auto activation*, *Manual opening*, *Manual closure*
  - *Deluge TL2*: *Auto activation*, *Manual opening*, *Manual closure*
  - *Deluge LC1*: *Auto activation*, *Manual opening*, *Manual closure*
  - *Deluge LC2*: *Auto activation*, *Manual opening*, *Manual closure*
  - *Deluge LC3*: *Auto activation*, *Manual opening*, *Manual closure*
  - *Deluge LC4*: *Auto activation*, *Manual opening*, *Manual closure*
  - *Deluge EL1*: *Auto activation*, *Manual opening*, *Manual closure*
  - *Deluge EL2*: *Auto activation*, *Manual opening*, *Manual closure*
  - *Deluge EL3*: *Auto activation*, *Manual opening*, *Manual closure*
  - *Deluge EL4*: *Auto activation*, *Manual opening*, *Manual closure*

Legends

HECS:
Hyperbaric Environment Regeneration System

ECU:
Environment Control Unit

DMS:
Diver Monitoring System

PSU:
Power Supply Unit

IPS:
Independent Protection System

LC:
Living Chamber

EL:
Entry Lock

TL:
Transfer Lock

PLC:
Programmable Logic Controller

1.2.8.14 - Configuration of the room and ergonomics

In addition to the fact that they must be at the direct proximity of the chambers and their facilities, the saturation control rooms must be designed to accommodate and protect people and the elements previously described and also provide satisfactory ergonomics to the Life Support Technicians:

- As already explained, the rooms of built-in systems are usually in a protected area inside the vessel. However, it is not the case of those of portable saturation systems that are usually organized in a container installed on deck. As for the other parts of the system, this container must be designed to protect the personnel working in it from the external conditions and small dropped objects. Also it should be away from lifting and working areas.
- The temperature inside the room must be controlled to be comfortable for the technician and not create overheating of electronic components. A temperature between 19 and 25 Cº is considered suitable for electronic systems and agreeable for the personnel. Also, according to computer specialists, the humidity must be kept as close as possible to a level of 40% - 30% to prevent water droplets from forming on the machines and inside electronic components. Keeping the humidity level low avoids problems such as the failure of circuits, chips, and other components. Note that such a level of moisture is sometimes challenging to obtain in the maritime environment, particularly when the control room has a door opening directly to the deck. In this case, dehumidification systems can be added in the forced ventilation system, or directly in the room.
- The control area must be well lighted such that the life support personnel are able to read any instruments easily and to carry out their duties without difficulty. Norsok U 100 recommends a minimum of 300 Lux in all areas of the room and a minimum of 500 Lux near the control panels and desks. Manufacturers often use white colour coatings to increase the luminescence of the room.
- According to NORSOK U100, noise exposure in the room should be 65 dB maximum. Note that lower values are commonly obtained with saturation systems that are integrated into the ship. This value is also possible with portable systems that are isolated with correct materials. However, the thickness of these materials reduces the space available in the container that initially offers a reduced space.
- The life support personnel must have suitable access to all controls. Note that the panels should be arranged so that any audible and visual alarm can be heard and seen from any part of the room. Also, comfortable chairs should be provided so people can rest during their shift.
- The contractor's saturation and life support manuals, including emergency procedures, must be present in the room with the documentation of the equipment used by the LSTs. Also, there must be a full set of the required logbooks or sheets available in the control area to allow the recording of all necessary parameters and other required information. A desk must be provided to enable the LSS to carry out their paperwork. A suitable computer with internet and Ethernet connections should also be available to write reports and transmit them by emails and throughout the relevant offices onboard the vessel.
- A satellite phone must be provided to communicate with the diving medical specialist appointed by the company *(also indicated in* *point 1.2.8.7**)*. Note that systems such as the Fathom communications allow direct unscrambled phone communication to the doctor (who is not on site) from the inside of the chamber. Also, the terminal of the system that allows a doctor who is remote in his office visualizing the essential information of a patient in the chamber at the same time a medical intervention is practiced should be ready for use.
- IMCA says that medical equipment in a suitable protective container must be provided to the level specified in the diving contractors manuals and as a minimum meet the requirements of DMAC 15 and DMAC 28 (or as agreed with company medical adviser) unless local regulations prohibit any of the contents.

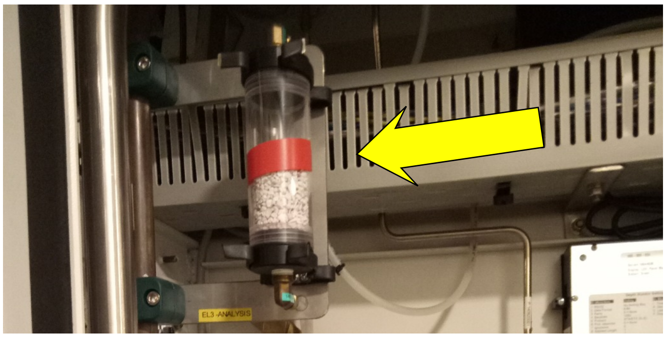
1.2.8.15 - Maintenance

IMCA D 024 recommends the following minimum frequencies of maintenance. However most visual examinations that are recommended every six months should be performed daily when the system is at work.

Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure*	*Other*
Communications	6 months			
Gauges calibration	6 months			
Pipework	6 months	2 years	When new	
Relief valves	6 months	2 years ½		
Electrical & electronic systems	6 months			
Portable firefighting	6 months			Specifications of the manufacturer
Fixed firefighting	Visual: 6 months Function test: 12 months			Specifications of the manufacturer
Automatic fire detection	Visual: 6 months Function test: 12 months			Specifications of the manufacturer
Breathing apparatus	6 months	2 years ½ (cylinder + gas leak)	5 years (cylinder)	
Medical equipment	6 months			
Gas panel analysers	6 months			Specifications of the manufacturer
Alarms & room analysers	6 months			Specifications of the manufacturer

In addition to the guidelines from IMCA, the manufacturer gives the following recommendations:

- Valves should be function tested and checked for leaks daily. Corrosion should be removed.
- Desiccants such as silica gel or similar products are installed in small transparent containers to dry the gas flow coming from the chambers to the analysers. These containers must be checked every day, and the desiccant replaced as soon as the colour indicates that it becomes saturated.



- Function tests to ensure that the regulators are operating correctly, with no unexpected pressure creeping or venting should be performed every month.
- The emergency breathing apparatus should be function tested and their communications checked every month. Note that the operator should ensure that the panel quick connects and supply valves are operating correctly.

Precautions must be implemented with the computers of the Dive Monitoring System (DMS) and those used for other functions:

- Daily maintenance tasks include the cleaning of the keyboards, mouse, cooling fans, monitors/displays, and removable media drives. Note that specific products and microfiber cloths should be used to clean monitors without damaging them. Alcohol is recommended to clean mice and keyboards that are reputed to become nests of microbes.
- The technicians should also ensure that there is always sufficient hard disk space on the DMS server and the other computers. Space can be made by selectively archiving historical data to permanent storage drives.
- The manufacturer of the Diver Monitoring System says that it is not provided with a backup server. However,

this function can be added for increased system availability/redundancy with a computer that would take over from the main system server in the event of failure. Any of the client terminals can be replaced by a PC of opportunity if there is a failure. Alternatively, the system laptop can be used as a spare in emergencies. If a computer fails and is replaced by an extra unit, the necessary software for the area of use must be installed on the replacement unit. The software can be installed from the DMS software distribution disks, or can be copied over from the data server where the current version of all files should be kept.

Last generation analysers such as those explained in this document should be maintained as follows:

- Calibration should be performed at least every 12 hours.
- Function test should be performed every day.
- Visual inspection and routine calibration of depth sensors should be performed every three months.
- Full inspection of all components and calibration should be performed every year.
- The equipment should be sent to the factory for full revision and update every two years.

The manufacturer of the chamber regeneration System Shutdown Controller recommends the following:

- Calibration and function test should be performed every day
- Routine transducer and display calibration using pressure calibrator should be performed every three months with the visual inspection of the shutdown valves and E-Stop operation.
- Depth monitor functional safety test procedure should be performed every six months
- Full inspection of all components and calibration should be performed every year
- The equipment should be sent to the factory for full revision and update every two years.

1.2.9 - Life support package

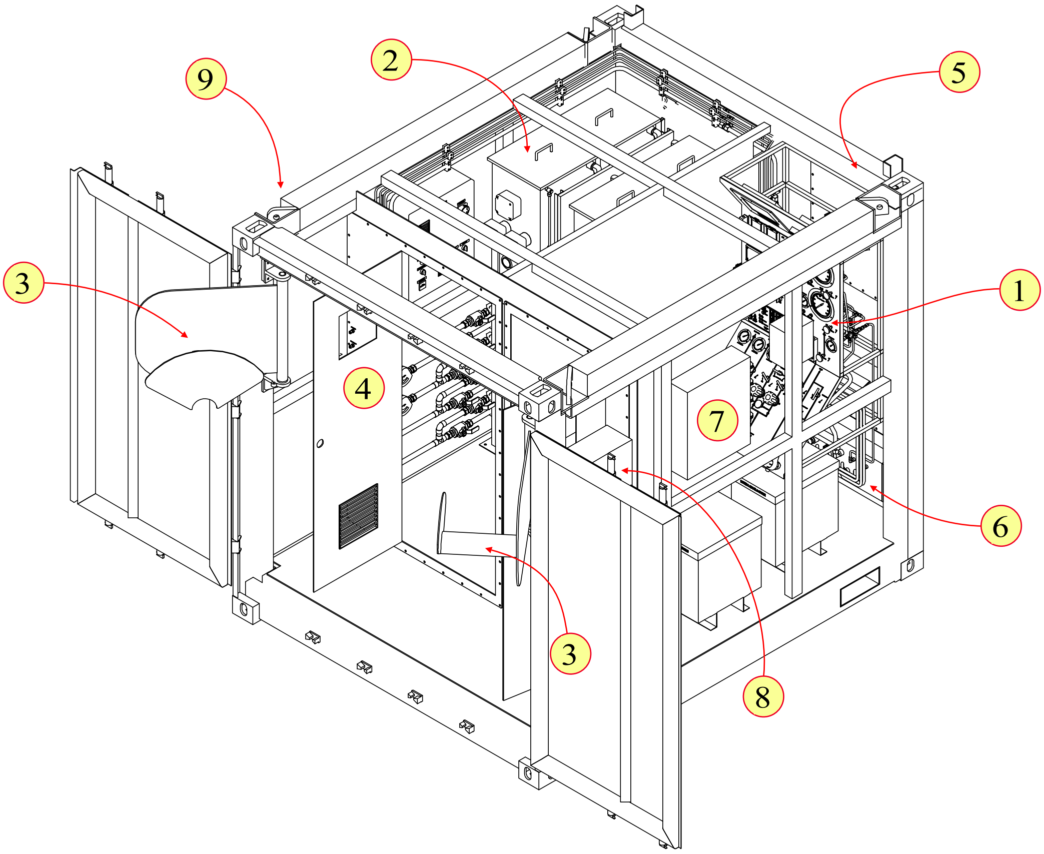
1.2.9.1 - Purpose

In the early times of saturation diving, when there was no Hyperbaric Reception Facility (HRF) where the divers could have been transferred and decompressed, the Hyperbaric Rescue Units were planned for this purpose. The Life Support Package (LSP) function was to provide the necessary gasses and environmental controls to complete the decompression of the divers in the best possible manner. The Life Support Package was also designed to provide medical re-compression after the decompression in the case of decompression illness, and that no proper installation was available on-site.

Since such decompression units are available today, the Life Support Packages (LSP) are mainly used to maintain optimal living conditions of the divers during the transfer to the place where the decompression facility has been installed. Note that most clients request that the contractor selected for the project organizes for a rescue vessel ready to pick up the hyperbaric rescue unit to its board as soon as possible. IMCA D 052 also says: “the HRU needs to be lifted onto a rescue vessel or allocated installation as soon as possible”. Besides, the document NORSOK U100 says that arrangements must be in place for the mobilization of the LSP on board a suitable rescue vessel capable of reaching the SPHL within 12 hours of the launch of the SPHL. In complement of the previous, IOGP 478 says that Vessel(s), equipment and marine services necessary to protect and support the SPHL(s) should be at the SPHL location within 12 hours of the launch of the SPHL. Note that some rescue boats are provided with a Hyperbaric Reception Facility (HRF) that is designed to perform the decompression from the most profound storage depth planned for the diving operation, and to which the hyperbaric rescue unit is connected as soon it is transferred onboard. In this case, the Life Support Package can be used upon the HRU is on deck, and as long as the transfer of the divers to the HRF is not performed. However, it may happen that decompression facilities are not available in the area where the activities are undertaken and that clients, contractors, and authorities admit together that decompression in the Hyperbaric Rescue Unit is acceptable. In this case, the LSP can be used to perform the decompression as in the old time.

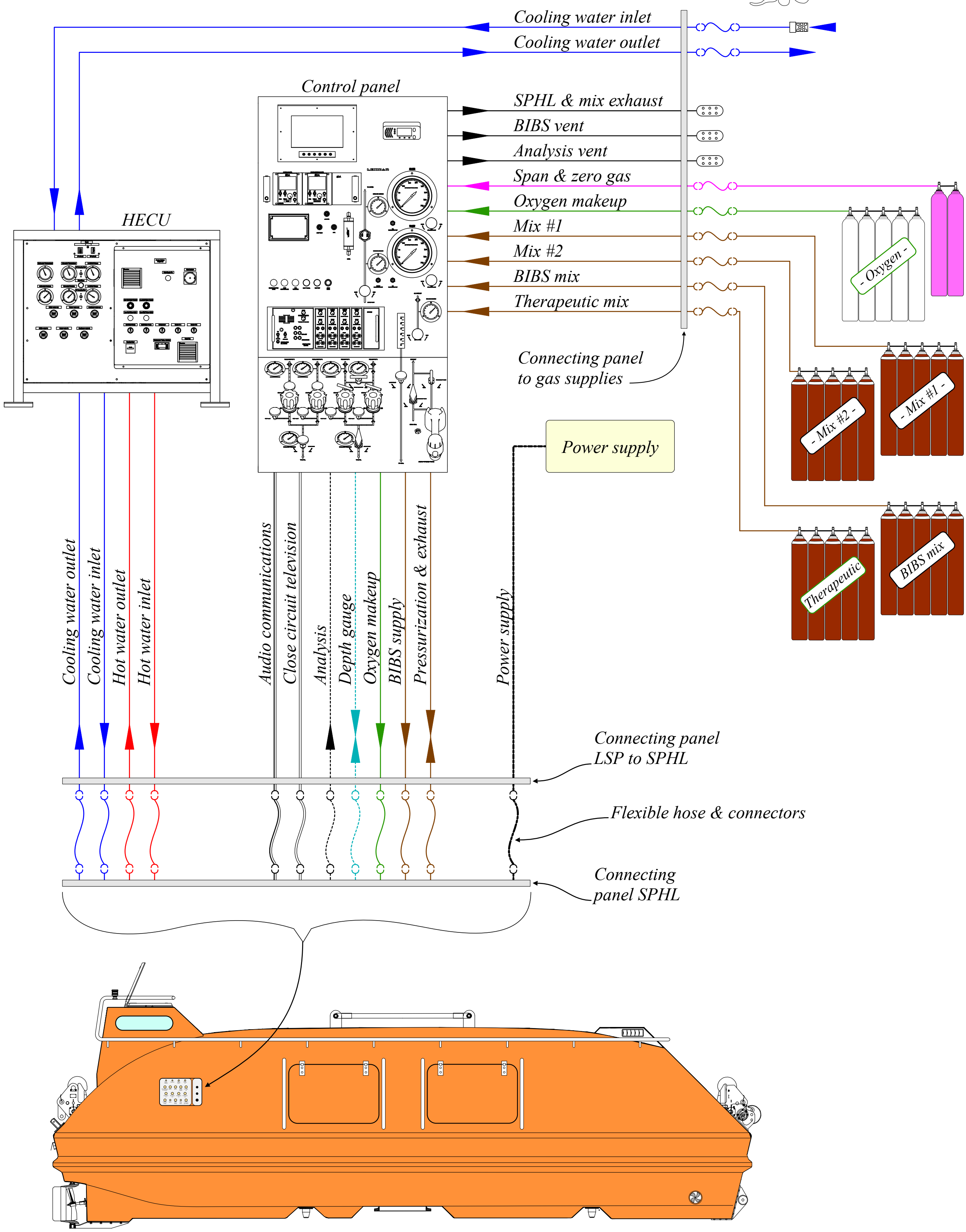
1.2.9.2 - General design

Most Life Support Packages currently in use are portable systems that are installed on boats of opportunity during the preparation of the saturation operations. They are considered a part of the saturation system in use on the diving support, and it is the reason they are described in section 16 of the Diving Equipment Systems Inspection Guidance Note (DESIGN) IMCA D 024.
Such systems are composed of suitable gas reserves that are connected to a saturation control panel, and an environmental control unit, usually accommodated in an offshore container from which connecting hoses terminated by the quick connectors described in point 1.2.7.2 are fitted to the Hyperbaric Rescue Unit.



Legends

1 - Saturation control panel	*4 - Isolation door*	*7 - Electrical distribution 220 volt*
2 - Environmental Control Unit	*5 - Access hatch to the back of the panel*	*8 - Electrical distribution 440 volt*
3 - Umbilicals & cables storage	*6 - Connectors to HRU*	*9 - Offshore lifting pad eye*



As a reminder offshore containers are reinforced units with a maximum gross mass not exceeding 25000 kg for repeated use in the transport of goods or equipment, that are designed to be handled in open seas, to, from or between fixed and floating installations and ships. They must be approved by a certification body.
IMCA D 024 says that when the environmental control machinery is accommodated in the same container than the saturation control panel, it must be isolated by a wall *(see the drawing on the previous page)* with access doors that can be opened from both sides. Note that penetrator panels for electrical and other supplies should not be near these doors. Also, IMCA says that there must be heating or cooling devices when the ambient temperature inside the container is likely to be too high or too low.

The saturation control area must be designed as every control room:

- It must be isolated against weather conditions and noises, and well illuminated:
    - Depending on the area where the operation are undertaken, heating and/or cooling systems must be present to maintain an ideal temperature (It should be between 19 to 25 degrees).

    - Noise emissions should be reduced to 65 dB maximum.
    - Illumination should be as indicated in point 1.2.8.13 of this document, so 300 Lux in all areas of the room and a minimum of 500 Lux near the control panels and desks.
- Fire alarms and fire fighting systems (fixed or portable) must be in place. Note that the fire fighting systems in these rooms are usually extinguishers. Also, an automatic emergency lighting system should be available.
- Emergency breathing apparatus fitted with communications must be available for the life support technician on duty and his assistant. Note that these breathing apparatus are the same models as those used in the other control rooms. When they are connected to the panel, the supply must never be from an air compressor.
- There should be main and backup communications to the chamber of the hyperbaric control unit. The main communicator must be unscrambled. As usual, the secondary means of communication can be a sound powered phone. However, it is a common practice to provide a second unscrambled portable unit.
- Communications to the bridge, people on deck, and the shore should be provided to allow the Life Support Technician on duty, giving and receiving instructions without leaving the saturation control panel.
    - A minimum of four hand-held Very High Frequency (VHF) radios should be available.
    - Some organizations say that when the LSP is on board the rescue vessel, the communications systems onboard that vessel would normally be sufficient. However, the Life Support Technician on duty cannot go to the bridge to communicate to external locations if he is the only qualified person on duty, because the control panel would be left without surveillance. For this reason and as for every saturation control, a portable satellite phone or an extension of the onboard unit should be available in the control room.
      A mobile phone can be used as a complement to the satellite phone but cannot replace it due to the reduced range of such systems that can be used only when the boat is at the direct proximity of the shore of inhabited areas. Note that a mobile phone can communicate through Voice over Internet Protocol (VoIP) if the vessel is equipped with a satellite internet system and wireless networking (WiFi) to which the phone can be paired. However, such systems which efficiency depends on the quality of the bandwidth cannot guarantee 100% successful communication despite significant progress.
    - It may happen that VHF transmissions are difficult or impossible due to the channels used by these devices occupied by more powerful units, or other interferences. For this reason, it is advisable to install dedicated wired communications between the saturation control area and the bridge of the vessel. Note that such systems are mandatory for saturation control rooms onboard dive supports.
- The life support technician cannot see what happens in the chamber from the control area which is remote. For this reason, the camera inside the chamber should be connected to a screen on the saturation panel.
- The saturation control panel must provide the functions to maintain the living conditions of the divers within acceptable values and eventually perform a decompression.
    - The gauges must be similar to those used in any saturation control panel and provided so the operator is aware of the depth of the chamber and of the pressure of the main and back-up supplies. They should be equipped with pressure limiting devices and positioned such that the operator can easily see which function is indicated. In case cross overs are installed, a system must be in place to ensure that incorrect readings cannot happen in certain valve positions. IMCA says that such valves should either be fixed in one position (the handles may be removed to avoid accidental changes) or should indicate very clearly what supply they are connected to. In any event any gauge fitted with a cross-over valve must indicate very clearly at all times exactly what it is reading.
    - Depth gauges must be designed to perform a decompression if needed:
        - They should operate in the range 25 to 75% of full scale deflection although they will need to operate in the 0 to 25% range during decompression.
        - They must have scale divisions of no more than 0.5 msw/2 fsw.
        - They should be marked in the same unit system (imperial or metric) or have dual scale marking that must be large enough to be easily and accurately read.
        - If used, digital gauges must have a display large and clear enough to be read in all conditions and provide a precision of at least one decimal. The unit system used must be as visible as the digits.
    - Pressure gauges should be designed as the depth gauges except they are smaller.
    - The valves must be designed so the operator can control the gas inlet and outlet to and from the chamber and the oxygen makeup. Their function must be clearly indicated and they must be easy to operate and not corroded.
      As previously indicated, valves carrying oxygen or mixes with more than 25% O2 (22% with Norsok) at a pressure higher than 15 bar must be ¼ turn valves. Note that needle valves with non-rotating stem are the preferable option. Also, these valves and their pipework must be cleaned for oxygen service.
      Also, IMCA says that there must be a flow indicator at the control point on the downstream side of the chamber O_2 make-up line to indicate that O_2 is flowing in to the chamber.
    - The rule for exhausts previously explained should be in place, so the vents are organised outside the room, and in a well ventilated area that is far from places where people are working.
    - Pressure relief valves may be installed to protect the pipeworks of the panel (it is optional). Note that their vents are not considered exhaust pipeworks. It is also the case of the exhaust of analysis sampling.
    - There must be main and backup oxygen and carbon dioxide analysers with high and low alarms to control the parameters of the chamber. Note that IMCA says that the backup analysis may be provided

- by another means than the system indicated. Note that portable units are often used.
- Also, hygrometry and temperature of the chamber should be indicated in the saturation control.
- Gas leaks may happen in the control area. For this reason, an oxygen analyser similar to the model described in point 1.2.8.9, which purpose is to control the atmosphere of the room should be in place.

The Life Support Package must be equipped with devices that provide sufficient cooling and heating to maintain the chamber at optimal temperature values whatever is the number of divers it accommodates (but not exceeding the maximum). Also, IMCA says that there must be 100% redundancy, so two complete systems must be present.
Due to the reduced space in the container and the fact that only one chamber is to be controlled, these systems are similar but more compact as those described in point 1.2.4 of this document. However, they are often sufficiently powerful to supply a portable saturation system. It is the case of the machine explained in the scheme below, which is extracted from a system designed by Lexmar (JFD group).

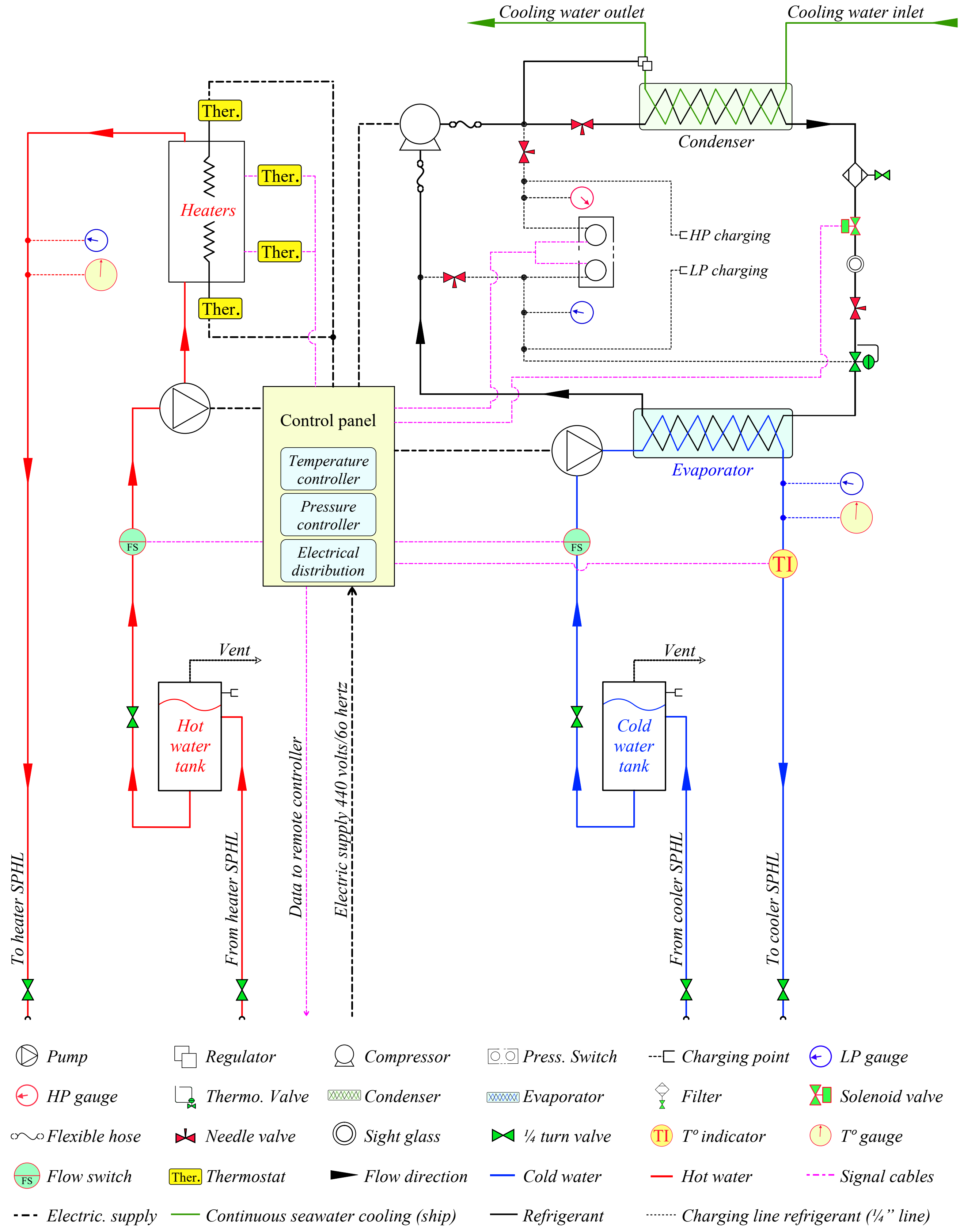
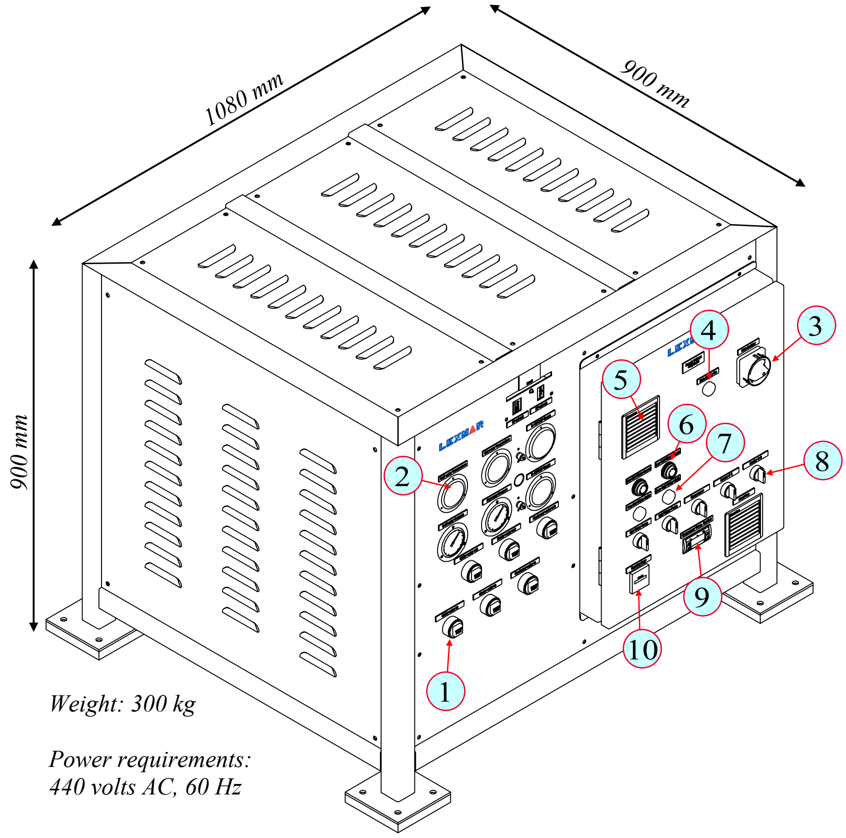


Table of contents



Weight: 300 kg

Power requirements:
440 volts AC, 60 Hz

1 - Connectors:
. Cold water out
. Cold water in
. Hot water out
. Hot water in
. Condenser water (vessel) out
. Condenser water (vessel) in

2 - Gauges:
. Cold water temperature
. Hot water temperature
. Refrigerant high pressure
. Refrigerant low pressure
. Cold water pressure
. Hot water pressure

3 - Main switch

4 - Power supply "on" lamp

5 - Cooling fan

6 - Buzzers low cold and hot water

7 - Lights low cold and hot water

8 - Switches:
. Cold water pump
. Hot water pump
. Compressor refrigerant
. Heater #1
. Heater #2

9 - Temperature controller compressor

10 - Running hours recorder

These Hyperbaric Environmental Conditioning Units (HECU) are composed of hot water, and cold water circuits that use the same principles of work as the bigger machines explained in point 1.2.4 of this document.

- The cold water circuit is chilled by the refrigeration circuit that consists of a standard vapour compression refrigeration cycle similar to the one already explained in point 1.2.4 of this document. The reference of the refrigerant used in the system is R407C, which is a mixture of hydrofluorocarbons, that is environmentally-friendly. Note that the refrigerant used with the model presented in point 1.2.4 is another hydrofluorocarbon which reference is R-134A. The refrigeration circuit works as follows:
  1) The refrigerant gas is compressed by the compressor and then passes through the condenser (heat exchanger), where it turns into a cooled liquid form. This condenser is seawater cooled and hence is an open circuit with the output water dispensed back to sea.
  2) The liquid is expanded to form a combination of low-pressure liquid and gas when passed through the expansion valve. A sensing bulb, connected to the evaporator outlet, allows the correct amount of refrigerant to pass through this valve.
  3) The refrigerant is then evaporated inside the evaporator, where it cools the water circuit and absorbs its heat before returning to the compressor.

  The cold water circuit is another closed-loop system that works in parallel with the refrigeration circuit that cools it. It is filled with a mixture of water and glycol that is circulated by a pump through the pipes and the evaporator, where it removes the absorbed heat and is cooled again before being pushed to the cooling element of the chamber. A water tank that allows filling the circuit provides the necessary suction to the pump and assists in relieving any air pockets that may be trapped.

  Note that the manufacturer says that The temperature of cold water and glycol mixture supplied to the living chamber of SPHL must be maintained at 5°C or lower at all times during operation.
- The hot water circuit is also a closed loop. It consists of a heater tank that is an energy and storage buffer that absorbs the fluctuations in the process. This tank is equipped with two heaters of 12 kW each. However, only one heater is used to heat the water and glycol mixture during the operations, failing that the standby heater is available. A safety thermostat on the heater tank controls the temperature of hot fluid from exceeding dangerous levels. This fluid is circulated through the heater tank and then to the heating unit located inside the living chamber of the hyperbaric rescue unit by a centrifugal pump. A similar water tank as above allows filling the circuit and provides the necessary suction to the pump and removes air pockets.
- The machine described provides a cooling capacity of 20.5 kW/hr and a heating capacity of 12 kW/hr.

Electrical supply must be provided to the system. The energy used by the saturation control panel is usually negligible as only 230 volts AC and 24 volts DC are usually employed to energize the lighting and the instruments. However it is not the case of the Hyperbaric Environmental Conditioning Unit and the lights that illuminate the deck by night. As an example, it is said that the machine described above consumes 40 kW/hr of tri phased current 440 volts AC 60 Hz. The additional lighting necessary to illuminate the deck depends on the illumination already in place, nevertheless it often happens that 2 to 4 kW 230 volts AC are necessary. Also, it must be noted that more energy is necessary during a very short period when the motor starts. As an example, a 44 kW motor would consume five times the normal operating kW, or 220 kW. For these reasons, it is necessary to identify the electrical power required by the life support package.

Note that IMCA says that electrical schematics of the system should be available. Thus, the result of the assessment for the necessary power of the saturation control area and the Hyperbaric Environmental Conditioning Unit should be indicated in this document. Also, IMCA D 024 says the following:

- The primary power supply is assumed to be by connecting to the vessel or shore-based main supply. This connection should be by isolating the transformer.
- The life support package must be able to continue operating if the primary power is lost. For this reason, a backup generator is usually ready for this purpose. If a UPS is used as emergency support for critical low powered electrical apparatus (such as communications and analysis equipment), an assessment should be available detailing its duration under load against the time necessary to provide emergency power.
- Two transformers with variable input and providing outputs of 220/110 volts AC and 24/12 volts DC should form part of the Life support Package.
- As a minimum, there should be electrical supply points inside the container (or control area) available for 4 off 110 volts AC, 1 off 32 Amperes 3-phase and 1 off 16 Amperes single phase.
- The electrical equipment must be securely installed with all power leads and wiring secured (as far as is practical in the circumstances) in such a way that it is protected from accidental damage.
- A certificate should be available confirming that Residual Current Devices, also called Residual-Current Circuit Breakers, are fitted wherever possible to protect against electrical failures and that all components and any containers are correctly earthed. Note that a Residual-Current Circuit Breaker is a device that quickly breaks an electrical circuit to prevent serious harm from an ongoing electric shock .
- All electrical equipment must be securely installed with all power leads and wiring secured in such a way that it is protected from accidental damage.

Note that the composition of the gasses to provide and their quantities must conform to those specified in the emergency response plan. However, such calculations are not explained in this point, which purpose is only to describe how the Life Support Package should be designed. Nevertheless, we can say that the quantities of gasses and soda lime that should be provided onboard are dependent on the following factors:

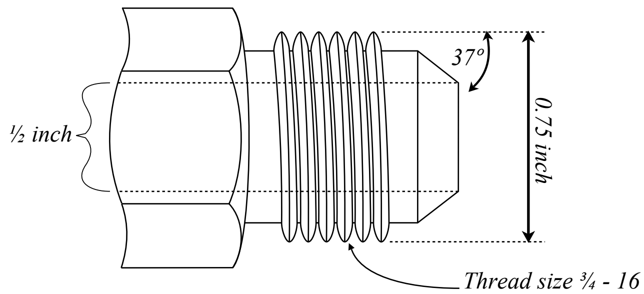
- The number of divers in the Hyperbaric Rescue Unit, and their depth.
- Whether the life support package is to be used to maintain the divers at depth and in optimal conditions during the transit to the Hyperbaric Reception Facility, or to be used to carry on a full or a partial decompression.
- The estimated duration of the transit to the place where the decompression is planned to start.

The hoses that supply the gasses to the saturation panel and then the Hyperbaric Rescue Unit must be suitable for the mixture they carry. They should be organized as follows:

- IMCA says that there must be at least five sources of gasses:
  - Breathing mix #1
  - Breathing mix #2 (backup)
  - Oxygen supply to panel (oxygen makeup)
  - One supply to BIBS
  - Calibration gas
  - Note that in addition to the minimum recommended by IMCA, a lot of manufacturers provide a supply line for therapeutic gas as for a normal chamber *(see the scheme at the beginning of this topic)*.

  As a result, IMCA says that the following hoses should be provided:
  - A hose 15 m long for breathing mix #1
  - A hose 15 m long for breathing mix #2
  - A hose 15 m long for BIBS mix with less than 25% oxygen *(22% O2 if applying Norsok standards)*
  - A spare hose 15 m long for mixes with less than 25% oxygen.
  - A hose 5 m long for the oxygen supply that must be compatible and cleaned for oxygen service.
  - A hose 5 m long for the heliox mixes with more than 25% oxygen *(22% O2 with Norsok standards)* that must be compatible and cleaned for oxygen service *(Hose not indicated by IMCA)*.
  - A spare hose 5 m long for mixes with more than 25% oxygen.

  Note that these hoses should be of 1/2” internal diameter and terminated by JIC end fittings size #8.



- Oxygen and therapeutic mixes with more than 25% O_2 *(22% with Norsok)* must be regulated down to 40 bar or less at the source (quad). Depending on the conception of the saturation panel, the other gasses can be delivered at high pressure or be pre-regulated at the source. IMCA says that the regulators used should be all compatible for oxygen. Also, in addition to the necessary regulators, two spare units should be available.

Electrical cables and water hoses should be organized such that the Life Support Package is easily installed and not off-duty if one of them fails:

- The power cable should be of the characteristics requested to supply the unit. Note that IMCA says that it should be 20 m long at a minimum. Also, a backup should be provided in case the cable in service is damaged.
- The water hoses to be connected to the water supply system of the vessel to cool the Hyperbaric Environmental Control Unit (condenser supply and exhaust) should be of the diameter recommended by the manufacturer and sufficiently robust. Couplings allowing to connect them to the machinery and the water supply quickly should be pre-installed. That obliges the technician to get information about the model of couplings available on board and to prepare the hoses accordingly. A unit of 20 m long is usually sufficient for the inlet and less for the outlet that can be organized overboard. A spare should be available in case one of the hoses is damaged during the operations.

The hyperbaric rescue unit is usually connected to the life support package by an umbilical that groups all the functions and supplies. IMCA says that this umbilical should be 50 m long minimum. Spare hoses and cables should be provided in the case of the failure of one piece. The fittings to the hyperbaric rescue chamber must be those described in point 4.3.20.4. As a reminder they should be designed as follows:

HRC/ SPHL	*Description*	*Life Support Package*
4 PIN 8 CONN EO (51F8F-1) or 4 PIN 8 CONN EO (53F8F-1)	*Comms*	*4 PIN 8 CONN EO (51F8M-1)*
4 PIN 4 CONN EO (51E4M-1) or 4 PIN 4 CONN EO (53E4M-1)	*Power*	*4 PIN 4 CONN EO (51E4F-1)*
SVHN 12-12F	*Hot water supply*	*SVHC 12-12F*
SVHC 12-12F	*Hot water return*	*SVHN 12-12F*
BVHN 6-6F	*Oxygen make up*	*BVHC 6-6F*
SVHN 4-4F	*Depth*	*SVHC 4-4F*
SVHN 4-4F	*Analyse*	*SVHC 4-4F*
SVHN 12-12F	*Blow down*	*SVHC 12-12F*
SVHN 12-12F	*Exhaust*	*SVHC 12-12F*
BVHN 12-12F	*BIBS supply*	*BVHC 12-12F*
IMCA says that normally only two water hoses being an inlet and outlet as these can be used for either hot or cold water. However, a lot of hyperbaric rescue units are equipped with hot and cold water supplies and outlets. It is the case of the units of the saturation systems taken as references.		

Medical equipment should be available that complies with the requirements of DMAC 15, unless local regulations prohibit any of the contents. It should be in a suitable protective container clearly marked with a white cross on a green background. Also, there should be facilities available for the provision of treatment of minor injuries. IMCA says that it may be by means of a local first aid kit, a nearby sickbay, or similar.

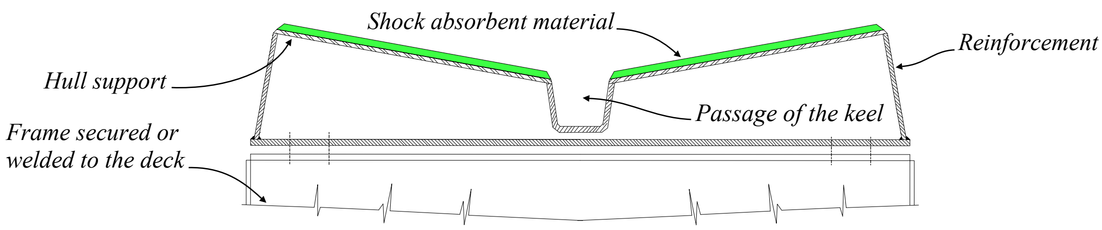
1.2.9.3 - Installation

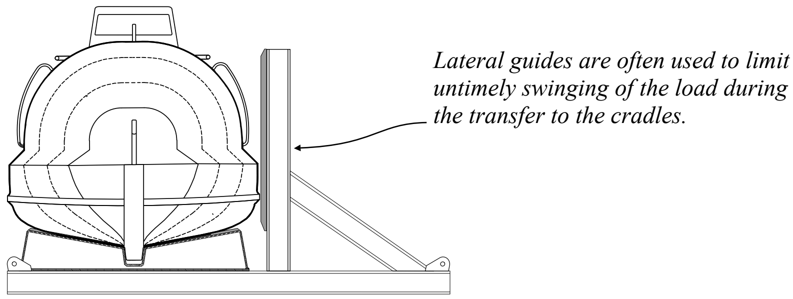
The Life Support Package (LSP) must be installed on the deck or inside the vessel in the same manner that the other elements of the saturation system. Note that this system must be designed to be operated by reduced personnel during catastrophic events. For this reason, it should be ready to be started as soon as possible with only the umbilical to the Hyperbaric Rescue Unit and a minimum of hoses to connect.

- The Life Support Package must be installed such that it does not disturb the transfer of the Hyperbaric rescue Unit on board the vessel and is not damaged during this operation.
- There must be access to the various components, so their identification and maintenance can be easily and safely performed. Also, the organization of the system must be such that usual activities on deck do not interfere with those of the life support technicians and the access to the LSP from and to the living areas of the boat is secured.
- Dangers such as tripping hazards, falling objects, electric shocks, machines starting unexpectedly, and others should be eliminated or minimized to an acceptable level. Note that adequate warning signs should be in place and the hazards that cannot be fully removed must be highlighted so people are aware of them.
- Linked to above, arrangements should be in place to ensure that the umbilical that that is to be connected to the Hyperbaric Rescue Unit (HRU) does not create a tripping hazard and cannot be damaged. During the standby period, it must be stored in a safe place away from the lifting area of the HRU, but ready to be connected as soon as possible.
- The areas around the system should be appropriately illuminated to allow the personnel to move safely by night. Note that by NORSOK U100 says that lighting of 100 Lux is suitable to enlighten the general areas of a chamber, so equivalent brightness should be provided. Also, localized additional illumination is necessary for

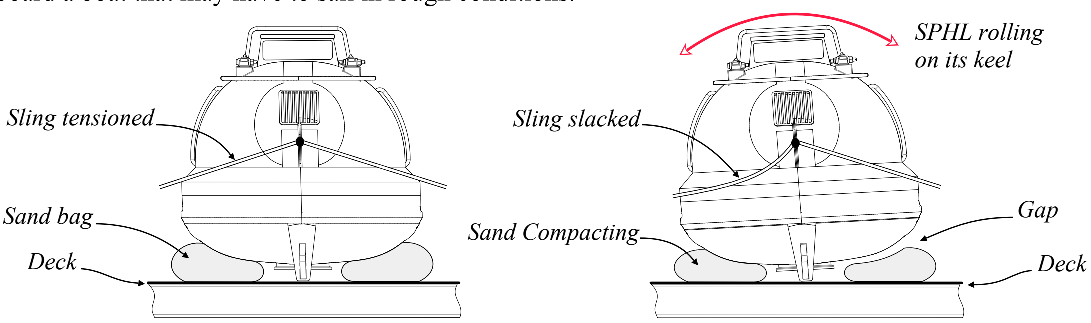
areas where gauges have to be read, and connections and maintenance performed. Based on the same document, 300 Lux should be required. Note that IMCA says that there must be a main and backup supply. Also, battery-powered emergency lighting should be available in addition to portable lights.

- The elements that compose the LSP must be appropriately fastened to the deck: As explained in the previous topics, sea fastening involves complex calculations taking into account the environmental parameters, the forces suffered by the ship in the environment, the effects the ship's motion to the cargo. Note that the forces applied on the load depend on factors such as size, weight, and center of gravity. Pre-installed fastenings may be present on a rescue vessel. In this case, the elements of the LSP must be secured using the recommended procedure. However, such fastening points may be missing or unsuitable. In this case, the sea fastening has to be calculated and approved by competent persons, and the welds should be checked using relevant Non-Destructive Testing (NDT) procedures. When elements are secured by welded sea fasteners, direct welds to their frame must be banished as repetitive heating affect the metal. Instead, welded sea fasteners must be calculated to block the container or be fitted to it by bolting or a similar arrangement. Note that calculations and inspection of the sea-fastening points should be documented and available.
- The hyperbaric rescue unit must also be secured to the deck so it cannot move whatever are the weather conditions.
    - Hyperbaric Rescue Chambers (HRC) are provided with skids and pad eyes that allow easy fastening.
    - Self Propelled Hyperbaric Life Boats (SPHL) are designed with a keel, so they fall to one side if they are not maintained, which is uncomfortable to the divers in the chamber. For this reason, suitable cradles to which the unit can be secured must be installed on deck. This method of immobilization is also suggested in point 13 of section 16 of IMCA D 024. Note that the cradles must be designed such that the centralizing pins and the connecting flange are not damaged *(see below)*. Also, shock-absorbent materials should be installed between the cradle and the hull to avoid damaging it during the landing and the transit.





Note that sandbags used in replacement of cradles are not a suitable means of protection of the SPHL on a vessel sailing to the shore as the sand is compacting as a result of the movements of the ship and the vibrations. As a result, the SPHL will not be correctly maintained to the deck and may start to roll on its keel and slide on the floor. So, this method of wedging, that is suitable on a jetty, should not be used on board a boat that may have to sail in rough conditions.



1) When the SPHL is installed on the deck, the sand in bags is not yet compacted, and the slings are still under tension.

2) During the sailing, the sand in bags is compacting, so the SPHL is no more maintained in place and starts moving.

- During the mobilization, the technicians ensures that the following documents are available in the control room:
    - A copy of the audit and certification of the LSP.
    - A copy of the assessment of the LSP and its sub-systems confirming that the equipment provided is both adequate and fit for its intended use. This document should provide a systematic assessment for the identification of potential failure modes, to determine their effects and to identify actions to mitigate the failures. Note that it can be a detailed risk assessment or a FMEA.

- The check list of the components that must be present.
- The list of the gasses with their composition and pressure *(+ the same list indicated on a board)*.
- Plans of the electrical installation and of the gas supplies
- Diving manuals with chamber procedures, decompression procedures, and emergency procedures *(the emergency procedures should integrate topics such as fire fighting & taping code procedures)*.
- The emergency response plan *(It should indicate the list of contacts, procedures of evacuation, and the coordinates of the diving medical specialists)*
- A quick start manual *(It is usually a document of two - three pages easy to read),* and more detailed maintenance manuals.

1.2.9.4 - Maintenance

IMCA D 024 recommends the following minimum frequencies of audit. However most visual examinations that are recommended every six months should be performed every day when the system is at work.

Items	***Visual external + function test , calibration***	***Visual internal + external + leak test at max. Working pressure***	***Internal + external+ leak test 1,5 max. working pressure***	***Other***
Classification certs				According to classification society.
Sea Fastening (Design & calculations)				During mobilisation
Sea Fastening (Installation)				During mobilisation
Protection against electrical failure	6 months (Recommendations)			At the installation
Emergency Power	6 months			
BA set testing	6 months	2 ½ years 5 years		Full visual internal + external: 5 years
Communications	6 months			
Gauge calibration	6 months			
Pipework	6 months			
Relief valves	6 months	2 ½ years		
Electrical testing	6 months			
Analysers: Alarm testing	6 months			
Analysers: Calibration	6 months			
Communication systems function testing	6 months			
Environmental Control Unit	6 months			
Supply hoses components	6 months	2 years	When new	
Hoses components umbilical to HRU	6 months	2 years	When new	
Fire fighting: Portable systems	6 months			Manufacturer specifications
Fire fighting: Fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
Automatic fire detection	12 months			
Medical kit DMAC 15	6 month			

The Life Support Package must be ready for use at any time as long as the decompression of the divers is not completed.

Also, it is often installed on a chartered vessel where there is no specialized personnel to maintain it. For this reason, people must be transferred from the Diving Support Vessel (DSV) to check it regularly (every 2 - 3 days is common), or competent persons in charge of its maintenance and operation should be assigned on board the rescue vessel.
Note that due to the problems of maintenance indicated above, manufacturers usually build life support packages with robust components that are easy to maintain. However, humidity can accumulate in the electronic devices and damage them if it is not kept as close as possible to a level of 40% - 30%. Also, extreme temperatures can damage the elements that compose the system. For these reasons, a dehumidification system is to be installed, and the heating or cooling system should be activated.

Recommended routine maintenance and inspection of the Hyperbaric Environment Control Unit:

Checks for noises and vibrations that may indicate mechanical problems are to be performed each time the machine is activated.

- The manufacturer of the model explained recommends the following checks to be performed every fifteen days:
  - Visual Examination of piping systems.
  - Fluid levels in tanks.
  - Fluid levels of the tanks.
  - Refrigeration fluid level and compressor pressure.
  - Electrical continuity and insulation.
  - Visual examination and function test of the pressure indicating gauges and flow switches.
  - Inspection of the anodes that must be changed out if their wastage is more than 75% *(They are installed in the end cap of the condenser)*.
- Also, it is recommended to flush the condenser every 3 months.
- In addition, the following maintenance is to be performed every six months:
  - Cleaning of the condenser inner core tubes.
  - Replacement of the refrigerant filters.
  - Replacement of the anodes in the end of the condenser.

1.2.10 - Hyperbaric Reception Facility (HRF)

1.2.10.1 - Description

The Hyperbaric Reception Facility (HRF) is a saturation complex that is situated in a strategic place onshore or offshore, into which the divers are transferred from the Hyperbaric Rescue Unit (HRU) to perform their decompression. This ensemble must be sufficiently broad to accommodate the totality of the divers who were in the abandoned saturation system.
Depending on the area where the operation is undertaken, the logistical means, and the policy of the contractor, it can be a permanent installation that can be shared by the companies operating at a reasonable distance or a portable unit that is provided for the project undertaken.

The Hyperbaric Reception Facility (HRF) is composed of following elements:

- Chambers with their entry lock and the connecting flange to which the hyperbaric rescue unit is fitted to transfer the divers.
- A saturation control room with relevant control panels.
- An environmental control system.
- Gas reserves with their relevant distribution and charging hoses
- Electrical supplies and distribution systems
- Storage containers and workshop.

Most mobile Hyperbaric Reception Facilities are composed of a long chamber separated in two or three locks arranged as with classical Deck Decompression Chambers (DDC). This chamber is installed on a chassis, which function is to rigidify it and also support the frame that is designed to accommodate the Hyperbaric Rescue Unit connected to its topside flange *(see below)*. This frame and the system for the final approach of the flanges, which is designed for a slow and controlled mating so as not to damage them and their clamping mechanism, is the main difference from classical deck decompression chambers. Doors and connecting flanges are usually provided at the extremities and the side of the unit, so extensions can be added or an HRU can be connected laterally.

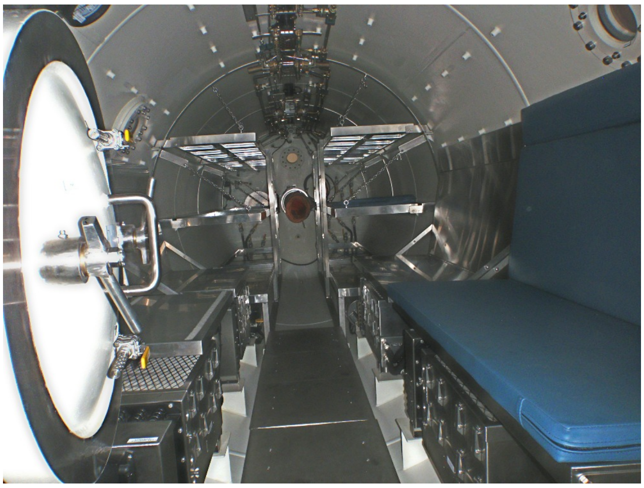
The elements that compose the Hyperbaric Rescue Facility are designed in the same manner as for saturation systems installed on diving surface supports. Thus, the rules for construction and inspection, which are described in IMCA D 053, are identical to those indicated in IMCA D 024, apart from some differences linked to the function of such a facility. A comparison of the sections below that compose this document allows us to be aware of it:

- Section #1 is identical to Section #1 of D 024 except for item #3 “procedures” that are specific for the function of the HRF. Also, sea fastening procedures that are present in the document D 024 are not indicated. It is probably due to the fact that most units that were initially built were situated onshore. Also, item #10 “interface compliance” is not part of IMCA D 024.
- Section #2 “Compression Chamber” is identical to section #3 of IMCA D 024.

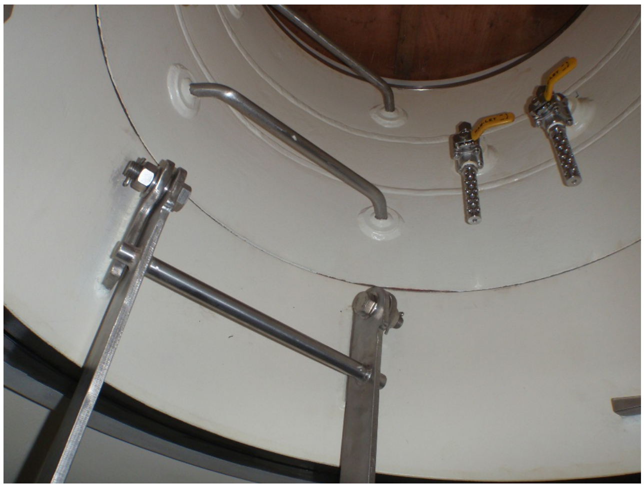
- Section #3 “HRU handling arrangements and interfaces” is specific to Hyperbaric Reception Facilities. So, is not indicated in IMCA D 024.
- Section #4 “Life support control” is identical to section #6 of IMCA D 024, except that the hyperbaric evacuation system and the general alarm indicated in IMCA D 024 are not integrated into it, probably for the reasons explained in section #1.
- Section #5 “Compressors, pumps, etc.” is identical to section #11 of IMCA D 024.
- Section #6 “High pressure gas storage” is identical to section #12 of of IMCA D 024, except the quantities of gas refer to contractor procedures instead of IMCA D 050 “minimum quantity of gas required offshore”.

Note that apart from the differences indicated above, a lot of units offer a reduced place to the divers when they are used at the full capacity, and in this case, “hot bunking” is to be organized. Regarding this point, IMCA D 52 says that at least 50% of the maximum number of occupants must be able to lie down comfortably.

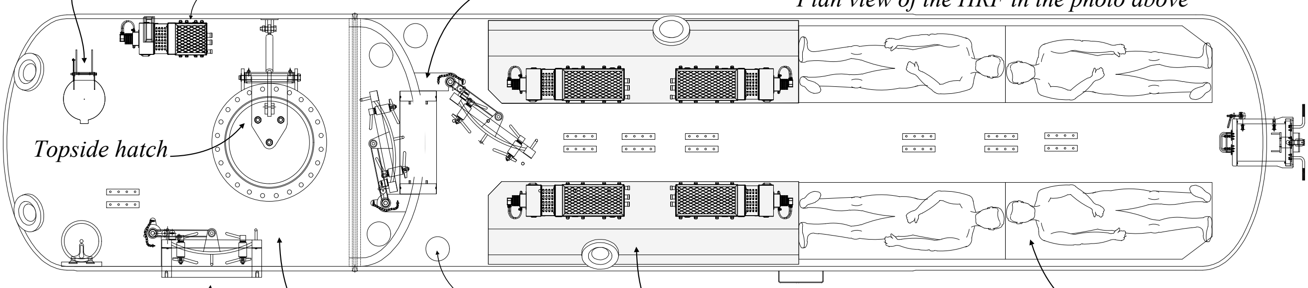
As with every saturation chamber, toilets and shower are mandatory and are provided in the entry lock. Also, the divers transferred into the Hyperbaric Reception Facility may have been a long time in the Hyperbaric Rescue Unit (HRU) during unfavourable sea conditions, so their clothes may have been contaminated by vomit or other dirties. For this reason, it is preferable to select a reception facility designed such that the transfer to the living chamber is made through the entry lock, where the divers can remove their filthy clothes and have a wash, before going inside the living chamber. Such a conception allows avoiding polluting the decompression facility that must always be clean and free of germs. Note that the system must be designed to transfer medical personnel inside or outside the chambers during the decompression. The entry lock is usually used for this purpose *(see the plan view below)*.



Chamber 24 divers designed by Flash tekk engineering: It provides 12 bunks and the equivalent number of seats



Access to the HRF from the topside hatch (See in the scheme below)

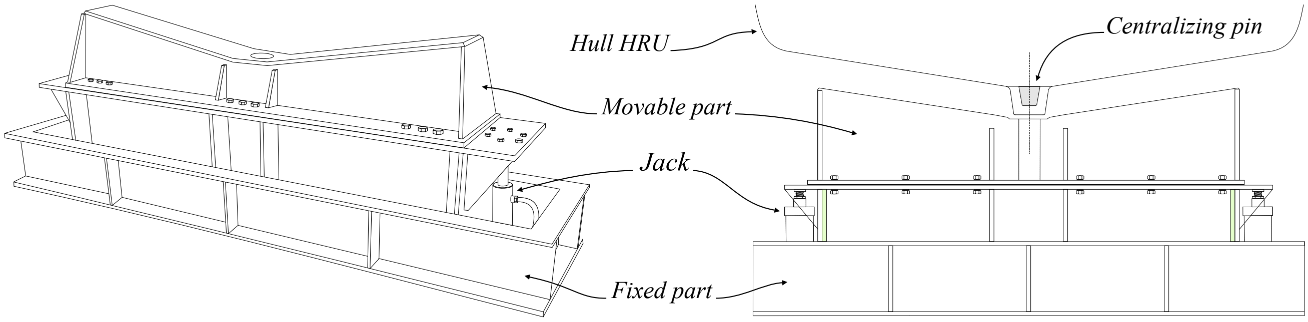


IMCA D 052 also says: *“The system must have the ability in terms of life support, toilets, etc. to support the maximum number of occupants without recourse to the HRU which may or may not remain mated to it”*. The fact that HRU cannot be used as an element of the Hyperbaric Reception Facility results that the manufacturers design the vast chambers described above that require space and specific means of lifting to install them. As an example, the weight of the unit in the photo on the previous page is 40 tons, and its overall length is 11.5 m for 2,5 m wide.

1.2.10.2 - Handling arrangements and interfaces

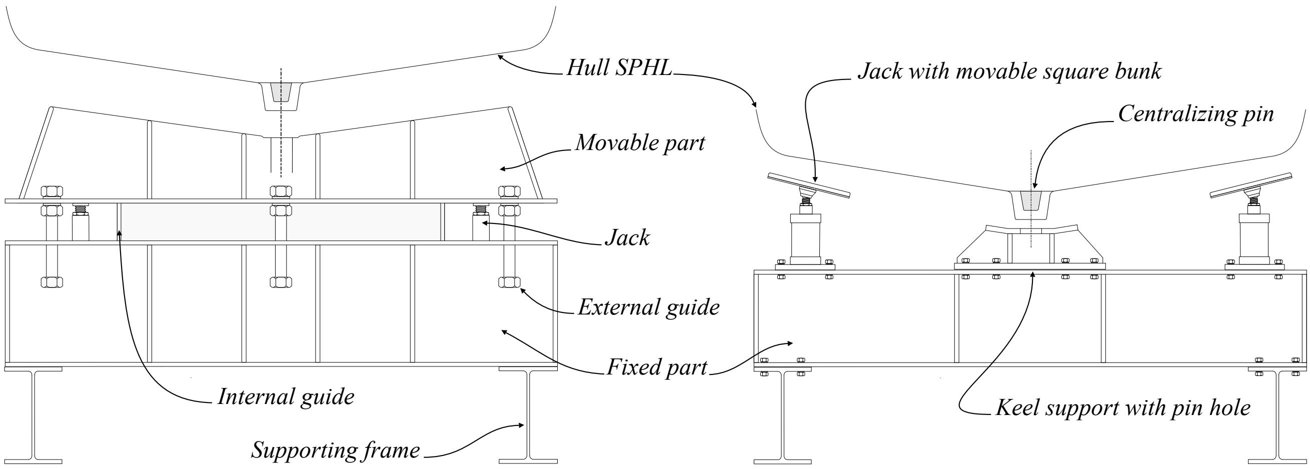
The connection of the flanges is a critical operation that requests precautions and methodology. It must be remembered that if the seal between the Hyperbaric Rescue Unit and the Hyperbaric Reception Facility cannot be established, the Life Support Supervisor is obliged to decompress the divers in the HRU, which may lead to unacceptable living conditions because the divers may have to stay several days and perhaps more than one week on a chair.
A crane or an A-frame is usually employed to remove the hyperbaric rescue unit from the water and transfer it to the Hyperbaric Reception Facility. Nevertheless, these devices are not sufficiently precise and progressive to allow for a connection of the flanges without taking the risk of damaging them. For this reason, IMCA says that the mating clamp

and its operating mechanism should be suitably protected from physical damage during the lowering of the HRU to the mating point. The most common method is to use cradles that can be raised so that there is a sufficient gap between the flange of the hyperbaric rescue unit and the flange of the hyperbaric reception facility and its clamping mechanism during the transfer of the hyperbaric rescue unit by the crane. These cradles are then gradually lowered using Hydraulic or mechanical jacks that can precisely move up or down *(see the drawing below)*.

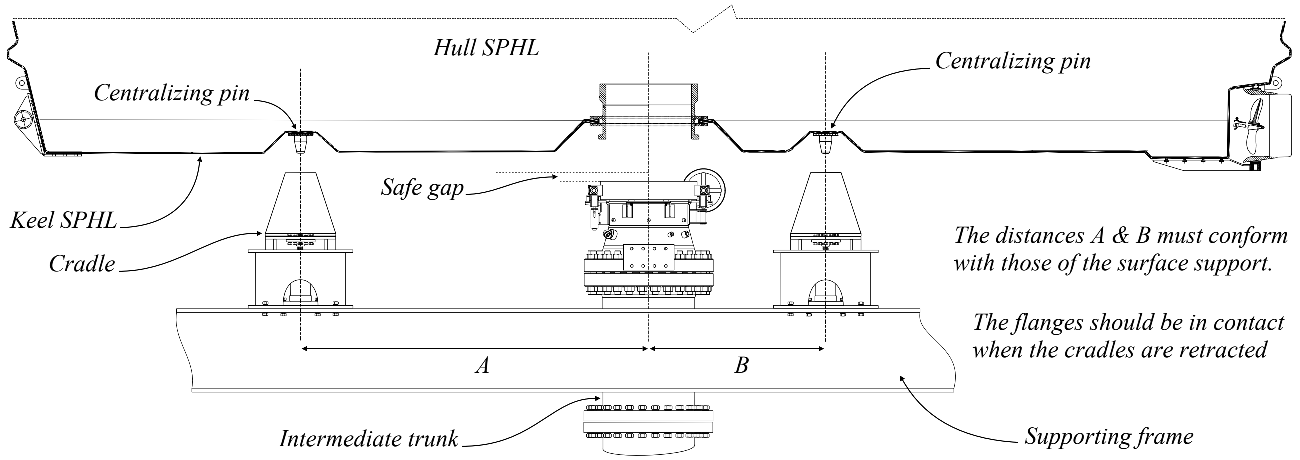


Manufacturers propose numerous models of lifting cradles. Their configuration depends on whether the HRF is designed to accommodate various types of hyperbaric rescue units or only one or two models, and the necessary space to protect the clamping system. We can classify these adjustable supports into two main categories:

- Cradles made of one piece that is moved up and down by two jacks, such as the model in the scheme above, or the model on the left side below. These types of cradles are currently the most encountered.
- Individual supports terminated by a square bunk with separate central support for the keel. These supports allow adapting to any hull shape *(see below on the right side)*.

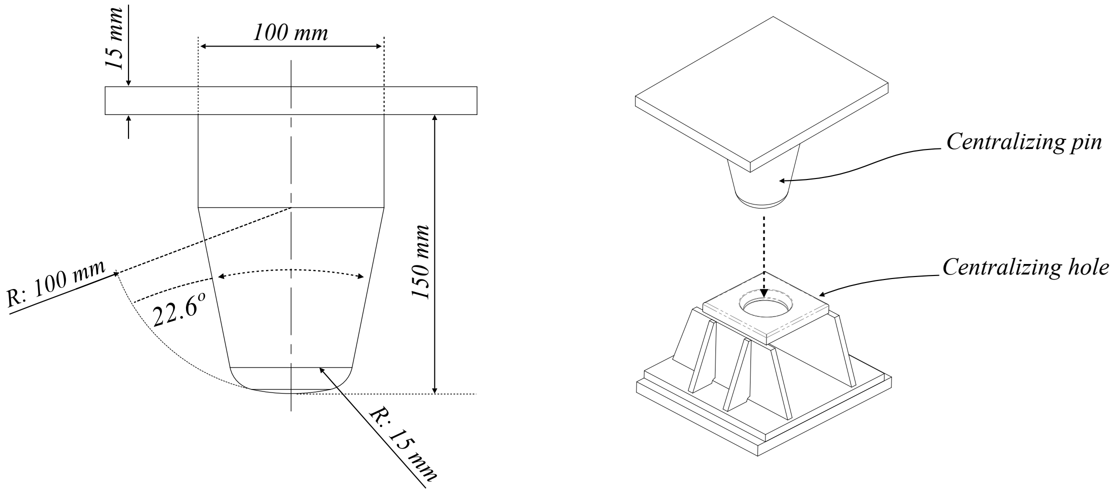


Note that the descent of the HRU must be organized such that the gap between the two flanges is perfectly regular to obtain a perfect matching. For this reason, the cradles are precisely adjusted at the recommended height to receive the unit, and the hydraulic jacks are all connected to a central pump, so they move up and down at the same time. Hydraulic jacks are currently the most used for this purpose as they are easy to install and provide excellent precision. However, some systems can be designed with mechanical jacks that are operated at the same time through a common gear.
In addition to the above, the corresponding sockets of the centralizing pins of the HRU, that have the measurements indicated on the next page, and are also previously described in point 1.2.7.2, are in the middle of each cradle and must be adjusted so that the flanges are precisely centralized. For this reason, these distances must be exactly those found on the Diving Support Vessel. Depending on whether the HRF is designed to accommodate several types of HRU or only one model, the distances of the cradles from the flange can be adjustable or not.

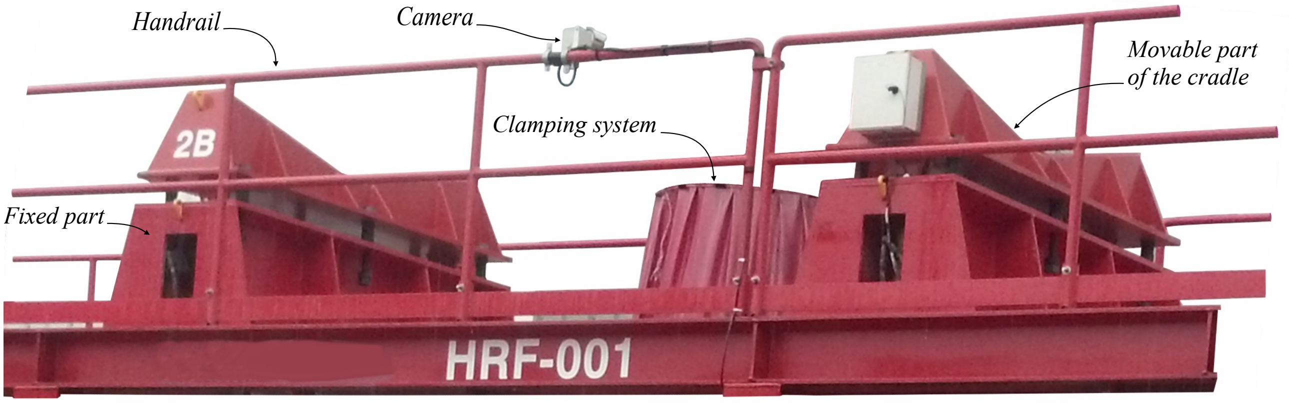


Note: IMCA recommends that the flanges are separated by at least 25 mm when the HRU is temporarily supported above its final mating position. However this minimum gap is often wider to protect the clamping mechanism.

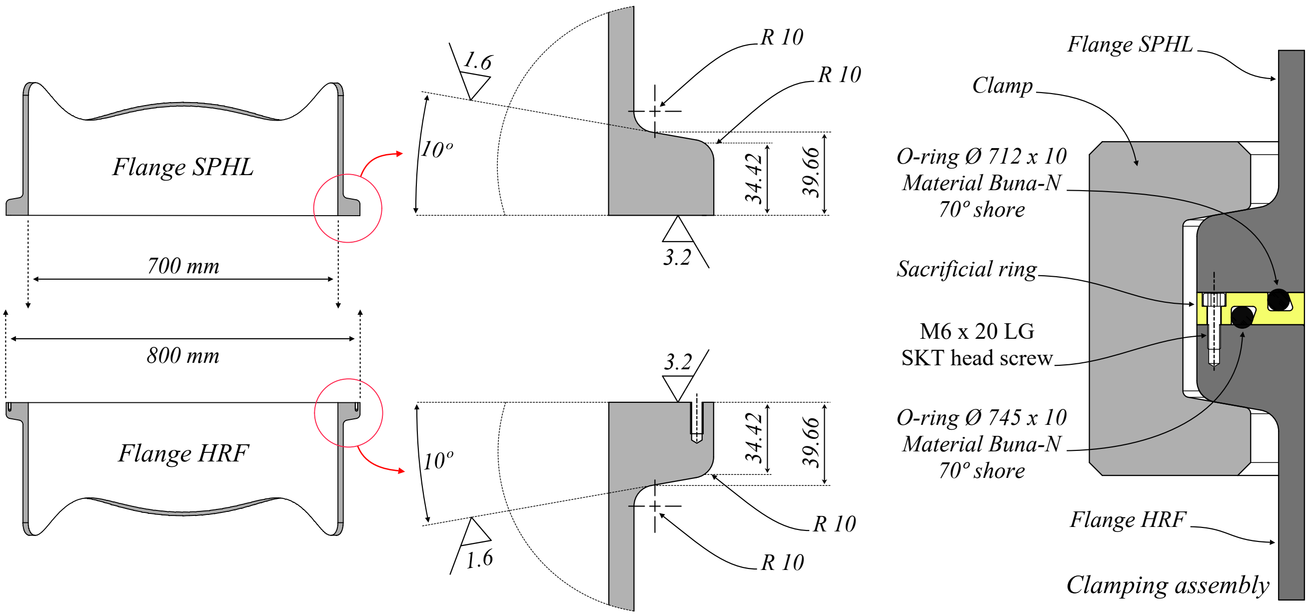
Note that the centralizing hole of the cradles must perfectly fit with the corresponding pin of the HRU. However, the pin of the HRU may be of a different size, which results that the use of an adaptation could be necessary. To avoid such a problem, IMCA D 051 recommends the measurements below with the aim that "Every HRU will be able to mate with every DSV or HRF of any class anywhere in the world". As a result, most manufacturers apply this standard to their recent productions since the first publication of this guideline in January 2013.



There should be safe access to the areas of the HRF where the lowering and the connection of the HRU are performed. Because the operators have to move on the top of the unit, handrails are provided around the working zone to protect them from falling *(see below)*. Also, communications must be provided so that the people on duty can discuss with the crane operator and the chamber control. Suitable lighting, providing at least 100 Lux and 300 Lux for the reading areas, should be available for operation by night. Note that portable lights are ideal for checking the gaps of the flanges. A camera can be installed like on the photo below, so the Life Support Technician has a view of the clamping system.



The flange should be of the standardised model with a taper of 10° and a sacrificial ring described in IMCA D 051, and previously explained in point 1.2.7.3 *(see the scheme below)*.

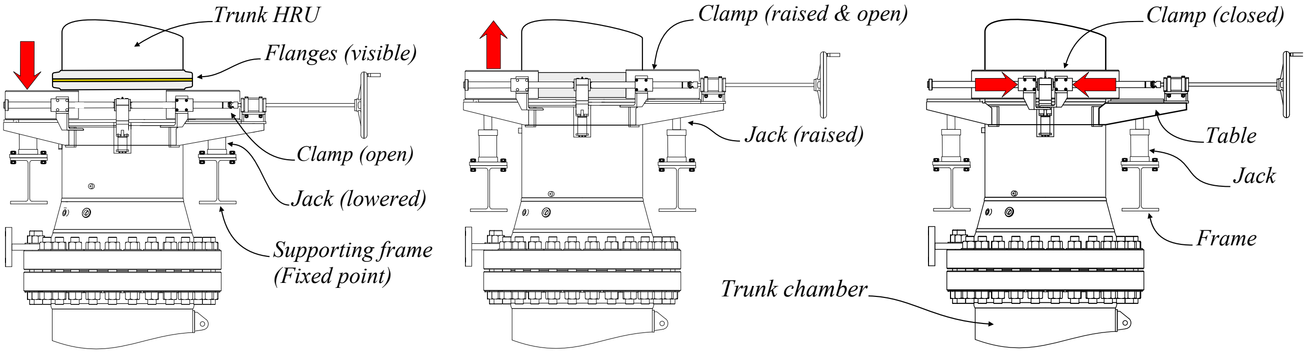


Several sacrificial rings and o-rings should be available, so those in place can be immediately replaced if they are damaged. Spare "SKT head screws" and tools to remove or extract them should also be ready for use.

Note that HRF operators consider that the flanges are ready for mating when there is a gap of 0.05 mm. However, this gap may not be perfectly regular all around the surfaces of contact, and it is said that a difference up to 0,3 mm is acceptable. Such distances can be checked with feeler gauges.

The flange of the SPHL could be a non standardized model. For this reason, Hyperbaric Reception Facilities that are designed to accommodate all types of Hyperbaric Rescue Units are provided with several kinds of flanges. Also, the intermediate trunk may have to be changed to adjust the flange in height.

The closing mechanism of the clamps is usually similar to the one used for the connection of the Hyperbaric Rescue Units to the saturation system of the surface support that is discussed in point 1.2.7.2. It can be operated manually through a hand wheel, or by hydraulic motors.
This clamping system is retractable with some units, and IMCA D 051 suggests a configuration similar to the scheme below. This system is based on the supporting table of the mechanism that can be lowered and raised using jacks. However, a lot of manufacturers do not adopt this solution and prefer using clamps which are at a fixed height, and are protected from damages by cradles that can be raised sufficiently high to allow for a safe gap during the crane operations.



1) The table is lowered, and the clamps are opened during the transfer and the controlled descent of the HRU.

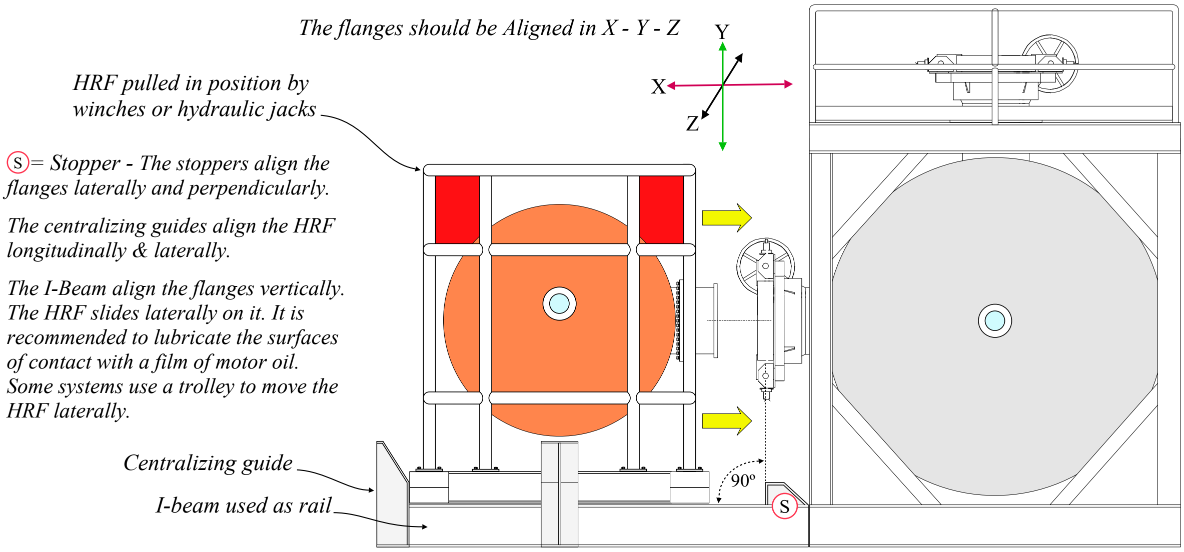
2) When the flanges are in contact, the supporting table of the clamps is raised using the jacks until the clamps can be closed.

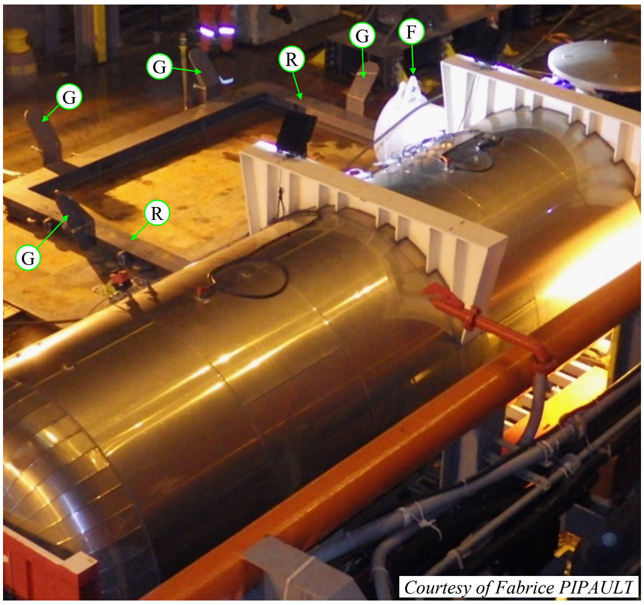
3) When the clamps are in position for closing, the supporting table is secured, and the clamps are shut. Then, the trunk is checked for leaks.

Other technical solutions for adjusting and protecting the flanges and their clamping mechanism may be used. For this reason, IMCA D 053 says that the trunking and flange intended for use in mating to the HRU must have been designed and built according to a recognized international standard and be fit for the purpose. Also, the same document says that if the trunk does not form an integral part of the chamber, then its design standard, serial number, date of manufacture, and the other details that must be indicated for any pressure vessel must be stamped on the device or be shown on a nameplate that cannot be removed accidentally. Note that these data must be clearly visible.

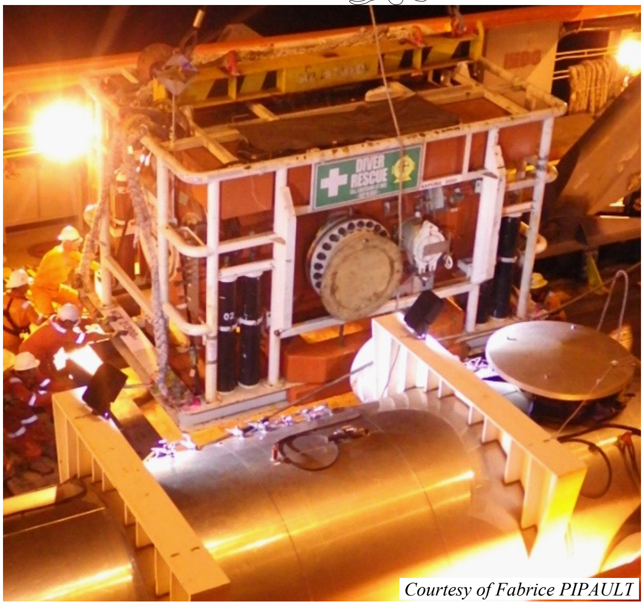
IMCA D 051 does not explain the mating of Hyperbaric Rescue Units (HRU) that are connected to the side of the hyperbaric reception facility (HRF). The procedure of approach and matching, that is mostly used with Hyperbaric Rescue Chambers (HRC) has a similar problem as for Hyperbaric Rescue Units connected to the top of the HRF, with the final approach that is is lateral instead of vertical.

- To protect the flanges and their clamping mechanism, the HRC, or the SPHL equipped with a lateral trunk (not common today), is pulled or lowered on a reception frame that allows to land it sufficiently far from the clamp. It must be perfectly parallel to the HRF. Also, removable protections should be installed on the flanges.
- The HRU is adjusted in length by centralizing guides so the flanges are facing.
- The reception frame must be adjusted in height and verticality, so the flanges are aligned. Then the platform is gradually slid to the HRF until the flanges are in contact with perfect alignments and gaps.
- The clamps are then closed, and the pressure test can be started.





Hyperbaric Reception Facility and its lateral reception frame:
- G= Centralizing guide - R= Sliding rail - F= Flange



Exercise of transfer of the HRU. The descent is done with the crane instead of the A-frame at the stern of the vessel.

1.2.10.3 - Transfer of divers saturated at different depths

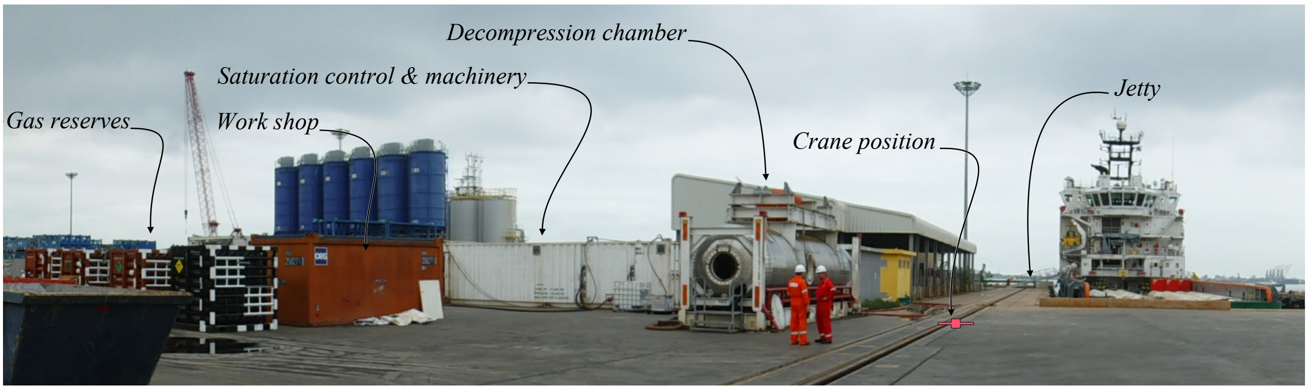
In point 1.2.7.7, it is said that several means of evacuation should be provided in case of operations with diving teams stored at depths that are too far to allow for a reasonable compression time to the deepest storage level to be able to evacuate the divers quickly. Also, the Hyperbaric Reception Facility may have to accommodate divers from two different projects when the decompression of the 1st steam arrives at its end.
In such cases, a facility with several compartments is recommended, because the earliest the divers start their decompression in suitable environmental conditions, the better it is.

1.2.10.4 - Type of installations

Permanent onshore Hyperbaric Reception Facilities (HRF) are often installed in a dedicated hangar, so they are protected from the weather conditions and are easier to maintain and manage.

- The loading of the Hyperbaric Rescue Unit to the HRF is performed using a traversing trolley that pickups the HRU from the truck that delivers it and moves it to the facility. Such a system of transfer is smooth.
- Depending on the distance of the installation from the jetty, specific road transfer may have to be organized. Also, a Life Support Package may have to be installed on the truck if the installation is not close to the jetty as the Environmental Control Unit of the HRU cannot be used, and the unit may not have sufficient gas reserves for the transfer.
- The requirements of IMCA D 51, D 52 ,& D 053 are considered sufficient *(see in the previous point).*
- Several chambers are usually available so divers at several depths can be decompressed.
- There is generally sufficient space to install a Hyperbaric Environment Regeneration System (HERS).
- Note that the cooling of the chillers may have to be organized through air heat exchangers instead of circulating water (similar design as air conditioning systems), except if there is a river at the immediate proximity.

Temporary onshore Hyperbaric Reception Facilities (HRF) are often installed at the direct proximity of a jetty, which provides the advantage that only a suitable crane is necessary to transfer the HRU to the HRF.

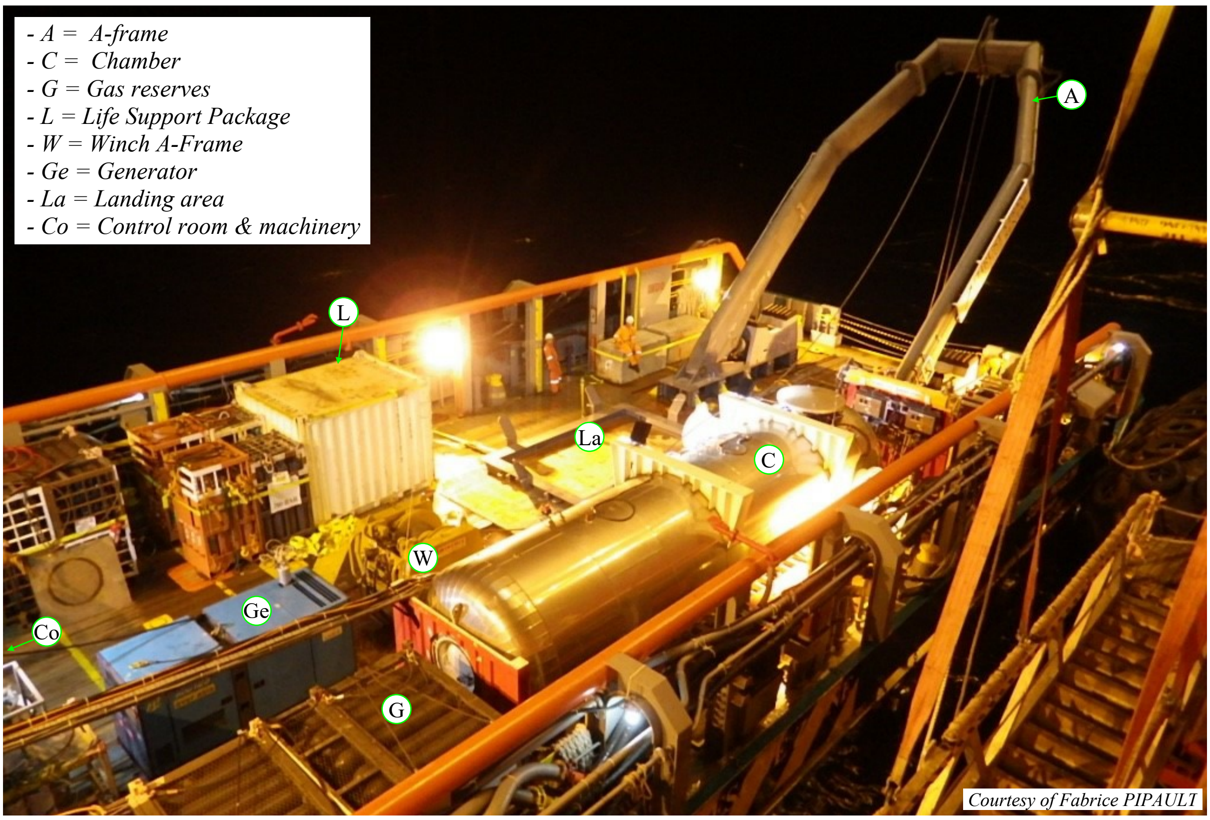


However, it may happen that the team is obliged to install it in a yard, which may oblige to organize for a transfer by truck and two cranes (one on the jetty and one in the yard).

- The requirements of IMCA D 51, D 52 ,& D 053 are considered sufficient *(see in the previous point).*
- Depending on the project covered, several chambers can be available.
- Such installations are not protected from the weather conditions.
- Chillers are usually refrigerated through water pumps installed on the jetty. However, air heat exchangers (similar design as air conditioning systems) may have to be installed if the HRF is set up in a yard.

Hyperbaric Reception Facilities can also be installed on the rescue vessel. The advantage of this system is that the decompression can start as soon as the HRU is transferred onboard the ship and connected to the chamber, so there is a gain of time. As for chambers installed onshore, the HRF can be on board a specific vessel that is shared between several companies or be installed on the rescue vessel of a particular project. Such a solution is an advantage for companies working according to IOGP standards that request that the rescue vessel is at the proximity of the surface support.

- As explained in point 1.2.7.9, the recovery of the HRU can be performed by the stern using an A-frame or a slope, or the side using A-frame, davits, or the crane if it is considered sufficiently stable. However, a crane installed on another surface support should not be used because an unexpected uncontrolled move of the vessel can damage the HRU or the HRF due to the lack of space on deck. For this reason, it is preferable to organize with a lifting system that is a part of the vessel.
- The requirements of IMCA D 51, D 52 ,& D 053 are not sufficient:
    - Sea fastening of the elements that compose the system must be performed and approved.
    - Hyperbaric evacuation system and the general alarm indicated in IMCA D 024 must be installed.
    - There should be sufficient gas onboard to safely complete the decompression.
- Depending on the project covered, several chambers can be available.
- Such installations are not protected from the weather conditions.



Courtesy of Fabrice PIPAULT

2.3.23.5 - Comfort of Hyperbaric Reception Facilities and mating trials

The Hyperbaric Reception Facility (HRF) is the logical complement of the Hyperbaric Rescue Unit (HRU), and the Life Support Package (LSP). However, such installation that has a cost that is at the charge of the contractor is designed to perform a safe decompression after an emergency, but not to support a diving campaign. So its comfort is limited with bunks that are generally shared by two people, reduced space available when the chamber is full, and limited commodities with often only one toilet and bathroom for up to 24 people.
Such an installation is indeed needed only in the case of an emergency, so the probability of using it is very low if the diving operations are organized safely. Nevertheless, the contractor must provide it to ensure that the divers will be decompressed safely in case of an abandoned ship. Note that a small chamber can be used if it is sufficient to accommodate the entire team, and it is considered fit for the purpose by a recognized certification body.

Note that a mating trial should be organized before starting the project, or every 12 months if the system has already been checked, to be sure that the HRU can be connected to the HRF. Regarding this point IMCA D 053 says the following:
"Experience has shown that actual physical mating trials of HRUs to HRFs always provide invaluable information and learning opportunities for those tasked with assembling and operating effective hyperbaric evacuation systems. Desktop assessments alone may fail to identify all the complications and problems which can arise during the HRU to HRF connection phase. Only mating trials can demonstrate conclusively that a particular HRU will readily be able to mate to a specific HRF design. It is therefore recommended that actual mating trials of HRUs to specific HRF designs are carried out rather than desktop assessments alone. A suitable third party should witness such trials that must be fully documented, preferably including photographs or video, etc."
Regarding the interface for mating, IMCA says that any HRF manufactured after 1 July 2014 should meet the common interface standards laid out in IMCA D 051 *(see in* *point 1.2.10.2**)*, or be able to accommodate a HRU that does meet the interface standards. Units manufactured before that date may not meet these standards or may partially meet them. An assessment should have been carried out to confirm if the HRF complies with these interface standards. This assessment should identify total compliance, partial compliance (identifying clearly what does and what does not comply) or total non-compliance. Where there is a non-compliance the assessment should identify the alternative arrangements made.

2.3.23.6 - Maintenance

IMCA D 053 recommends the following minimum frequencies of audit. However, as discussed in the previous points, most visual examinations that are recommended every six months should be performed every day when the system is at work.

Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure*	*Other*
Classification				Classification society rules
Emergency Power & UPS	6 months			
Compliance interface				At construction or after assessment
Design chamber				At construction or after assessment
Chamber testing	6 months	2 ½ years	5 years	
Viewports chamber	6 months	2 ½ years	5 years	1.25 max work pressure when new Renewal every 10 years
Portable firefighting chamber	6 months			Guide lines from the manufacturer
Fixed firefighting chamber	Visual: 6 months Test: 12 months			Guide lines from the manufacturer
Fire detection	1 year			
Medical kit DMAC 15	6 months			
Electrical penetrators				Cert at the origin
Food & equipment locks	6 months	2 ½ years	When new	
Relief valve chamber (external)	6 months	2 ½ years		

Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure*	*Other*
Communication food & equipment locks	6 months			
Flow fuse (or equivalent system)	12 months			
Pipework chamber (external)	6 months	2 ½ years	When new	
Electrical chamber (external)	6 months			
Emergency power chamber	6 months			
Communication chamber (internal)	6 months			
BIBS (internal chamber)	6 months			
Sanitary system chamber testing	6 months			
Portable firefighting internal chamber	6 months			Guide lines manufacturer
Fixed firefighting internal chamber	Visual: 6 months Test: 12 months			Guide lines manufacturer
Fire detection internal chamber	Test: 12 months			Guide lines manufacturer
Gauges calibration (internal chamber)	6 months			
Environmental control units chamber	6 months			Guide lines manufacturer
Pipework internal chamber	6 months	2 ½ years	When new	
Electrical internal chamber	6 months			
Mating flange trial	Test at mobilization when not used Test 12 months when already used			Witness 3rd party
Trunking	6 months	2 ½ years	5 years	Classification society guidelines
Valves trunking	6 months	2 years	When new	
Calibration depth gauge trunking	6 months			
Interlock clamping system	6 months	2 years	When new	
Communications to mating point	6 months			
HRU interface panel - Pipework	6 months	2 ½ years	When new	
Electrical interface panel with HRU	6 months			
Weight HRU + components to be lifted	12 months			
Certificate load test procedure by competent person				When established
Life support control : Communications	6 months			
Life support control : Gauge calibration	6 months			
Life support control : Pipework	6 months	2 ½ years	When new	

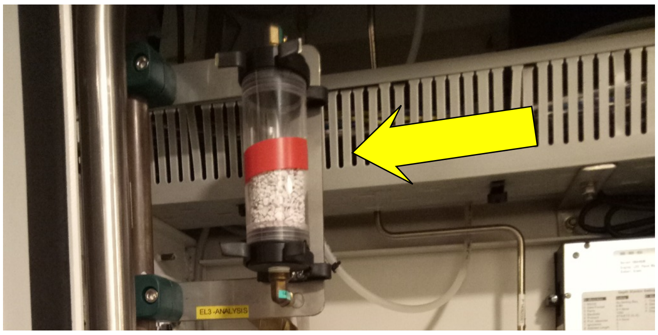
Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure / 1.5 max working load lifting*	*Other*
Electrical control room	6 months			Test resistance + continuity: 6 months
Portable fire fighting control room	6 months			Guide lines manufacturer
Fixed fire fighting control room	Visual: 6 months Test: 12 months			Guide lines manufacturer
Fire detection control room	Test: 12 months			Guide lines manufacturer
Kit DMAC 15 control room	6 months			
BA set control room	6 months	2 ½ years		
Alarms control room	Test alarm: 6 months			
Analysers control room	Calibration: 6 months Function test: 6 months			
Portable fire fighting machinery room	6 months			Test resistance + continuity: 6 months
Fixed fire fighting machinery room	6 months			Guide lines manufacturer
Fire detection machinery room	Visual: 6 months Test: 12 months			Guide lines manufacturer
Cracked plate detector membrane compressor *(if used)*	6 months			
Shut down device compressor	6 months			
Relief valves pressure containers	6 months	2 ½ years		
Pipework compressor room	6 months	2 ½ years	When new	
Gas receivers compressors	6 months	2 ½ years	When new	Recognized standard: During construction
Electrical compressors	6 months			Test resistance + continuity: 6 months
Compressors	6 months			Guide lines manufacturer
Cylinders high pressure gas storage	6 months	2 ½ years	5 years	Test 1.5 can be replaced by NDE followed by Max working pressure
Welded pressure vessels gas storage	6 months	2 ½ years	2 ½ years	Method at 2 ½ years is optional
Pipework gas storage	6 months	2 ½ years	When new	
Lifting equipment gas storage (quads slings …)	6 months		2 ½ years (lifting)	
Relief valves / Bursting discs gas storage	Visual: 6 months Function test: 2 ½ years	2 ½ years		Renewal busting disks: 10 years
Analysers + alarms	Calibration: 6 months Function test: 6 months			
Portable fire fighting gas storage	6 months			Test resistance + continuity: 6 months
Fixed fire fighting gas storage	Visual: 6 months Test: 12 months			Guide lines manufacturer
Fire detection gas storage	Visual: 6 months Test: 12 months			Guide lines manufacturer

The availability of the Hyperbaric Reception facility must be the same as with the Life support package and the Hyperbaric Rescue Unit:

- It must be ready for use at any time as long as the decompression of the divers is not completed.
- Competent persons in charge of its maintenance and operation should be assigned to maintain it daily.
- Note that humidity can accumulate in the electronic devices and damage them if it is not kept as close as possible to a level of 40% - 30%. Also, extreme temperatures can damage the elements that compose the system. For these reasons, a dehumidification system is to be installed, and the heating or cooling system should be activated.

In addition, the manufacturers give the following recommendations:

- Valves should be function tested and checked for leaks daily. Corrosion should be removed.
- Desiccants such as silica gel or similar products are installed in small transparent containers to dry the gas flow coming from the chambers to the analysers. These containers must be checked every day, and the desiccant replaced as soon as the colour indicates that it becomes saturated.



- Function tests to ensure that the regulators are operating correctly, with no unexpected pressure creeping or venting should be performed every month.
- The emergency breathing apparatus should be function tested and their communications checked every month. Note that the operator should ensure that the panel quick connects and supply valves are operating correctly.

If equipped with a Dive Monitoring System (DMS), precautions must be implemented with its computers and of those used for other functions:

- Daily maintenance tasks include the cleaning of the keyboards, mouse, cooling fans, monitors/displays, and removable media drives. Note that specific products and microfiber cloths should be used to clean monitors without damaging them. Alcohol is recommended to clean mice and keyboards that are reputed to become nests of microbes.
- The technicians should also ensure that there is always sufficient hard disk space on the DMS server and the other computers. Space can be made by selectively archiving historical data to permanent storage drives.
- The manufacturer of the Diver Monitoring System says that it is not provided with a backup server. However, this function can be added for increased system availability/redundancy with a computer that would take over from the main system server in the event of failure. Any of the client terminals can be replaced by a PC of opportunity if there is a failure. Alternatively, the system laptop can be used as a spare in emergencies. If a computer fails and is replaced by an extra unit, the necessary software for the area of use must be installed on the replacement unit. The software can be installed from the DMS software distribution disks, or can be copied over from the data server where the current version of all files should be kept.

Last generation analysers such as those explained in this document should be maintained as follows:

- Calibration should be performed at least every 12 hours.
- Function test should be performed every day.
- Visual inspection and routine calibration of depth sensors should be performed every three months.
- Full inspection of all components and calibration should be performed every year.
- The equipment should be sent to the factory for full revision and update every two years.

Recommended routine maintenance and inspection of the Hyperbaric Environment Control Unit:

- Checks for noises and vibrations that may indicate mechanical problems are to be performed each time the machine is activated.
- The manufacturer of the model explained recommends the following checks to be performed every fifteen days:
    - Visual Examination of piping systems.
    - Fluid levels in tanks.
    - Fluid levels of the tanks.
    - Refrigeration fluid level and compressor pressure.
    - Electrical continuity and insulation.
    - Visual examination and function test of the pressure indicating gauges and flow switches.
    - Inspection of the anodes that must be changed out if their wastage is more than 75% *(They are installed in the end cap of the condenser)*.

- Also, it is recommended to flush the condenser every 3 months.
- In addition, the following maintenance is to be performed every six months:
  - Cleaning of the condenser inner core tubes.
  - Replacement of the refrigerant filters.
  - Replacement of the anodes in the end of the condenser.

If the installation is equipped with a chamber regeneration system and a shutdown controller, the manufacturer recommends the following:

- Calibration and function test should be performed every day
- Routine transducer and display calibration using pressure calibrator should be performed every three months with the visual inspection of the shutdown valves and E-Stop operation.
- Depth monitor functional safety test procedure should be performed every six months
- Full inspection of all components and calibration should be performed every year
- The equipment should be sent to the factory for full revision and update every two years

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2) Gas management

2.1 - Gas transfer, and quality of gasses delivered

2.1.1 - Purpose

Gas transfer operations consist of connecting hoses and transferring gas from one gas container to another, or to a part of the diving system. If they are performed without precautions, these operations can cause injuries and fatalities such as:

- People injured or killed by an explosion or a fire due to oxygen quads improperly stored or operated, or the explosion of a gas container overfilled or not adequately maintained.
- People injured by the whipping of an unsecured open-ended hose under pressure.
- Personnel affected by blindness or deafness due to blast of high-pressure gas.
- Personnel affected by the loss of hearing due to regular exposure to the noise of venting gas.
- Divers affected, or killed by a wrong gas online.

Gas quality is also an important aspect, as suppliers' gasses may be polluted by other components, which may result in injuries to the respiratory system of the divers, loss of consciousness, and possibly death. For this reason, the gasses delivered to the system must be closely checked. Also, the gas quality may degrade due to improper maintenance of the system, pollutants introduced in it, the respiration and wastes of the divers, and if the filters and absorbents not changed on time.

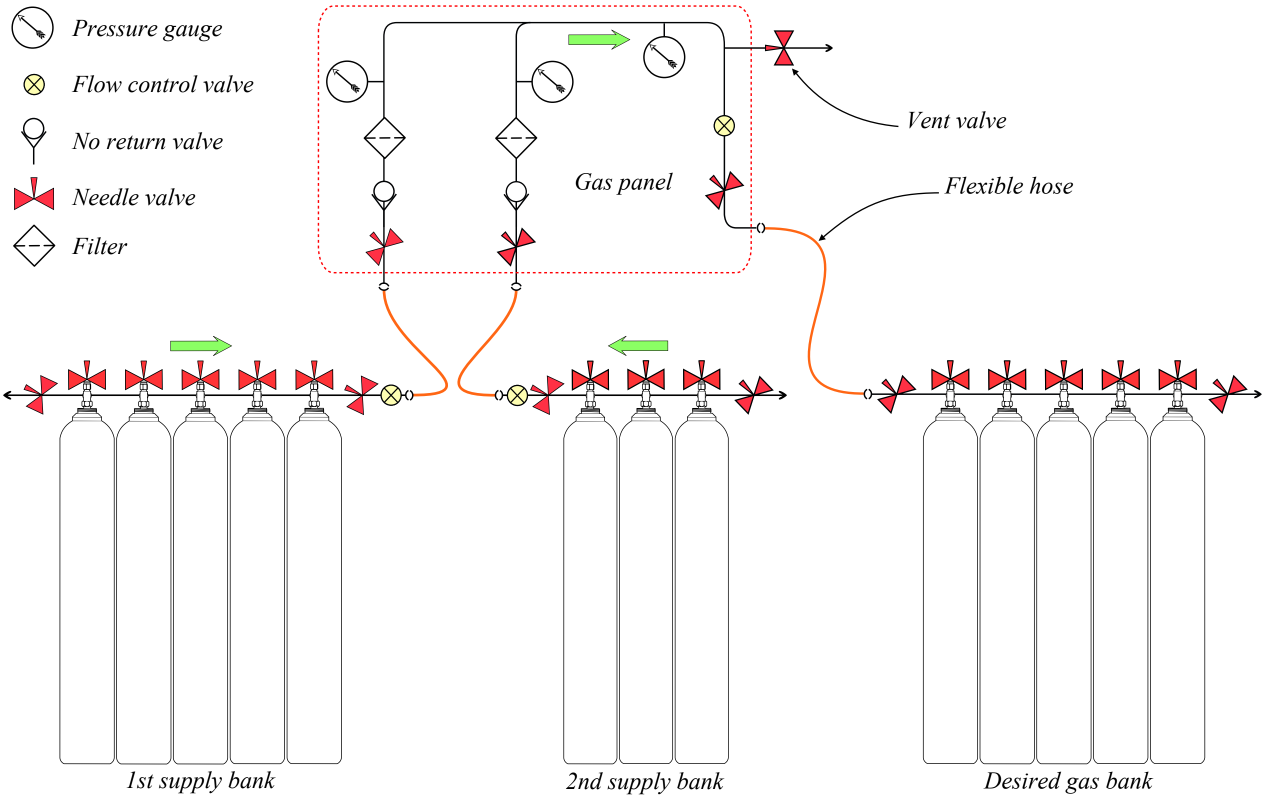
For these reasons, only personnel nominated should handle gas, and step by step procedures should be in place and followed at all times.

2.1.2 - Methods used for gas transfer, and precautions to be in place

Gas transfer operations are usually performed through flexible hoses. Two main methods are employed: Cascade and pumping.

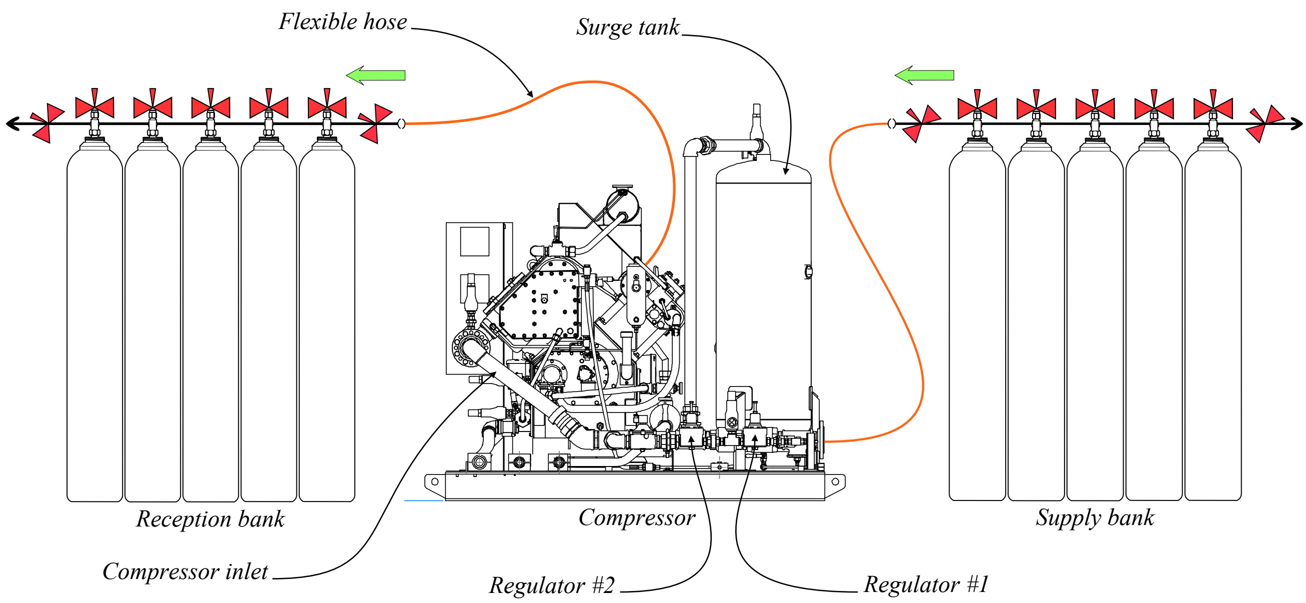
2.1.2.1 - Cascade filling

Cascade filling (also called decanting) is a procedure used to transfer compressed gas between storage cylinders or tubes by pressure difference from the more pressurized container to the less pressurized one.
This procedure, that is recommended by IMCA for the transfer of oxygen and high O_2 percentage heliox mix offshore, has the inconvenience that the gas to transfer must always be at higher pressure than the desired mix, which obliges to transfer the gas at lower pressure 1st.

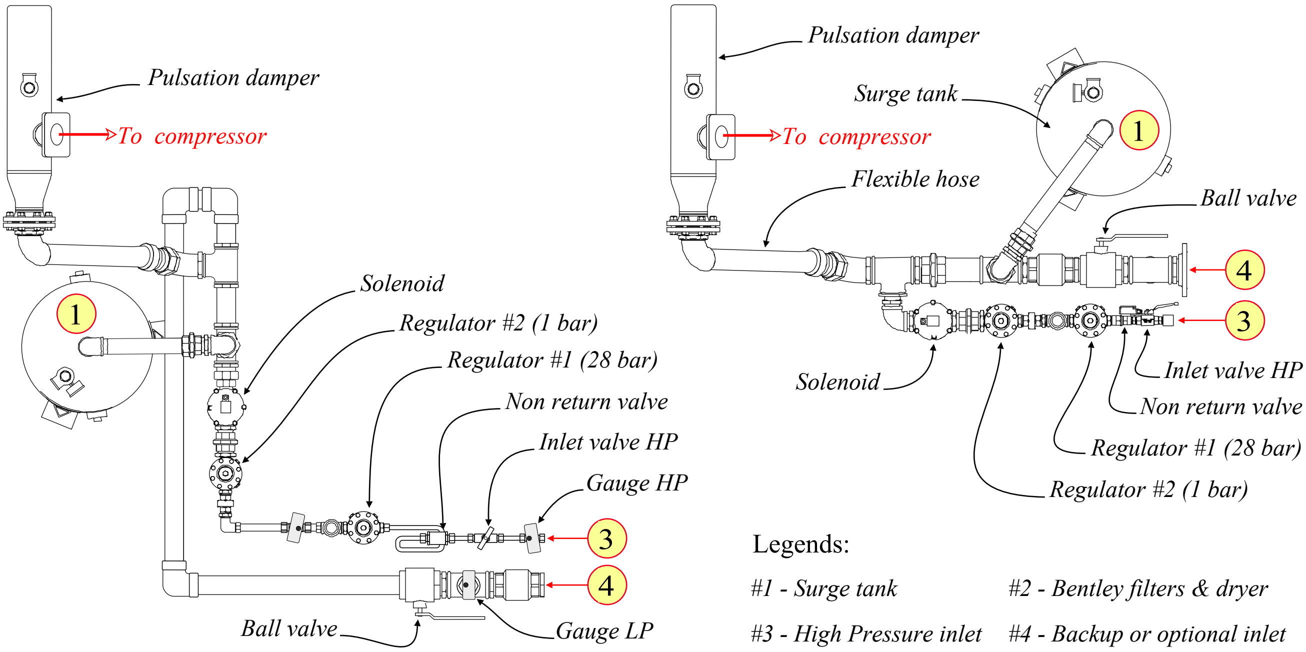


2.1.2.2 - Gas pumping

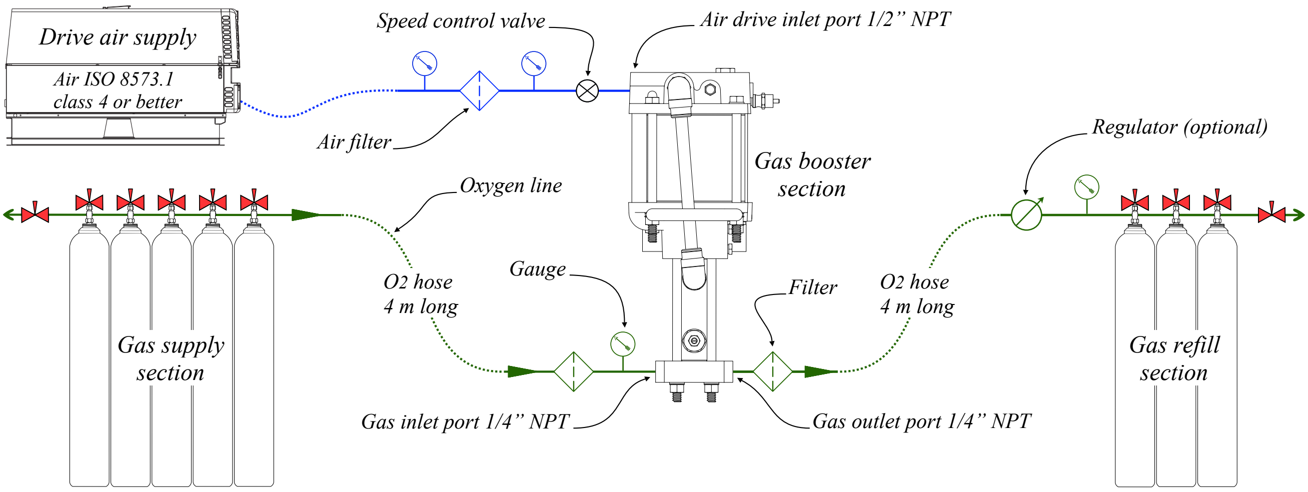
Pumping is used for transferring gas from quads or banks to other quads or banks and compensate for the inconveniences of cascade filling. It can be done using the piston compressors described in point 1.2.6.5 for gasses with less than 21% O_2, and membrane compressors such are those described in point 1.2.6.6 for all types of gasses, particularly those with more than 21% oxygen. With this method, the pressure of the gas to transfer from the quads or the tubes must be regulated down to the recommended inlet pressure of the compressor, which is usually a pressure close to the atmospheric pressure. It is usually done through regulators that are installed before the compressor. As an example, the pressure is reduced to 28 bar and then to 1 bar with the compressors taken as reference in point 1.2.6.5.



A surge tank, which is a closed reservoir of approximately 250 litres, is installed before the pulsation damper of the compressor to absorb the sudden rises of pressure and to return the gas stored in it to the inlet hose in case of a brief drop of the supply pressure. Another procedure is to reduce the pressure of the gas to be transferred in a sealed gas bag, such as those used with reclaim systems, and the system Helipure that are explained in point 1.2.5.



Gas boosters such as Haskel pumps, which are described in point 1.2.6.7, are another system commonly use to transfer gasses. As a reminder, Haskel pumps are powered by compressed air provided by an industrial compressor or any compatible source. The compressed air moves a large piston that moves a smaller piston that compresses the gas to transfer in a separate cylinder. As explained before, such pumps are often used for oxygen transfer.



2.1.2.3 - Precautions for gas transfer

Gas transfer is usually performed in dedicated places that are accessible to only the appointed personnel. However, it often happens that these operations are performed in areas of the ship or the installation that are not dedicated to this purpose. It is the case when receiving new gas containers on deck and transferring their content to the system. It is also the case when verifying or blending gasses in temporary storage areas. In such cases, a work permit is usually needed for these activities. Also, for every gas transfer operation, the following precautions should be in place:

- The operator wears clean Personal Protective Equipment. It should be fireproof in case of oxygen transfer.
- A precise task plan that indicates the gas to transfer, where it will be stored and the means of transfer to be used must be provided to the operator. This task plan is confirmed by the Life Support Supervisor before connecting hoses and operating the relevant valves. Note that gasses should not be put inline on the system as long as there is no confirmation of the life Support Supervisor.
- As already said, the gas to transfer must be analysed to ensure that it is the mix planned.
- Before connecting each hose, the operator must ensure that it is designed for the task (Its maximum safe working pressure should be visible, in addition to the gas it is designed for). He also ensures that the hose is of the recommended length, in perfect condition, and its fittings of the correct model. In addition, the container where the gas is transferred must be in optimal condition and designed to withstand the pressure it receives.
- Before being put under pressure, the hoses' end connections must be fastened to strong fixed points with ropes or whip checks to prevent whipping in the event of a fitting failure.

- Hoses should be routed so that they cannot cause injuries to personnel working at proximity in case of rupture. IMCA says that they should be fastened to supports every two metres. However, that would not stop them from whipping in the case of a rupture. For this reason, it is better to hold them at intervals less than 1 metre. The best policy is to secure them every 20 cm along ropes that can maintain them in one piece if they become cut.
- Valves for the gasses distribution are usually needle valves. They should be opened slowly at arm's length, so the operator is away from them. When the valve is fully open, the operator returns half a turn. That leaves the valve handle free to move and avoids blocking it in the open position. A small panel indicating that it is open should be installed on the opened valve.
- If the gasses connected are planned to be put online in the dive control or the saturation control, in addition to the analysis previously performed by the gasman before connecting the hose, the gasses must also be analyzed on the control panel before opening the final valves. Also, oxygen analysers with audio hi-lo alarms must always be online for each supply line.
- Note that every hose carrying gas to and from the dive control or the chamber control must be considered a "life line".
- When the gas transfer is completed, the operator ensures not to over-tight the valves in the closed position, which may damage the seats and may result that the valve may be difficult to reopen. A needle valve should close with two fingers. If it is not the case, it must be changed or repaired.
- When venting gas, the operator should wear ear defenders to prevent long term damage to hearing.
- When simultaneous air or surface gas operations are performed, the gasses used for these activities must be separated from those used for saturation diving. As for saturation diving, the diving supervisor in charge of these operations must analyze the gasses planned to be online.

Low-Pressure (LP) gasses can be transferred or used to energize some diving system components, such as Haskel pumps. It must be remembered that Low-Pressure gas may have the same capacity to injure as High-Pressure gas, depending on the pressure, the size of the hose, and the volume of gas flowing through it. For this reason, it should not be underestimated and handled as High-Pressure gas.

2.1.2.4 - Additional precautions for oxygen transfer

Pure oxygen and gas mixes containing over 25% oxygen, have the potential to generate a serious fire or explosion, as almost all materials can ignite and rapidly burn in high-pressure oxygen.
As an example, when a supply valve is opened too quickly, the oxygen that flows from high to low pressure through an orifice reaches sonic velocity and compresses the oxygen downstream against an obstruction, such as the seat of the next closed valve or regulator. The gas temperature can reach the auto-ignition point of plastics, organic contaminants, and metals. The following values from the American Society for Testing and Materials (ASTM), demonstrate that, depending on the pressure ratios, materials submitted to an immediate rise of pressure can be destroyed:

Initial pressure	***Initial temperature***	***Final pressure***	***Pressure ratio Pf/Pi***	***Final temperature***	***Comments***
1.013 bar	20 Cº	34.47 bar	34	530 Cº	Final temperature above auto-ignition temperatures of non-metallic materials
1.013 bar	20 Cº	137.9 bar	136.1	920 Cº	Final temperature above the melting temperature of brass (900 Cº)
1.013 bar	20 Cº	275.79 bar	272.1	1181 Cº	Final temperature above the melting temperature of bronze (1020 Cº)

Note that fire ignition can also be the result of small particles carried by the flowing gas in the oxygen system that strike the surfaces of the system, such as piping intersections or valve seats, and creates heat at the point of impact.

Melted pipe

Melted pipe

To avoid such a problem the following procedures should be implemented:

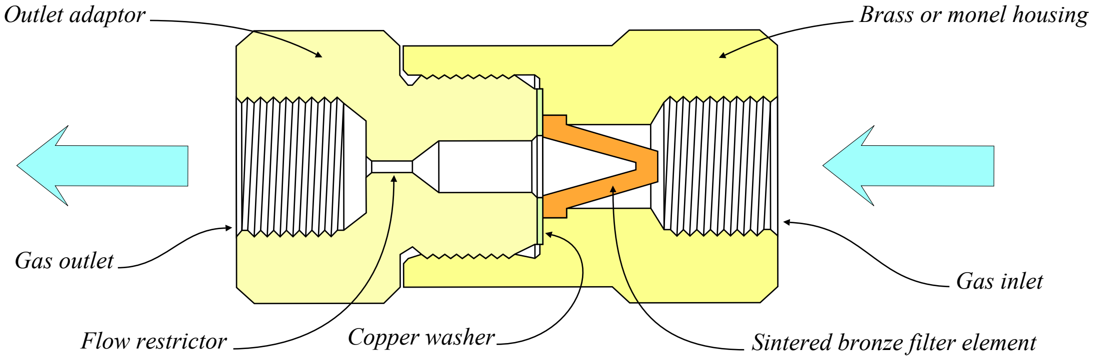
- Any gas mixture containing more than 25% oxygen by volume should be handled like pure oxygen (Note that NORSOK standards U-100 consider gasses with more than 22 % as pure oxygen).
- Flexible hose should be kept to a minimum in oxygen systems and rigid pipework should be used as much as possible. Note that Haskel recommends flexible hoses of 4 m maximum.
- The oxygen circuit should be designed for oxygen, and checked compatible by a competent person according to the following guidelines or similar recommendations, but not limited to:

- ASTM - G128 “Standard guide for control of hazards and risks in oxygen enriched systems”
- ASTM - G88 “Standard guide for designing systems for oxygen service”
- ASTM - G63 “Standard guide for evaluating nonmetallic materials for oxygen service”
- ASTM - G94 “Standard guide for evaluating metals for oxygen service”

- Stainless steel pipe or fittings should not be used, or be oxygen compatible in accordance with the guidelines from ASTM - G94 “Standard Guide for Evaluating Metals for Oxygen Service”, and ASTM “Safe use of Oxygen and Oxygen systems”.
- Quarter turn valves are designed to allow a quick opening, which can create a condition for ignition of the oxygen, and thus, should not be used with pressures above 15 bar. For this reason, only needle valves should be employed with pressures above 15 bar. Note that ASTM recommends valves with a non-rotating stem *(see in point 1.2.6.4)*. However, IMCA says that quarter-turn valves may be in-line as emergency shut off valves and that in this case, they should be labeled as such and lightly taped open to prevent routine use.
- Also, when preparing the transfer line, sharp bends and numerous piping intersections should be avoided for the reasons highlighted above.
- The hoses should be labelled with their purpose in addition to the identification numbers. As for every hose dedicated for gas transfer, their maximum safe working pressure should be visible.
- All pipework, hoses, valves and other fittings used in the oxygen system must be cleaned for oxygen service. This topic is discussed in point 1.2.6.10 of this book.
- Using sealants is a standard procedure to reduce the risks of leaks at the connections. However, only oxygen compatible thread seal tape or oxygen compatible liquid sealants should be employed. The table below gives some recommendations regarding the selection of these materials.

Thread compound	***Auto ignition temperature Cº***	***Description***
PTFE pipe tape *(Teflon tape)*	420 to 427	Polytetrafluoroethylene (PTFE) film, also called Teflon tape, can be used for sealing conic valve stem threads. Note that manufacturers use a colour code (white all industrial application, green Oxygen applications). When burning, PTFE pipe thread can emit toxic gases such as fluorocarbon alkene, and fluoride. Inhalation of gases from burning may result in irritation, irregular heartbeat, symptoms of drunkenness, suffocation, lung congestion. Long Term Exposure may result in kidney and liver damage. Threshold limit value of fluoride is 3 mg/m³
Epoxy cement	210 to 230	Epoxy cement are resins that can be used to seal and lock threads. Inhalation of gases from burning may cause allergy or asthma symptoms or respiratory difficulties if inhaled. Exposure to is limited to 150 mg/m³
Polyester thread sealant	140 to 150	Polyester sealant are very adhesive resins. However, their performances with oxygen are limited and they are not recommended for this purpose. Inhalation of gases from burning may result in cough, sneezing, nasal discharge, headache, hoarseness, and nose and throat pain. The threshold limit value of some gases they may emit is 5 mg/m³

- Flow restrictors, such as in the drawing below, which is based on a model from Oxycheck, should be installed at the source to prevent rapid pressurization and so adiabatic compression of the oxygen in the system. Note that such devices are recommended by the US Navy.



- In addition to the “flow restrictor”, a flow control valve should be used to ensure a precise fill rate and avoid ignition. Note that suitable “flow control valves” are proposed by several manufacturers, and that the valve of the gas container is not a real flow control valve.
- Oxygen and gas mixes containing more than 25% oxygen should be stored in a safe area on deck, or in a very well ventilated protected area, as a fire or an explosion could arise from oxygen leakages in a confined space.

- Greases, oil, and other materials which could ignite with oxygen should not be stored in the vicinity of oxygen and spare parts for oxygen service. Regular housekeeping should be carried out to ensure that the storage areas are clean. Also, tools with naked flame or emitting sparks should not be used in the proximity where oxygen is stored and transferred. Firefighting means must be provided and be ready for immediate use.
 Of course, the transfer of oxygen is to be performed only in such areas, or areas that are prepared accordingly
- In addition to the elements indicated above, the following precautions should be taken when handling oxygen:
    - The operator must ensure that the fittings are clean, so he should not touch the surfaces exposed to oxygen with dirty hands or contaminated objects.
    - It is common to open and closes a valve rapidly to remove particles of dirt before connecting a hose to air quads and cylinders. This procedure must not be used with oxygen as it can cause ignition. If cleaning is necessary, it is recommended to clean the valve with a suitable material and cleaning agent.
    - The first cylinder is to be opened slowly with the technician standing to the side of the quad and wait for the pressure to equalize slowly in the manifold. Then, he slowly opens the remaining cylinders to be opened. The same procedure is applied to fill the flexible hose connected to the gas container to fill and the control panel.
    - IMCA D 022 recommends that oxygen used for gas mixing is not pumped and slowly transferred by decanting at the lowest possible pressure. For this reason, oxygen is usually transferred first. The US Navy manual recommends nitrox and oxygen maximum fill rates of 5 bar (70 psi) per minute.
    - Vented oxygen can accumulate in clothing. For this reason, the operator should not smoke or go near someone who is smoking or near any naked flame immediately after completing oxygen transfer to avoid having his clothes ignite.

Note that when oxygen or mixes with 25% of O2 (22 % with NORSOK) are to be put online to supply several parts of the saturation system, the pressure must be reduced at the source to a maximum of 40 bar. Note that the regulator should be fitted with a filter that must be in good condition (generally it is a porous bronze filter): The function of this filter is to stop the impurities which may come from the cylinders or have been introduced in the circuit.

2.1.3 - Verification of the gasses delivered to the ship

2.1.3.1 - Condition of the gas containers delivered

Gasses are usually delivered in Multiple Elements Gas Containers (MEGCs) that should be checked for conformity before being transferred on-board the vessel.
In case suspicious points are detected on one or more gas containers, the units affected should not be accepted. For this reason, the person in charge should focus on the following:

- The cylinders and their piping should not be corroded, and a certificate of examination should be available in addition to the legal markings on their shoulders. Although full internal and external inspection of cylinders is performed every two years, corrosion can set up if the container is exposed to harsh conditions and not correctly maintained during the interval between these examinations, despite the six-monthly visual inspections. For these reasons, considering that it is impossible for the Life Surface Technician (LST) in charge of the reception to investigate the extent of a defect, the precaution principle should prevail, and he should reject every gas container that presents the following visible defaults:
    - Surface corrosion covering more than 20% of the external surface of the gas container
    - Local corrosion that seems affecting the wall thickness.
    - Corrosion forming a narrow longitudinal or circumferential line or strip, or isolated craters, or pits which are almost connected.
    - Corrosion forming isolated craters, or pits without significant alignment, but may affect the wall thickness.
    - Corrosion taking place in, or immediately around an aperture.
    - Visible deformation of the shapes such as swellings, depression.
    - Cuts and cracks on the body or around the neck.

  Note that the inspection of cylinders is explained in the diving study CCO ltd "Organize the maintenance of diving cylinders" (page 66) that can be downloaded for free at this address: http://www.ccoltd.co.th/index-b.htm
- Multiple gas container frames should be without corrosion, defects, or shocks that may affect their integrity. If corrosion is present, similar requirements as above should be used to evaluate the extent of the damages. The safe working load and manufacturing identification plate in conformity with the International Convention for Safe Containers (CSC) should be visible. Also, the lifting pad-eyes should conform to the specifications described in point 1.2.6.4. When the gas containers are fitted with lifting rigging, the relevant certificates must be provided.
- The valves should be easy to open and close, and the connectors should conform to those available onboard. Note that there are infinities of models of valve outlet connectors for gas cylinders and tubes, which usually are not compatible with each other, as a lot of countries continue using their national standards. This point is also explained in point 1.2.6.4 "Storage and distribution of the gasses" of this book.
- The pressure test and certifications should conform to what is also indicated in point 1.2.6.10 "maintenance" of the chapter "Gas storage and distribution", which are based on IMCA D 018.
- The colour code and labelling should conform to what is indicated in point 1.2.6.3 "Identification of gasses in containers" of the chapter "Gas storage and distribution".

2.1.3.2 - Verification of the contents of the gas containers delivered

Each breathing gas reservoir should be accompanied by an analysis certificate, that describes the gas it contains and the standards used for the analysis.
As already said in point 1.2.8.4, the gas of each container must be analysed for conformity before being transferred to the gas storage of the diving system.

The analysis of the gasses delivered is usually performed using portable oxygen and helium analysers. A lot of new models combine these two functions. The sampling of the gasses is done using a rubber bladder that is filled on each cylinder and then emptied through the analyser using an appropriate flow restrictor, or a regulator with a flow restrictor that optimise the gas flow for accurate sampling. The flow restrictor should be associated with a flow meter, which is a visual indicator of the flow rate that can be adjusted for a reliable pressure delivery to the gas sensors. Note that exposing analyser sensors to high flow and pressure would damage them.

It is crucial to compare the percentages of heliox and oxygen to ensure that no undesirable gas is present in the mix. A gap between these values indicates that another gas is present, and in this case the container should be rejected.
Also, the team in charge of the analysis should focus on the conformance of the content of the gas container with the gas analysis sheet attached to it. Note that the proportion of oxygen and helium indicated in this document should comply with what is stated on the gas container (painted values on the cylinder or the frame).

The gas delivered should conform to a recognized standard of breathing gas purity. Such a standard may vary from one country to another. Nevertheless, international standards like the European Norm EN 12021, which is displayed on the next page, is adopted by professional and national organizations such as IMCA, NORSOK, and the official safety organizations of a lot of countries.
It must be considered that among the other national standards of breathing gas available, the US navy specifications of oxygen *(Military Specification MIL-PRF-27210G)*, and helium *(Military Specification, MIL-PRF-27407D)* are in force in some countries. Note that the US Navy manual does not provide specifications for heliox.

EN 1221: Composition of breathing oxygen

Component	*Concentration at 1 013 mbar and 20 °C*
Oxygen	> 99.5 %
Water	≤ 15 mg m³
Carbon dioxide	≤ 5 ml m³ (ppm)
Carbon monoxide	≤ 1 ml m³ (ppm)
Oil	≤ 0,1 mg m³
Total volatile non-substituted hydrocarbons (vapour or gas) as methane equivalent	≤ 30 ml m³ (ppm)
Total chlorofluorocarbons and halogenated hydrocarbons	≤ 2 ml m³ −3 (ppm)
Other non-toxic gases such as argon and all other noble gases	< 0,5 %

EN 1221: Composition of oxygen and helium gas mixtures (heliox)

Component	*Concentration at 1 013 mbar and 20 °C*
Oxygen content: ≤ 10 % by volume > 10 % to ≤ 20 % by volume > 20 % by volume	 (Stated* ± 0.25**) % (Stated* ± 0.5**) % (Stated* ± 1.0**) %
Helium	Remainder
Water	≤ 15 mg m³
Carbon dioxide	≤ 5 ml m³ (ppm)
Carbon monoxide	≤ 0.2 ml m³ (ppm)
Oil	≤ 0.1 mg m³
Total volatile non-substituted hydrocarbons (vapour or gas) as methane equivalent	≤ 30 ml m³ (ppm)
Hydrogen	≤ 10 ml m³ (ppm)
Other non-toxic gases such as argon and all other noble gases	< 0,5 %
* = Percentage as stated by the supplier. ** = Tolerance value is a percentage of the total gas mixture.	

Gasses must be free from unsatisfactory odour or taste. Regarding this point, EN 12021 says that ISO 13301 gives guidelines for measuring odour or taste detection thresholds, and ISO 13301 for the determination of odour concentration.

Note that pure gasses such as helium and nitrogen, which standards are displayed on the next page, may be supplied as they are sometimes used for calibration. However, these gasses must be separated from the breathing gasses and stored in a dedicated ventilated area as breathing them would result in an immediate loss of conscious and a rapid death.
This point is linked to the recommendation DMAC 05 on minimum level of O2 in helium supplied offshore that says:
The DMAC (Diving Medical Advisory Committee) recommends that an oxygen and helium mixture should be used in place of pure helium supplied to offshore diving installations (It is recognised, however, that contractors may need to use pure helium as a calibration gas).
The choice of the mixture supplied should be left to the diving contractor, but a minimum of perhaps two percent of oxygen should present no problems operationally from 50 to 150 metres, and from 150 metres a smaller percentage may be appropriate.
To comply with this guidance heliox mixes with oxygen percentages of 2% or less are commonly supplied in place of pure helium.

EN 1221: Composition of pure helium

Component	*Concentration at 1 013 mbar and 20 °C*
Oxygen	< 0,1 %
Helium	> 99.9 %
Water	≤ 15 mg m³
Carbon dioxide	≤ 5 ml m³ (ppm)
Carbon monoxide	≤ 0.2 ml m³ (ppm)
Oil	≤ 0,1 mg m³
Total volatile non-substituted hydrocarbons (vapour or gas) as methane equivalent	≤ 30 ml m³ (ppm)
Hydrogen	≤ 10 ml m³ (ppm)
Other non-toxic gases such as argon and all other noble gases	Remainder

En 1221 does not provide table for pure nitrox. However, we can consider that the maximum levels of pollutants for nitrogen should be the same as for helium.

As said previously, US Navy gas purity standards are in force in several countries, and It may happen that for logistical reasons, the gasses have to be renewed in such countries. For this reason, they cannot be ignored.

US Navy: Gaseous oxygen

Component	*Specification*
Oxygen	> 99.5 %
Carbon dioxide (by volume)	10 ppm *(max)*
Methane (CH4 by volume)	50 ppm *(max)*
Ethylene (C2H4)	0.4 ppm *(max)*
Ethane (C2H6 and other hydrocarbons)	6 ppm *(max)*
Nitrous Oxide (N2O by volume)	6 ppm *(max)*
Halogenated Compounds: Refrigerants	2 ppm *(max)*
Halogenated Compounds: Solvents	0.2 ppm *(max)*
Moisture (at dew point)	7 ppm , < -82 Fº *(max)*
Odor	Odor free *(max)*

US Navy: Helium

Component	*Specification*
Helium	99.997 %
Moisture	9 ppm
Dew point	-78 Fº
Hydrocarbons (as methane)	1 ppm
Oxygen	3 ppm
Nitrogen + Argon	5 ppm
Neon	23 ppm
Hydrogen	1 ppm

2.1.3.3 - Conformance with the purchase order

The conformance of the gasses delivered to the purchase order of the company is another important point.:
Life Surface Supervisors usually require certain quantities of gasses to be able to perform mixing for the project ongoing. Incorrect delivery in quantities or percentages may seriously impact the project.
For this reason, the person in charge of checking the gas containers should be provided with a list of the gasses that are planned to be delivered. A specific form should be used for this purpose and indicate:

- The company name
- The invoice reference number
- The reference number from the supplier
- The date
- The department
- The project
- The name of the person in charge of the inspection and his/her signature
- The description of the gas and equipment delivered
- The specifications or/and the reference number from the manufacturer
- The quantity
- Whether it conforms or not
- Comments

At the end of this process, the list is hierarchically transmitted to the department manager.

Hyperlink Table of contents

2.2 – Gas blending and making up of the chamber atmosphere

2.2.1 - Purpose

Diving vessels carry a vast range of mixes that can be fabricated by the gas supplier and delivered as described in the previous points, or mixed onboard the vessel by the gasman. It is also usual that mixes that are no longer needed for the project are used to fabricate new blends that are more appropriate for the operations ongoing.

Another function of the Life Support team is to make up the chamber atmosphere so that the chamber arrives at the storage depth with the correct PPO2. Depending on the depth where the divers will be accommodated, which is called "storage depth", that is done using only one gas, called "ideal gas", or using an original mix from the surface to a first depth and then a lean blend to obtain the ideal gas at the storage depth.

Mixing gasses and making up the chamber atmosphere are activities that require method and precision because the gas proportions must be precise enough to conform with those recommended by the decompression model used. It is especially the case for blends that are to be used for deep dives that require less than 2% oxygen, and where the margin for error for the mixes employed is much reduced compared to mixes employed for dives at shallow depths.
For this reason, these calculations and their implementation must be performed by appropriately trained and experienced personnel.

2.2.2 - Units of measurement used for gas blending and transfer

2.2.2.1 - Metric and Imperial systems

Two systems of measurement are commonly used in diving:

- The metric system, also known as the MKS (Metre, Kilogram, Second) system or SI "Système International" which means "International System of Units", has been invented by the French at the end of the 19th century. It is very easy to use since all the units are based on a scale of 10. Note that European publications and those of the majority of countries are expressed in metric.
  It must be noted that because the metric system is recognised as the reference system by the whole scientific community; by today, every measurement should be expressed in metric.
- The Imperial or FPS (Foot, Pound, Second) system comes from a previous system of measure instituted as the official system by kings of England during the 15th century, and that have been continuously developed to become the Imperial system of measures in 1824. This system is still in use in countries which culture has been influenced by British such as the United States of America. It is also used in industries such as the petroleum and aviation industries. Note that there are slight variations between Imperial and US units on the FPS system.

2.2.2.2 - Distance, area, and volume

Gas blending involves volumes of gas, which cannot be calculated without the notion of distance and area. The official SI unit of distance is the metre.

- Distance:

Metric	Imperial
1 metre	3.28 feet (ft)
1 metre	39.37 inches (in)
1 centimetre	0.394 inches (in)
1 metre	1.094 yard (yd)
1 kilometre (km)	0.5399555 nautical miles (M)

Note: 1 m = 1000 mm 1 m = 100 cm

Imperial	Metric
1 foot	30.48 cm / 0.3048 m
1 inch	0.0254 metres
1 inch	2.54 cm
1 yard	0.914 metre
1 nautical mile (M)	1.852 kilometres

Note: 1 foot = 12 inches 1 inch = 0.08333 foot

- Area:

Metric	Imperial
1 square metre (m^2)	10.76 $foot^2$
1 square metre (m^2)	1550.003 $inch^2$
1 square centimetre (cm^2)	0.1550003 $inch^2$
1 square metre (m^2)	1.196 $yard^2$

Imperial	Metric
1 $foot^2$	929.0304 cm^2
1 $inch^2$	0.00064516 m^2
1 $inch^2$	6.4516 cm^2
1 $yard^2$	0.836 m^2

- Volume:

Metric	Imperial
1 cubic metre (m^3)	35.315 $foot^3$
1 cubic centimetre (cm^3)	0.06102374 $inch^3$
1 cubic metre (m^3)	1.307951 $yard^3$

Note: 1 m^3 = 1000 litres 1 litre = 0.03531 $foot^3$

Imperial	Metric
1 $foot^3$	28316.85 cm^3
1 $inch^3$	16.38706 cm^3
1 $yard^3$	0.7645549 m^3

Note: 1 ft^3 = 28.31 litres

2.2.2.3 - Temperature

Kelvin is the official SI unit of temperature. Celsius, Fahrenheit, and Rankin are unofficial systems that are used because they were used before the Kelvin, or are more practical for some calculations.

- Convert Celsius to Kelvin: C° + 273.15 = K
- Convert Kelvin to Celsius: K - 273.15 = C°

- Convert Celsius to Fahrenheit: (Cº x 1.8) + 32 = Fº
- Convert Fahrenheit to Celsius: (Fº - 32) / 1.8 = Cº

- Convert Fahrenheit to Rankin: Fº + 460 = R°
- Convert Rankin to Fahrenheit: R° - 460 = Fº

2.2.2.4 - Pressure

Pascal is the official SI unit of pressure. However, depending on the units' system, bar, atmosphere, and psi are commonly used for the same reasons as those indicated above.

- 1 bar = 100 000 Pascal, or 0.987 atmospheres, or 750 mm hg
- 1 atmosphere = 760 mm of mercury (mm hg), or 1.01325 bar, or 29.52999 inches of mercury, or 760 Torr
- 1 bar = 14.5 Psi

- 1 atmosphere = 14.7 Psi
- 1 PSI (pound per square inch) = 0.0689 bar, or 0.068 atmospheres
- 1 millibar = 0.001 bar = 0.000987 atmosphere

2.2.2.5 - Mass

Kilogram is the official SI unit of mass.

- 1 kg = 2,204 pounds (Ibs)
- 1 pound = 0.4536 kg
- 1000 kg = 2204 Ibs (pounds)
- 1 ton GB (also called "long ton") = 2240 Ibs = 1016 kg
- 1 ton US (also called "short ton") = 2000 lbs = 907.2 kg
- 1 metric tonne = 1000 kg = 0.984 Ton GB
- 1 metric tonne = 1000 kg = 1.102 Ton US
- 1 metric tonne = 2204.62 pounds (lb)
- 1 ft^3 of fresh water = 62.5 lbs
- 1 ft^3 of sea water = 64.38 lbs
- 1 m^3 of fresh water = 1000 kg
- 1 m^3 of sea water = 1030 kg

2.2.2.6 - Amount of substance

The mole is the unit of measurement for amount of substance in the International System of Units (SI).
The mole is related to the mass of an element in the following way: one mole of carbon-12 atoms has 6.02214076 × 1023 atoms and a mass of 12 grams.
The units may be electrons, atoms, ions, or molecules, depending on the nature of the substance and the character of the reaction (if any)
Note that Avogadro (1776 - 1856) said that number of units in one mole equals to 6.02214076 × 1023.

2.2.2.7 - Molecular weight

Molecular weight is a measure of the sum of the atomic weight values of the atoms in a molecule.
Thus, molecular weight is mass per mole, which is written: m/n
Where the mass " m " is usually expressed in kilograms, and " n " is a measurement of the number moles.

2.2.2.8 - Molar volume

The molar volume (Vm) is the volume occupied divided by the amount of substance at a given temperature and pressure.
It is equal to the molar mass (M) divided by the mass density (ρ).
The Molar volume is directly proportional to molar mass and inversely proportional to density.

The formula of the molar volume is expressed as: *Vm= Molar mass / Density*
Where Vm is the volume of the substance.

2.2.3 - Physical laws involved in gas blending

Three laws are essential for diving and the calculation of gas mixes: Boyle- Mariotte, Charles, and Dalton. The other laws can be considered as complement and improvements of these three basic laws.

2.2.3.1 - Boyle-Mariotte law

This law was established in 1662 by R. Boyle, and independently in 1676 by E. Mariotte.

It is commonly employed in gas mixing and the calculation of pressures, and is considered a description of the process of ideal gas. It states that at constant temperature the volume of a given mass of a dry gas is inversely proportional to its pressure. Most gases behave like ideal gases at moderate pressures and temperatures.

It can be expressed by the equation: *Pressure 1 x Volume 1 = Pressure 2 x Volume 2*

2.2.3.2 - Charles' law

Jacques Charles (1746 - 1823) was a French scientist who established the physical principle that states that the volume of a gas equals a constant value multiplied by its temperature as measured on the Kelvin scale where zero Celsius degree = 273.15 Kelvin degrees (for convenience 273.15 is rounded to 273).

This law allows to estimate the volume of a gas according to the variation of the temperature. Combined with Boyle-Mariotte law, it provides the formula: *Pressure x Volume / Temperature = Constant*

As a result: $\dfrac{\text{Pressure \#1 x Volume \#1}}{\text{Temperature \#1 (K}^o\text{)}} = \dfrac{\text{Pressure \#2 x Volume \#2}}{\text{(Temperature \#2 (K}^o\text{)}}$

Example:

Find the final pressure at 19 C° of a 12 litres cylinder filled to 250 bar which reached a temperature of 35 C° immediately after the operation.

Temperature #1 = 273 + 35 = 308 k°

Temperature #2 = 273 + 19 = 292 k°

Applying the formula above:

250 x 12 / 308 = ? x 12 / 292 ⟶ 250 /308 = ? / 292 ⟶ 250 x 292 / 308 = 241.88 bars

Based on the fact that compressing a gas results in heat, this law is to consider when filling a gas container or a chamber to calculate the final pressure after cooling. It can also be used to calculate the variation of depths in chambers exposed to weather conditions.

2.2.3.3 - Dalton's law

Dalton (1766-1844) published the law of partial pressures that states that the total pressure of a gas is equal to the sum of the partial pressures of the gasses that compose it.

It can be expressed with the following equation: *Pressure final = Pressure 1 + Pressure 2 + Pressure 3 …*

2.2.2.4 - Avogadro's Law

Avogadro (1776 - 1856) was an Italian scientist who published a law stating that the volume of a gas is directly proportional to the number of moles of gas when the temperature and pressure are held constant.

The mathematical expression of this law is: *V = k x n and V1/n1 = V2/n2*

Where "n" is the number of moles of gas and "k" is a constant.

Avogadro's law says that adding gas to a rigid container makes the pressure increase while adding gas to a flexible container makes its volume increase.

2.2.2.5. - Van der Waals equation

Van der Waals (1837 - 1023), a Dutch scientist, has provided an equation that states that the ideal gas law does not act ideally as expressed by Boyle-Mariotte law and deviates from assumptions at low temperatures or high pressures.

The equation is written as: $(P + an^2/V^2)\ (V – nb) = n\ RT$

Where, P, V, T, n are the pressure, volume, temperature and moles of the gas. 'a' and 'b' constants specific to each gas. This equation is used to calculate the compressibility of gasses.

2.2.2.6 - Compressibility factor " Z " of gasses

Linked to the Van der Waals equation discussed above, the compressibility factor " Z " is a thermodynamic property for modifying the ideal gas law to account for behavior of real gases.

For an ideal gas, Z always has a value of 1. For real gases, the value may deviate positively or negatively, depending on the effect of the intermolecular forces of the gas. The closer a real gas is to its critical point or to its saturation point, the larger are the deviations of the gas from ideal behavior.

The ideal gas law is commonly written as: *P1 x V1/T1 = P2 x V2/T2*

Scientist also define it as: $PV_m = RT$

Where P is the pressure; V_m The molar volume of the gas; R the universal gas constant; and T the temperature

The ideal gas law corrected for non-ideality is defined as: $PV_m = ZRT$ ⟶ Thus: $Z = PV_m / RT$
The compressibility factor may also be expressed as: $Z = V\ actual / V\ ideal$
Where P is the pressure; V_m The molar volume of the gas; R the universal gas constant; T the temperature; and Z the compressibility factor.

Note that gasses with a compressibility factor less than " 1 " can be more easily compressed than gases with values greater than " 1 ".
The compressibility factors of helium and oxygen at temperatures between 15 and 20 degrees can be expressed as in the following table:

Pressure (bar)	***Oxygen***	***Helium***	***Pressure (bar)***	***Oxygen***	***Helium***	***Pressure (bar)***	***Oxygen***	***Helium***
20	*0.99*	*1.01*	***120***	*0.94*	*1.06*	***220***	*0.95*	*1.11*
40	*0.97*	*1.02*	***140***	*0.94*	*1.07*	***240***	*0.96*	*1.12*
60	*0.96*	*1.03*	***160***	*0.94*	*1.08*	***260***	*0.97*	*1.13*
80	*0.95*	*1.04*	***180***	*0.94*	*1.09*	***280***	*0.97*	*1.14*
100	*0.95*	*1.05*	***200***	*0.95*	*1.1*	***300***	*0.97*	*1.14*

To calculate the pressure of a gas with the compressibility factor the formula is: P1 x V1 / Z1 = P2 x V2 / Z2

As an example, using the Boyle-Mariotte formula P1 x V1 = P2 x V2, 20 bar of oxygen added in a cylinder of 50 litres volume equals 1000 litres of oxygen (20 bar x 50 litres = 1000 litres) , so a percentage of 10% in the mix.
Using this formula taking the compressibility factor into account, the calculation becomes:
(20 bar x 50 litres) / 0.94 = 1063 litres, so a mix with 10.6% oxygen.

2.2.4 - Gasses used with saturation procedures

Two gasses are used with the saturation procedures currently in force: Helium and Oxygen. The characteristics of these gasses are as follows.

	Helium	*Oxygen*	*Nitrogen*
Symbol	*He*	O_2	N_2
Molecular weight	*4 g/mol*	*31.99 g/mol*	*28.01 g/mol*
Weight per litre (@ 0 °C)	*0.1875 gram*	*1.429 gram*	*1.251 gram*
Molar volume	*0.022424*	*0.011196*	*0.011197*
Thermal Conductivity (W/m°C)	*0.086 to 0.149*	*0.015 to 0.026*	*0.015 to 0.026*
Sound velocity in gas (m/s)	*1015*	*329*	*353*
Boiling point at 760 mm Hg	*-268.78 °C*	*- 182.97 °C*	*- 195 °C*
Flammability	*Not flammable*	*Oxidiser*	*Not flammable*

Note that nitrogen is indicated in the table above for information only as it is not used and is considered a pollutant when binary mixes helium/oxygen are used.

2.2.5 - Methods used for gas blending

The preferred method of gas mixing is the one explained in the document IMCA D 022 that remains the most used by teams working offshore. However, other methods exist that must not be ignored.

2.2.5.1 - Mixing by weight

Mixing by weight consists in calculating the proportions of the gases in the final mixture by their weight.
For this reason, it is necessary to know the receiver volume and weight, the final pressure, the temperature at which the receiver is to be filled, and the gaseous constituents of the mixture and their proportions. From these it is possible to calculate the weight of each gas to be added to the receiver.
That can be done using the molecular weights of the gasses to add:

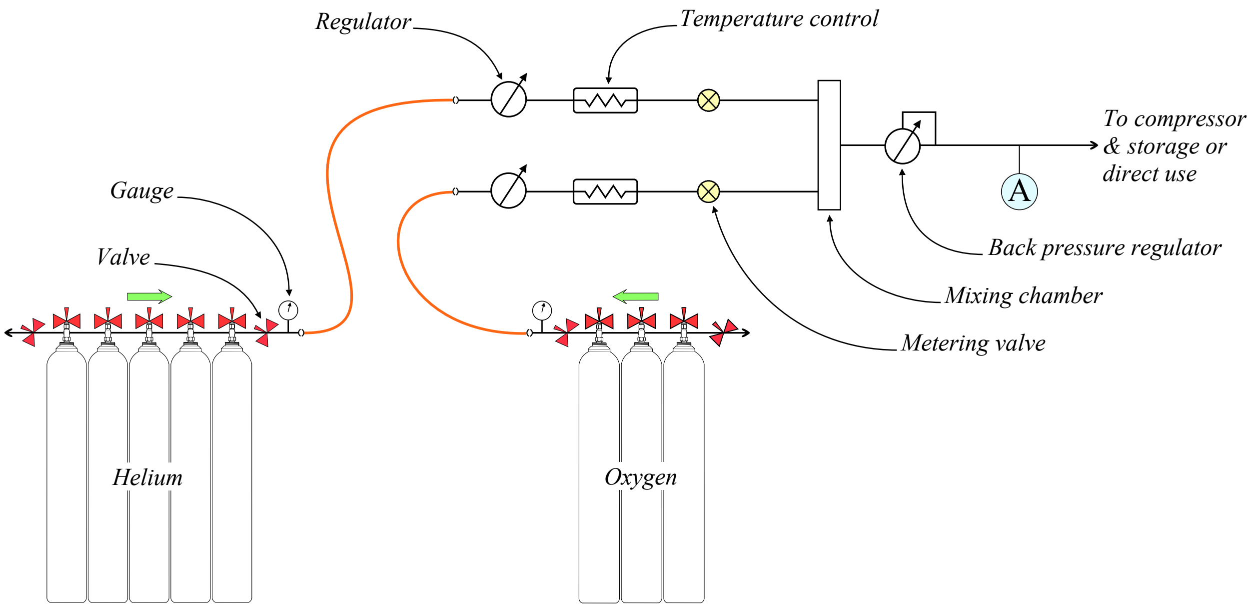
- Oxygen molecular weight : 31.99 g/mol
- Helium molecular weight: 4 g/mol
- Nitrogen molecular weight: 28.01 g/mol
- Air molecular weight: 28.96 g/mol

It can also be done by using the weight per litre of each gas:

- The weight of 1 litre of helium is 0.1875 gram at 0°C
- The weight of 1 litre of oxygen is 1.429 gram at 0°C
- The weight of 1 litre of nitrogen is 1.251 gram at 0°C
- The weight of 1 litre of air is 1.293 gram at 0°C

2.2.5.2 - Continuous flow gas mixing procedure

This procedure implies the use of a pre-calibrated system by which the flows of the gasses that compose the final mix are controlled as they are delivered to a mixing chamber where the blending process takes place.
The gases that compose the mix are regulated to the same pressure and temperature before they are metered through precision micro-metering valves and nozzles. The valve settings are pre-calibrated and displayed on curves that correlate the settings with the desired mixture percentage.
The mixing system usually has feedback controls that adjust the valve settings automatically if abnormalities are observed in the gas percentage values.



Several methods are used to implement this procedure:

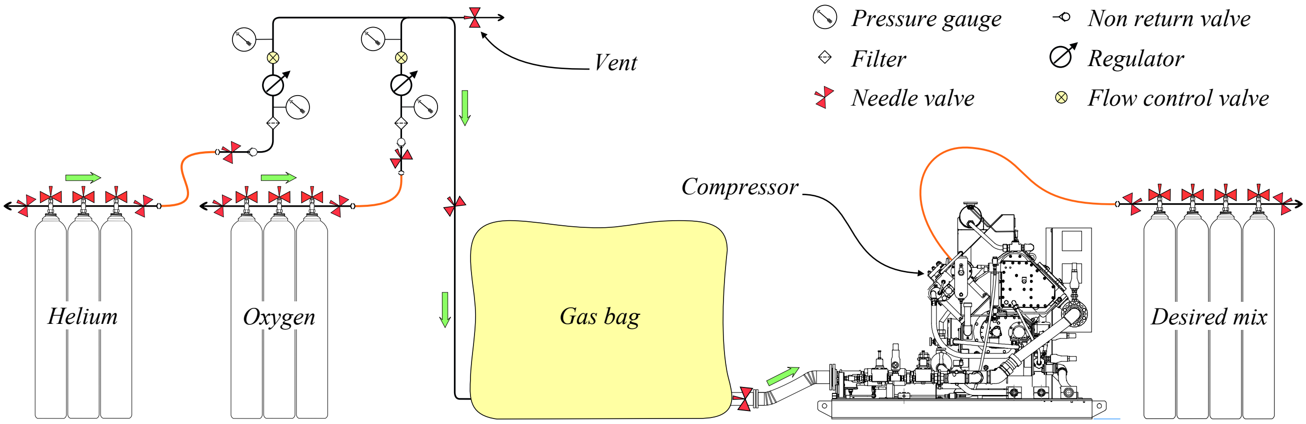
One is the use of one or more micrometer valves for flow modulation. The actual flow is calibrated using charts of settings for desired flow rates and mixtures. The gas is mixed in a chamber maintained under slight pressure by a back pressure regulator to avoid variations of flow.

A second method uses several subsonic and sonic nozzles that can be valved in and out of the flow circuit with solenoid valves in various combinations to provide variable flow rates.
The “ flow nozzle” are composed of a converging section where the flow accelerates, reaching its maximum speed at the throat, and a diverging section where the flow decelerates.
The difference between the sonic and the subsonic nozzles is that with a subsonic flow, the flow speed is below Mach 1, and any change of the pressure affects the differential pressure, which in turn affects the flow through the nozzle. Thus a back-pressure regulator is necessary to regulate the flow. It is not the case with a sonic nozzle where the reduced size of the throat and the gas speed reached, which is equal or above Mach 1, allow a more constant flow rate.

Note that the regulator installed before the valves reduces the cylinder's gas pressure to a pressure allowing regulated gas flow through the metering valves or the subsonic and sonic nozzles.

2.2.5.2 - Mixing by volume

This mixing procedure consists of regulating the gasses to be used in the mix that are usually stored in high-pressure tubes or cylinders to near atmospheric pressure and storing the planned volume of each gas in a gas reservoir at near-atmospheric pressure. This reservoir is usually an inflatable bag, which is similar to those used with reclaim systems, large enough to contain the total volume of gas required for the mix. This bag also acts as the mixing chamber. The final mixture is then compressed into high-pressure tubes or cylinders.
US Navy says that this procedure requires accurate gas meters for measuring the volume of each gas added and that the gasses being mixed should be at the same temperature unless the gas meters are temperature compensated. Another problem is that the size of the bag limits the volume of gas fabricated (50 litres @ 200 bar =10000 m³).



2.2.5.3 - Calculate a gas mix using the IMCA procedure

The procedure explained in this point is also explained in the document IMCA D 022, and is based on Boyle-Mariotte and Dalton equations. This procedure is currently the most employed offshore.

The formula to apply is as follows:

$$\text{Pressure of high mix} = \text{final pressure} \times \frac{(\%\ \text{final mix} - \%\ \text{low mix})}{(\%\ \text{high mix} - \%\ \text{low mix})}$$

To mix two gases in an empty quad, mix #1 and mix #2 are mixed together to give the final mix. As a result, the percentage of the final mix is between the percentages of mix #1 and mix #2.

Mix 1 is the richer mix (the one with more oxygen). As a general rule, the richer mix should be introduced first. Also, there is a fire risk associated with high-pressure pumping with mixes containing over 21% oxygen. For this reason, IMCA D 022 chapter 9 - point 9.6 (page 161) recommends to decant oxygen at a rate of 5 to 7 bar per minute instead of pumping it. Note that this rate of decantation is also indicated in the US Navy manual.

Example 1:

To make 200 bar of 9% using 2% and 12%:

Final pressure = 200 bar

% final mix = 9

% mix #1 = 12

% mix #2 = 2

The formula is: $\text{Pressure mix 1} = \text{final pressure} \times \frac{(\%\ \text{final mix} - \%\ \text{mix \#2})}{(\%\ \text{mix \#1} - \%\ \text{mix \#2})}$

$$\text{Pressure of mix 1} = \frac{200 \times (9 - 2)}{(12 - 2)} \longrightarrow = \frac{200 \times 7}{10} \longrightarrow = 140 \text{ bar of } 12\ \%$$

To determine the pressure of the low mix: 200 bar - 140 bar = 60 bar of 2%

140 bar of 12% and 60 bar of 2% are needed to make 200 bar of 9%

Example 2:

To make 200 bar of 16% using 2% and 20%:

Final pressure = 200 bar

% final mix = 16

% mix #1 = 20

% mix #2 = 2

The formula is: $\textit{Pressure mix 1} = \textit{final pressure} \times \dfrac{(\%\ \textit{final mix} - \%\ \textit{mix \#2})}{(\%\ \textit{mix \#1} - \%\ \textit{mix \#2})}$

$$\text{Pressure of mix 1} = \frac{200 \times (16 - 2)}{(20 - 2)} \longrightarrow = \frac{200 \times 14}{18} \longrightarrow = 155.6 \text{ bar of } 16\ \%$$

To determine the pressure of the low mix: 200 bar - 155.6 bar = 44.4 bar of 2%

140 bar of 12% and 60 bar of 2% are needed to make 200 bar of 9%

The proof of the mix can be proved by adding the PPO_2:

$$PPO_2 = \frac{\% \times \text{press.}}{100}$$

The addition of the PPO_2 of the weak and rich mixes should equal the PPO_2 of the final mix

$$\text{Partial pressure final mix} = \frac{16 \times 200}{100} = 32 \text{ bar}$$

$$\left.\begin{array}{l} \text{Partial pressure rich mix (\#1)} = \dfrac{20 \times 155.6}{100} = 31.12 \text{ bar} \\ \text{Partial pressure low mix (\#2)} = \dfrac{2 \times 44.4}{100} = 0.888 \text{ bar} \end{array}\right\} 31.12 + 0.88 = 32 \text{ which is the } PPO_2 \text{ of final mix}$$

For some, the gas mixing, the triangle based formula, is easier to remember and to use. Using the 1st example:

To make 200 bar of 9% using 2% and 12%:

Final pressure = 200 bar

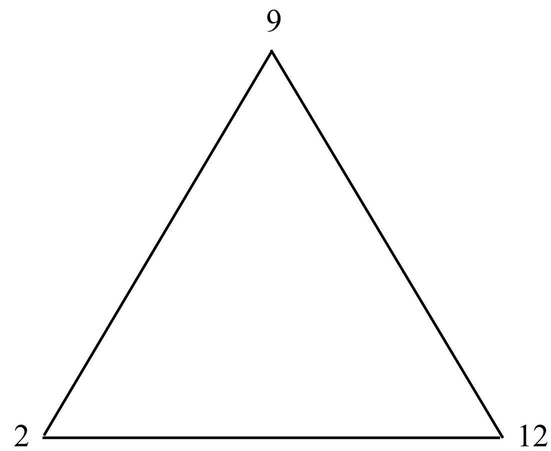
% final mix = 9

% mix #1 = 12

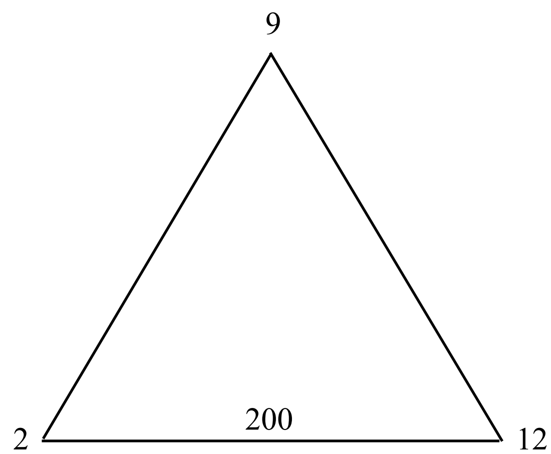
% mix #2 = 2

Draw a triangle and write the oxygen (O_2) percentages of the mix at each corner of this triangle.

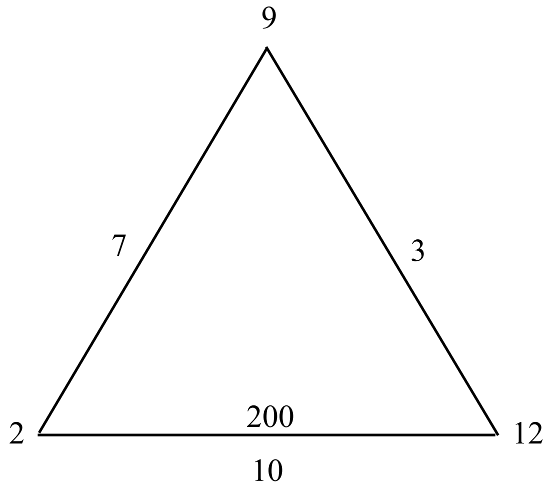
Always put the mix that you know the pressure of at the top.
In this case, it is 9%. It does not matter where the other mixes go: The important fact is that the pressure must remain with the percentage it refers to, i.e. 200 bar of 9%.



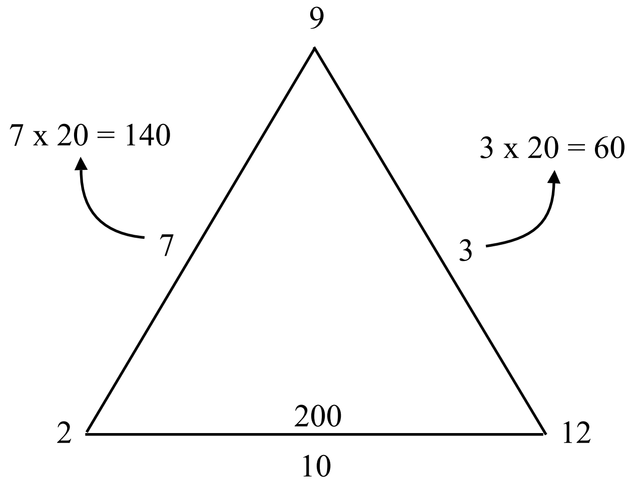
Write in the pressure that you know inside the triangle opposite to the mix with that pressure



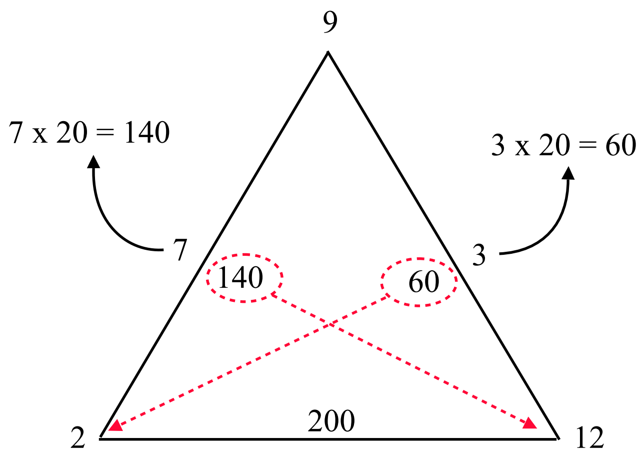
Subtract the small figure (%) from the larger figure (%) and write the answer between the same two percentages along each side of the triangle.



Divide the pressure by the figure underneath it. In this case, that is 200 divided by 10 which equals a factor of 20. Multiply the factor by the other two figures as shown.



Write 140 inside the triangle. Do the same on the other side of the triangle (i.e. insert 60). Reading the opposite corners shows that you need 140 bar of 12% and 60 bar of 2%. Remember, the percentage figure at the corner of the triangle goes with the figure on the opposite side.



The procedure above shows the principles of calculations. However, having to fill an empty quad is rare, and mixing usually involves transferring gas into a not empty quad or tube. In this case, the formula should be turned round to calculate the final pressure:

$$\textit{Final pressure} = \textit{pressure mix 1} \times \frac{(\%\ \textit{mix 1} - \%\ \textit{mix 2})}{(\%\ \textit{final mix} - \%\ \textit{mix 2})}$$

Example 1:

Determine the final pressure of a mix 10% O_2 made with a quad at 100 bar of 4% O_2 by pumping in a quad of 20% O_2:

The formula is: $\textit{final pressure} = \textit{Pressure mix 1} \times \frac{(\%\ \textit{mix 1} - \%\ \textit{mix 2})}{(\%\ \textit{final mix} - \%\ \textit{mix 2})}$

Pressure mix #1 = 100 bar

% mix #1 = 4

% mix #2 = 20

% final mix = 10

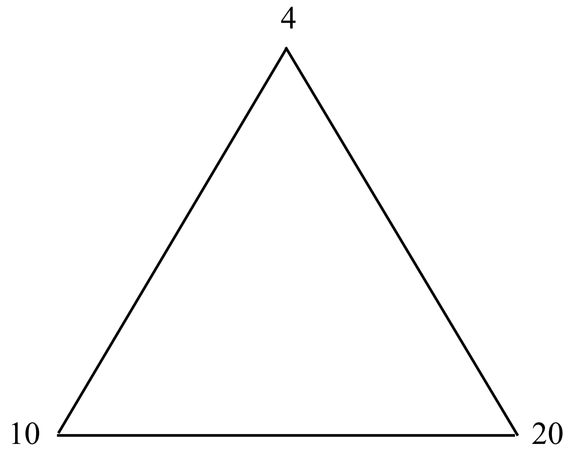
$$\text{Final pressure} = \frac{100 \times (4 - 20)}{(10 - 20)} \longrightarrow = \frac{100 \times -16}{10 - 20} \longrightarrow = \frac{100 \times -16}{-10} \longrightarrow = \frac{100 \times 16}{10} \longrightarrow = 160 \text{ bar of } 10\ \%$$

The final pressure is 160 bar.

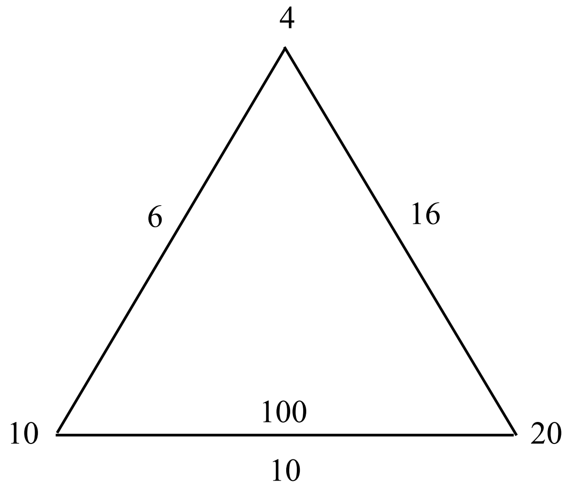
Mix #2 (20% O2) should be transferred until the pressure reaches 160 bar (or a little bit more to allow for cooling)

Using the triangle method:

As before, write the mix that you know the pressure of at the top. In this case it's 4%. It does not matter where the other mixes go.

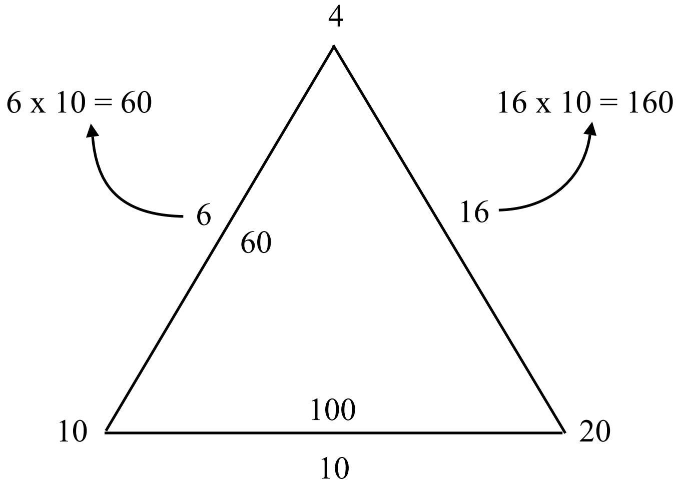


Write in the pressure that you know, inside the triangle opposite the mix.



Subtract the small figure (%) from the larger figure (%) and write the answer between the same two percentages along each side of the triangle. Divide the pressure by the figure underneath it. In this case that is 100 divided by 10 which equals a factor of 10. Multiply the factor by the other two figures as shown.

Write 60 inside the triangle. Do the same on the other side of the triangle. Reading the opposite corners shows that the pressure of 10% will be 160 bar. This is achieved by pumping 60 bar of 20% into the existing 4%



Important notes:

- The procedures used for transferring the desired mix components are cascade filling or gas pumping that are discussed in points 2.1.2.1 and 2.1.2.2. Because gas compression generates heat, the desired gas's temperature stored in cylinders or tubes is increased. It thus generates a false indication of the real pressure in the gas storage

Container. Note that this phenomenon is valid with all gas mixing procedures where these gas transfer techniques are used. The real pressure in the container after cooling to the ambient temperature can be calculated using Charles law, which is explained in point 2.2.3.2, using the formula below:

$$\textit{Final pressure} = \frac{\textit{Initial pressure x final temperature (°K)}}{\textit{Initial temperature (°K)}}$$

Celsius degrees (°C) are converted to Kelvin (°K) by adding 273 to the temperature in °C.
The formula used to convert Fahrenheit to Kelvin is: Temperature °K = (Temperature °F + 459.67) x 5/9.

- This gas mixing procedure does not take into account the variation of the compressibility of gasses previously discussed in point 2.2.2.6. That may result that the composition of the mix may not be exactly the one desired. Also, the gas may not be perfectly mixed, and an immediate analysis may result in an incorrect reading. For these reasons, it is recommended to stand the mix for at least six hours to permit the gases to mix homogeneously. Following this time, an analysis should be done to verify the percentages of the content, and adjustments to obtain the desired proportion should be performed using the formulas explained above.
  Note that many teams wait for the mix to homogeneous for 24 hours minimum, particularly when the desired gas mix is stored in large banks.

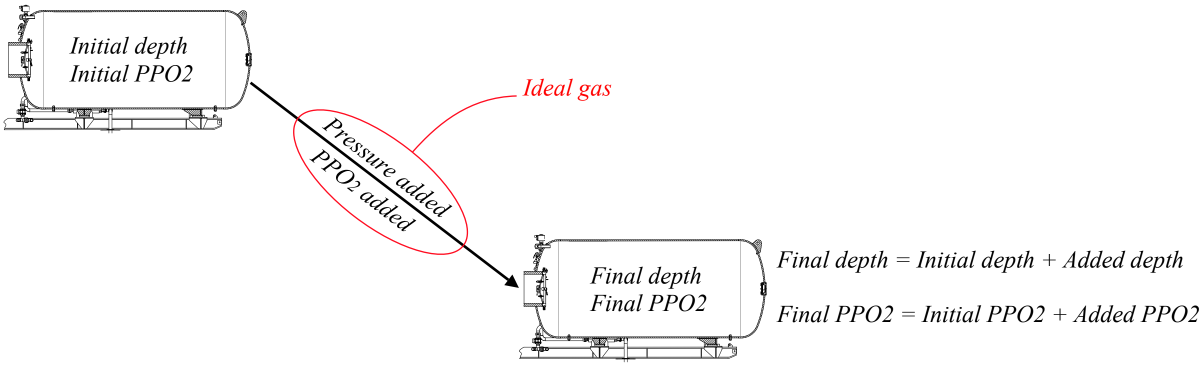
2.2.6 - Make up the chamber atmosphere *(IMCA D 22, various competent bodies)*

As indicated in point 3.2.1, to pressurize the chambers, the gases have to be arranged so that the chamber arrives at the storage depth with the correct PPO2. However a slightly elevated PPO2 at the arrival at depth can be tolerated.
The Life Support Technician has several different options such as:

- A single gas to storage depth sometimes called an ‘ideal gas’.
- A rich mix to an initial depth then a lean mix to storage.

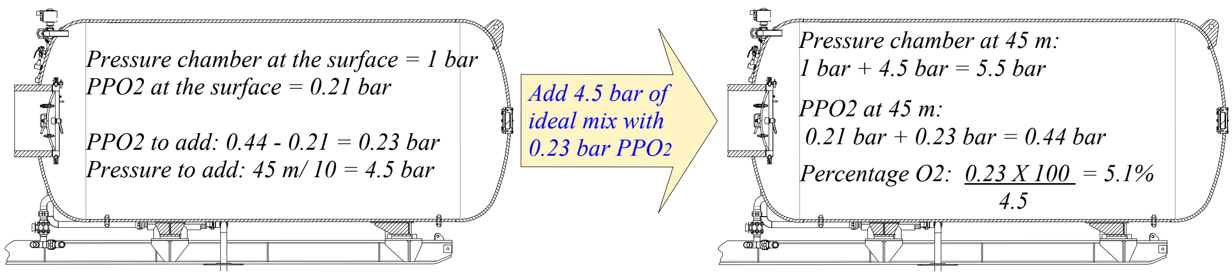
2.2.6.1 - Calculation of an “ideal gas”

- The procedure consists of finding the percentage of oxygen of the mix to be added to the atmosphere already present in the chamber to obtain the final mix at the planned storage depth using the Dalton partial pressure formula:
  - The first step consists of finding the PPO_2 to add to the existing partial pressure of the chamber. So, if compressing from the surface, the 21% of oxygen that compose the atmosphere at the surface (air), which partial pressure is 210 mb, or 0.21 bar, or 0.21 ATA. It is obtained by subtracting the initial PPO2 from the PPO2 desired: *PPO2 final - PPO2 initial = PPO2 to add, which is the PPO_2 of the “ideal mix”.*



  - Then, using partial pressure formula, find the percentage of the ideal mix. Several methods can be used, depending on the measurement system used:
    - Using pressure in bar:
      PPO_2 to add in bar x 100 / Pressure added to the initial pressure in bar = % ideal mix
    - Using pressure in ATA :
      PPO_2 to add in ATA x 100 / Pressure added to the initial pressure in ATA= % ideal mix
    - Using millibar and depth:
      PPO_2 to add in millibar / depth = % ideal gas

- *Example using pressures in bar*:
If a chamber is to be pressurized to 45 metres and to have a PPO2 of 0.44 bar arrived at depth, the ideal gas can be calculated as follows:
  - Before the blow-down, the chamber contains 0.21 bar of oxygen, which is the PPO_2 of air at the surface.
  - The ideal gas will need to have a PPO_2 of 0.44 - 0.21 which is 0.23 bar.
  - 45 metres of gas must be added to the chamber atmosphere to achieve this, so 4.5 bar:
    - The partial pressure formula is: PPO_2 = pressure added x % / 100
    - Transposing the formula: % = PPO_2/depth = 0.23 x 100 / 4.5 = 5.1%



- *Example using millibar and depth*:
If the chamber above is to be pressurized to 45 metres and to have a PPO2 of 440 millibars arrived at depth (so 0.44 bar), the ideal gas can be calculated as follows:
  - The ideal gas will need to have a PPO_2 of 440 mb - 210 mb, which is 230 mb.
  - 45 metres of gas are added to the chamber to achieve this:
    - The formula to use is: PPO_2 = % x depth
    - Transposing the formula: % = PPO_2/depth = 230/45 = 5.1%

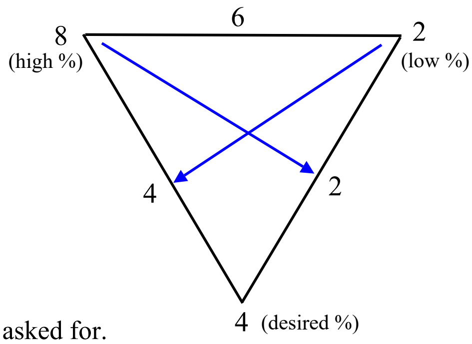
The chamber can be compressed to 45 metres using 5.1 % and should arrive with a PPO_2 of 440 mb, which is 0.44 bar.

2.2.6.2 - Calculation of a rich mix to an initial storage depth, then a lean mix to storage

It is not often that an ideal gas is available, and for this reason, chambers are often compressed using a rich mix and a lean mix, which are mixed in the chamber to form the ideal gas. The procedure consists of starting the compression with the rich mix to a certain depth and then continue with the lean mix. Thus, the depth where the compression with the rich mix is stopped must be calculated. That can be done according to the procedure explained in the example below:

- Suppose that a chamber is to be pressurized to 55 metres with 8 % and 2 %, and the PPO2 on arrival is planned to be 430 mb; the initial depth using the 8 % can be calculated as follows:
  - PPO2 of ideal gas = 430 - 210 = 220 mb
  - PPO2= % x Depth
  - % = PPO2/depth = 220/55 = 4%

  55 metres of 4 % is required to be mixed using 8 % and 2 %.
  - Using the triangle formula: Pressure of 8% = $\frac{2 \times 55}{6}$ = 18.3 m



Proof:
Surface air = 210 mb
PPO2 of 8% is 18.3 x 8= 146.4
PPO2 of 2% is 36.7 x 2=73.4
Added together = 429.8 mb, which approximately equals the 430 millibars asked for.

- To make the calculation shorter the following formula can be used :

$$\textit{Initial Press} = \frac{(1000 \times (PPO_2 \text{ required in bar} - PPO_2 \text{ present in bar}) - (\text{Low } \% \times \text{Depth})}{(\text{High } \% - \text{Low } \%)}$$

Using the values of the example, the calculation using this formula will be as follows:

$$\text{Initial Press} = \frac{(1000 \times (0.43 - 0.21)) - (2 \times 55)}{(8-2)} = \frac{220 - 110}{6} = 18.3 \text{ metres, which is the same answer.}$$

- The formula can also be used with millibar. In this case, the formula is simplified as follows:

$$\textit{Initial Press} = \frac{(PPO_2 \text{ required in millibar}) - PPO_2 \text{ present in millibar}) - (\text{Low } \% \times \text{Depth})}{(\text{High } \% - \text{Low } \%)}$$

- The formulas above are in metric. Using the imperial system, the formula is as follows:

$$\textit{Initial Press (fsw)} = \frac{(3{,}300 \times (PPO2 \text{ required in atm} - PPO2 \text{ present in atm})) - (\text{Low } \% \times \text{Depth})}{(\text{High } \% - \text{Low } \%)}$$

Example:

A chamber is to be pressurised to 250 fsw, using 16% and 2%. The final ppO 2 must be 0.5 ata. What depth of 16% should be added to start the pressurisation?

PPO_2 required = 0.5 ATA

PPO_2 present = 0.21 ATA

Bottom depth = 250 fsw

% weak mix = 2

% rich mix = 16

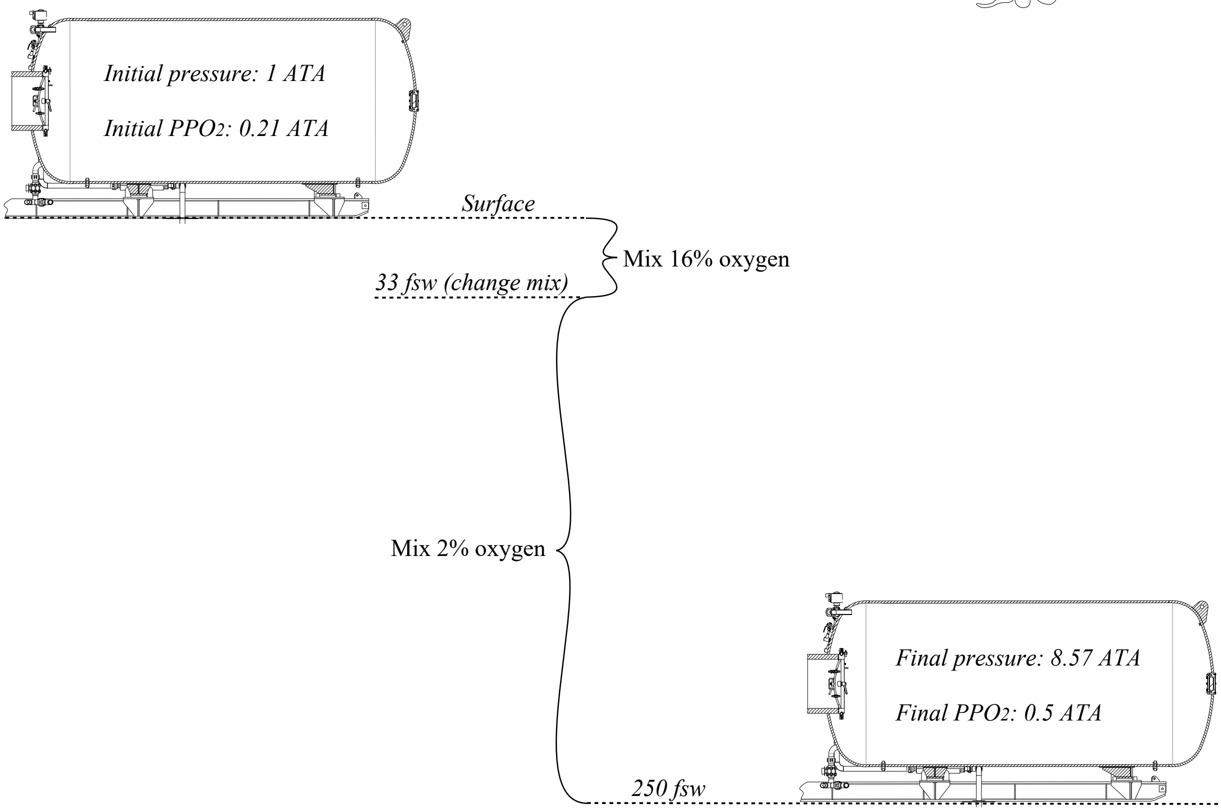
$$\text{Depth of rich mix} = \frac{((3300 \times (0.5 - 0.21)) - (250 \times 2)}{16 - 2}$$

$$= \frac{(3300 \times 0.29) - 500}{14}$$

$$= \frac{(957 - 500)}{14}$$

$$= \frac{457}{14} = 32.6 \text{ fsw}$$

Start the pressurisation by adding 33 fsw of 16%, then carrying on to bottom depth (250 fsw) with 2%



2.2.5.3 - Gas volumes for pressurisation

To calculate the volume of gas to be added, the formula used to find how much gas there is in a quad is used. Thus, the floodable volume is multiplied by pressure. The gauge depth, so the pressure added, must be used instead of absolute depth for these calculations. If absolute pressure is used, the air volume in the chamber before pressurization would be included so that the calculation would be false.

- The formula is:

> *Free gas volume = chamber volume x pressure added*

- When there is only one mix, the calculation consists of using the formula above. As an example, consider a chamber system with a volume of 40 m^3 that is pressurized to 150 msw:

  Free gas volume = chamber volume x pressure added

  Chamber volume = 40 m^3

  Pressure added = 150/10 = 15 bar gauge

  Free gas volume = 40 x 15 = 600 m^3

  600 m^3 of gas is required

- When several mixes are used, their volume are calculated separately and then added. As an example, consider a chamber system with volume of 30 m^3 that is pressurized to 90 msw using 21 msw of 12% and 69 msw of 2%:

  Free gas volume = chamber volume x pressure added

  Pressurization on 12%

  Floodable volume = 30 m^3

  Pressure added = 21/10 = 2.1 bar gauge

  Free gas volume = 30 x 2.1 = 63 m^3

  Pressurization on 2% = 69/10 = 6.9 bar gauge

  Free gas volume = 30 x 6.9 = 207 m

  The pressurization requires 63 m^3 of 12% and 207 m^3 of 2%

- The principle of calculation using the imperial measurement system is similar as with the metric system. As an example, consider a chamber system with a volume of 1,200 ft^3 that is pressurized to 500 fsw:

  Free gas volume = chamber volume x pressure added

  Chamber volume = 1,200 ft^3

  Pressure added = 500/33 = 15.15 ATA

  Free gas volume =1,200 x 15.15 = 18,180 ft^3

  18,180 ft^3 of gas is required

2.2.6.4 - Adding gas to the Chamber

Gas losses must be compensated by new gas. As a result, the partial pressure of oxygen may increase, and must be calculated.

- The formula below allows to calculate the PPO2 added using the depth added in metric:

$$ppO_2 \text{ added (bar)} = \frac{\text{depth added (msw)} \times \text{percentage}}{1000}$$

Example: Consider that 5 metres of 20% is added: 5 x 20 / 1000 = 0.1 bar

- The formula above can also be used using pressure instead of depth:

$$ppO_2 \text{ added (bar)} = \frac{\text{Pressure added (bar)} \times \text{percentage}}{100}$$

If we consider the parameters of the example above, we obtain: (5 m / 10) x 20 / 100 = 0.1 bar

- To be used with the Imperial system the formula using the depth added is:

$$ppO_2 \text{ added (ATA)} = \frac{\text{depth added (fsw)} \times \text{percentage}}{3300}$$

Example: Consider that 16.4 fsw of 20% is added: 16.4 x 20 / 3300 = 0.099 ATA

- As with metric system, the formula above can also be used using pressure instead of depth:

$$ppO_2 \text{ added (ATA)} = \frac{\text{pressure added (ATA)} \times \text{percentage}}{100}$$

If we consider the parameters of the example above, we obtain: (16.4 / 33) x 20 / 33 = 0.099 ATA

2.2.6.5 - Metabolic oxygen make up

During saturation, the divers use up oxygen and give out carbon dioxide. The rate at which oxygen is consumed is impossible to calculate accurately as consumption varies from diver to diver and with exercise. However, as for breathing rates, an approximation can be used, and this is generally taken as:

- 0.5 l/min, 30 l/hour, or 0.72 m³/day per diver, using the metric system.
- 0.018 ft³/min, 0.108 ft³/hour, or 25 ft³/day per diver, using the imperial system.

This is irrespective of the depth.

- *Example 1:*

Consider 4 divers in saturation for 20 day at 100 m:

Oxygen used per day for 4 divers = 0.72 x 4 = 2.88 m³

Oxygen used in 20 days = 2.88 x 20 = 57.6 m³

- *Example 2:*

Considering a bell of 4 m³ at a depth of 55 metres that is occupied by one diver. If the PPO_2 is 0.5 bar and the $PPCO_2$ is 1 mb. Assuming the scrubber has stopped and no oxygen is added, the time it takes to fall to 0.4 bar and the PPCO2 to rise to 20 mb can be calculated as follows:

- First calculate the amount of each gas needed to change the partial pressures:
  - Oxygen change 0.5 - 0.4 = 0.1 bar.
- The quantity of oxygen needed for this change is:
  - Free Gas Volume = Floodable Volume x Pressure = 4 x 0.1 = 0.4 m³ or 400 litres
  - If the diver is breathing 0.5 l/min then it would take 400 divided by 0.5 which equals *800 min* to change the partial pressure of oxygen from 0.5 bar to 0.4 bar.
  - Carbon dioxide change 20 mb - 1 mb = 19 mb or 0.019 bar.
- The quantity of carbon dioxide needed for this change is:
  - Free gas volume = Floodable volume x Pressure = 4 x 0.019 = 0.076 m³ or 76 litres.
  - If the diver is producing 0.5 1./min then it would take 76 divided by 0.5 which equals 152 min to change the partial pressure of carbon dioxide from 1 mb to 20 mb.

It can be seen from this calculation that it is the increase in carbon dioxide which is the greatest danger in a bell.

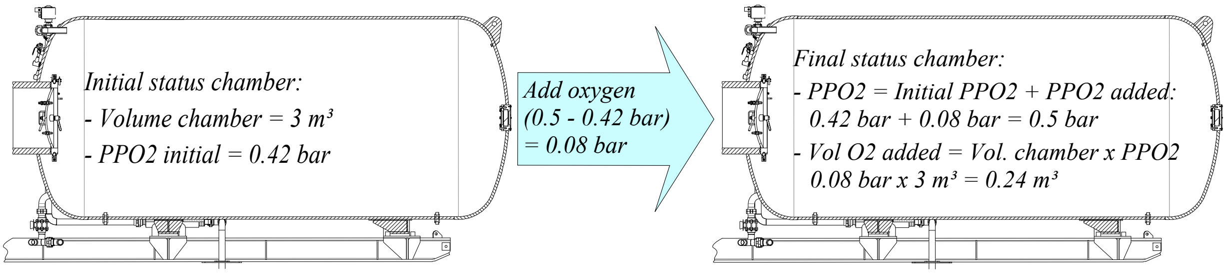
2.2.5.6 - Oxygen and Decompression

Before a saturation decompression begins the PPO_2 in the chamber is normally raised to about 480 mb - 500 mb (0.48 - 05 bar). This is carried out by adding 100 % oxygen through the oxygen add system.
The quantity of oxygen added to the system can be calculated using the formula on the next page:

Free Gas Volume of added oxygen = Floodable Volume of system x Partial Pressure

As an example, the quantity of oxygen to be added to a 3 cubic metres chamber to raise its PPO2 from 0.42 bar to 0.5 bar can be calculated as follows:

- First calculate the increase in PPO_2 from the added oxygen: Increase in PPO2 = 0.5 - 0.42 = 0.08 bar.
- Free Gas Volume of added oxygen = chamber's floodable Volume (3 m³) x Pressure (0.08) = 0.24 m³.



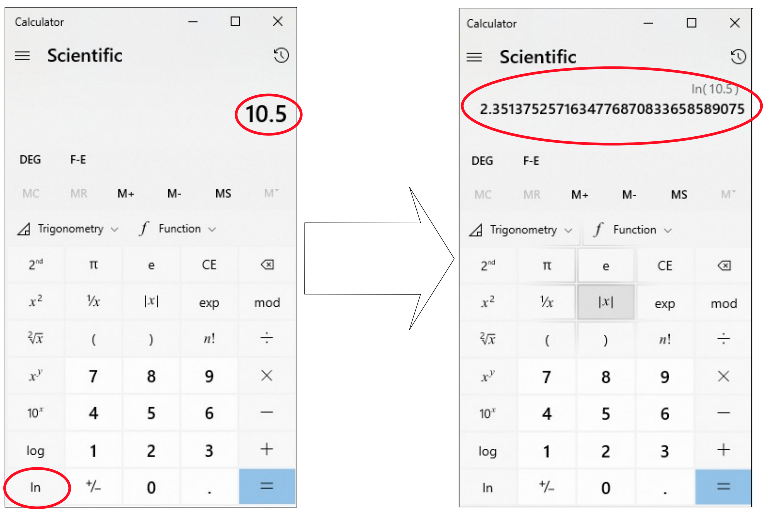
As a result of the ascent of the chamber, the oxygen partial pressure set up at the beginning of the decompression will vary. As an example, for a chamber with a partial pressure of 500 mb (0.5 bar) at 100 m, the oxygen percentage in the mix is 4.54%. This partial pressure will drop to 272 mb at 50 m if no oxygen add is made (4.54 x 6/100 = 0.272 bar). The following formula given in IMCA D 022 allows to calculate the oxygen to add during the ascent:

Oxygen used due to the ascent = (Ln initial pressure) x PPO2 (bar) x chamber volume

- "Initial pressure" is the absolute pressure in the chamber at the start of the decompression.
- Ln is "logarithm to the base e" or "natural logarithm", a mathematical function found on most scientific calculators where "e" equals the approached value of 2,71828.
  The key might be labelled 'Ln' 'ln' or 'log e'. Press 'Ln', enter the initial pressure, then multiply by the ppO_2 and chamber volume.

IMCA D 022 says that this formula does not take into account the high percentage which results of maintaining a partial pressure 500 mb close to the surface. For this reason, no further oxygen additions are made after the percentage reaches a level of 23% (note that 500 mb PPO_2 at 10 m = 25% O2), and so more oxygen than necessary is calculated by the formula. However, it provides the advantage to quickly calculate a safe estimation. As an example, if a decompression from 95 metres takes two days, with a PPO_2 of 600 mb, with two divers in the chamber of a floodable volume of 10 m³ the calculation can be as follow

- Metabolic use: 2 divers x 2 days x 0.72 m³ = 2.88 m³
- Oxygen used due to the ascent: (Ln of the initial absolute pressure) x ppO_2 (bar) x chamber volume
  To find Ln value of 10.5 bar using a scientific calculator, enter the value in the scientific calculator and press "ln"

  (Ln 10.5 bar) x 0.6 bar x 10 m³
  2.35 *(from calculator)* x 0.6 x 10 = 14.1 m³
  The result of the calculation must be added to the oxygen consumed by the divers (metabolic oxygen consumption).
- Total oxygen: Metabolic consumption + Oxygen added due to the ascent = 2.88 + 14.1 = 16.98 m³

A more exact calculation of the oxygen to add as a result of the ascent can be made using a spreadsheet (calculation sheet) that taking into account the phase when the percentage of oxygen of the mix will reach 23%.

- The depths of the spreadsheet are referenced to the depths of the decompression sheet.
- The initial partial pressure is calculated for each depth.
- Then, the difference with the desired partial pressure is calculated in another cell.
- Using the formula PPO2 x chamber volume, the volume of oxygen to be added is calculated.
- The percentage is calculated with the desired partial pressure for the depth and used to calculate the initial partial pressure of the next depth.
- The process described above is renewed until the percentage reaches 23%.
- Then, the volumes of oxygen calculated at each depth are added to calculate the Total of oxygen to add.

3.2.6.7 - Remember "chronic oxygen poisoning"

"Chronic Oxygen Poisoning" , which is explained more in the document "diving Accidents" of the saturation manual CCO Ltd, is due to long exposure to oxygen at a partial pressure above 500 mbar. Note that some specialists consider that this value should be 450 mbar.

The pulmonary toxicity, intervenes in a manner not yet fully elucidated: The assumptions are that the alveoli are collapsing or the enzymes of cells forming the alveoli do not play their roles, or an oxidative phenomenon occurs, creating inflammations and increasing the thickness of the alveolar membrane which is limiting the oxygen diffusion into the blood and at the same time the elimination of the CO_2. The pulmonary toxicity symptoms are coughs and a significant decrease in vital capacity of affected individuals.

NORMAM-15 procedures partial pressures and maximum times of exposures are calculated to avoid this phenomenon. However, note that a too rich mix may result in such a problem.

2.2.6.8 - Manage the oxidation resulting from long exposures to elevated oxygen partial pressure.

Recent studies have highlighted that repetitive and long exposures to hyperbaric oxygen may lead to diseases not immediately detectable.
Oxidation reactions are crucial for life, but on the other hand, they can be involved with mechanisms of cells destruction: "Oxidation" is a chemical reaction that transfers electrons from a substance to an oxidizing agent (thus, a loss of electrons in the substance). Oxidation reactions can produce free radicals. In turn, these radicals can start chain reactions that can cause damage or death to the cells that compose the body.
To control this phenomenon, the body maintains complex systems of multiple types of antioxidants. Antioxidants are molecules that inhibit the oxidation of molecules. These systems are influenced by diet and genetic factors. It is said that the ability to produce antioxidants decreases with the age, nevertheless the specialists do not currently know the capacity for antioxidant defense.
Many studies have linked the decreased production or the inhibition of antioxidants to diseases such as cancer, insulin resistance, diabetes mellitus, cardiovascular diseases, atherosclerosis and others.
It has been proved that, at sufficient pressure and exposure duration, oxygen can inhibit the antioxidant defense, and cause functional impairment. The severity of effects that occur in different tissues are dependent upon interactions between the oxygen dose, and relative susceptibilities of the exposed tissues.
In an article named "Saturation diving; physiology and Pathophysiology", published by "Comprehensive physiology", doctors Alf O. Brubakk, John A.S. Ross, and Stephen R. Thom say that the regulation of these highly reactive molecules and the defense mechanisms must be kept under tight control.

To control these phenomena, NORSOK U100 says point 5.2.3.6.2: *The PO_2 levels shall be kept at a level as close as possible to 21 kPa (210 mbar), balanced against the diver's need for a higher than normal PO_2.*

To take into account what is said above, it is recommended to kept the partial pressure of oxygen within the lower values indicated in the decompression table.

2.2.6.9 - DMAC 5 "Minimum level of O2 in helium supplied offshore" with deep and exceptional saturations.

DMAC 5 says: *"DMAC endorses the recommendation that an oxygen and helium mixture should be used in place of pure helium supplied to offshore diving installations. (It is recognised however that contractors may need to use pure helium as a calibration gas.)*
The choice of mixture supplied should be left to the diving contractor but a minimum of perhaps two percent of oxygen should present no problems operationally from 50 to 150 metres, and from 150 metres a smaller percentage may be appropriate."

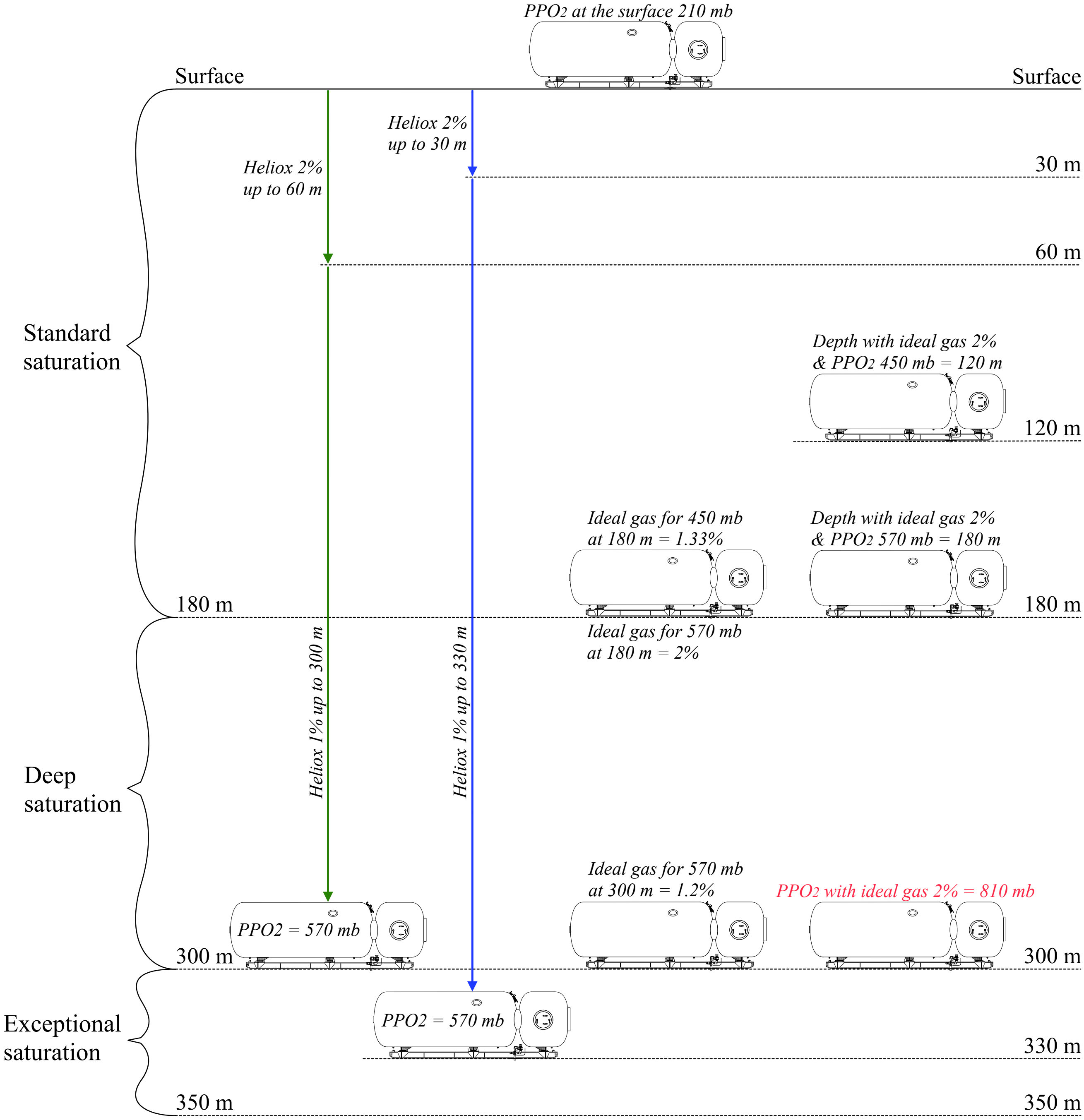
To illustrate what DMAC 5 says, the following results, obtained with the formula for the calculation of an ideal gas "*(desired PPO2 - Initial PP O2) / depth = % ideal gas",* should be kept in mind:

- % ideal gas for a PPO2 of 450 mb at 180 m = 1.33%
- % ideal gas for a PPO2 of 570 mb at 180 m = 2%
- Depth with an ideal gas 2% O_2 and a PPO2 of 450 mb = 120 m
- Depth with an ideal gas 2% O_2 and a PPO_2 of 570 mb = 180 m
- Ideal gas from the surface to 300 m with a PPO_2 of 570 mb = 1.2 %
- PPO2 of a mix with an ideal gas 2% O_2 at 300 m = 600 (ideal gas). Thus: 600 mb + 210 mb = 810 mb

Mixes of 2% oxygen cannot be used as "ideal gas" to obtain the PPO2 of 570 mb at depths below 180 m. Note that the depth of 195 m is possible when pushing the PPO2 to 600 mb. However, passed these limits the metabolic consumption of the oxygen in excess by the divers can be too slow and chronic oxygen poisoning may occur. It is for this reason that, in addition to the problems posed by the High-Pressure Nervous Syndrome (HPNS), a lot of companies who do not want to use mixes below 2% O2 decide to limit their operations to 180 - 200 m maximum.

Compression to depths between 180 and 350 m is possible using mixes with percentages O2 between 2% and 1%. Compression to these depths is also possible using two mixes such, as an example, 2% O2 and 1% O2:

- Depth of 300 m using mixes 2% O2 and 1% O2 and a partial pressure oxygen of 570 mb at the arrival at depth: (570 - 210) - (300 x 1)/ (2-1) = 60 m , which means 2% until 60 m and then 1%.
- Depth of 330 m using mixes of 2% O2 and 1% O2 and a PPO2 of 570 mb at the arrival at depth: (570 - 210) - 330 x 1) / (2-1) = 30 m , which means mix 2% PPO2 until 30 m and then 1%.



Note that, the final depth of a deep saturation can be reached using heliox mixes with an oxygen percentage of 2% or above and a correct PPO2 at the arrival if the dive is organized with one or several intermediate storage levels suitably arranged. This also depends on whether the operations at these shallower levels are of sufficiently long duration to metabolically deplete the oxygen in excess of the lower partial pressure limit prior to moving to the next level. It also depends on the distances between the storage levels.
Also, an alternative procedure promoted by some companies for the compression to a deep saturation is pressurizing the chamber initially with heliox to establish a PPO2 of 0.4 bar and then continuing with pure helium until the final storage depth. However, this procedure obliges to implement specific precautions to protect the divers against pure helium and does not comply with DMAC 5 that recommends a small percentage of oxygen in the mixes used to pressurize the divers.

Note that the implementation of heliox below 2% requires equipment capable of precisely analysing the mixtures and give readings in % with decimals or in Part Per Million (PPM), which is more appropriate when dealing with small decimals values. As a reminder:

- To find the part per million: *PPM = Partial Pressure x 1000,000 / Abs pressure*
- To convert Percentage to Part Per Million (PPM): *PPM = % x 10,000*

Also, only experienced technicians and supervisors should be selected to manage deep, and exceptional saturations as the margin for error at these levels is much reduced compared to those of dives at shallower depths.

2.2.6.10 - Connecting two chambers with different oxygen partial pressures

When connecting two chambers, their gas contents slowly merge. As a result, if the PPO2 in a chamber is more elevated, it will increase the PPO2 of the other chamber, and its PPO2 will decrease after full mixing. However, note that chambers are linked by trunks of 80 cm diameter and that opening the doors is not possible if the units are not at the same pressure. So, full mixing will take a long time.
The formula to calculate the final partial pressure after mixing is as follows:

$$\text{New PPO2} = \frac{(\text{PPO2 unit \#1 x floodable volume unit \#1}) + (\text{PPO2 unit \#2 x floodable volume unit \#2})}{(\text{volume unit \#1} + \text{volume unit \#2})}$$

As an example, in the theoretical case that a chamber with PPO2 of 0.6 bar is connected for a long period (which is not recommended) to a chamber with a PPO2 of 0,4 bar, and that the volume of each lock is 12 m³, the final partial pressure should be:

- Oxygen volume in chamber #1: 0.6 bar x 12 m³ = 7.2 m³
- Oxygen volume in chamber #2: 0.4 bar x 12 m³ = 4.8 m³
- Total volume oxygen: 7.2 + 4.8 = 12 m³
- Volume chamber #1 + chamber #2: 12 + 12 = 24 m³
- Partial pressure chamber #1 + chamber #2 after mixing: 12 / 24 = 0.5 bar (500 mb)

2.3 – Maintain the quality of the chamber atmosphere

2.3.1 - Gas quality

The reclaim system should ensure a perfect quality of the gas delivered to the divers. Nevertheless, contamination or unexpected changes of the proportion of O2/He due to technical problems may happen.

- Some possible sources of contamination are:
  - Impurities in pipework, oil leakage from compressors, overheating or burning of materials, dust, micro particles, Electrical arcing. Gasses introduced during maintenance (Nitrogen)
  - Produced/natural gas (hydrocarbons, H 2 S, Hg etc.) and contaminants associated with the diving operation
  - Food, drinks, medicines, hygiene, microbiology
  - Unusual events, emergencies, contingencies.
- Contamination may happen in the following sections:
  - Divers' equipment
  - Bell(s) & chambers
  - Exhaust equipment
  - Reprocessing units & gas boosters
  - Gas storage and supplies
  - Control consoles

Thus, to make sure of a perfect filtration and regeneration, the gas must be continuously monitored.

2.3.1.1 - Gas analysing

- NORSOK std. says point 5.2.3.3:
  - Breathing gases shall be accompanied by an analysis certificate. Certificates should not be accepted as correct until a competent member of the dive team has analysed it for O_2 and CO content, as a minimum. Results for contaminants shall be < 0,1 HEL at actual pressure.
  - Any new calibration gas should be checked against another calibration gas with similar content, before taken in use, see ISO 6143, ISO 13752, ISO 16664 Annex A , ISO/IEC 17025, and ISO Guide 35.
  - Gas breathed by diver(s) during normal operation, shall as a minimum continuously be analysed online for O_2 and CO_2 content When a diver gas reclaim system is used, a CO_2 analyser with audio and visual hi alarm shall be installed into the diver downstream gas supply.
  - If there is danger of contamination of the bell from natural/produced gas, there shall be online indication with alarm of hydrocarbons, Hg and H_2S. This equipment should be activated at all times. For saturation/living compartments there shall be on-site periodic monitoring of at least CO and N_2.
  - As it is not possible to electronically/chemically monitor for all possible contaminants, the benefits of human sensation by olfactometry (odour, smell) should be facilitated, by having trained persons from the surface crew, checking the gas of each living compartment at least once a day, according to guidance ISO 13301.
  - All living compartments, welding habitat and breathing gas reclaim system shall in addition to O_2, temperature and humidity control, be equipped with gas purification that as a minimum removes CO_2 (e.g. sodalime), CO (e.g. catalyst), VOC (activated charcoal) and odorous compounds (e.g. Sofnofil).
- Analysis can be carried out using the analysers described in point 1.2.8.4. As a reminder:
  - Oxygen analysis can be carried out using fuel cell analyser, magneto-dynamic cell (also called paramagnetic) analyser, thermal conductivity detection, acoustic gas analysis. Note that Magneto-dynamic and thermal conductivity detectors are the most employed in saturation systems.
  - N_2 can be monitored using a thermal conductivity detector, acoustic gas analysis, or photo-acoustic analysis.
  - CO_2 and CO analysis can be carried out using an infra-red analyser, thermal conductivity detector or sampling tube.
  - Contaminants can be monitored using thermal conductivity detectors, chemical sampling tubes (Dräger tubes), Photo-acoustic spectroscopy, Acoustic Gas Analysing (AGA), or by olfactometry (odour, smell) as indicated above in the rules from NORSOK standard.
- Every analyser should be calibrated on a regular basis according to national regulations and manufacturers' instructions. Note that the following recommendations should be taken into account:
  - A change of angle or local electromagnetic fields may affect readings. For this reason, the instrument should be calibrated in the position in which it will be used.
  - Instruments using fuel cells give erratic readings if the cell is too old or has been used for a time above the recommendations of the manufacturer. Note that installed fuel cells that have not been used must be changed every 6 months. It is the reason fuel cells are delivered in air-proof sealed bags.
  - Most analysers require a dry gas sample and have a silica gel filter or similar in-line. The silica gel must be renewed when its colour that is deep blue when it is dry turns to pink. Additional filters may be installed to increase the protection of the analysers.

- Opposite to the analysers of the previous generation that give only one type of display, most recent digital analysers are designed to give a reading in partial pressure, percentage, or part per million, which can be selected in the menu.
- Note that chemical sampling tubes are not originally designed to give a reading in percentage or ppm (parts per million) at depth. For this reason, a correction must be applied when they are used under pressure:
  - For a true percentage or parts per million, divide the scale reading by the absolute pressure in bars.
  - For a true partial pressure, regardless of depth, divide a percentage scale reading by 100 or a parts per million scale reading by 1,000,000.
  - To convert a surface reading from a bell or chamber to a Percentage Surface Equivalent, simply multiply the surface reading by the absolute pressure.

2.3.1.2 - Acceptable gas values

NORSOK standard uses Hyperbaric Exposure Limit (HEL) to set up the limit of exposure to contaminants. HELs take into consideration the special conditions including high pressure, elevated pressure O_2, long exposures and the effects of multiple contaminations.

2.3.1.2.1 - Oxygen and carbon dioxide

Oxygen and carbon dioxide in excess in the breathing gas is poisonous.
The recommended partial pressures of oxygen of the procedures NORMAM 15 are as follows:

Action	Partial pressure O2
Pressurisation to 1st storage depth	0.4 to 0.57 bar (400 to 570 mbar)
Initial storage depth	Chamber: 0.4 up to 0.57 bar at the arrival then stabilized between 0.38 & 0.45 bar (380 to 450 mbar) Bell: 0.5 to 0.8 bar (500 to 800 mbar)
Compressing the chamber to deeper storage depth	0.4 to 0.57 bar (400 to 570 mbar)
Chamber at deeper storage depth than the initial storage depth	Chamber: 0.4 up to 0.57 bar at the arrival then stabilized between 0.38 & 0.45 bar (380 to 450 mbar) Bell: 0.5 to 0.8 bar (500 to 800 mbar)
Decompressing the chamber to shallower storage depth	0.48 to 0.5 bar (480 to 500 mb) up to the depth in which PPO2 is 23%. Then % O2 between 21 to 23%
Chamber at shallower storage depth than the initial storage depth	Chamber: up to 0.5 bar at arrival, then stabilized between 0.38 & 0.5 bar (380 to 500 mbar) Bell: 0.5 to 0.8 bar (500 to 800 mbar)
Decompressing the chamber to surface	0.48 to 0.5 bar (480 to 500 mb) up to the depth in which PPO2 reaches 23% (<). Then % O2 at 21 to 23%
Emergency decompression	DMAC 31: PPO_2 chamber 1.01 - 1.52 bar (1013 -1520 mbar) and 23% O_2 BIBS PPO_2 at 1.5 - 2.8 bar

The partial pressure of carbon dioxide should be less than 5 mbar.
Norsok says that in case that the concentration reach 30 mbar, the exposure should be less to 15 minutes.

2.3.1.2.2 - Argon, nitrogen, and carbon monoxide

Argon (Ar) and nitrogen (N2) in the breathing gas produce narcotic effects and change the composition of the mix for which the decompression table is designed.

Hyperbaric exposure limits for argon and nitrogen

	When not in saturation decompression			During decompression after saturation
	Ceiling value	8 h time weighted average	Continuous	Continuous
pN2	3,5 bar (350 KPa)		1,5 bar (150 KPa)	0,8 bar (80 KPa) and < 10 %
pAr	1,5 bar (150 KPa)	1,0 bar (100 KPa)	0,5 bar (50 KPa)	10 mbar (1 KPa)
(2 • pAr) + pN2	3,5 bar (350 KPa)			

Hyperbaric exposure limits for CO

	Duration of exposure	Exposure limits
Breathing gas at work or at rest in bell, chamber, welding habitat etc	Continuous	0.005 mbar (0,5 Pa)
	<12 h	0.02 mbar (2 Pa)
	<15 min	0.05 mbar (5 Pa)
Ambient gas when diver is using breathing apparatus		0.1 mbar (10 Pa)
Breathing gas in emergency situations	No exposure planned, but system to be active for minimum 24 h	0.05 mbar (5 Pa)

2.3.1.2.3 - Hydrogen sulphide (H_2S)

5 ppm is the UK HSE limit beyond which respiratory protection should be used. For safety reasons, the proportion should be always below 1 ppm.

Notice that rotten egg smell is noticeable at 1 ppm, but with no effect on the body.

2.3.1.2.4 - Hydrocarbons contaminants listed by US Navy

Alarms of hydrocarbons analysers used in bells and chambers are pre-calibrated by the manufacturers. However, note that the US Navy manual revision 7 gives the maximum concentrations of the following contaminants.

Hydrocarbons	Maximum concentration	Description
Acetone	200 ppm	Acetone is produced directly or indirectly from propylene, also known as propene or methyl ethylene, and is the second simplest member of the alkenes class of hydrocarbons.
Benzene	1 ppm	Benzene is a natural constituent of crude oil, and is one of the most elementary petrochemicals. Benzene is an aromatic hydrocarbon. It is a colourless and highly flammable liquid with a sweet smell. It is an important component of gasoline.
Trimethyl Benzenes	3 ppm	The Trimethyl benzene constitute a group of substances of aromatic hydrocarbons, which structure consists of a benzene ring with three methyl groups (–CH_3) as a subsistent.
Toluene	20 ppm	Toluene is an aromatic hydrocarbon that is widely used as an industrial feedstock and as a solvent. Like other solvents, toluene is sometimes also used as an inhalant drug for its intoxicating properties; however, inhaling toluene has potential to cause severe neurological harm.
Xylenes	50 ppm	A Xylenes is an aromatic hydrocarbon consisting of a benzene ring with two methyl substituents. The mixture is a slightly greasy, colourless liquid commonly encountered as a solvent.

2.3.1.2.5 - Other contaminants listed by US Navy

Contaminant	Maximum concentration	Description
Ethanol	100 ppm	Ethanol, also called ethyl alcohol, pure alcohol, grain alcohol, or drinking alcohol, is a volatile, flammable, colorless liquid with the structural formula CH3CH2OH, often abbreviated as C2H5OH or C2H6O. A psychoactive drug and one of the oldest recreational drugs known, ethanol produces a state known as alcohol intoxication when consumed as a beverage. Best known as the type of alcohol found in alcoholic beverages, it is also used in thermometers, as a solvent, and as a fuel. In common usage, it is often referred to simply as alcohol or spirits.
Chloroform	1 ppm	$CHCl_3$,is a clear, colorless, heavy, sweet-smelling liquid, used in refrigerants, propellants, and resins, as a solvent, and sometimes as an anaesthetic. Chloroform, once widely used in human and veterinary surgery, has generally been replaced by less toxic, more easily controlled agents.

Contaminant	Maximum concentration	Description
Freon	100 ppm	The name Freon is a trademark registered by E.I. du Pont de Nemours & Company. They are a fluorinated aliphatic organic compounds that are used in commerce and industry. In addition to fluorine and carbon, the Freons often contain hydrogen, chlorine, or bromine. The Freons are colourless, odourless, nonflammable, non corrosive gases or liquids of low toxicity that were introduced as refrigerants in the 1930s; they also proved useful as propellants for aerosols and in numerous technical applications. Their low boiling points, low surface tension, and low viscosity make them especially useful refrigerants. They are extremely stable, inert compounds also used as cleaning agents
Freon 11	100 ppm	Trichlorofluoromethane, also called freon-11, CFC-11, or R-11, is a chlorofluorocarbon *(organic compound that contains only carbon, chlorine, and fluorine*). It is a colorless, nearly odorless liquid that boils at about room temperature. It was the first widely used refrigerant. Because of its high boiling point (compared to most refrigerants), it can be used in systems with a low operating pressure, making the mechanical design of such systems less demanding than that of higher-pressure refrigerants R-12 or R-22.
Freon 12	100 ppm	Dichlorodifluoromethane, also called R-12, is a colorless gas, and usually sold under the brand name Freon-12, is a chlorofluorocarbon halomethane (CFC), used as a refrigerant and aerosol spray propellant.
Freon 114	100 ppm	1,2-Dichlorotetrafluoroethane, or R-114, is a chlorofluorocarbon (CFC) with the molecular formula ClF2CCF2Cl. Its primary use has been as a refrigerant. It is a non-flammable gas with a sweetish, chloroform-like odor with the critical point occurring at 145.6 °C and 3.26 MPa. When pressurized or cooled, it is a colorless liquid. It is listed on the Intergovernmental Panel on Climate Change's list of ozone depleting chemicals, and is classified as a Montreal Protocol Class I, group 1 ozone depleting substance. The US Navy uses R-114 in its centrifugal chillers in preference to R-11 to avoid air and moisture leakage into the system.
Isopropyl Alcohol	1 ppm	Isopropyl alcohol is a common name for a chemical compound with the molecular formula C3H8O or C3H7OH. It is a colorless, flammable chemical compound with a strong odor. Isopropyl alcohol is commonly used as a disinfectant, antifreeze, and solvent, and typically comprises 70 percent of "rubbing alcohol”.
Methanol	10 ppm	Methanol, also known as methyl alcohol, wood alcohol, wood naphtha or wood spirits, is a chemical with the formula CH3OH. Methanol acquired the name "wood alcohol" because it was once produced chiefly as a byproduct of the destructive distillation of wood. Modern methanol is produced in a catalytic industrial process directly from carbon monoxide, carbon dioxide, and hydrogen. It is the simplest alcohol, and is a light, volatile, colorless, flammable liquid with a distinctive odor very similar to, but slightly sweeter than, that of ethanol (drinking alcohol). it is used as an antifreeze, solvent, fuel, and as a denaturant for ethanol.
Methyl Chloroform	30 ppm	The organic compound trichloroethane, also known as methyl chloroform, is a chloroalkane. This colourless, sweet-smelling liquid is used as a solvent. It is classified as an ozone-depleting substance. It is a superior solvent for organic compounds that do not dissolve well in hydrocarbons such as hexane.
Methyl Ethyl Ketone	30 ppm	Butanone, also known as methyl ethyl ketone or MEK, is an organic compound with the formula CH3C(O)CH2CH3. This colorless liquid ketone has a sharp, sweet odor reminiscent of butterscotch and acetone. It is produced industrially on a large scale, and also occurs in trace amounts in nature. It is soluble in water and is commonly used as an industrial solvent.
Methyl Isobutyl Ketone	20 ppm	Methyl isobutyl ketone (MIBK) is an organic compound manufactured from acetone. It is used as a solvent for nitrocellulose, lacquers, and certain polymers and resins.
Methylene Chloride	25 ppm	Dichloromethane (DCM) or Methylene chloride is an organic compound with the formula CH2Cl2. This colorless, volatile liquid with a moderately sweet aroma is widely used as a solvent. Although it is not miscible with water, it is miscible with many organic solvents. It is widely used as a paint stripper and a degreaser and also as aerosol spray propellant and blowing agent for polyurethane foams.

2.3.1.2.6 - Periodicity of analysis

Only oxygen and carbon dioxide are detectable online by the current models of panel analysers used in the saturation and dive control rooms. As a result, the other contaminants are to be detected periodically using the models of analysers indicated previously.
Note that most contaminants and particles are eliminated by the "Gas pure" and "Helipure" systems described in points 1.2.5.5 & 1.2.5.6. Also, note that a search for contaminants must be done after any intervention on the system to ensure that everything is correct.
In case that some of the contaminants listed by the US Navy or others are detected that cannot be quickly removed by the filtration, the system must be cleaned, and a new analysis must be made.
Expose the divers to a maximum exposure limit to contaminants that cannot be eliminated from the system is considered a heresy, considering that there is a risk to pass over the recommended limit value. So, we can say that the only valid tolerance with pollutants that cannot be eliminated quickly by the system's filtration should be close to zero.

Note that many pollutants to which people working inside the machinery of a ship or a submarine are confronted would not contaminate chambers and gas reserves installed in isolated rooms that are usually far from the machinery and polluted areas. I should be also the case with portable system that must be installed in a protected part of the deck that is far from other activities and accessible only by the divers. So we can say the the protection of the system from pollutants is also linked to its isolation from the sources of contamination.

2.3.1.3 - UK HSE - Occupational Exposure Limits (OELs) for hyperbaric conditions EH75/2

UK-HSE has published a document that describes a methodology for the use of established Occupational Exposure Limits (OELs) to the hyperbaric setting, taking into account the changes in absolute pressure and exposure duration, such that the resultant Hyperbaric Occupational Exposure Limits (HOELs) represent adequate control for the hyperbaric environment.
Occupational Exposure Limits (OELs) are concentrations of hazardous substances in the air, averaged over a specific period referred to as a time-weighted average (TWA). Two duration of exposures are usually used:

- Short-Term Exposure Limits (STEL) are set to prevent acute effects such as eye irritation, which may occur following exposure for a few minutes. They are usually limited to 15 minutes.
- Long term exposure limits (LTEL) are set to prevent effect that may not be noticeable during the intervention but may appear as a result of long and repeated exposures. They are normally limited to 8 hours.
  Note that the "8-hour reference period" refers to occupational exposures within a 24-hour period. It can be a single uniform exposure for 8 hours (the 8-hour time-weighted average (TWA) exposure) or an addition of several short exposures.
  The calculation proposed is: Time in decimals x concentration in $mg.m^3$ / 8
  Note that time is decimal consists in dividing the minutes by 60 and multiply them by 100. Example: 7:20 hours = 7.33.
- The list of contaminants and their maximum exposure limits to can be found in the UK HSE document EH40 “Workplace exposure limits” that can be downloaded free of charge.
  Note that a lot of substances have several names, and are usually listed under one of them only: That obliges to find the name used through the list of synonyms of the document or through the Internet.

The UK HSE document EH75/2, “Occupational exposure limits for hyperbaric conditions”, which can be downloaded at the address https://www.hse.gov.uk/pubns/books/eh75-2.htm, gives formulas to adjust the surface values of the contaminants listed in the document EH40 to divers in a saturation system.
This publication, which is based on theoretical calculations, concludes that the 8 hours long term exposure limits described above can be adjusted for 24 hours exposures at depth using the formula: *Surface 8-hour TWA in* $mg.m^3$ */ 5*
The study also states that no time-related adjustment of a 15-minute exposure is necessary for the hyperbaric setting.

The calculations using this procedure can replace the maximum values of hydrocarbons in chambers from the US Navy manual displayed at the beginning of this point.

2.3.2 - Change the soda-lime

2.3.2.1 - Elements regarding soda-lime

Soda-lime is used to remove the CO_2 resulting from the divers' breathing from the bell or the chamber atmosphere, or a closed-circuit breathing apparatus. This product has the following characteristics:

- The average consumption of a diver is 6 kg per day (6 kg soda-lime/diver/day)
- The weight of soda-lime is 0.75 kg/litre
- The average consumption of a diver in litres is 8 litres per day (8 litres soda-lime/diver/day)
- The production of CO_2 of a diver is estimated to 0.5 litres per minute, and thus 30 litres per hour
- 1 kg of soda lime absorbs 120 litres of CO_2
- 1 litre of soda lime absorbs 90 litres of CO_2

2.3.2.2 - Change the soda lime of the bell reclaim system

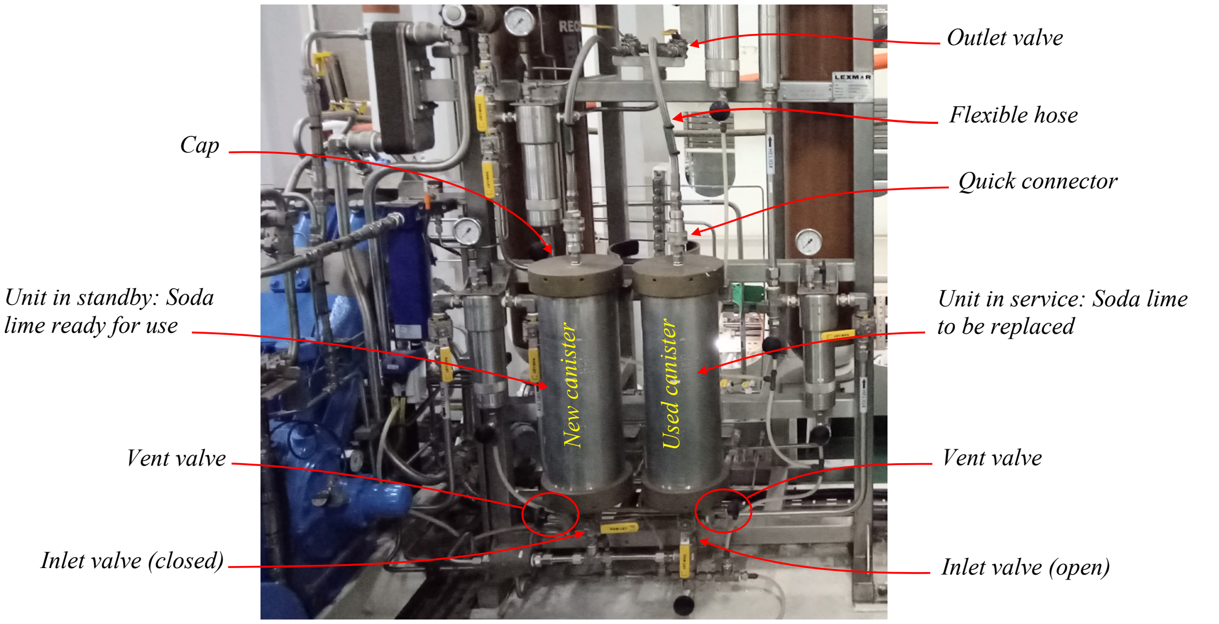
Two scrubber units that consist of housings into which a canister assembly filled with soda-lime (also called soda-sorb) and Purafil are provided. They are installed on the surface unit of the system *(see #10 below)*.
Soda lime is a widely used absorbent for carbon dioxide. 1 kg of soda lime absorbs 120 litres of CO_2 (1 litre of soda-lime absorbs 90 litres of CO_2). A canister assembly of the model below is to be changed every 8 hours for 1 diver at work. Thus, the duration of one canister is 4 hours for two divers at work.
Purafil is used to remove odours and a wide range of trace contaminants. They can be listed as follows:

- Mercaptans, amines and ketones *(responsible for many common odours)*;
- Ammonia;
- Hydrogen sulphide;
- Sulphur dioxide;
- Carbon monoxide *(trace quantities only)*.

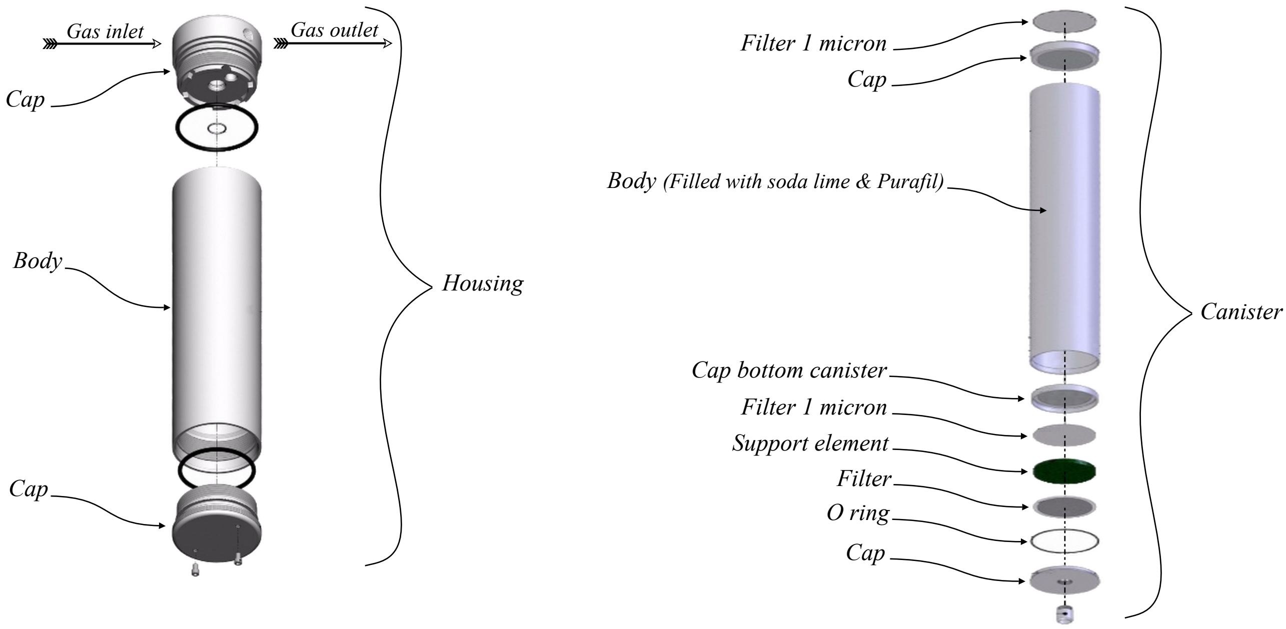
#1: Water trap	*#5: Receiver volume tank*	*#9: Water trap*
#2: floating valve	*#6: Filter 0.01 micron*	*#10: Scrubbers*
#3: Filter 1 micron	*#7: Compressor (gas booster)*	*#11: Filter 0.01 micron*
#4: Back Pressure Regulator	*#8: Heat exchanger*	*#12: Electrical control enclosure*

This operation is often performed when the machine is running, so it is under pressure. For this reason, the gas flow cannot be interrupted, and the operator must ensure the initial status of the canisters: Usually, one unit is active with its bottom valve (inlet) open while the 2nd unit is in standby, ready to be put online with its bottom valve closed.
In the photo above, the canister on the right side is active, and the one on the left side is in standby.

1. When the canister in standby (new canister) is identified, the operator ensures that the flexible hose is connected through the quick connector to the cap of the assembly.
2. Then, the operator slowly opens the “new canister” inlet valve that is situated at the bottom of the tower body.
3. When the inlet valve is opened, the operator slowly opens the new canister outlet valve to which the flexible hose fitted to the top of the tower cap is connected. At this moment, the gas starts to flow through the new canister.
4. When the gas flow through the new canister is established, the operator slowly closes the inlet valve of the “used canister” at the bottom of the tower body.
5. Then, the operator slowly closes the outlet valve of the used canister at the top of the tower cap. At this moment, the unit is isolated from the circuit.
6. The operator slowly opens the drain valve at the base of the used canister and waits for the unit to fully vent.
7. When all pressure has been vented, the operator disconnects the quick connector from the top of the used tower, and unscrews the top cap by hand.



8. When the unit is opened, the operator removes the internal soda lime canister using the handle, remove the top gauze and empty its contents.
9. The internal canister is then filled to the two thirds with fresh Soda lime, and 100 ml of Purafil is added above the soda lime. Then the operator fills the remaining space of the cartridge to the top with soda lime, and replace the top filter gauze.
10. The operator lowers the inner canister slowly into the tower body, and ensures its is seated on the lower seal.
11. The operator inspects the top cap O-ring, clean or replace as required, replaces the top cap in position, ensures the O-ring is sealed, and finishes to hand tighten the cap.
12. The operator closes the drain valve at the base of the unit,
and reconnects the quick connect hose to the top of the upper cap.



14. Then the canister must be pressure tested: For this purpose, the operator slowly opens the inlet valve at the bottom of the scrubber tower to pressurise it, closes the Inlet valve when the unit is pressurized, and check for leaks.
15. If no leak is detected, the refilled canister is now ready for use.

2.3.2.3 - Other elements to take into account

Filters:

- Filter pads on the top and bottom of the canisters of the scrubbers should be renewed every 500 hours
- Filters are installed on the line that must be drained every 4 hours. It is said that, depending on the environmental conditions, the 1 micron filter should contain about a cup of condensate maximum and that the 0.01 micron filters should not contain more than a spoon of condensate.
  It is recommended to change these filters at intervals of 500 operating hours. The procedure to change them is similar to the one explained for the soda sorb, except the cartridges cannot be refilled and thus have to be changed, and this operation cannot be performed when the system is in use, except in the case that bypass lines are installed.
- The drain valve installed on the bell should be checked every 40 hours

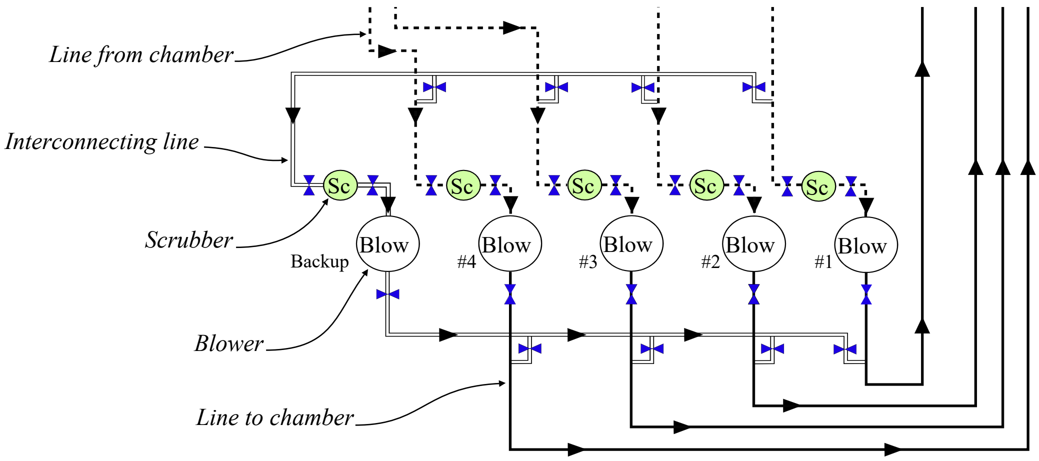
When calculating the gas necessary for the bell reclaim system, it is important to consider all the elements that compose the system, as the addition of small volumes results in a large volume:

- The volume of the bell umbilical and the parts of the system in the bell
- The volume of the receivers
- The volume of the volume tank *(Reclaimed gas storage)*
- Volume of the scrubbers and the other parts of the pipework.

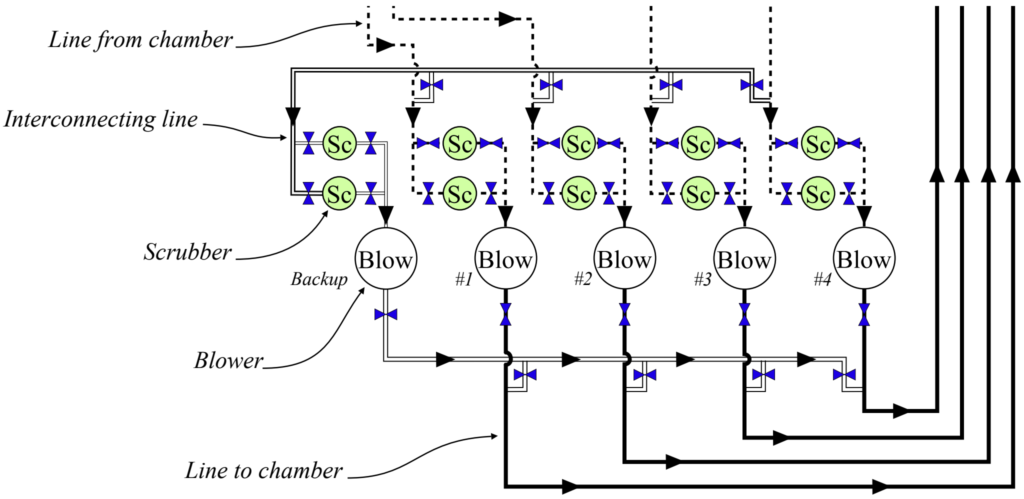
2.3.2.2 - Change the soda lime of the Hyperbaric Environment Regeneration System

Several systems of scrubbers can be in service:

- Some systems are composed of one scrubber and a blower for one chamber plus an additional single scrubber ensemble that can be used as a backup and can be connected at the same time to change the soda-lime of the scrubber in service.



- Other systems are composed of two scrubbers plus a blower per chamber line plus another backup line with double scrubber. The advantage of this system is that the soda sorb can be changed without using the backup scrubber that is available at all times in case of a break down of a line.



The procedure explained below is based on systems fitted with two scrubber pots, such as those taken as reference in point 1.2.4 of this book.

As explained above, such systems are fitted with one scrubber online (Scrubber Pot A), the other on stand-by (Scrubber Pot B). The stand by (Scrubber Pot B) should be kept clean and the canisters charged with absorbent ready to be put online. When the online (Scrubber Pot A) absorbent is exhausted, the stand by (Scrubber Pot B) can be put online with the following procedure.

1. There is a ½” equalisation valve and vent to atmosphere on the side of each scrubber pot. The scrubber pots are connected by the equalisation pipe, this equalisation pipe can be vented to atmosphere by a ½” vent ball valve. All these three valves should be closed if the system is operating.

1 - Equalization valve scrubber

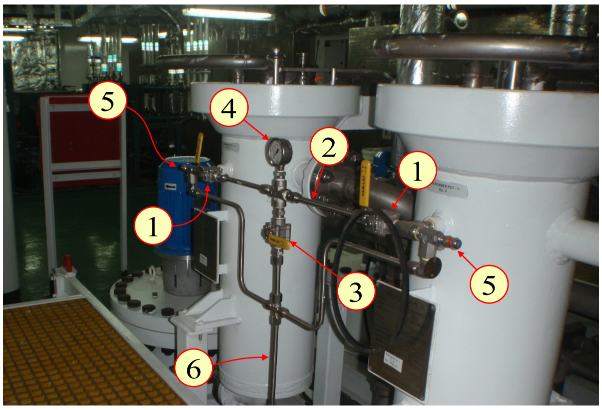
2 - Equalization line

3 - Vent valve scrubbers

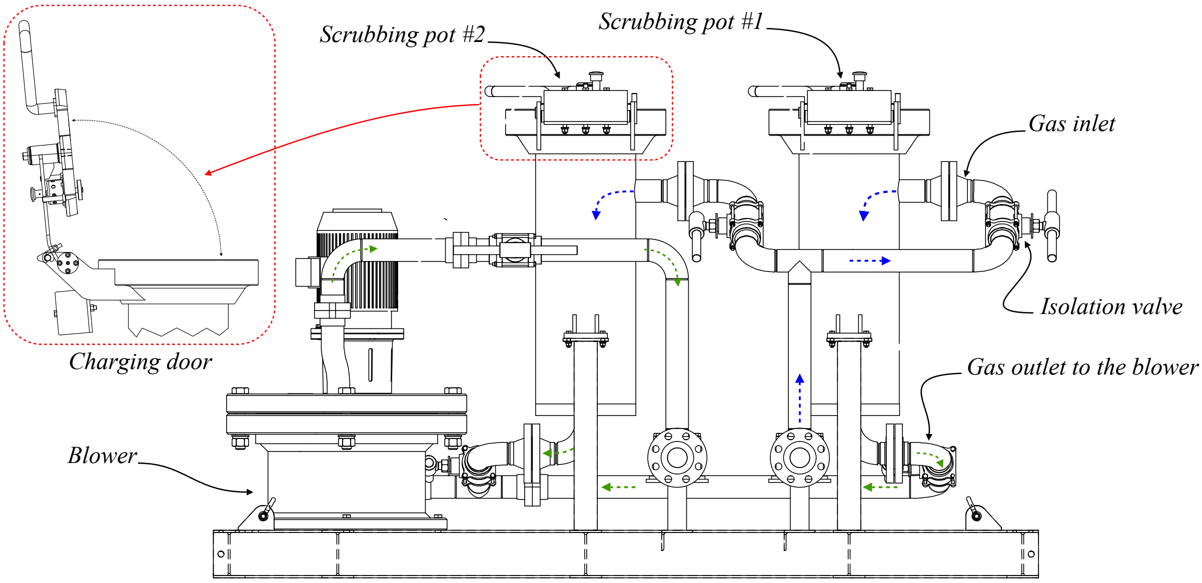
4 - Gauge control

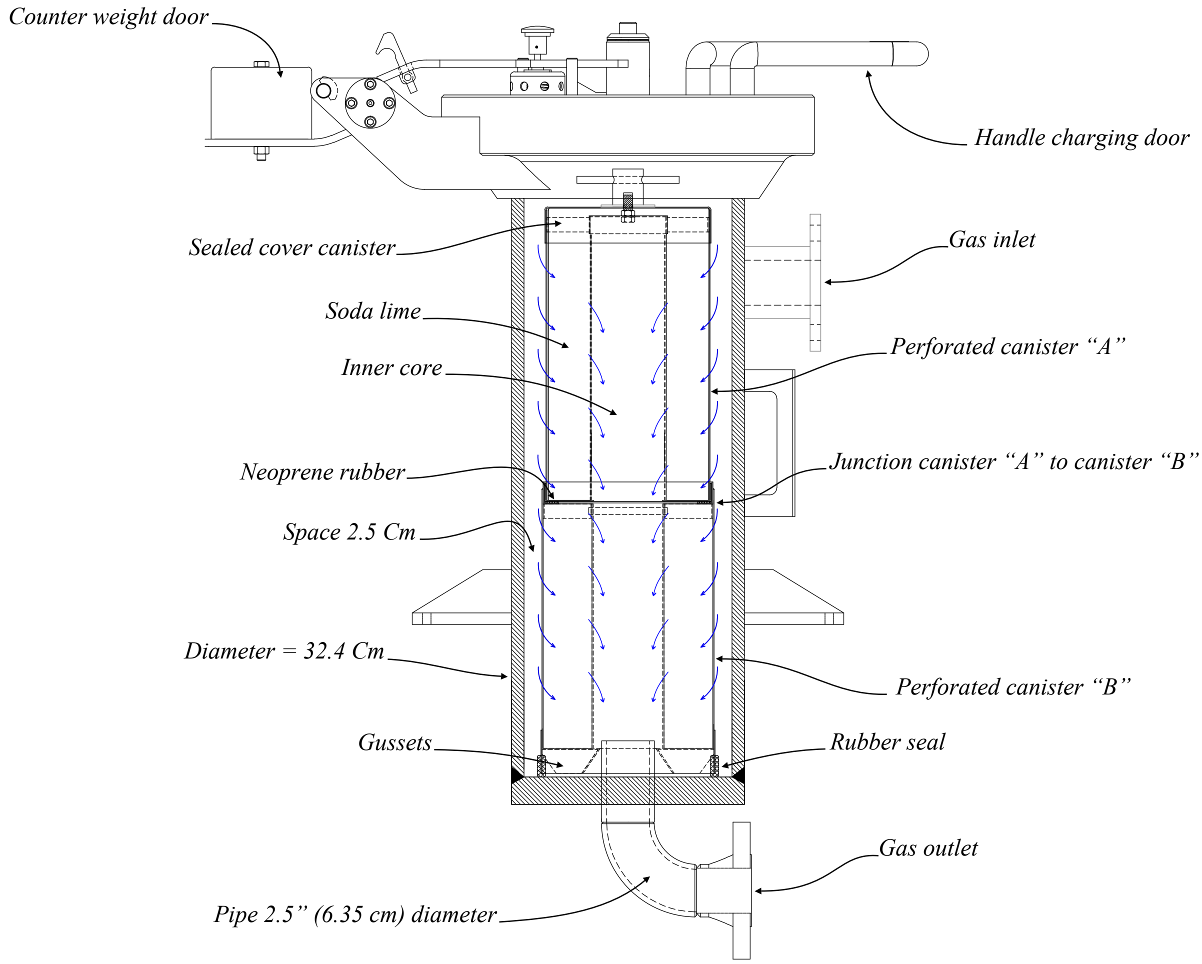
5 - Relief valve

6 - Vent line



2. The operator ensures that the scrubber pot that is planned to be online (pot #2) has been charged with fresh absorbent, and that its cover is closed correctly and that the vent valve is closed.
3. The operator slowly opens the equalisation valve of the scrubber in use (pot #1), and then the equalization valve of the scrubber to be online (pot #2). This action pressurises the scrubber to be online (pot #2). The reason to open the equalization valve slowly is that the regeneration system may shut down if this action is done to quickly.
4. When the scrubber pot to put online (pot #2) is fully equalised, the operator closes both equalisation valves.
5. Then the operator opens the 2 ½” inlet and outlet valves to the scrubber to put online (pot #2), and closes the 2 ½” inlet and outlet valves to the scrubber that is in use (pot #1). The scrubber pot that was planned to be online (pot #2) is now “online”.
6. The operator vents scrubber pot that was in use (pot #1) to atmosphere by the equalisation valve and vent valve to atmosphere.
7. The operator ensures that the scrubber pot is wholly vented to the atmosphere. Then, the interlock valve (push button) on the scrubber pot cover is depressed, and the operator fully turns the cover clockwise with the door handle. The operator releases the push button interlock when the cover has completed its rotation and lifts the cover.
8. Then, the operator removes the absorbent canisters from the scrubber pot and empties the exhausted absorbent.
9. The canisters are then refilled with fresh soda-lime absorbent. Before reinstalling them, the operator cleans the inside of the scrubber pot to remove dust or debris, and ensure lip seal is clean and lubricated.
10. When the scrubber pot is clean, the operator reloads the canisters into the scrubber pot and ensures that they are fully seated. Then the cover is closed and rotated into the locked position. As indicated in *point 1.2.4.1*, the interlock vent valve closes automatically when the cover is fully closed.
11. The equalisation and vent valves on the side of the scrubber pot is closed, and the scrubber is ready to be used.


Scrubbing pot #2
Scrubbing pot #1
Gas inlet
Isolation valve
Gas outlet to the blower
Charging door
Blower

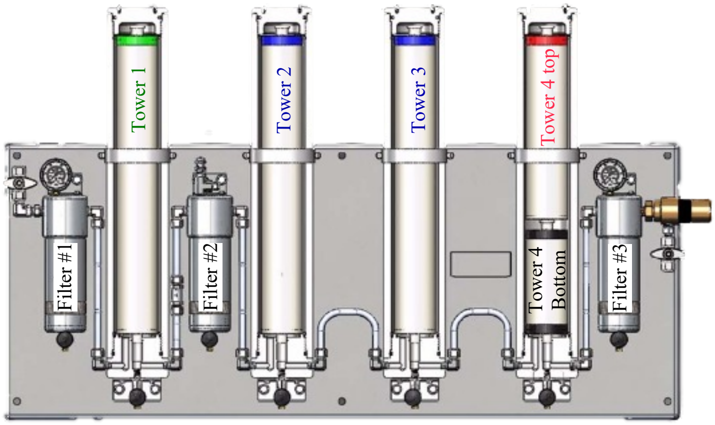

Counter weight door
Handle charging door
Sealed cover canister
Gas inlet
Soda lime
Perforated canister “A”
Inner core
Junction canister “A” to canister “B”
Neoprene rubber
Space 2.5 Cm
Diameter = 32.4 Cm
Perforated canister “B”
Gussets
Rubber seal
Gas outlet
Pipe 2.5” (6.35 cm) diameter

2.3.3 - Reminder regarding the change of the filters of the "Gaspure" and "Helipure" systems.

The procedures below are also indicated in point 1.2.5.8

2.3.3.1 - "Gaspure" system

Regarding the change of filters of the system Gaspure, Divex says that the disposable cartridge set is designed to process 2830 m³ *(100,000 standard cubic feet)* of gas before replacement is required, as indicated in the chart below. However, the cartridge of "tower #4 Bottom" *(CO removal)* has a maximum life of three years from the date of manufacture.



Compressor flow rate	*Running hours*
25 m³ /hr (15 scfm)	*100*
50 m³ /hr (30 scfm)	*50*
100 m³ /hr (60 scfm)	*25*
125 m³ /hr (75 scfm)	*20*

2.3.3.2 - "Helipure" system

Regarding the system Helipure, Divex says the following:

The membranes in the Helipure will work efficiently for many years as long as the gas supplied to the unit is clean and free from moisture ideally -50°C dew point or below. All gas supplied to the unit which has passed through a gaspure system is -50°C dew point and filtered to 0.01 micron.

Set up a supply of 7 bar of dry air to each membrane in turn using a calibrated gauge. The clean gas flow from each membrane should be less than 30 litres/minute flow rate measured by routing the gas through a test hose and into the sample flow meter on the panel.

If either membrane has a flow rate well in excess of 40 litres/minute, replace the o-rings on the v.c.o fittings on the end of the faulty membrane. If this does not rectify the fault, the membrane may be damaged from exposure to higher than normal operating temperatures or by moisture in the gas and so should be replaced. All existing faults must be rectified before replacement of membranes as further damage is likely to occur.

New membranes must not be exposed to moisture or high humidity after removal from packing before installation in the Helipure housing.

2.4 - Make sure of the gas reserves

2.4.1 - IMCA D 050: Minimum quantity of gas required offshore

(This topic is also discussed in point 1.2.6.1.)

2.4.1.1 - Purpose

A lot of gas is necessary to pressurize the components of the saturation system. Also, despite the efficiency of the new regeneration and reclaim systems, a part of the heliox used is lost during the normal operations that must be replaced in addition to the oxygen that is naturally depleted by the metabolism of the divers. This uncontrolled gas dumping outside the system results from the various manipulations such as food and tools transfer, disconnection of the bell, divers transfer to and from the bell during the dive, and also undetected small leaks. It is commonly considered that this quantity is approximately 10% of the total volume in use.
Note that every intervention that consists of bringing a lock previously under pressure to the surface results that the remaining quantity of heliox that is in it is irremediably lost when the door is opened. Also, despite a well-planned maintenance system, unforeseeable massive leaks may happen, which may result that huge quantities of gas that cannot be fabricated onboard can be suddenly lost. That obliges to plan for gas reserves taking these factors into account.

IMCA D 050 is a guideline that sets up the absolute minimum amount of emergency breathing medium (air or mixed gas) required to be kept at an offshore dive site before and during the dive.
However, this guideline also indicates that attempting to formalise these minimum levels is difficult as they are heavily dependent on individual circumstances such as:

- The breathing mixtures used;
- The decompression schedules;
- The depth planned for the dives;
- The work rate;
- The environmental conditions at the site.

This document is not perfect, as demonstrated in the “Diving management study CCO Ltd #7”. However, it is today the reference in force that is the most used by the manufacturers to design systems with sufficient operational capabilities, and the Life Support Supervisors (LSS) to calculate the necessary gas to be provisioned for a project. It provides the following recommendations, which are reinforced here according to the “Diving management study CCO Ltd #7” recommendations. Note that this guideline classifies the gasses into two categories:

- “Consumable gasses” are provided for ongoing use and will vary in quantity available on use and re-supply
- “Reserve gasses” must be provided and kept to solve emergencies. They are therapeutic gas, Built-In Breathing System (BIBS) gas, gas reserves to compress the chambers, and others.

Note that backup supplies must be immediately available. Also, a gas container at less than 20 or 30 bar pressure cannot be considered part of the reserve.

2.4.1.2 - Surface orientated air or nitrox diving

Gas purpose	*Classification IMCA D 050*	*Minimum requirement IMCA*	*Comments / Additional precautions CCO Ltd*
Operational in water gas + in-water decompression gas	Consumable	Sufficient gas should be provided for the bottom time and decompression, based on a breathing rate of 35 l/min at work & 25 I/min at rest.	Operational in-water gas and in-water decompression are grouped. <u>There should be sufficient gas for two dives instead of one</u> (working time + decompression).
Diver personal gas reserve (Bailout)	Reserve	10 m/min of umbilical deployed from the surface (basket) or the wet bell at emergency breathing rate.	Breathing rates from UK HSE report RR 1073 (50 to 75 l/min) should be promoted to the detriment of the IMCA rate of 40 l/min
Diver rescue air or nitrox	Reserve	2 dives of 30 min bottom time to the maximum intended diving depth at emergency breathing rate.	Emergency breathing rate of 62.5 litres /min instead of 40 litres (see above)
Wet bell / basket gas reserve	Reserve	It must be sufficient to recover the divers safely from the longest and deepest planned dive at emergency breathing rate.	Emergency breathing rate of 62.5 litres /min instead of 40 litres (see above)
Surface decompression gasses	Consumable	Sufficient gasses to compress both chamber’s locks to the max. surface deco depth + three (3) surface decompression cycles per chamber	The surface decompression cycles include the full compression and decompression of the chamber + the gas used for flushing. Note that 20 - 25 l/min is the breathing rate.
Chamber scrubber		Not indicated in the guidance IMCA. Consumption: 0.25 kg/diver/hour	Soda lime and Purafil for 3 surface deco. dives + the longer therapeutic treatment planned + the same quantity as a reserve.

Surface orientated air or nitrox diving (continuation)

Gas purpose	*Classification IMCA D 050*	*Minimum requirement IMCA*	*Comments / Additional precautions CCO Ltd*
Therapeutic treatment gasses	Reserve	Sufficient gas to pressurize both locks of each DDC to the maximum possible treatment depth + 90 m³ Oxygen	The quantity of gas to pressurize the locks should be doubled Also, plan for sufficient gas for 3 decompression of medics and 3 compressions of the entry lock. If a heliox table such as COMEX 30 is used: add 90 m³ heliox 50/50 and 90 m³ heliox 20/80.
Calibration gasses (Analysers)	Consumable	No calibration gas required	Sufficient quantities for the calibration processes recommended by the manufacturer for the entire duration of the project + the same quantity as reserve
Dive crew evacuation air	Reserve	Allows to evacuate the area at emergency breathing rate	62.5 litres / minute instead of 40 litres (see above)
Diver transfer oxygen	Reserve	Allows to transfer the divers to the facility at emergency breathing rate	62.5 litres / minute instead of 40 litres (see above)

2.4.1.3 - Heliox wet bell diving

Gas purpose	*Classification IMCA D 050*	*Minimum requirement IMCA*	*Comments / Additional precautions CCO Ltd*
Operational in water gas + in-water decompression gas	Consumable	Sufficient for the working time and decompression, at a breathing rate of 35 l/min at work & 25 I/min at rest.	Operational in-water gas and in-water decompression are grouped. There should be sufficient gas for two dives instead of one
Diver personal gas reserve (Bailout)	Reserve	1 min of 10 min of umbilical deployed from the wet bell at emergency breathing rate.	Breathing rates from UK HSE report RR 1073 (50 to 75 l/min) should be promoted to the detriment of the IMCA rate of 40 l/min
Diver rescue gas	Reserve	2 dives of 30 min bottom time to the maximum intended diving depth at emergency breathing rate.	Emergency breathing rate of 62.5 litres /min instead of 40 litres (see above)
Wet bell gas reserve	Reserve	It must be sufficient to recover the divers safely from the longest and deepest planned dive at emergency breathing rate.	Emergency breathing rate of 62.5 litres /min instead of 40 litres (see above)
Surface decompression gas	Consumable	Sufficient gasses to compress both chamber's locks to the max. surface deco depth + three (3) surface decompression cycles per chamber	The surface decompression cycles include the full compression and decompression of the chamber + the gas used for flushing. Note that 20 - 25 l/min is the breathing rate
Calibration gasses (Analysers)	Consumable	100 % He + 20% O2 (balance He)	Sufficient quantities for the calibration processes recommended by the manufacturer for the entire duration of the project + the same quantity as reserve
Therapeutic treatment gas	Reserve	Sufficient gas to pressurize both locks of each DDC to the maximum possible treatment depth + 90 m³ Oxygen	The quantity of gas to pressurize the locks should be doubled + sufficient gas for 3 decompression of medics and 3 compressions of the entry lock. If a heliox table such as COMEX 30 is used: add 90 m³ heliox 50/50 + 90 m³ heliox 20/80.
Chamber scrubber		Sufficient soda lime and Purafil for 3 surface decompression dives + the longer therapeutic treatment planned	Not indicated in the procedure IMCA Consumption = 0.25 kg/diver/hour
Dive crew evacuation gas	Reserve	Allows to evacuate the area at emergency breathing rate	62.5 litres / minute instead of 40 litres (see above)
Diver Transfer oxygen	Reserve	Allows to transfer the divers to the facility at emergency breathing rate	62.5 litres / minute instead of 40 litres (see above)

2.4.1.4 - Saturation diving

Gas purpose	*Classification IMCA D 050*	*Minimum requirement IMCA*	*Comments / Additional precautions CCO Ltd*
Operational in-water gas	Consumable	Sufficient mixed gas for the intended bell run plus the same quantity of gas to be held as a reserve.	Gas carried onboard the bell in cylinders must not be included in these calculations
Divers personal gas reserve (Bailout)	Reserve	10 m/min of umbilical deployed from the bell at emergency breathing rate.	Breathing rates from UK HSE report RR 1073 (50 to 75 l/min) should be promoted to the detriment of the IMCA rate of 40 l/min
Diver rescue gas	Reserve	2 dives of 30 min bottom time to the maximum intended diving depth at emergency breathing rate.	Emergency breathing rate of 62.5 litres /min instead of 40 litres (see above)
Closed bell onboard oxygen	Reserve	Sufficient oxygen for metabolic consumption of all divers at 0.5 l/min per diver for the duration of the bell run and at least 24 hours at the end of a bell run (emergency).	
Bell onboard breathing gas reserve	Consumable	Emergency supply of breathing gas sufficient to support each working diver plus the bellman outside the bell for a minimum of 30 minutes at at emergency breathing rate at the maximum depth of the dive	Breathing rates from UK HSE report RR 1073 (50 to 75 l/min) should be promoted to the detriment of the IMCA rate of 40 l/min
Calibration Gasses to 100 m (Analysers)	Consumable	100% Helium; 10% O_2 and 1000 ppm CO_2, 20% O_2 & 4000 ppm CO_2.	Calibration gasses and frequencies according to the recommendations of the manufacturer and at least for 3 weeks of operations
Calibration Gasses to 300 m (Analysers)	Consumable	100% Helium, 5% O2 & 500 ppm CO2, 10% O2 & 1000 ppm CO2, 20% O2 & 4000 ppm CO2.	Calibration gasses and frequencies according to the recommendations of the manufacturer, and reserves for at least for 3 weeks of operations
Chamber pressurisation gas	Consumable	Sufficient gas to pressurize the system is required for the planned operation to the maximum intended storage depth, plus at least an equal amount as a reserve.	
Chamber metabolic oxygen (Saturation + decompression)	Consumable	Sufficient oxygen for each diver metabolic consumption throughout the saturation period, plus that required to maintain the ppO_2 during decompression. This quantity should be doubled and held in two separate banks.	
Living Chamber BIBS	Reserve	Sufficient gas to allow each diver to breathe for four hours on BIBS (ppO2 400 mbar –1400 mbar) at the deepest depth.	
Therapeutic Gas	Reserve	Sufficient quantities of therapeutic gas for the depths involved as detailed in the company's rules	Refer to the therapeutic procedures selected (COMEX, US Navy, or others)
Soda lime and Purafil		Not indicated in this guidance Consumption per diver = 6 kg/day	Two weeks of autonomy without further supplies being received at a minimum (IMCA D 022).
Dive Crew Evacuation Gas	Reserve	Allows to evacuate the area at emergency breathing rate	62.5 litres / minute instead of 40 litres (see above)
Diver Transfer Oxygen	Reserve	Allows to transfer the divers to the facility at emergency breathing rate	62.5 litres / minute instead of 40 litres (see above)

2.4.1.5 - Hyperbaric Rescue Unit (HRU) and Life support package (LSP) - *Life support package not used for decompression*

Gas purpose	*Classification IMCA D 050*	*Minimum requirement IMCA*	*Comments / Additional precautions CCO Ltd*
Calibration Gasses (Analysers)	Consumable	- 1 cylinder 100% He - 1 cylinder 20% O_2 & 4000 ppm CO_2 (balance He)	Calibration gasses and frequencies according to the recommendations of the manufacturer and at least 72 h + 1 day. HRU analysers pre-calibrated with onboard calibration gasses.

Gas purpose	*Classification IMCA D 050*	*Minimum requirement IMCA*	*Comments / Additional precautions CCO Ltd*
Pressurisation gas	Consumable	The gas quantities for the HRU are not indicated in this guideline. LSP: 16 cylinders @ 200 bar of 98%/2% He. LSP: 16 cylinders @ 200 bar of He (PPO_2 200 – 1400 mbar).	Add the gas reserves of the HRU: Calculated by the manufacturer for 72 hrs with the maximum number of occupants. The gas mixture should conform with the chamber storage depth.
Metabolic oxygen	Consumable	HRU: Not indicated LSP: 16 cylinders O2 @ 200 Bar	Add the oxygen reserves of the HRU: 72 hrs with the maximum number of occupants.
Chamber BIBS	Reserve	Sufficient gas to allow each diver to breathe for four hours on BIBS	(ppO2 400 mbar –1400 mbar) at the deepest depth.
Therapeutic Gas	Reserve	Sufficient quantities of therapeutic gas for the depths involved as detailed in the therapeutic tables	Refer to the therapeutic procedures selected (COMEX, US Navy, or others)
Soda lime and Purafil		Not indicated in this guidance Consumption per diver = 6 kg/day	HRU: At least 72 hrs of autonomy + 1 day LSP: At least 72 hrs of autonomy + 1 day

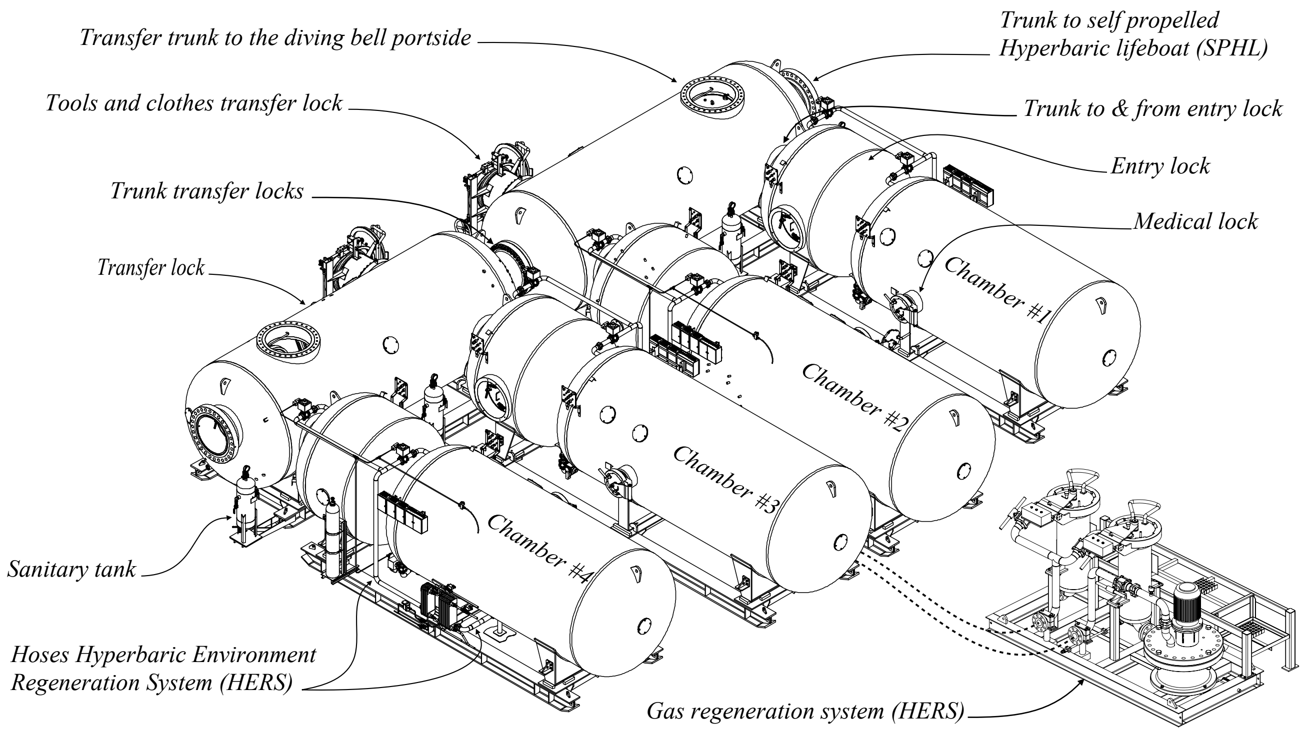
2.4.1.6 - Hyperbaric Reception Facility (HRF)

Gas purpose	*Classification IMCA D 050*	*Minimum requirement IMCA*	*Comments / Additional precautions CCO Ltd*
Chamber pressurisation gas	Consumable	Sufficient gas to pressurize the system is required for the planned decompression , plus at least an equal amount as a reserve.	
Chamber metabolic oxygen (Saturation + decompression)	Consumable	Sufficient oxygen for each diver metabolic consumption throughout the saturation period, plus that required to maintain the ppO_2 during decompression. This quantity should be doubled for safety reasons and held in two separate banks.	
Living Chamber BIBS	Reserve	Sufficient gas to allow each diver to breathe for four hours on BIBS (ppO2 400 mbar –1400 mbar) at the deepest depth.	
Therapeutic Gas	Reserve	Sufficient quantities of therapeutic gas for the depths involved as detailed in the company's rules	Refer to the therapeutic procedures selected (COMEX, US Navy, or others)
Soda lime and Purafil		Not indicated in this guidance IMCA	Provide at least sufficient reserve for the decompression from the maximum depth planned before starting the operations and double this value. Consumption per diver = 6 kg per day
Calibration Gasses to 100 m (Analyzers)	Consumable	100% Helium; 10% O_2 and 1000 ppm CO_2, 20% O_2 & 4000 ppm CO_2.	Calibration gasses and frequencies according to the recommendations of the analyser manufacturer and the time of decompression.
Calibration Gasses to 300 m (Analyzers)	Consumable	100% Helium, 5% O2 & 500 ppm CO2, 10% O2 & 1000 ppm CO2, 20% O2 & 4000 ppm CO2.	Calibration gasses and frequencies according to the recommendations of the manufacturer and the duration of the decompression.
Dive Crew Evacuation Gas	Reserve	Sufficient to evacuate the area at emergency breathing rate	Breathing rate of 62.5 litres / minute instead of 40 litres (see above)

2.4.2 - Elements to consider for the calculation of the gas needs

2.4.2.1 - Identify the volume used, and the sources of gas loss

It often happens that the saturation system is not used with the maximum of occupants it is designed for. In this case, the divers are often stored in the necessary chambers, and the rest of the system remains unoccupied to save gas. However, it is prudent to plan for an empty chamber to transfer divers to and from the system if needed.
It is important to ensure the exact volume that will be used, and identify the elements that are sources of gas loss. For this reason, a list of the parts of the system that will be in service and their floodable volume should be established. Besides, note that gas losses also result from micro-leaks that are difficult to locate since helium is a very light gas and that junctions that do not leak with air may slightly do it with heliox.



Taking into example the system above the elements can be listed as follow. However, note that variations may exist.

No	Element	function	Connected to the reclaim system	Potential gas loss
1	Living chamber #1	Storage divers.	Yes	Volume at the surface (21.4 m³ in the example)
2	Medical lock chamber #1	Transfer food & medications	No (usually)	Volume of the lock at depth (vol x press)
3	Trunk chamber #1 to entry lock #1	Transfer of the divers to & from the chamber	Yes	Volume at the surface (vent in chambers)
4	Entry lock #1	Toilets, bathroom, transfer to transfer lock	Yes	Volume at the surface (7.1 m³ in the example)
5	Toilets entry lock #1	Evacuation faeces	No	Volume of canalization + sanitary tank x press
6	Bathroom entry lock #1	Hygiene	No	Gas may be lost when removing the accumulated water under the floor.
7	Gas regeneration system chamber #1	CO_2, odours, and moisture removal	Partially	Volume of the entire system at the surface. Volume of the pot x pressure any soda lime change during the operations
8	Trunk entry lock #1 to transfer lock # 1	Transfer of the divers to & from the chamber	Yes	Volume at the surface (vent in chambers)
9	Living chamber #2	Storage divers.	Yes	Volume at the surface (21.4 m³ in the example)
10	Medical lock chamber #2	Transfer food & medications	No (usually)	Volume of the lock at depth (vol x press)
11	Trunk chamber #2 to entry lock #2	Transfer of the divers to & from the chamber	Yes	Volume at the surface (vent in chambers)

No	*Element*	*function*	*Connected to the reclaim system*	*Potential gas loss*
12	Entry lock #2	Toilets, bathroom, transfer to transfer lock	Yes	Volume at the surface (7.1 m³ in the example)
13	Toilets entry lock #2	Evacuation faeces	No	Volume of canalization + sanitary tank x press
14	Bathroom entry lock #2	Hygiene	No	Gas may be lost when removing the accumulated water under the floor.
15	Gas regeneration system chamber #2	CO_2, odours, and moisture removal	Partially	Volume of the entire system at the surface. Volume of the pot x pressure any soda lime change during the operations
16	Trunk entry lock #2 to transfer lock Port.	Transfer of the divers to & from the chamber	Yes	Volume at the surface (vent in chambers)
17	Transfer lock Portside	Divers' transfer to bells and SPHLs.	Yes	Volume at the surface (26 m³ in the example)
18	Lock transfer tools Portside	Transfer tools and clothes	Yes	Volume of the lock at the surface
19	Trunk transfer lock Port. to bell portside	Transfer of the divers to & from the bell	Yes	Volume of the trunk at the surface
20	Trunk transfer lock Port to SPHL Port	Access SPHL Portside	Yes	Volume at the trunk at the surface
21	Toilets transfer lock portside	Evacuation faeces	No	Volume of canalization + sanitary tank x press
22	Bathroom transfer lock portside	Hygiene	No	Gas may be lost when removing the accumulated water under the floor.
23	Trunk transfer lock Port. to transfer lock Starboard side	Transfer of the divers to & from the bell	Yes	Volume of the trunk at the surface
24	Transfer lock Starboard side	Divers' transfer to bells and SPHLs.	Yes	Volume at the surface (26 m³ in the example)
25	Lock transfer tools Starboard side	Transfer tools and clothes	Yes	Volume of the lock at the surface
26	Trunk transfer lock starboard side to bell starboard side	Transfer of the divers to & from the bell	Yes	Volume of the trunk at the surface
27	Trunk transfer lock Port to SPHL Port	Access SPHL Portside	Yes	Volume at the trunk at the surface
28	Toilets transfer lock portside	Evacuation faeces	No	Volume of canalization + sanitary tank x press
29	Bathroom transfer lock portside	Hygiene	No	Gas may be lost when removing the accumulated water under the floor.
30	Living chamber #3	Storage divers.	Yes	Volume at the surface (24 m³ in the example)
31	Medical lock chamber #3	Transfer food & medications	No (usually)	Volume of the lock at depth (vol x press)
32	Trunk chamber #3 to entry lock #3	Transfer of the divers to & from the chamber	Yes	Volume at the surface (vent in chambers)
33	Entry lock #3	Toilets, bathroom, transfer to transfer lock	Yes	Volume at the surface (7.1 m³ in the example)
34	Toilets entry lock #3	Evacuation faeces	No	Volume of canalization + sanitary tank x press
35	Bathroom entry lock #3	Hygiene	No	Gas may be lost when removing the accumulated water under the floor.
36	Gas regeneration system chamber #3	CO_2, odours, and moisture removal	Partially	Volume of the entire system at the surface. Volume of the pot x pressure any soda lime change during the operations
37	Trunk entry lock #3 to transfer lock # 3	Transfer of the divers to & from the chamber	Yes	Volume at the surface (vent in chambers)

No	Element	function	Connected to the reclaim system	Potential gas loss
38	Living chamber #4	Storage divers.	Yes	Volume at the surface (21.4 m³ in the example)
39	Medical lock chamber #4	Transfer food & medications	No (usually)	Volume of the lock at depth (vol x press)
40	Trunk chamber #4 to entry lock #4	Transfer of the divers to & from the chamber	Yes	Volume at the surface (vent in chambers)
41	Entry lock #4	Toilets, bathroom, transfer to transfer lock	Yes	Volume at the surface (7.1 m³ in the example)
42	Toilets entry lock #4	Evacuation faeces	No	Volume of canalization + sanitary tank x press
43	Bathroom entry lock #4	Hygiene	No	Gas may be lost when removing the accumulated water under the floor.
44	Gas regeneration system chamber #4	CO_2, odours, and moisture removal	Partially	Volume of the entire system at the surface. Volume of the pot x pressure any soda lime change during the operations
45	Trunk entry lock #4 to transfer lock # 4	Transfer of the divers to & from the chamber	Yes	Volume at the surface (vent in chambers)
46	Bell Portside	Transfer to depth	Partially	Gas is lost when the divers are transferring to and from the water. The volume of the bell is lost when it is returned at the surface
47	Reclaim bell portside	Renew the gas of the bell	Partially	The volume of the pipes and the tanks is lost when the installation is surfaced. The volume of the filters' housings is lost when changing them (vol x pressure).
48	Gas reserves Bell Portside	Emergency support of the bell	No	Gas is lost only in case of emergency and when checked. Note that the gas reserves should be full
49	Bell Starboard side	Transfer to depth	Partially	Gas is lost when the divers are transferring to and from the water. The volume of the bell is lost when it is returned to the surface
50	Reclaim bell Starboard tside	Renew the gas of the bell	Partially	The volume of the pipes and the tanks is lost when the installation is surfaced.. The volume of the filters' housings is lost when changing them (vol x pressure).
51	Gas reserves Bell Starboard side	Emergency support of the bell	No	Gas is lost only in case of emergency and when checked. Note that the gas reserves should be full
52	Bell Portside	Transfer to depth	Partially	Gas is lost when the bell is opened at depth and the divers transferring to and from the water. The volume of the bell is lost when it is returned at the surface
53	Reclaim bell portside	Renew the gas of the bell	Partially	The volume of the pipes and the tanks is lost when the installation is surfaced for maintenance. The volume of the filters' housings is lost when changing them (vol x pressure).
54	Gas reserves Bell Portside	Emergency support of the bell	No	This gas is lost only in case of emergency and when checked. Note that the gas reserves should be full
55	SPHL Port side	Emergency evacuation of the system	When connected	The gas of the chamber can be recovered as long the SPHL is connected . The volume of the chamber is lost if the SPHL is surfaced.
56	Gas reserves SPHL Port side	Emergency support of the SPHL	No	This gas is lost only in case of emergency and when checked. Note that the gas reserves should always be full.

No	Element	function	Connected to the reclaim system	Potential gas loss
58	SPHL Starboard side	Emergency evacuation of the system	When connected	The gas of the chamber can be recovered as long the SPHL is connected . The volume of the chamber is lost if the SPHL is surfaced.
59	Gas reserves SPHL Starboard side	Emergency support of the SPHL	No	This gas is lost only in case of emergency and when checked. Note that the gas reserves should always be full

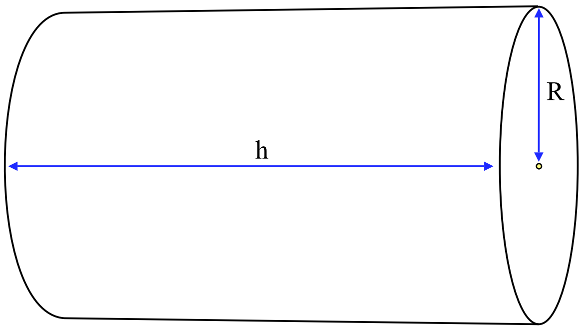
Note that small quantities of gas are lost when charging the gas reserves of the bell and the SPHL.
Also, the main reclaim system may have some small leaks, and as for other parts of the system that are under pressure, the volume of the components is lost when it is opened for maintenance.

It is difficult to evaluate precisely the loss of gas. Also, the consequences of a massive leak due to a technical failure are to be considered. For this reason, Life Support Supervisors usually plan for more gas than the minimum indicated by IMCA and correlate their calculation using elements from a database that groups the elements of previous projects.

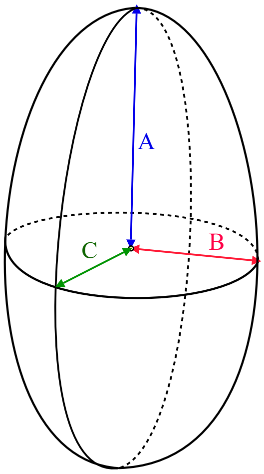
2.4.2.2 - Elements for the calculation of volumes

Every pressure vessel is normally fitted with an identification plate that, in addition to the information regarding its construction process, indicates its volume. The manufacturer is also required to indicate the volume of the elements that compose the dive system in a document that should be accessible to the people in charge. Thus, the Life Support Supervisor should have all information to calculate the volume of the system.
In the improbable case that the volume of a chamber or a lock has to be calculated, the following method and formulas can be used:

- For medical locks of pressure vessels with a similar shape, the formula to apply is the one for the calculation of the volume of a cylinder: Vol. = π R^2 h



- In the case of a chamber with rounded ends, which are today very rare, the volume of the item is equal to the volume of the cylinder + the volumes of the two half spheres at the extremities. As two half spheres equal a sphere, the formula for the calculation of the volume to be used is: Vol. = 4/3 π R^3, where R is the radius of the sphere.
- Most chambers are provided with oblate spheroid ends, which can be considered ellipsis. In this case, the following formula can be applied: Vol. = 4/3 π x A x B x C *(see A, B, C in the scheme below)*. This volume is to be added to the volume of the cylinder to give the volume of the chamber.
  Note that when A = B = C, the ellipsis is a sphere.



- To find the volume of the pipes, the formula for the volume of a cylinder can be applied.

2.4.2.3 - Elements to consider for the calculation of consumption.

- Oxygen metabolic consumption is 0.5 litres/ minutes per diver . That corresponds to 30 litres per hours (1 .05 ft^3). It also corresponds to 720 litres / day per diver (25.42 ft^3)

- The average consumption of gas using the BIBS system is given to 20 litres (0.706 ft³)/minute per diver by IMCA (the divers are usually at rest). That is equal to 1200 litres per hour per diver (42.377 ft³). Note that depending on the persons and the conditions, it can raise to 25 litres
- Note that the production of CO_2 is proportional to the consumption of oxygen (0.5 litres per minute, and thus 30 litres per hour)
- The consumption of Soda lime is given in point 2.3.2.2:
  - The average consumption of a diver is 6 kg per day (6 kg soda-lime/diver/day)
  - The weight of soda-lime is 0.75 kg/litre
  - The average consumption of a diver in litres is 8 litres per day (8 litres soda-lime/diver/day)
  - 1 kg of soda lime absorbs 120 litres of CO_2
  - 1 litre of soda lime absorbs 90 litres of CO_2
- The frequency of opening of the soda lime pots depends on their volume and the number of divers accommodated in the saturation system. With the system taken as an example:
  - Bell reclaim: 8 hours per diver at work, plus the bell scrubber cartridge (Bellman) that must be renewed every bell run (transferred with tools and clothes).
  - Chambers: 21 kg soda lime allows for 84 hours (3.5 days) per diver
- The frequency of toilet use depends on the person and the food, resulting in between a few times a week to several times per day. A frequency of two times a day seems reasonable.
- Food transfer and recovery are to be taken into account: Three meals are organized per shift of 2 or 3 divers. Depending on the medical lock's size, each meal may require several transfers to send the food inside the chamber, and several others for recovering the food residues.
- Tools, clothes, and equipment transfer is usually performed two times per shift.

2.4.2.4 - Breath In-Built Breathing System (BIBS), and therapeutic gasses

Gasses must be provided for the Breath In-Built Breathing System (BIBS), which is an emergency breathing supply that can provide oxygen, an oxygen-rich mix, or a bottom mix to the divers. IMCA D 050 says that “Sufficient gas should always be available to allow each diver four hours breathing on BIBS masks at the deepest storage depth in addition to other gas reserves”. For this reason, a suitable bottom mix should be online at all times. Also, note that the recommendation is to organize for more gas than the minimum requirement indicated by IMCA.
In addition, therapeutic mixes with an oxygen partial pressure range of 1.5 and 2.8 ata (1 ata = 1.013 bar) should be available in the event of decompression sickness. These treatment gases should be available as soon as the treatment depth is reached, and there should be sufficient quantities to carry out any foreseeable treatment and treat each chamber occupant. Regarding this point, the percentages and quantities of mixes that may be used for the depths scheduled should be calculated according to a gas consumption of 20 litres per minute per diver at the surface. The mixes should also be organized so that they overlap slightly, and a suitable breathing gas is always available during the ascent of the chamber.

The table below indicates the depths with 2.8 bar and 1.5 bar PPO_2 for various oxygen percentages

Percentage oxygen	Depth in metres with 1.5 bar PPO_2	Depth in metres with 2.8 bar PPO_2		Percentage oxygen	Depth in metres with 1.5 bar PPO_2	Depth in metres with 2.8 bar PPO2
100 %	5	18		***13 %***	105	205
70 %	11	30		***12 %***	111	223
60 %	15	36		***11 %***	126	244
50 %	20	46		***10 %***	140	270
40 %	27	60		***9 %***	156	301
30 %	40	83		***8 %***	177	340
20 %	65	130		***7 %***	204	390
15 %	90	179		***6 %***	240	456
14 %	125	190		***5 %***	270	550

Note the following:

- The external and internal BIBS and dump valves should be open. If there are minor leaks, either through the masks or dump valves, the internal valves may be closed. They can be opened quickly by the divers in an emergency.
- Under normal conditions, only bottom mix should be connected to the BIBS to prevent the accidental supply of a toxic oxygen mix. A rich mix should only be connected for treatment purposes.

2.4.2.5 - Daily gas report document

The life support supervisor is in charge of the publication of the daily gas report that is transmitted to the diving superintendent, the offshore construction manager, and the client representative.

This document is kept to create a database used to evaluate the gas consumption of future projects and correlate the Life Support Supervisor's calculation.

It should indicate:

- The gasses on board the vessel and their location.
- The gasses with the Life Support Package.
- The volume of gas reclaimed or waiting for recycling and the efficiency of the reclaim system.
- The minimum gas reserves that must be onboard (IMCA limit)
- The possible duration of the operations with the reserves on board.
- The gas ordered, and the date planned for their delivery
- The empty gas containers to be returned to the shore

These elements are usually indicated using tables such as the example below:

No	*Description*	*Volume at project start*	*Previous volume*	*Gas received today*	*Gas used today*	*Remaining gas on board*	*Maximum saturation time possible*	*Total used*
1	2% mix							
2	Mix #1							
3	Mix#2							
4	Mix#3							
5	BIBs reserve							
6	Oxygen							
7	Zero gas							
8	Span gas							
9	Soda lime							
10	Purafil							

Notes:

- Mixes are the bottom mixes in use for the project and other mixes that are stored with the system. As a result there is usually more than three mixes.
- BIBS reserves are the bottom mixes ready to be online to supply the BIBS. The therapeutic gasses status is not included in the table above, and in this case, it should be published in a separate record.
- Gas status of the mixes to be used by the life support package is usually published in a separate chart that is also available in the life support package control room.
- Reclaimed gasses are sometimes highlighted in a specific column.

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3) Chamber management

3.1 - Pre-dive chamber preparation

3.1.1 - Hygiene to be in place during the preparation of the system

3.1.1.1 - Clean the chamber

During the saturation, the partial pressure of oxygen in the complex is between 380 and 450 millibar with the procedure NORMAM 15, which in addition to the congested space and ideal humidity, creates a favourable environment for the development of pathogens and rapid contamination of the divers present in the chamber. To ensure of no pathogens in the system, the chambers must be cleaned prior to the starting of the operations:

- Bedding must be laundered and mattresses and pillows cleaned and aired. Any suspicious bedding must be replaced.
- Personal items from any previous dive must be removed.
- The chamber wall, bulkheads and bilges must be washed with hot water and soap and rinsed with fresh water.
- The shower head, valve handles, toilet seat and bed rails should be disinfected (Alcohol, “Tego”, “Trigene” or similar)
- BIBS masks must be disinfected and dried.
- The chamber should be ventilated and dried.
- The chamber must be closed to protect if from contamination when the cleaning is completed.

3.1.1.2 - Precautions after cleaning the chambers

Pathogens and fungus develop quickly in chambers during the saturation due to the partial pressure of oxygen that is more elevated than in normobaric conditions (Approximately 400 mb instead of 210 mb). Polluting agents can be transported in the chamber by people entering it for various pre-dive interventions, and their effect can be multiplied by the pressure. For this reason, some precautions have to be implemented to preserve the chamber that had been cleaned.

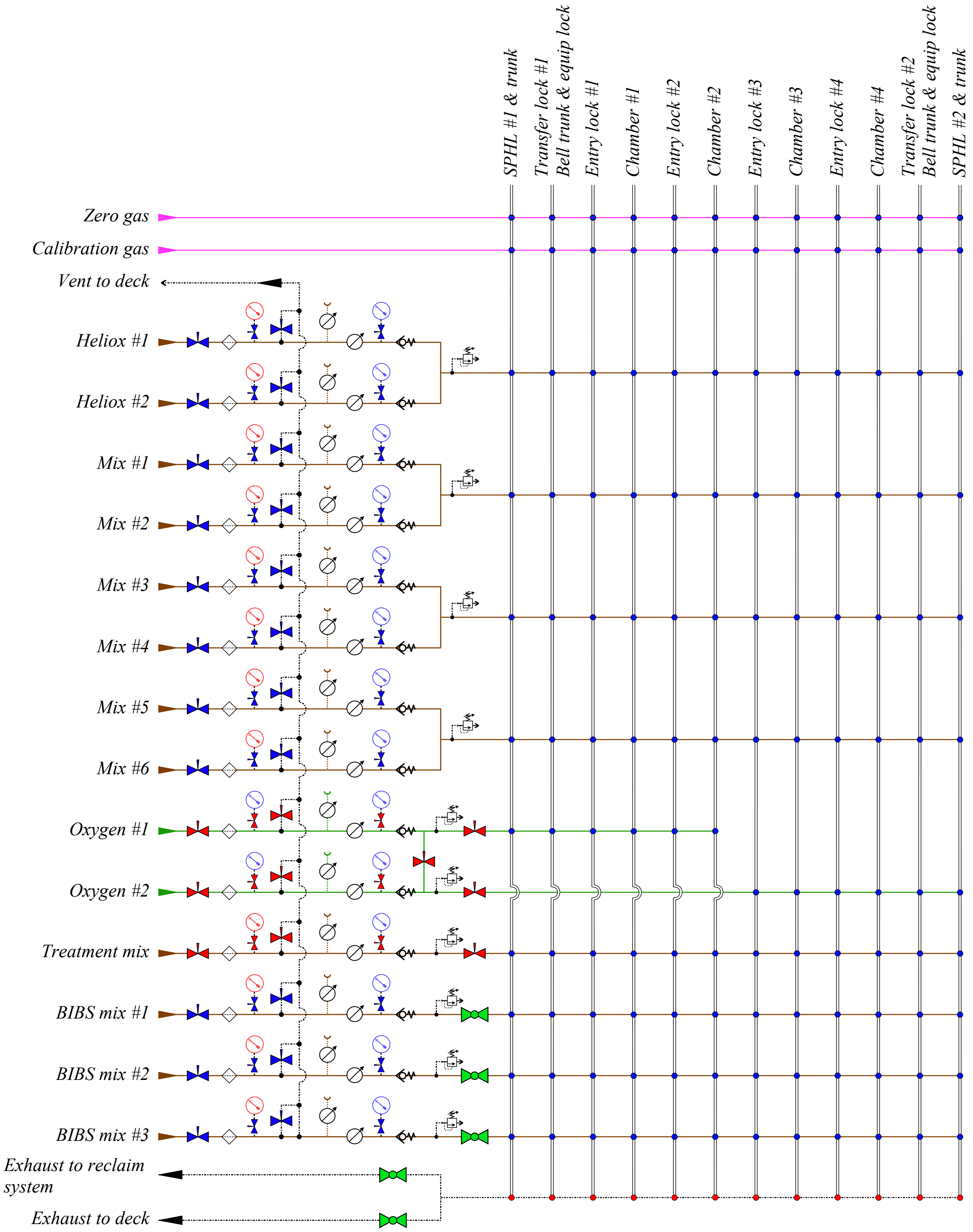
- Medical checks of the technicians should be performed on arrival at the worksite to ensure that they are not infected by pathogens.
- People entering the chamber should not be sick to avoid any pathogen deposits in the chamber. They should inform those in charge of any potential or declared infections, illness and do not enter the chambers as long they are not confirmed clear to do so by the onboard medic.
- People entering the chamber should:
    - Wear clean clothes (cotton is recommended), and be clean. As an example, hands should be washed and not polluted with greases from previous interventions.
    - Not wearing shoes or boots used to work on deck and other parts of the vessel in the chambers. Instead, dedicated clean shoes for chamber use should be worn.
- It may happen that some repairs have to be performed. In addition to the above recommendations, the technicians in charge should:
    - Not use products based on chemicals that may pollute the chamber atmosphere.
    - Ensure that no tool is forgotten in the chamber when the repair is completed and that the chamber is as clean as found before the intervention.
- Before entering the chamber the technician should:
    - Informs the saturation control room.
    - Ensures that the door is secured in the open position and cannot be closed unexpectedly.

3.1.2 - Starting the saturation system

For convenience, this description is based on the systems taken as an example in the previous points. However, this point aims to indicate rules instead to provide precise checklists as such a document must be dedicated to the system used. Each element planned to be in service must be function tested, and any suspicious component that is discovered should be replaced or repaired. For example, essential devices such as valves should be confirmed easily opening and closing within their full range. As a result, due to the complexity of saturation diving systems, such an essential preparation takes a lot of time, and the system checks should not be performed at the last minute. For these reasons, it is accepted that parts of the system that have been checked remain unused several hours, provided that the system is not accessible to unauthorized personnel. Nevertheless, it is recognized that this duration should not be more than 24 hours.

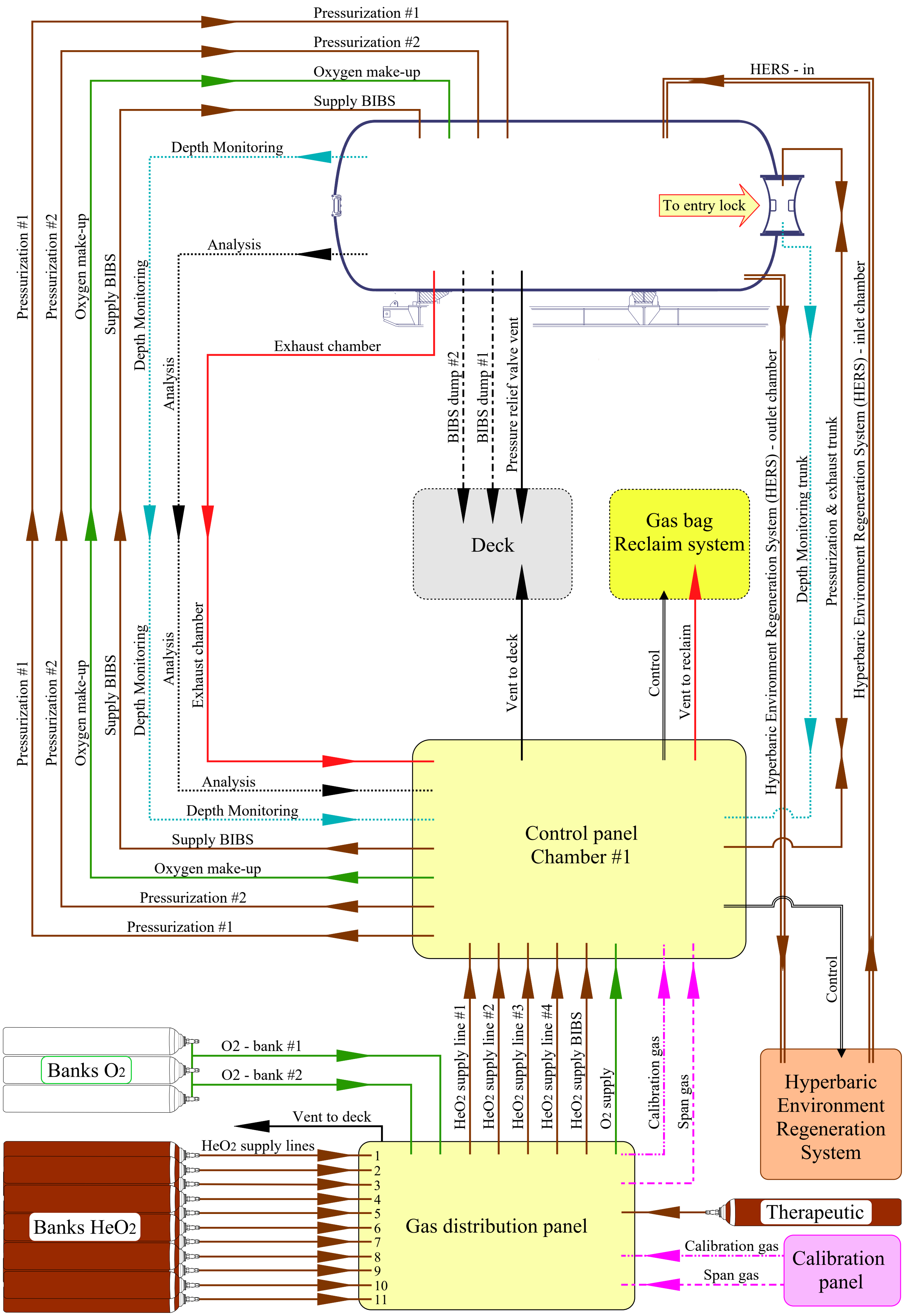
3.1.2.1 - Prepare the gasses

Gasses must be be ready to use sufficient time before the divers are committed to the saturation system to ensure a good homogenisation.



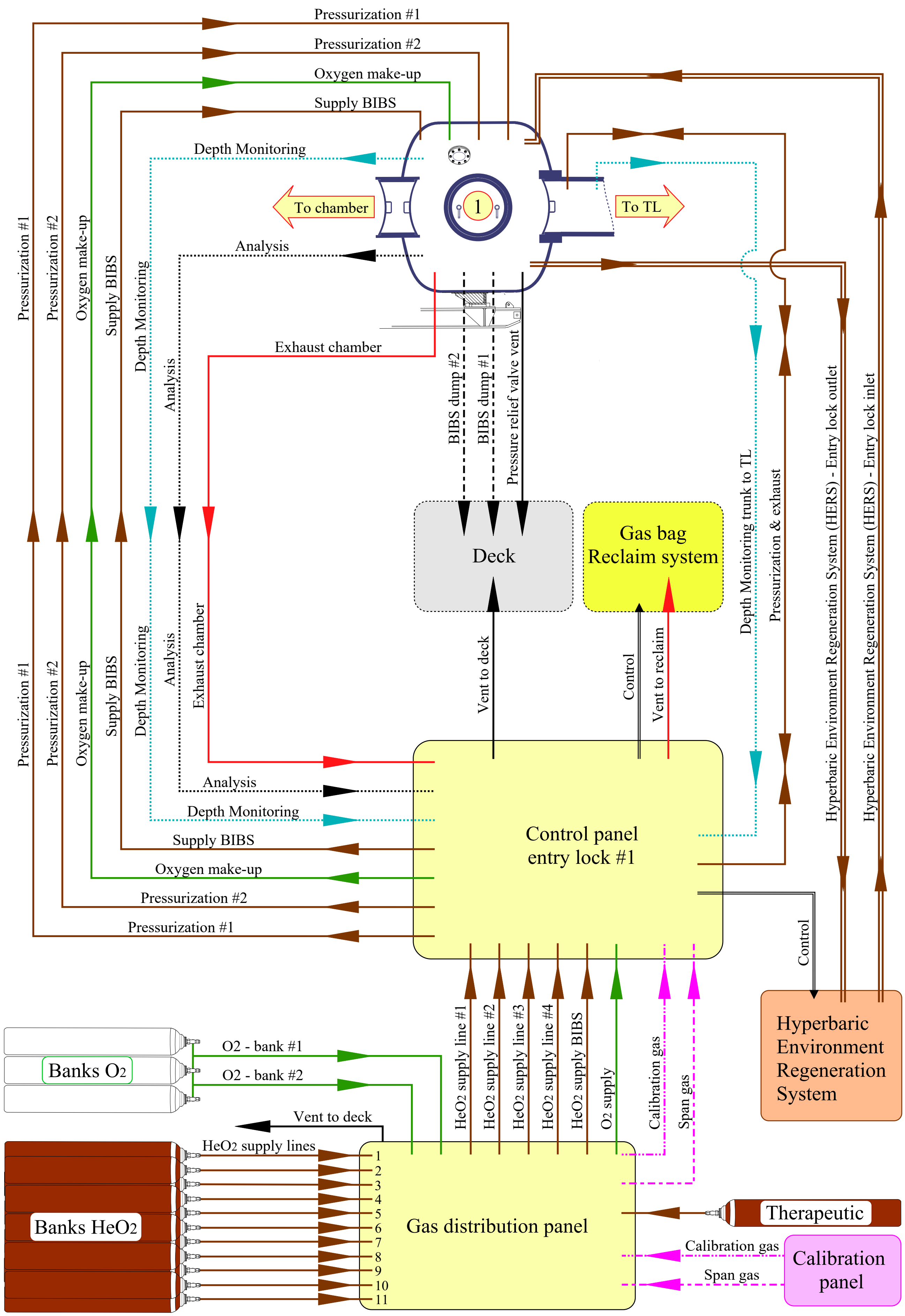
Before organizing the gasses and chamber checklists, it is essential to ensure that the life support team knows the supply and exhaust gas lines of the saturation system perfectly. Such knowledge allows for establishing proper checklists and avoid mistakes.

- #1 - Chambers' main gas lines

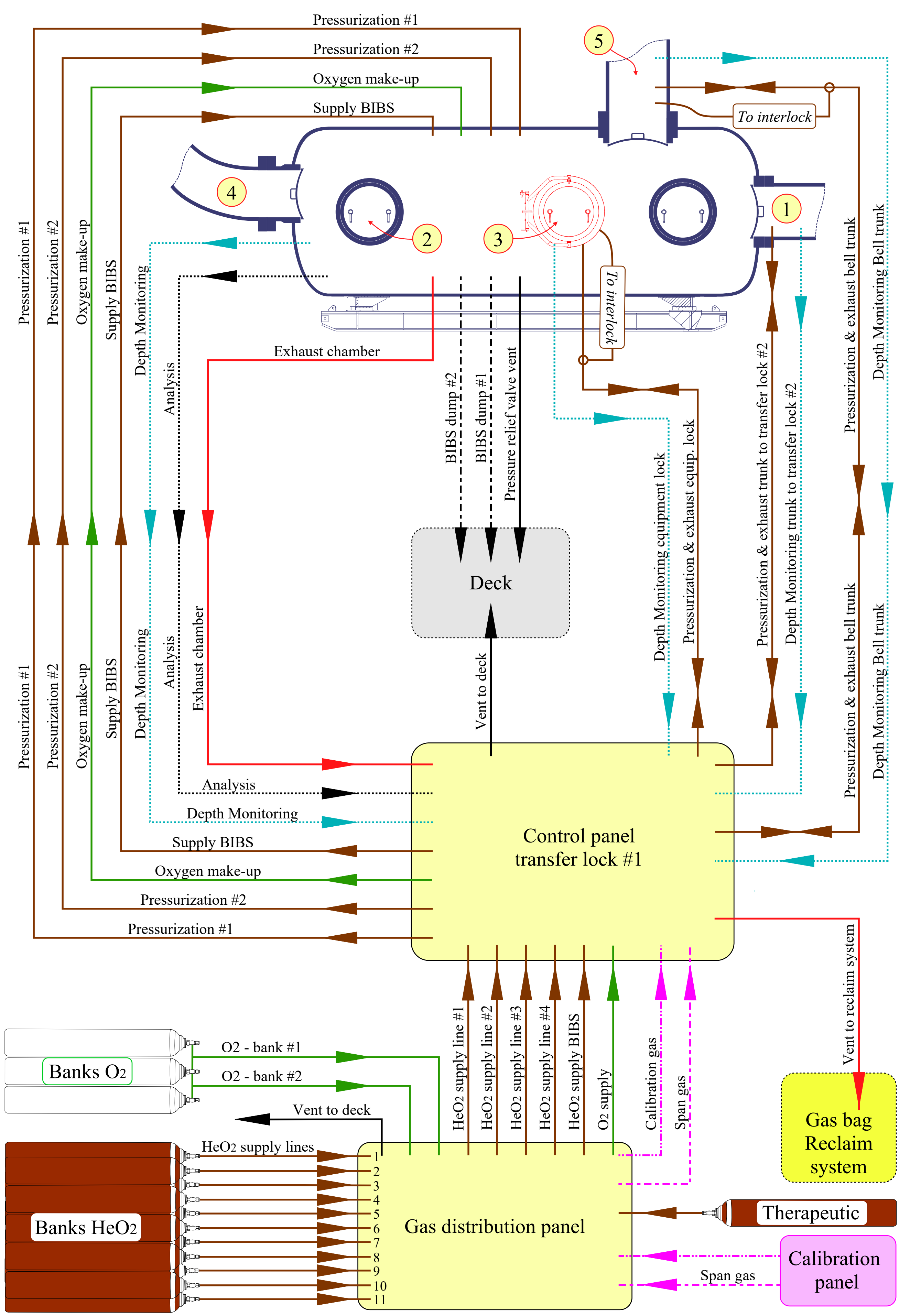


Hyperlink Table of contents

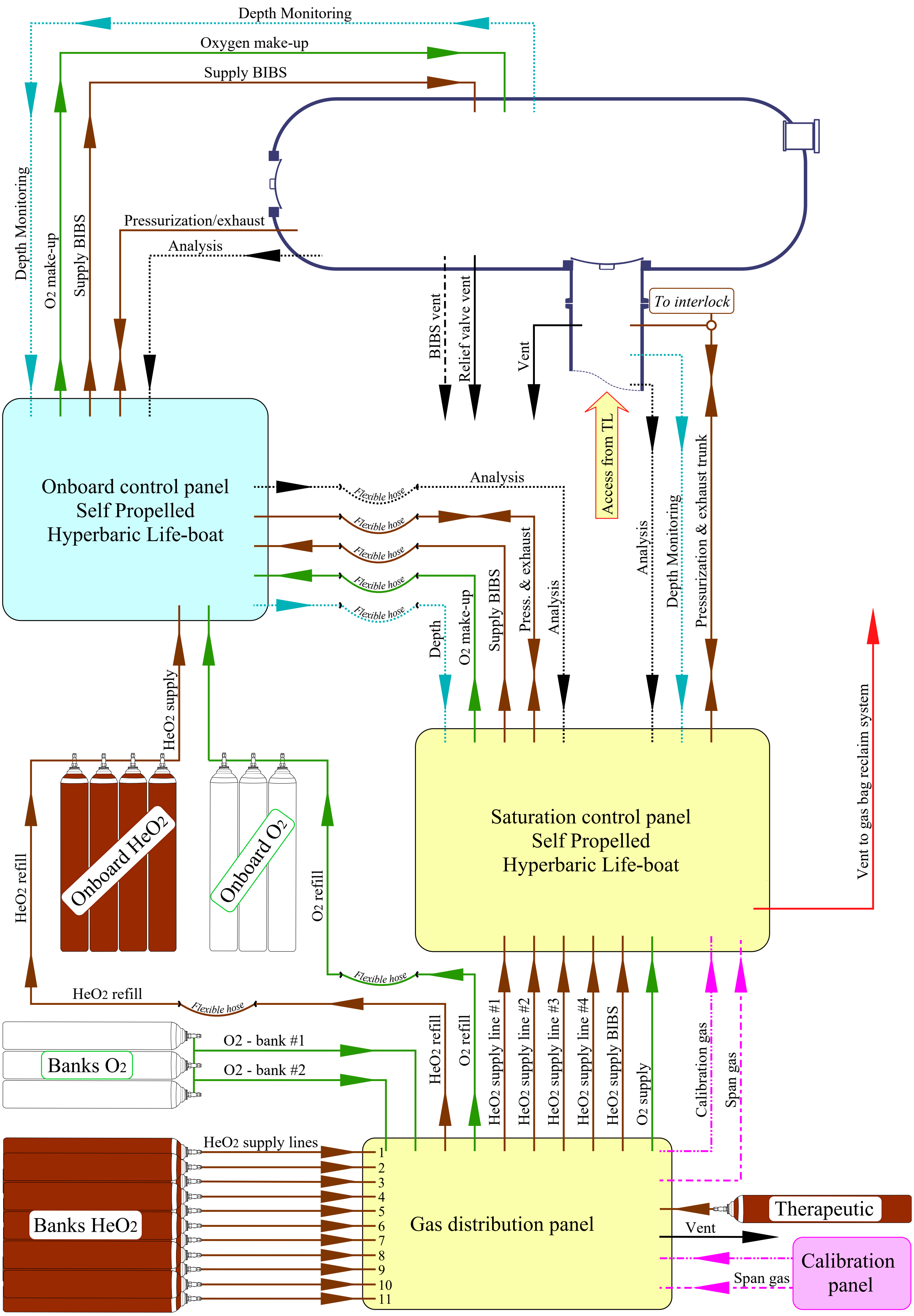
- #2 - Entry locks' main gas lines



- #3 - Transfer locks' main gas lines



- #4 - Self Propelled Hyperbaric Life-boats' main gas lines for the Diving Support Vessel



The “gasman” is responsible for fabricating the mixes and connecting the gas reservoirs to the various chambers' supplies and the dive control. He works under the Life Support Supervisor's responsibility, who is also responsible for ensuring that sufficient gas is available and works under the authority of the Diving superintendent.

The gas distribution system and the panels in the saturation control are described above and in points 1.2.6 and 1.2.8.
The control panels of the chambers to be used should be prepared for the operations with all the supply lines connected.
With the systems taken as references in this document, the saturation control is supplied by:

- One therapeutic gas line
- Two oxygen supply lines
- Three BIBS gas supply lines
- Two heliox lines
- Six mix lines
- One line of spam gas and one line of zero gas

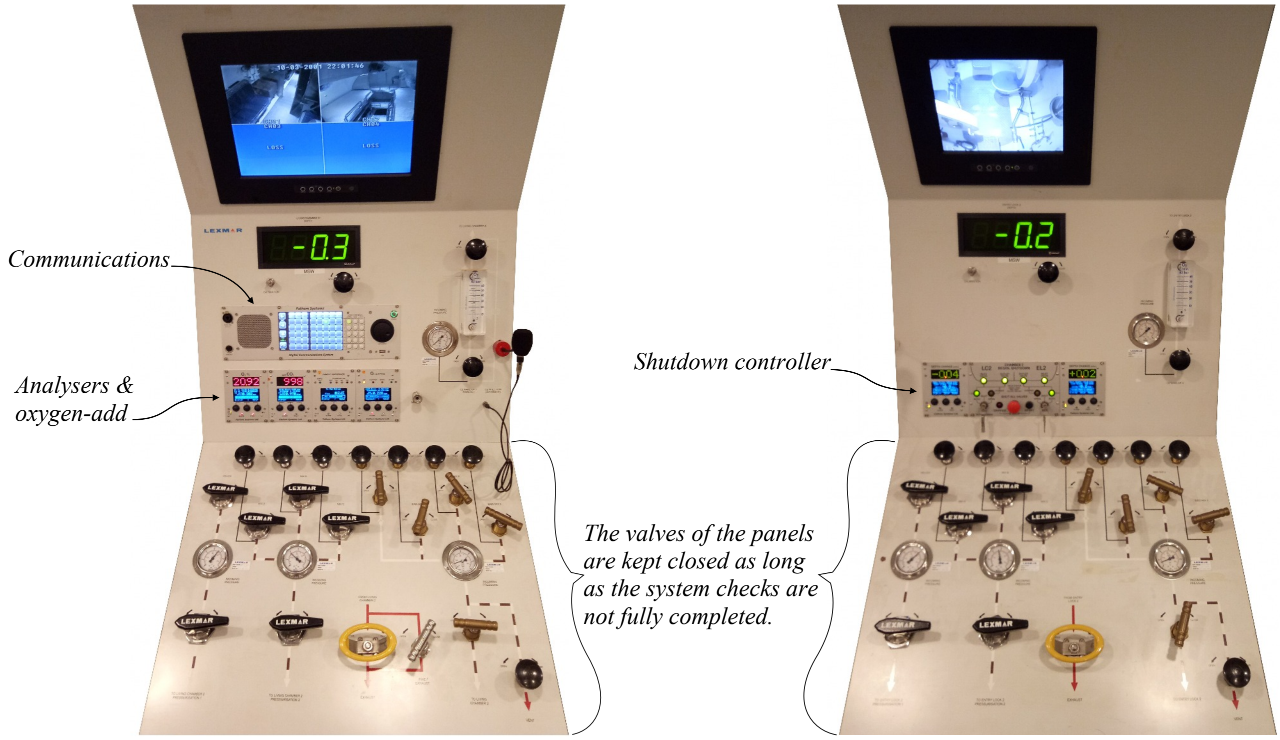
These lines are connected to the gas distribution panel that groups the regulators and then distributes the gasses to the various chambers' panels. These regulators will have to be calibrated.
Also, each dive control is supplied by:

- Three heliox lines
- One makeup reclaim line
- One oxygen line
- One line of spam gas and one line of zero gas

Note that the management of these panels is the diving supervisor's responsibility.

3.1.2.2 - Prepare the control panels

Before putting the gasses on line, the Life Support technician should ensure that the panels are ready for use:



Living chamber panel *Entry lock panel*

- The electrical systems of the saturation system should be checked. That can be done through the electrical supply panels and the electrical control panels in the saturation control room that group all the system's functions.
- The valves must be function tested and open and close easily in their full range.
- Pressure and depth gauges should have been calibrated and indicate zero.
- The regulators' adjusting knobs should move freely.
- The calibration gasses should be online and all the analysers to be in service must be calibrated.
- The close circuit television and the recording of each chamber should be activated and checked. It may happen that some cameras have to be readjusted to provide a better visual of the chamber. That should performed during the inspection of the chambers
- Communications (intercom + sound powered phone) to the chambers should be opened. They will be checked during the inspection of the chambers.
- Communications to the bridge and the other parts of the vessel (intercom and phone) should be tested.

- Direct satellite phone communications to the appointed diving doctors should be tested.
- The lighting should be checked and lost lights replaced.
- Alarms should also be tested and the muting system as well.
- Breathing Apparatus sets and extinguishers should be in place with their certifications up to date.

When the elements above have been checked, the operator ensures that all the valves are closed and the "gasman" can pressurize the supply lines to the gas distribution panel.

When the gas distribution panel is supplied with the relevant gasses, the operator adjusts the regulators to the planned pressure. However, the supply and exhaust lines to and from the chambers should not be opened as long as they have not to be checked, and the Hyperbaric Environment Regeneration system is not ready to start.

- When the system is equipped with, the shutdown controller , that is described in point 1.2.8.6 is made ready to be in service.
- The automatic oxygen add of the chambers should be made ready for use.
- Also, for the saturation systems equipped with the diver monitoring system described in point 1.2.8.8, this system is made ready to be in service.

When the panels are ready, the inspection of the system can be started. During this phase, at least one LST should be present in the saturation control room to test elements such as communications and cameras.

Also, note that the deluge fire fighting system of the saturation control room is controlled from the bridge as are all systems of the boat except the hyperbaric system of the chambers that are controlled from the saturation control room or the inside of the chambers.

3.1.2.3 - Prepare the fire fighting system of the chambers

The hyperbaric firefighting system of the chambers must be prepared.

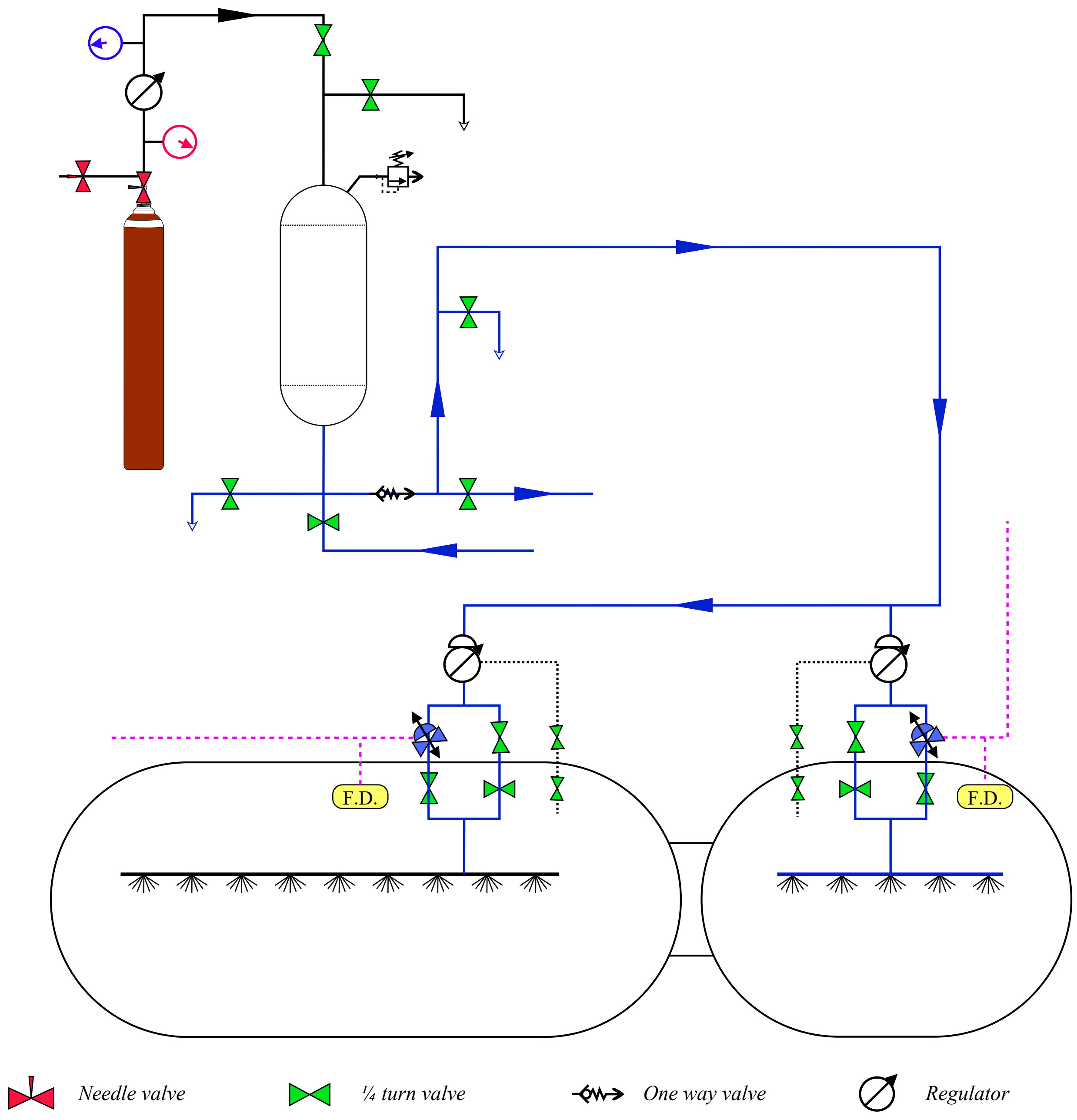


Table of contents

High pressure gauge	Low pressure gauge	Relief valve	Actuated valve
Dome regulator	Pressurised heliox line	Pressurised water	Electrical line
Sprinkler	F.D. Flame detector	Pneumatic line	Pressure sensing line

On the firefighting system squid, the technician ensures that:

- The water tank is filled.
- A sample of the heliox supply bottle should have been analyzed and is confirmed between 7% and 2% oxygen. The reason is that a flame cannot happen if the oxygen content of a gas is equal or less than 7% and that a minimum of oxygen must be in any mix delivered to the system to avoid immediate asphyxia.
- The gas supply (bottle king valve) should be opened, and turned back ¼ turn.
- The regulator on the gas supply bottle should be set up (usually @ 40 bar).
- The inlet gas valve of the tank should be open.
- The drain valve should be closed.
- The vent valve should be closed.
- The drain valve should be closed.
- The water supply valve should be closed.
- The cross over valve should be closed.
- The test valve should be closed

The elements of the chamber are then verified during the chamber checks.

3.1.2.3 - Prepare the chambers

Chambers are described in point 1.2.2 of this document. They have different functions but are based on the same design, and the principle of use of the components is globally the same, except for some particular components that are linked to the function of the chamber. For this reason, general rules are indicated below that can be used to prepare checklists and should be adapted to the chamber's design. In addition, particular rules linked to the function of some chambers are discussed separately. Note that chambers must be checked externally and internally and that must be logged in two different check lists.

3.1.2.3.1 - General rules

The elements described below are common to every chamber.

Remember that penetrations of gas supplies and exhaust should be provided with external and internal isolation valves mounted on the hull.

- External checks

- Viewport should be is in perfect condition (no shocks, cracks and corrosion), and be less than 10 years old.
- Electrical and hollow penetrators should be in perfect condition.
- New systems are provided with firefighting deluge systems such as the one described in the previous point. The operator should ensure that pressurised air is provided and that the pneumatic valve is closed and has been function tested. Also, the isolation valve of the water supply to the actuated valve should be open.
- The deluge system is equipped with a backup inlet circuit that is operated manually by the divers in the chamber. Its isolation valve should be open.
- Sensing lines are provided to adapt regulators located outside the chamber to the pressure inside the chamber. It is the case of the deluge system regulators, but also, the regulators of the Built-In Breathing System (BIBS), and potable water supply system. The isolation valves of sensing systems should be kept open.
- The relief valve that protects the chamber from overpressure is provided with and external isolation valve. This valve must be kept open and easily accessible to the chamber operators.
- A small pipe is used to carry the chamber's gas to the analysers of the control panel. Its isolation valve must be kept open.
- Another small pipe is used for the depth gauge of the control panel. Its isolation valve must be kept open.
- The BIBS supply and exhaust isolation valves should be open as this system must be immediately available to the divers.
- Pressurization is done from the control panel in the control room. The isolation valves on the chamber must be kept open.
- One or several oxygen makeup pipes are provided. Their isolation valves should be kept open.
- Isolation valves of the exhausts should be kept open.
- The isolation valve of the bilge discharge should be closed.
- The isolation valves of the hot and cold liquid supply and exhaust of the heater/cooler system should be kept open.

- Internal checks

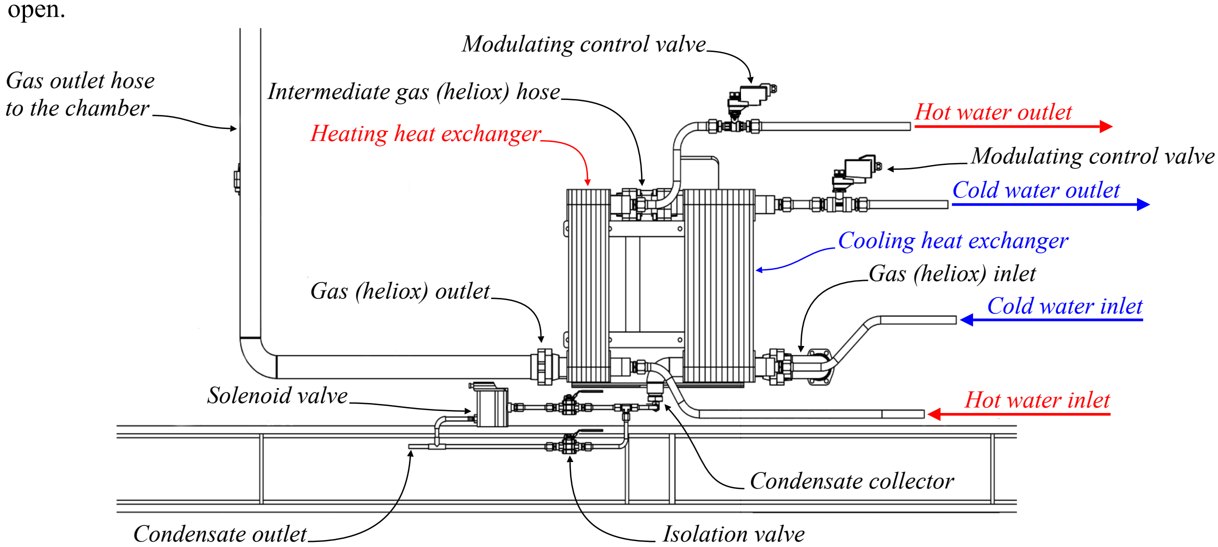
- Autoclave doors must be fully checked. They should be clean, and their O rings should be undamaged and slightly lubricated with silicone grease or a lubricant that does nos damage the O ring material and does not ignite with oxygen.
- The viewports must be inspected from the inside of the chamber, and this side must also be in perfect condition. Note that if the viewport is used to provide artificial light in the chamber, the person who examines it should verify whether it is hot. If it is the case, the external light should be adjusted to avoid this problem as exaggerate heat may damage it.
- Water often accumulates below the floors. For this reason, they must be removed and their underneath should be closely inspected for corrosion and other damage. If moisture or water are present, they must be removed and the compartment dried.
- The electrical and hollow penetrators should be verified and be in perfect condition.
- The water supply valve of the firefighting system from the actuated valve should be kept open. Also, the water supply valve from the manual (backup) firefighting supply is closed with the handle removed and attached to the pipework. In addition, the inspector should verify the condition of the hoses.

  A hyperbaric extinguisher should be provided, and its pressure gauge should be in the green zone. Also, the inspection sticker should show that it has been reviewed on time.
- There are two equalizations valves on the doors. One set of valves (Set A) is open chamber side and closed trunk side, and the 2nd set (set "B") is closed chamber side and open trunk side. As a result, pressure equalization can be performed from both sides of the door.
- As already said for the external checks, all sensing lines that allow piloting regulators installed outside the chamber should be kept open. It is the case for the firefighting, BIBS, and potable water supply systems.
- Ceiling lights should be checked for damages, internal moisture, and should work satisfactorily.
- The intercom and the call ring must be function tested. It is also the case of the sound-powered phone. Note that the conversation must be clearly audible.
- The internal gauge and the hygrometer should be calibrated and function tested. Note that the gauge should indicate zero.
- The isolation valve of the relief valve should be kept open.
- The isolation valves of the BIBS supply and exhaust should be closed. A breathing mask should be provided to each diver. Also, a spare mask must be available. These masks should have been tested. The team in charge of the checklist should also verify whether the quick connectors can be inserted, secured, and removed easily. That should be done for each unit.
- Scrubbers are provided in all chambers. They should be tested, and a brand new cartridge should be provided.
- Two pressurization systems are usual in saturation chambers. Their isolation valves should be kept open. Silencers should be fitted to them and be in perfect condition.
- The isolation valves of the exhausts should also be kept open. An anti suction system should be in place.
- The valve of the small pipe to the control panel's depth gauge should be open. It is also the case of the valve of the pipe that carries gas to the analysers mounted on the control panel.
- The isolation valve of the oxygen supply should closed.
- Internal gauge and hygrometer should be provided and calibrated. The depth gauge should indicate zero.
- Cameras are provided to monitor the divers during the saturation. They should be undamaged, and function tested. Such a function test is usually performed during the control panel checks.

3.1.2.3.2 - Particularities of living chambers

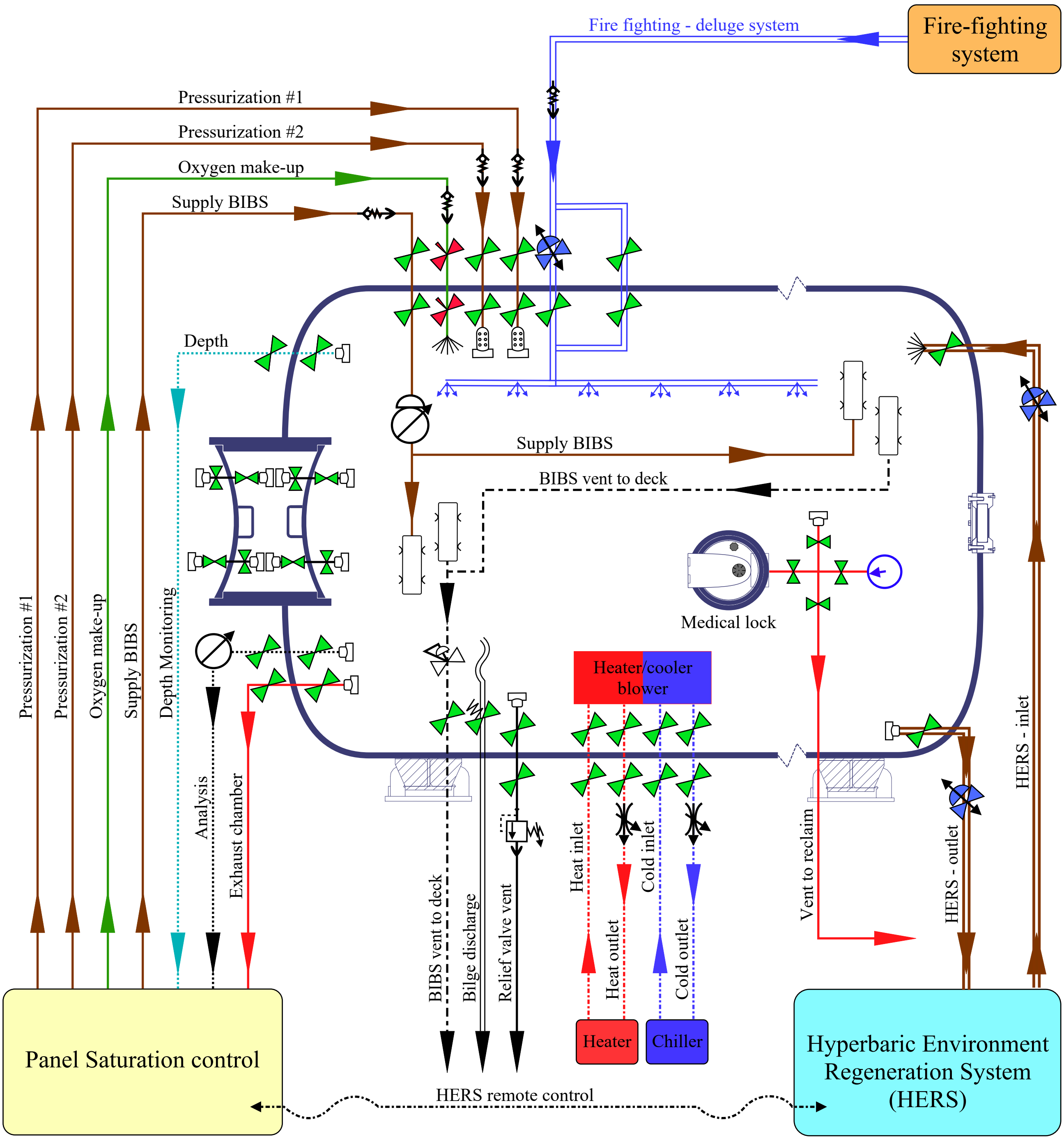
Living chambers are designed for accommodating the divers. As explained in the description in point 1.2.2, they are equipped with bunks, tables, medical transfer lock, and a regeneration system.

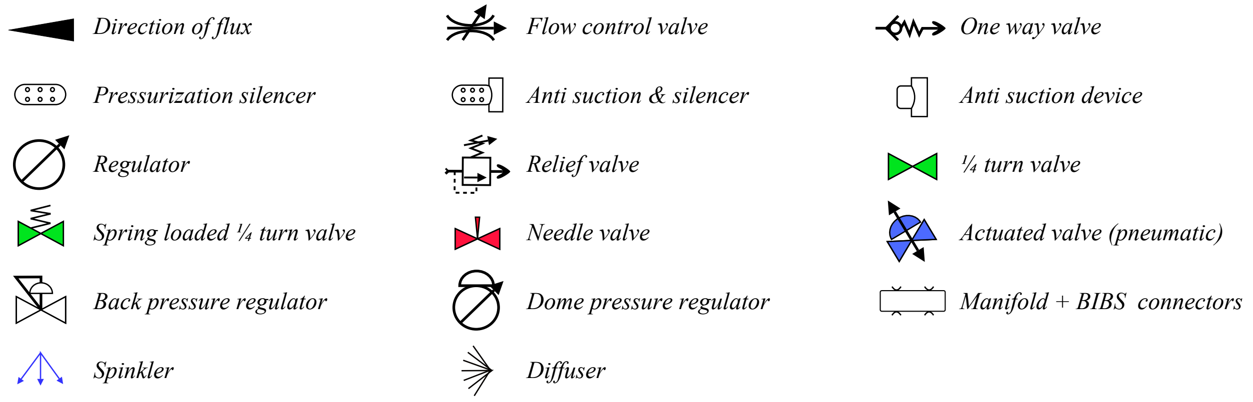
- The Hyperbaric Environment Regeneration System (HERS) inlet isolation valves (internal & external) should be open.



- The Hyperbaric Environment Regeneration System (HERS) return system is usually composed of an isolation valve situated inside the chamber and a flow fuse or a pneumatic actuated valve that shuts automatically in case of a pressure drop. The isolation valve inside the chamber must be kept open. The flow fuse or the automatic actuated valve should be tested. It may happen that an isolation valve is provided in addition to the flow fuse. In this case, this valve must be kept open.
- The heat exchanger of the HERS is situated externally along with the chamber. Hot water and refrigerant liquid inlet and outlet isolation valves are usually provided (not visible in the drawing below). The valves should be opened to allow the liquids to circulate.
- A quarter-turn valve often isolates the solenoid valve that is designed to drain the exchanger. This valve must be kept open. A backup bypass drain system is usually provided in which the isolation valve should be kept closed.
- The medical lock must be closed and kept at the surface. For this reason, the equalization valves and the vents to the reclaim or the deck must be closed. Also, the interlock of the external door must be ready to secure the door if the lock is pressurized. Note that the doors must be in perfect condition with their O rings slightly lubricated.

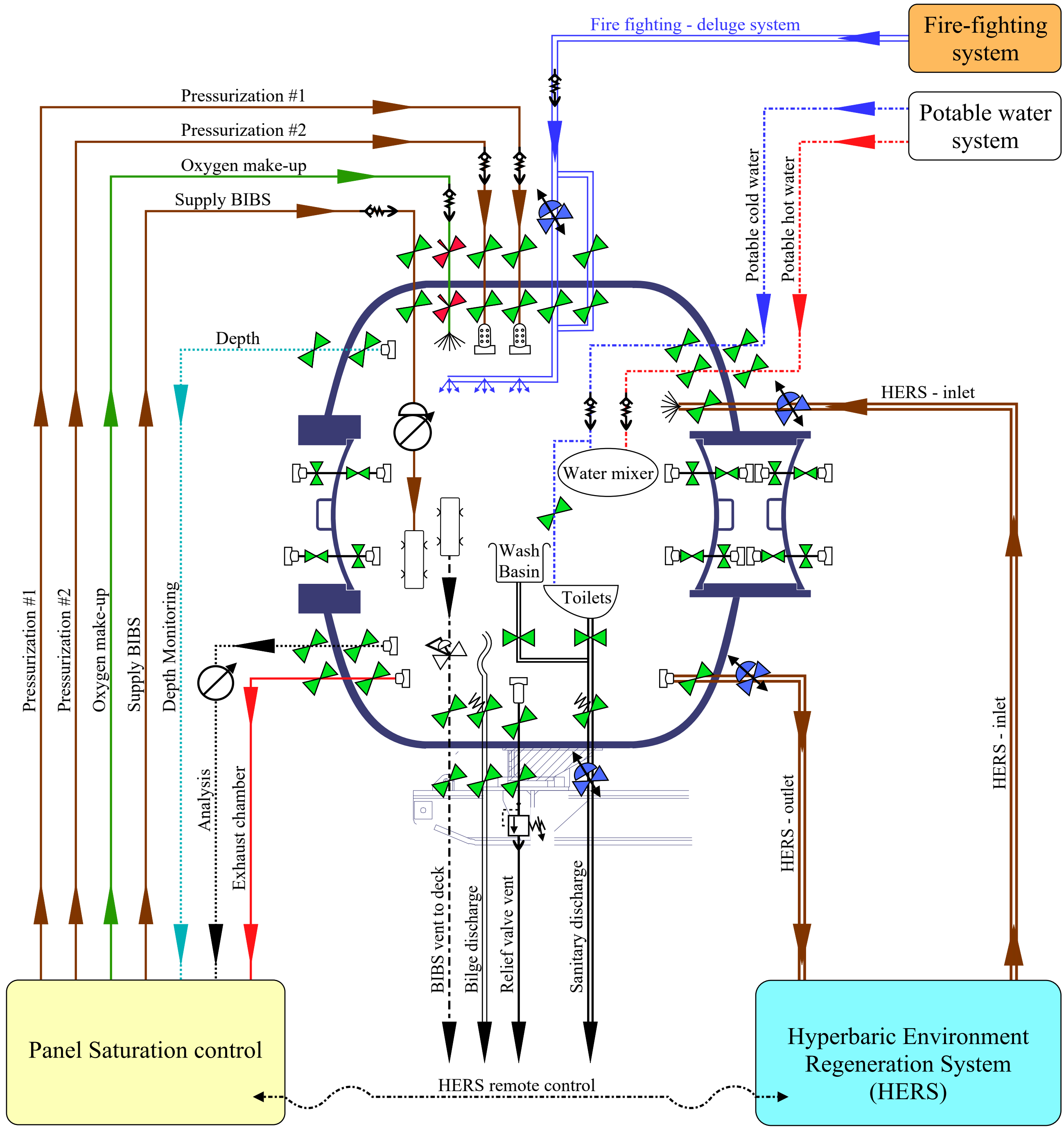
  with silicone grease. The pressure gauge should be calibrated and indicate zero. If fitted with an isolation valve, it should be open.
- To allow a safe transfer of the food and medications, communications are provided near the medical lock. They should be fully tested. Also, a sound-powered phone is provided that must also be tested.
- The bunks should be in good condition. Their lights and communication blocks should be function tested.





3.1.2.3.3 - Particularities of entry locks

The entry lock is used as an intermediate room to transfer the divers to and from the transfer lock. Also, it is designed to provide a toilet and bathroom to the divers.



- The entry is usually connected to the same Hyperbaric Environment Regeneration System (HERS) than the living chamber. For this reason, it also shares its heat exchanger with the living chamber. The procedure to check the inlets and outlet components is the same as for the living chamber.

- Inside the chamber, the toilets should be function tested (The ball valve should close when the cover is opening), and disinfected. The sanitary discharge valve inside the chamber should be closed. Also, the toilet dump that is situated outside the chamber should be closed.
- The potable water supplies (hot and cold) should be kept open outside the chamber. Inside the chamber, the water supplies' isolation valves should be closed (to be opened by the divers when using water, and then closed). Also, the valves of the shower and the sink should be closed. Note that a piloted regulator is used to adjust the water pressure to the depth of the chamber. As already indicated, the internal and external isolation valves of its sensing line should be kept open.

3.1.2.3.4 - Particularities of the connecting trunks

These trunks are those used to transfer from one chamber to another one.

- Note that the doors' valves must be in open and close positions, as indicated in point 3.1.2.3.1.
- The isolation valve for depth monitoring should be kept open. Note that usually, there is no valve in the trunk.
- The isolation valve of the pressurization should be kept open. Note that usually, there is no valve in the trunk.
- The isolation valve of the exhaust should be open.

3.1.2.3.5 - Particularities of bells' vertical connecting trunks

These trunks are those connected to the bottom of the bell. They are fitted with a bottom door that is usually hydraulically closed. This hydraulic system is similar to those used with bells. The people in charge of the checks should ensure that:

- The valves of the accumulator and the actuator are open.
- The counterbalance valve that avoids the door free falling when opening it has been tested and works satisfactory, so the door will not be damaged by an unexpected drop.

3.1.2.3.6 - Particularities of trunks to Hyperbaric Rescue Units

Except for Hyperbaric Rescue Chambers (HRF) of portable systems, these trunks are often more than 3 m long. It is particularly the case of those connected to Self Propelled Hyperbaric Lifeboats (SPHL) of built-in systems. These long elements are also in slope, and for this reason, they are equipped with rungs to help the divers climb to the Hyperbaric Rescue Unit. The condition of these rungs should be checked. Also, lighting and communications to the control room are provided that should be checked as for any chamber.

3.1.2.3.7 - Particularities of transfer locks

Transfer locks are wet chambers used to transfer to and from the bell and the Hyperbaric Rescue Unit. They are equipped with toilets and sinks as the entry locks. They are also fitted with the tool transfer lock and the medical treatment bed. However, they are usually not equipped with Hyperbaric Environment Regeneration System (HERS).

- The tool transfer lock should be kept at the surface with its doors closed and the interlock in place. If the pressurization & exhaust are remote, their isolation valves should be open. However, if the pressurization & exhaust are not remote, these valves should be closed. If fitted with, the isolation valve of the pressure gauge mounted on the device should be open.
  If the door is hydraulically closed, The valves of the accumulator and the actuator should be open, and the bypass gauge should be closed.
- The medical treatment bed and its dedicated lights should be verified. Also, the medical breathing assistance system and the data transmission system to a diving doctor located remote should be tested.
- Note that a stretcher designed to transfer a casualty through the connecting trunk to the Hyperbaric Rescue Unit , and the medical kit DMAC 15 should be in the chamber, or the saturation control, ready for transfer through the tool transfer lock. This medical kit should have been checked and be up to date.

3.1.2.3.8 - Particularities of Hyperbaric Rescue Units (HRUs)

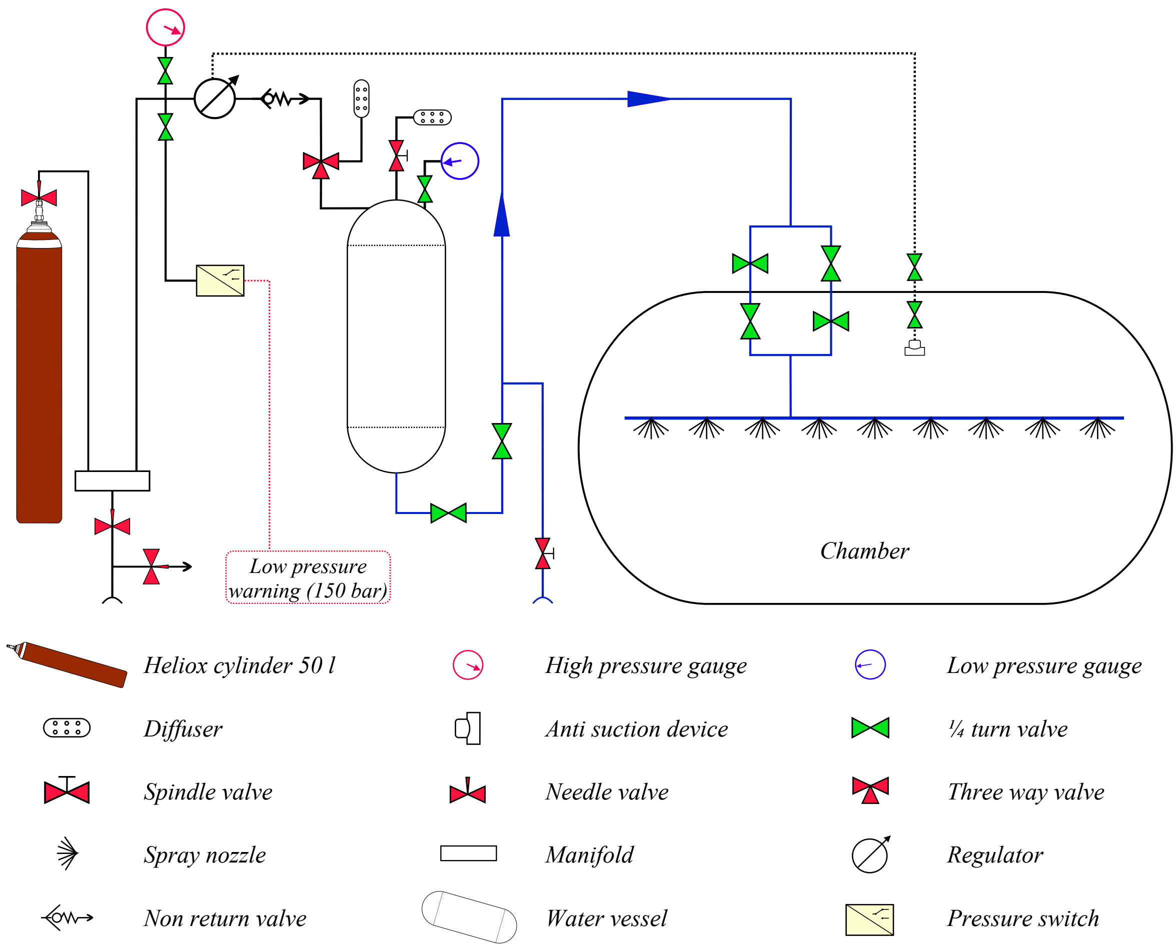
As indicated in point 1.2.7.1, most new saturation systems are equipped with Self Propelled Hyperbaric Lifeboats (SPHL) despite a lot of old systems are still equipped with Hyperbaric Rescue Chambers (HRC) which are slightly different. For this reason this description focus of SPHL It must be noted that these equipment are to be used only in the case of an abandon ship and is controlled from the saturation control room during normal operation. Also, when launched at sea, chambers of SPHLs are monitored through a control panel, which is not possible with HRCs. Besides, it should be remembered that the HRU should not be used as a living chamber during the normal operations.

- HRUs are provided with oxygen and heliox reserves that are charged and distributed through panels.

- Regarding the connecting panel of the Diving Support Vessel that is used to connect the supplies and exhausts of the chamber during normal operations, note the following:
  - The oxygen and heliox charging points of the gas distribution panel of the diving support vessel should be closed. They are to be opened only when filling the gas reserves.
  - The O_2 makeup supply valve from the saturation control panel should be open.
  - The BIBS mix supply valve from the saturation control panel should be open.
  - The pressurization & exhaust valve from/to the saturation control panel should be open.
  - The depth monitoring valve to the saturation control panel should be open.
  - The analysis valve to the saturation control panel should be open.
  - The hot and cold water inlet and outlet valves of the environmental control system should be open.
  - The distribution hoses a the quick connectors to the external connecting panel of the SPHL should be tested.

- Onboard gas panels and gas reserves should be organized to be quickly in line if the SPHL is launched, but be secured during normal status where the chamber is controlled from the saturation control room.
    - The oxygen and heliox filling valves should be closed
    - The isolation valves of the gauges of the oxygen and heliox banks should be open (if fitted with).
    - The oxygen cylinders (2 sets of 4 cylinders/50 litres) should be full.
    - The distribution valves from the oxygen cylinders to the onboard gas panel should be closed.
    - The bypass valve(s) between the oxygen banks starboard side and port side should be closed.
    - The heliox cylinders (2 sets of 3 cylinders/50 litres) should be full.
    - The distribution valves from the oxygen cylinders to the onboard gas panel should be closed.
    - The bypass valve(s) between the heliox banks starboard side and port side should be closed.
    - The bypass valves of the filters (if fitted with) should be closed.
- The onboard control panel of the chamber should be organized to be quickly active if the SPHL is launched and not interferes with the commands from the saturation control room during normal operations:
    - The valve of the pressurization/decompression system from the vessel should be kept open.
    - The hot water inlets and outlets of the environmental control unit from the diving support vessel should be connected and open.
    - The hot water inlets and outlets of the environmental control unit from the inboard system of the SPHL should be closed and be ready to be opened as soon as the boat reaches the water.
    - The onboard pressurization and exhaust valves should be closed.
    - The oxygen makeup valve from the saturation control room should be open.
    - The oxygen makeup valves of the onboard control panel should be closed.
    - The isolation valve of the analysis of the saturation control should be open.
    - The isolation valve of the onboard analysis should be open, and the analysers calibrated.
    - The isolation valve of the depth gauge of the saturation control should be open.
    - The isolation valve of the depth gauge of the onboard control panel should be open.
    - The intercom to the saturation control is working. Also, the communications from the onboard panel to inside the chamber should be checked and then closed.
    - The other valves of the control panel should be function tested and closed. It is also the lights that must be sufficient to allow reading a document and the instruments.

- The integrated fire fighting system of the chamber works on the same principle as those installed in the other chamber except it is triggered manually by the chamber operator. For this reason the main line is closed externally and open in the chamber and the backup line is open externally and closed in the chamber *(see in the drawing below)*.



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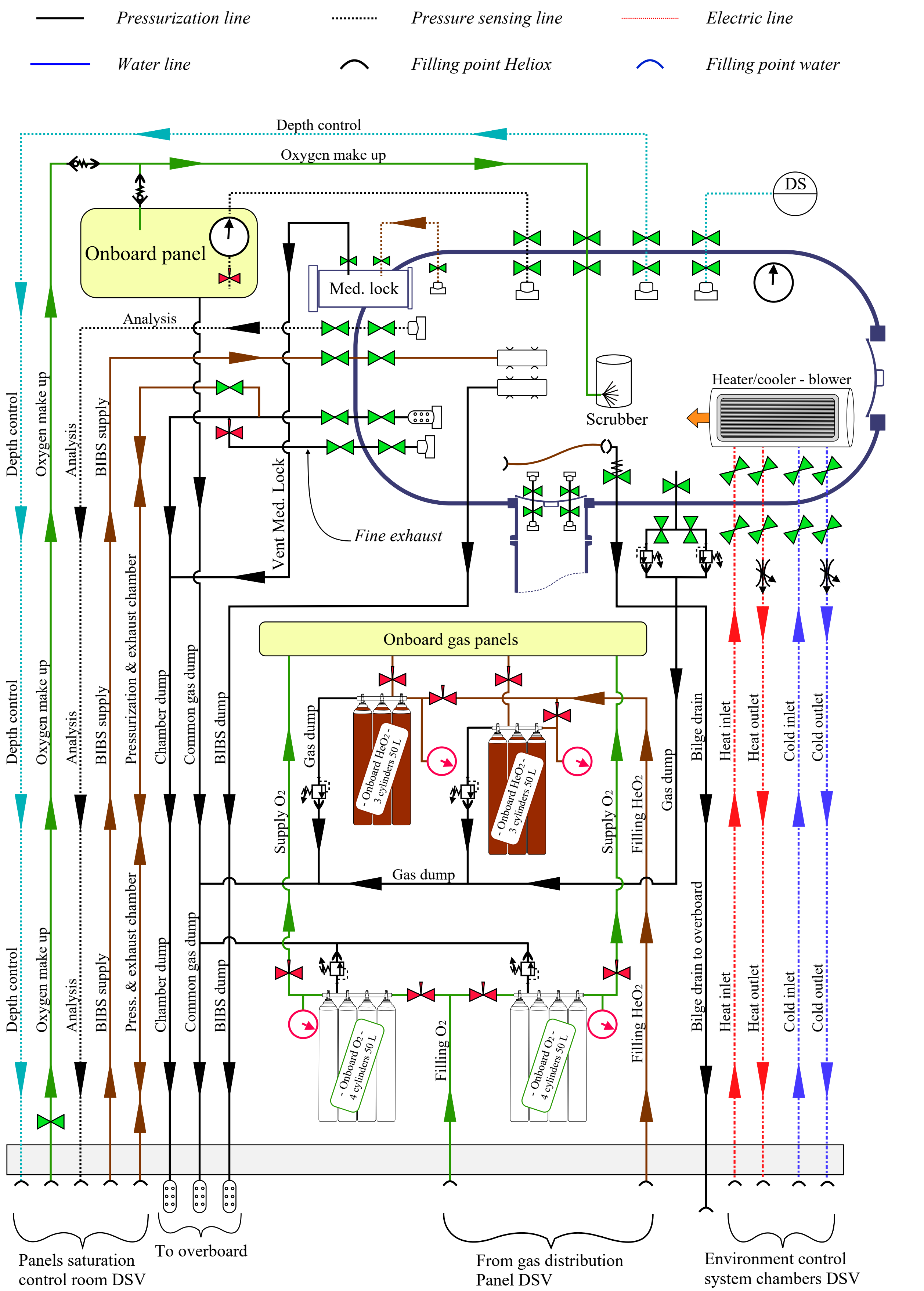


- Due to the function , the internal parts of the HRU are provided with particular elements that must be checked:

- The bottom door of modern SPHLs slides on rails instead to be articulated on a hinge. It should be clean and should slide easily on its rails. Also, its O ring should be undamaged and slightly silicone greased. It should be easy to close and open, and a spare O ring should be provided.
- A rubber mallet + the relevant tapping code should be provided and visible.
- At least two hand lights should be provided.
- Seasick tablets should be provided in sufficient quantities. Note that such tablets should also be available in the transfer lock.

- Lung powered scrubbers should be provided (1 per diver + at least 1 backup unit).
- Passive survival suits should be provided plus one spare.
- Urinary sheaths and vomit bags should be provided in sufficient quantities.
- Toilet paper should be provided in sufficient quantity.
- Every seat should be checked for general condition and be equipped with a four points harness.
- Helmets of rope access work type must be present (one per diver + one spare).
- The pulley block with its dedicated rope to transfer an injured diver through the connecting trunk should be available.
- Saddles to secure the stretcher, ropes, and a roll of duct tape should be present.
- Food should be stored onboard to feed the divers and the crew for at least 72 hours, based on 37 calories/kg + 10 calories/hour effort. Note that military combat rations provide 3200 calories each, and thus are appropriate for this purpose. Also, fluid intake must be stored ready for use. It should be based on a consumption of 100 to 150 ml/hour per person. Three can openers should be ready for use near the food rations. The maximum possible quantities should be secured inside the chamber to avoid lock transfers that are gas consuming and must be reduced to the minimum.

- The clamping system of the HRU must also be verified:
  - The clamp should have been tested and be closed with the interlock in position to engage when the trunk will be pressurized.
  - The pressurization & exhaust isolation valves should be open.
  - The local exhaust valve should be closed.
  - The intercom to the saturation control room should be tested.
  - The pressure gauge should be calibrated and indicate zero. If a valve is fitted to isolate it, it should be open.
  - The emergency breathing apparatus set for the clamp operator should have been tested.
- Besides the clamping system, the external parts of the boat should be visually checked. Note that it is normally the responsibility of the pilot.
  - Besides the clamping system, the external parts of the boat should be visually checked. Note that it is normally the responsibility of the pilot.
    - The hull, propeller, rudder, and water inlets and exhausts should be in perfect condition
    - The lifting and towing rigging should be in place, secured, and their certification should be visible and up to date.
    - The sea fastening of the HRU should be in place, in good condition, and secured.
  - The boat should also be designed and be fitted with the navigational, communication, and survival tools indicated in point 1.2.7.2. These elements should be checked by the pilot in charge of the SPHL and his aid.
  - Water and food for the divers inside the chamber are already indicated in the previous point. Also, water and meals should be provided to the LSTs on duties and the sailing crew. They should be calculated on the same basis as for the divers.

3.1.2.5 - Starting the Hyperbaric Environment Control Systems (HECS)

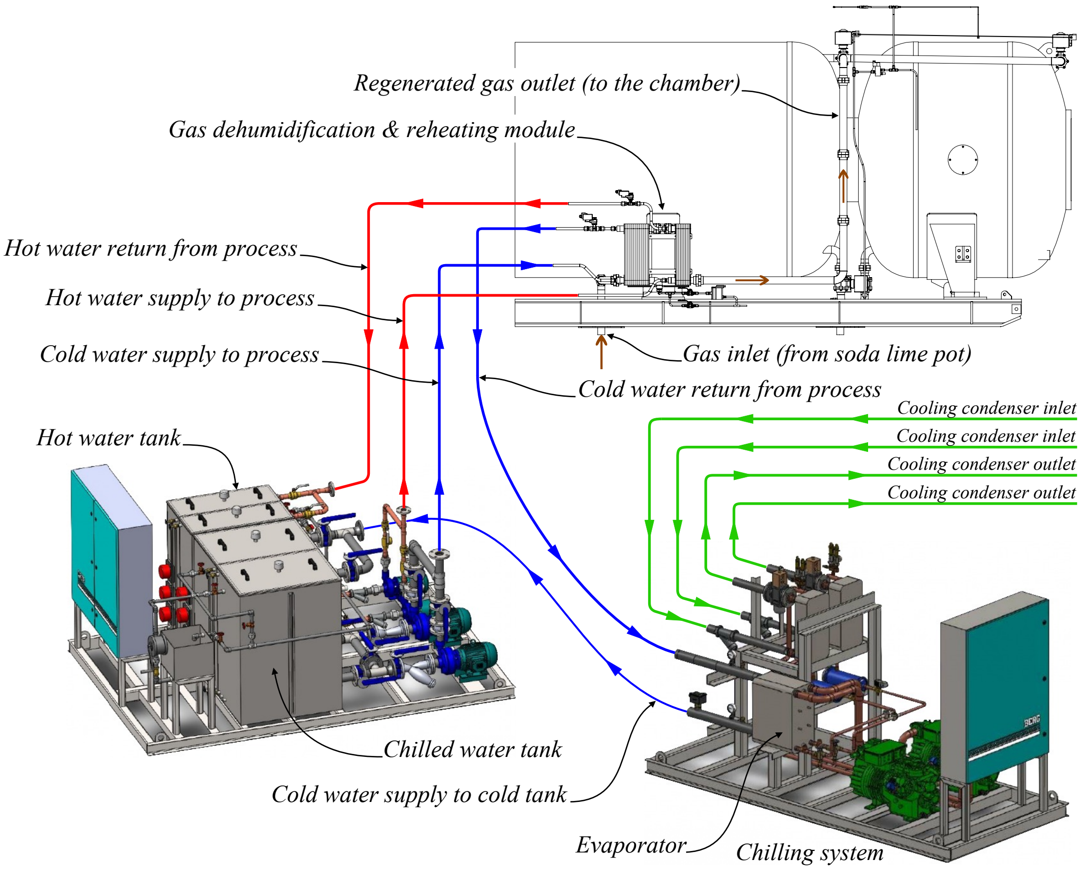
Note that this description is based on the systems taken as reference that are described in point 1.2.4.

The first operation consists of setting up the cooling and heating system. Note that the valves of the chambers should have been made in the correct position during the chamber checks. However, the technician must be 100% sure that these valves have been opened or closed if the checks of the chambers have been performed by other people.

1. The technician ensures that the hot and chilled water/glycol supply and return valves on the hot and chilled water/glycol manifold at each chamber that is to be made ready for occupation are open. He also ensures that the supply and the return hot and chilled water valves of the chambers not to be in service are closed. Note that hot and chilled water/glycol is supplied to all the Hyperbaric Environment Regeneration System heat exchangers alongside each chamber *(see in points 1.2.4.1 & 3.1.2.3.2, and the drawing above)*.
2. Internally, in each chamber and transfer Lock, the technician ensures that the hot and chilled water/glycol skin valves connected to the atmosphere handling unit to be in service have been opened. Also, he ensures that the skin valves to the standby atmosphere handling unit are closed.
3. On the Pump/Tank skid, the technician selects the cold water/glycol tank to be on line and then opens the supply valve from this tank to the selected circulation pump. He then opens the discharge valve from this pump to the cold water/glycol manifold. On the chambers' return line, the technician opens the return valve to the selected cold water/glycol tank and closes the return line valve to the standby tank.
4. At the selected chilled water plant compressor skid, the technician opens the cold water/glycol return valve to the evaporator and opens the discharge valve from the evaporator to the cold water/glycol tank. At the selected cold water/glycol tank, he opens the water inlet valve from the compressor skid.
   Then the technician closes the tank cross over balance valve between the two cold water/glycol tanks and opens the selected tanks discharge valves to the selected tanks circulating pump. Then, he closes the standby pumps discharge valve and opens the online pumps discharge valve.
5. When the cold water/glycol circuit is open. The next step is to set the required cold water/glycol temperature at

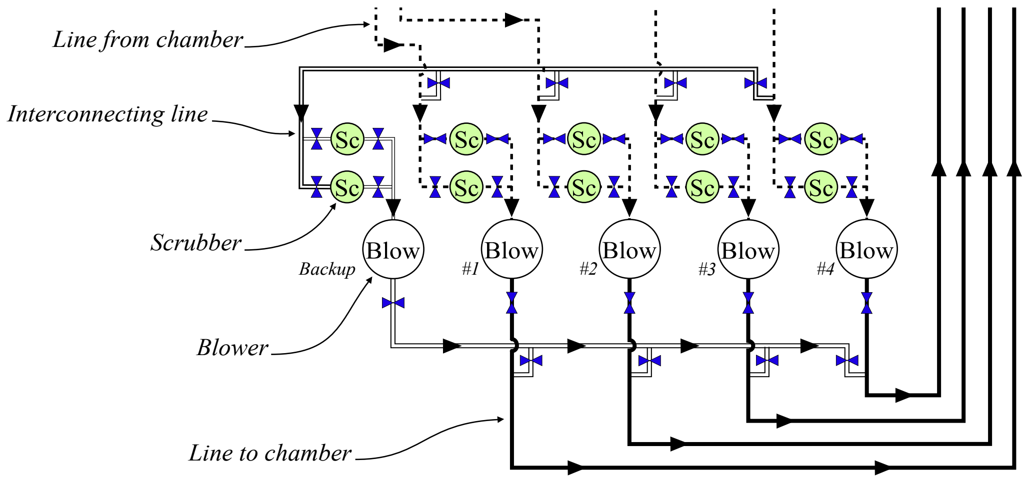
the cold water/glycol compressor skid:
- At the tank/pump skid, the technician starts the selected circulating pump. As a result, the cold water circulates in the system, and the compressors start and stop automatically to control the temperature of the water/glycol in the tank at the set point.
- The water/glycol pressure in the supply manifold is controlled to 2 bar by a back pressure control valve, and the water in excess is being dumped back into the return line.

6. When the cold water is set up, the technician selects the online hot water tank at the Pump/Tank skid and ensures that the tanks cross-over balance valve is closed. He then opens the two pump suction valves from the online tank, opens the return line valve to the online tank, and closes the standby tank's return line valve. To finish, he opens the online pump discharge valve and closes the standby pumps discharge valve, and sets the required hot water temperature at the control panel. When these operations are completed, the hot water circuit is open.



When the heating and cooling circuits are set up, the technician must setup the blowers and scrubbers. It is assumed that we are at the chambers' preparation and that the units are not yet pressurized.

1. The technician ensures that the soda-lime and Purafil have been renewed as the saturation must start with fresh soda lime. If the soda-lime has not been changed for any reason, the technician prepares the CO2 scrubbers for the chambers that are to be occupied.
   The procedure to open the pots, change the cartridges, and close them is already explained in point 2.3.2.2. The only difference is that the system is not yet pressurized, which does not remove the precautions that are to be in place for this operation. When this operation is completed, the technician ensures that the covers are fully secured, and the vent interlock valves are closed.



2. The technician opens the inlet and outlet ball valves to the online scrubber pots and closes the inlet and outlet valves to the scrubber pots. He also closes the cross over valve of each blower skid inlet and outlet that connects to blower skid #5, which is the standby blower skid.
   He then closes all the scrubber pot isolation valves and the blower outlet valve on the standby blower skid.
   Then, he closes all the scrubber pot balance line valves and vent valves.
   In the saturation control room, the chamber operator opens the Hyperbaric Environment Regeneration System (HERS) inlet and outlet valves of the Living Chambers and Entry Locks to be used.
3. When the valves are confirmed open, the blowers that are to be used for the occupied chambers can be started (that is usually done on the electrical panel at the proximity of the machine), the speed of the blowers can be set using the variable speed drive on the blower control panel. As a result, the gas starts to circulate through the system. At the chambers, the airflow to the Entry Lock can be reduced by partially closing the internal inlet isolation valve. Some adjustments can also be made later when the chambers are occupied, and the environmental gas is heliox. Similar adjustments can be made to the adjustable vents in the inlet duct at the top of the Living chamber to give a good distribution of gas throughout the chamber.
4. When the blower is started, the technician sets the required temperature and humidity for each chamber. That can be done through the control panel of the machine, or the Proportional Integral Derivative (PID) controller that is situated in the saturation control *(see point 1.2.4.2)*. The advantage of the PID controller is that it automatically manages the position of the modulating flow control valves on the outlets of the HERS heat exchangers at the side of each chamber. These control valves regulate the flow of hot water and cold water/glycol through the heat exchanges depending upon the PID controller's signal. In case that the system is not equipped with such a device, these adjustment have to be performed manually.

1 - main isolator switch
2 - Variable speed drive
3 - Start button
4 - Panel fan
5 - Stop button
6 - Emergency stop button
7 - Reset button
8 - No flow warning light
9 - Run fault light
10 - Motor run light

5. When the setup is completed, each chamber's doors are closed, so each unit is fully isolated, and the team waits until the internal temperature and humidity have stabilized before the divers can enter the chamber and begin the blowdown.
6. When the chamber is compressed, the density of the gas increases, and the load on the blower motor increases accordingly. For this reason, the blower speed and amperage must be readjusted according to the guidelines provided by the manufacturer. If that is not done, the blower may trip. As an example Lexmar provides the following tables:

Depth (msw)	*VFS (Hz)*	*Speed (RPM)*	*Depth (msw)*	*VFS (Hz)*	*Speed (RPM)*
15	60	3600	100	45	2700
24	55	3300	150	40	2400
50	50	3300	200	35	2100
75	50	3000	300	30	1800

3.1.2.6 - Prepare the Life Support Package (LSP), and the Hyperbaric Reception Facility (HRF).

The divers cannot be committed to saturation as long the hyperbaric reception facility and the life support package onboard the rescue vessel are not checked and activated.
To do it, the LSTs have to transfer to the rescue vessel. If the Hyperbaric Reception Facility is situated onshore, the checks have to be performed by the LSTs in charge. These checks are based on the same principle as those of the system onboard the diving support vessel.

- When the checks of the LSP are completed, the installation is made ready to start immediately if needed and closed. Regular checks will have to be organized to ensure it is ready to be activated. If for any reason, this system cannot be used, the saturation cannot be launched or continue. Regarding these checks, the ideal is to perform them every day. However, due to complications in transferring the LSTs safely, many companies do them every week.

- When the Hyperbaric reception facility checks have been fully completed, it is pressurized at the relevant depth, and the Life Support Supervisor (LSS) onboard the diving support vessel is informed that the installation is activated and that the saturation can start. A daily report regarding this installation's statement will have to be sent to the LSS and the diving superintendent every day. As for the LSP, if a technical problem makes this installation unusable, the saturation has to be aborted.

3.1.3 - Set a policy for electronic devices in chambers

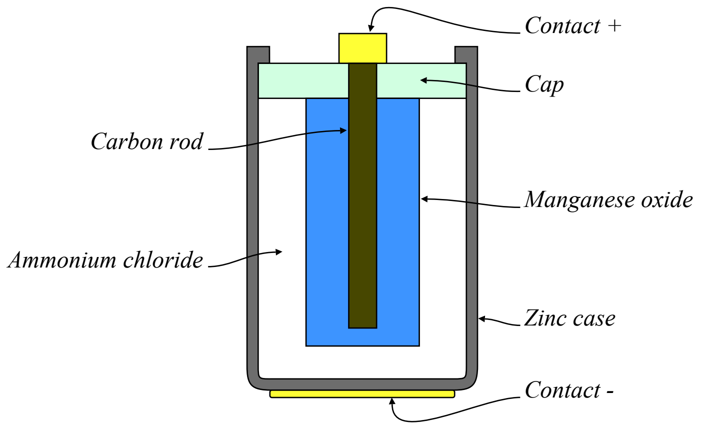
The electronic and computing industries propose products that are increasingly reliable, compact, and easy to implement, in addition, to the fact that they provide much more functions than the electromechanical devices they are gradually replacing for all these reasons. Thus, we can say that digital electronic apparatuses have become an essential part of our universe as we are today fully dependent on them.
An aspect of this dependence is that most people working in the offshore industry consider cell phones, tablets, laptops, and video games essential means of contact and entertainment they do not want to be deprived of. As a result, these devices are omnipresent in the accommodations and consequently in the hyperbaric chambers.
However, the use of electrical and electronic apparatus in hyperbaric chambers poses several safety problems. The most discussed is that their batteries are often involved in undesirable events such as thermal runaways resulting in sudden fires. For these reasons, rules must be implemented regarding the transfer and use of such systems in chambers. These directives must be risk assessed to ensure that any hazard is considered and relevant control measures are in place. This process is to be done by the company management and, of course, the divers as they are the most involved in case of an incident. The purpose of this section is to provide elements for the elaboration of guidelines.

3.1.3.1 - Batteries that can be found in chambers

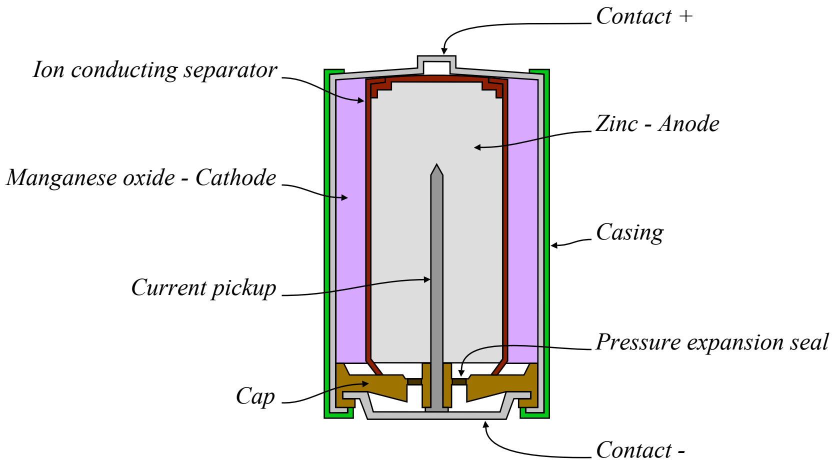
The batteries that can be used to energize portable items usually found in chambers, can be classified as follows:

3.1.3.1.1 - Non-rechargeable batteries

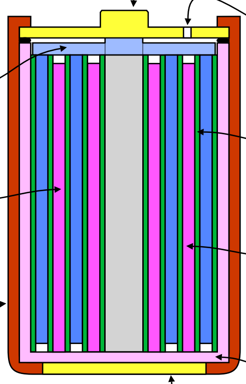
- zinc–carbon batteries:
  Zinc-carbon batteries are composed of a zinc can (anode) that contains a layer of ammonium chloride (NH4Cl) or zinc chloride (ZnCl 2), impregnating a paper layer that separates the zinc can from a mixture of powdered carbon (graphite) and manganese oxide (MnO2), which is packed around a carbon rod. These batteries are the 1st model commercialised, and are reputed very safe. However, they offer a limited capacity compared with more recent systems. Despite this inconvenience these batteries are still used to energize small items such as portable lights, remote commands, portable analysers, etc.. One of the reasons they are still fabricated is that they are cheap. Another inconvenience of these batteries is that their chemical components leak outside the container when they are at the end of their life, which may result in corrosion or destruction of the contacts of the items they energise.



- Alkaline batteries
  These batteries are composed of an alkaline electrolyte of potassium hydroxide (KOH), a negative electrode made of zinc, and a positive electrode made of manganese dioxide (MnO_2). The alkaline electrolyte, made of potassium hydroxide, is not part of the reaction; only zinc and manganese dioxide are consumed during discharge. These batteries are used for the same applications as zinc-carbon batteries. However, an alkaline battery has between three and five times the capacity of a zinc-carbon battery.

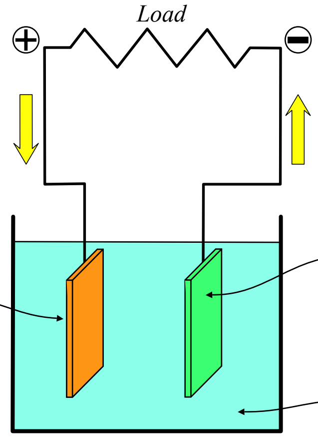


- Primary lithium batteries /lithium-metal batteries
  Disposable primary lithium batteries, also referred to as lithium-metal batteries, must be distinguished from secondary lithium-ion or lithium-polymer, which are rechargeable batteries.
  These batteries have metallic lithium as an anode. The most common type uses metallic lithium as the anode and manganese dioxide as the cathode, with a salt of lithium dissolved in an organic solvent as the electrolyte.
  These batteries provide high charge density and voltages from 1.5 V to approximately 3.7 V. They are much more durable than alkaline batteries, and can be used for the same applications. They are also the preferred batteries to energize items such as watches, clocks, cameras, calculators, computer BIOS, gas analysers, pacemakers, and other medical and scientific equipment.
  Note that such batteries have been involved in numerous incidents. For this reason, limitations regarding their transportation have been enforced.



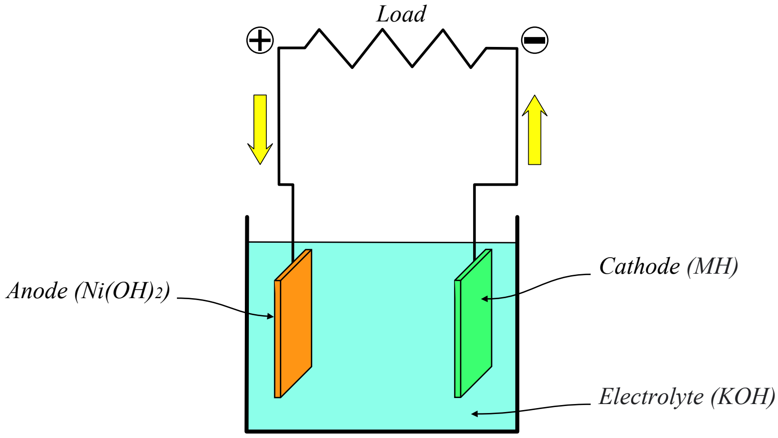
3.1.3.1.2 - Rechargeable batteries

- Nickel-cadmium batteries
  Nickel-cadmium batteries use nickel oxide hydroxide and metallic cadmium as electrodes. Typically, the positive electrode is made of Nickel hydroxide (Ni(OH)2), and the negative electrode is composed of Cadmium hydroxide (Cd (OH) 2), with the electrolyte itself being Potassium hydroxide (KOH). They are commonly developing 1.2 volts when used individually. Miniature units can be used for energizing cameras, computer-memory standby, gas detectors, and other devices. They can also be assembled into battery packs (power banks) that develop higher voltages and can be used to refill cell phones and other devices. The advantages of these batteries are that they can be stored for a long time, either discharged or charged.
  The main inconveniences of such batteries are their relatively low energy density and low charge capacity. Also, they have a limited number of charging and discharges cycles (about 1000 cycles). In addition, they start to lose their voltage after a certain number of cycles or repeated incomplete charges and discharges. This voltage depression is called the “memory effect”.
  Note that the electrolyte of these batteries is corrosive. As a result, contact with internal components may irritate the eyes, respiratory system, and skin. Improper charging can cause heat damage or even high-pressure rupture. Also, should an individual cell from a battery become disassembled, spontaneous combustion of the negative electrode is possible.

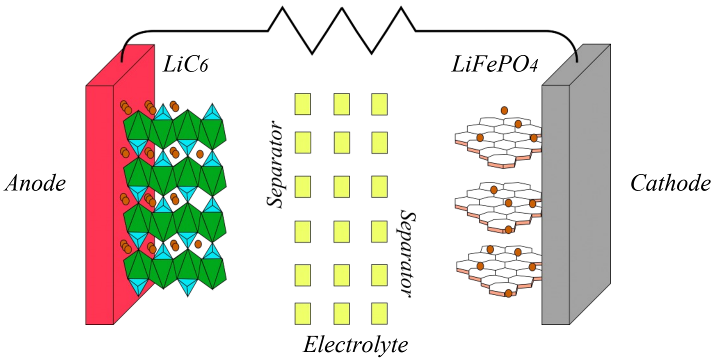


- Nickel metal hydride batteries
  Nickel metal hydride batteries have a chemical reaction at the positive electrode similar to that of the nickel-cadmium cell with the Anode made of nickel hydroxide (Ni(OH)2) and the electrolyte composed of potassium hydroxide (KOH). However, the Cathode is made of hydrogen-absorbing alloys (MH).
  These batteries have two to three times the capacity of nickel-cadmium batteries of the same size, with significantly higher energy density, although much less than lithium-ion batteries. They are used for similar applications to Nickel-cadmium batteries and replace traditional acid batteries and energize hybrid and electrical

cars, despite lithium-ion batteries being preferred for such applications.
These batteries are usually hermetically sealed. However, the electrolyte is composed of hazardous material that can cause severe irritation and chemical burns if released. Also, a harmful fume is emitted in case of a fire. Nevertheless, prevention of fire and explosion is said not to be necessary under normal use.



- Lithium-ion batteries
  Among the various existing energy storage technologies, rechargeable lithium-ion batteries are considered an effective solution to the increasing need for high-energy electro-chemical power sources.
  Rechargeable lithium-ion batteries offer energy densities 2 - 3 times and power densities 5 - 6 times higher than conventional nickel-cadmium and nickel-metal hydride batteries. Thus, they weigh less, take less space, and deliver more energy. In addition, these batteries have low self-discharge, high operating voltage, and no "memory effect."
  Each lithium-ion battery consists of an anode and a cathode separated by an electrolyte containing dissociated lithium salts, which enables the transfer of lithium ions between the two electrodes, as illustrated below:



  The electrolyte containing dissociated lithium salts, which enables the transfer of lithium ions between the two electrodes, is typically contained in a porous separator membrane that prevents the physical contact between the anode and cathode.
  When the battery is being charged, an external electrical power source injects electrons into the anode, composed of Lithium atoms intercalated between graphite sheets (LiC6). At the same time, the cathode, composed of lithium iron phosphate ($LiFePO_4$), gives up some of its lithium ions, which move through the electrolyte to the anode and remain there. During this process, electricity is stored in the battery in the form of chemical energy.
  When the battery discharges, the lithium ions move back across the electrolyte to the cathode, enabling the release of electrons to the outer circuit to do the electrical work.
  Lithium-ion batteries were mainly developed for portable devices such as cell phones, portable games, laptops, etc. They are also gradually designed for electric cars and the aviation industry. These batteries cumulate all advantages compared to the other models. However, they are also those the most involved in incidents such as unexpected fires. For this reason, their transportation is subject to stringent limitations.

3.1.3.2 - The certification process of batteries and electronic apparatus

Batteries cannot be sold without being certified as safe for the usage they are designed for. Regarding this matter, the high energy density of the lithium-ion batteries coupled with their flammable components creates new challenges regarding their storage and handling compared to the classical batteries using aqueous electrolytes that are considered more stable. As a result, and following incidents, the tests of Lithium-ion (Li-ion) batteries have been reinforced.
These tests are performed according to standards emitted by certification bodies that are internationally recognized and approved by the states where the batteries are sold, such as those listed below, but not limited to:

- UL, also known as Underwriters Laboratories, is a certification company involved in various industries, financial services, and governmental support, which operates worldwide and is headquartered in Northbrook in the USA.
- The International Electro-technical Commission (IEC) is an international standards organization involved in

electrical, electronic and related technologies that is headquartered in Geneva Switzerland.

- The Institute of Electrical and Electronics Engineers (IEEE) is an American non profit organization for electronic and electrical engineering with headquarters in New York.
- The United Nations "Manual of tests and Criteria" sets up procedures to be used for the classification of dangerous goods. The test requirements regarding batteries can be found in Part III/Subsection 38.3 (page 420).

The table below summarizes some tests and recommendations promoted by the organizations listed above.

Test purpose	***Description***	***Standards***
Insulation and Wiring	Minimum electrical resistance requirements for positive terminal and internal wiring insulation for batteries.	IEC 62133: 2.1
Maximum voltage Protection	The cell is subjected to the maximum voltage allowed by protection electronics; cell is insulated to create adiabatic conditions for 24 hours	IEEE 1725 6.14.5.1
Abnormal charging test	Over-current charging test (constant voltage, current limited to 3X specified max charging current); testing at 20°C (68°F); testing of fresh and cycled ("conditioned") cells; seven hours duration.	UL 1642, Sec 11 UL 2054, Sec 10 IEC 62133: 4.3.11
Overcharge	A discharged cell is charged by a power supply at a minimum of 10 V for an extended period.	IEC 62133: 4.3.9
	When the manufacturer's recommended charge voltage is not more than 18 V, the minimum voltage of the test is two times the maximum charge voltage of the battery or 22 V. When the manufacturer's recommended charge voltage is more than 18 V, the minimum voltage of the test is 1.2 times the maximum charge voltage.	UN - Manual of tests & criteria - Part III/38.3
Continuous low-rate charging	Fully charged cells subjected to manufacturer specified charging for 28 days, testing at 20°C (68°F); testing of fresh cells.	IEC 62133: 4.2.1
Forced discharge test	For multi-cell applications only; over-discharge test; testing at 20°C (68°F); testing of fresh and cycled cells.	UL 1642, Sec 12 UL 2054, Sec 12 IEC 62133: 4.3.10
	Each cell is forced discharged at ambient temperature by connecting it in series with a 12V D.C. power supply at an initial current equal to the maximum discharge current specified by the manufacturer.	UN - Manual of tests & criteria - Part III/38.3
Short-circuit test	Short circuit the cell through a maximum resistance of 0.1 ohm; testing at 20°C (68°F) and 55°C (131°F); testing of fresh and cycled cells.	UL 1642, Sec 10 UL 2054, Sec 9 IEC 62133: 4.3.2
	Short circuit the cell through a maximum resistance of 0.05 ohm; testing at 55°C (131°F); testing of fresh cells.	IEEE 1725 5.6.7
	The cell or battery to be tested is heated for a period of time necessary to reach a homogeneous stabilized temperature of 57 ± 4 °C, measured on the external case. This period of time depends on the size and design of the cell or battery and should be assessed and documented. If this assessment is not feasible, the exposure time shall be at least 6 hours for small cells and small batteries, and 12 hours for large cells and large batteries. Then the cell or battery at 57 ± 4 °C is subjected to one short circuit condition with a total external resistance of less than 0.1 ohm. This short circuit condition is continued for at least one hour after the cell or battery external case temperature has returned to 57 ± 4 °C, or in the case of the large batteries, has decreased by half of the maximum temperature increase observed during the test.	UN - Manual of tests & criteria - Part III/38.3
Evaluation of excess lithium plating	A production lot of cells is cycled 25 times at maximum charge/discharge rate specified by the manufacturer at 25°C (77°F). Minimum five cells then to be subjected to UL external short circuit test at 55°C (131°F). A minimum of five cells are examined for evidence of lithium plating.	IEEE 1725 5.6.6
Temperature cycling test	Test cells and batteries are stored for at least six hours at a test temperature equal to 72 ± 2 °C, followed by storage for at least six hours at a test temperature equal to - 40 ± 2 °C. The maximum time interval between test temperature extremes is 30 minutes. This procedure is to be repeated until 10 total cycles are complete, after which all test cells and batteries are to be stored for 24 hours at ambient temperature (20 ± 5 °C). For large cells and batteries the duration of exposure to the test temperature extremes should be at least 12 hours.	UN - Manual of tests & criteria - Part III/38.3
	The cell is cycled between high and low temperatures: four hours at 75°C (167°F), two hours at 20°C (68°F), four hours at - 20°C (-4°F), return to 20°C, and repeat the cycle a further four times; testing of fresh cells.	IEC 62133: 4.2.4

Test purpose	Description	Standards
Temperature cycling test	The cell is cycled between high- and low-temperatures: four hours at 70°C (158°F), two hours at 20°C (68°F), four hours at -40°C (-40°F), return to 20°C, and repeat the cycle a further nine times; testing of fresh and cycled cells	UL 1642, Sec 18 UL 2054, Sec 24
Heating test	Cell or battery placed into an oven initially at 20°C (68°F); oven temperature is raised at a rate of 5°C/minute (9°F/min) to a temperature of 130°C (266°F); the oven is held at 130°C for 10 minutes, then the cell is returned to room temperature; testing of fresh and cycled cells.	UL 1642, Sec 17 UL 2054, Sec 23 IEC 62133: 4.3.5
	Cell or battery placed into an oven initially at 20°C (68°F); oven temperature is raised at a rate of 5°C/minute (9°F/min) to a temperature of 130°C (266°F); the oven is held at 130°C for 1 hour, then the cell is returned to room temperature; testing of fresh and cycled cells.	IEEE 1725 5.6.5 and 1625 5.6.6.
Moulded case stress at high ambient temperature	The battery is placed into an air-circulating oven at 70°C (158°F) for seven hours; testing of fresh batteries	IEC 62133: 4.2.3
Altitude simulation	The cell is stored for six hours at 11.6 kPa (1.68 psi); testing at 20°C (68°F); testing of fresh and cycled cells.	UL 1642, Sec 19 IEC 62133: 4.3.7 UN - Manual of tests & criteria - Part III/38.3
Crush test	The cell is crushed between two flat plates to an applied force of 13 kN (3,000 lbs); testing of fresh and cycled cells.	UL 1642, Sec 13 UL 2054, Sec 14 IEC 62133: 4.3.6
Shock test	Three shocks applied with minimum average acceleration of 75 g; peak acceleration between 125 and 175 g; shocks applied to each perpendicular axis of symmetry; testing at 20°C (68°F); testing of fresh and cycled cells.	UL 1642, Sec 15 UL 2054, Sec 16 IEC 62133: 4.3.4
	Test cells and batteries are secured to the testing machine by means of a rigid mount which support all mounting surfaces of each test battery. Each cell is subjected to a half-sine shock of peak acceleration of 150 gn and pulse duration of 6 milliseconds. Alternatively, large cells may be subjected to a half-sine shock of peak acceleration of 50 gn and pulse duration of 11 milliseconds. Each battery is subjected to a half-sine shock of peak acceleration depending on the mass of the battery. The pulse duration is 6 milliseconds for small batteries and 11 milliseconds for large batteries.	UN - Manual of tests & criteria - Part III/38.3
Impact test	A 15.8 mm to 16 mm diameter bar is placed across a cell; a 9.1 kg (20 lb) weight is dropped on to the bar from a height of 24 inches (61 cm); testing at 20°C (68°F); testing of fresh cells.	UL 1642, Sec 14 UL 2054, Sec 15
	The test sample cell or component cell is placed on a flat smooth surface. A 15.8 mm ± 0.1 mm diameter, at least 6 cm long, or the longest dimension of the cell, whichever is greater. A type 316 stainless steel bar is placed across the centre of the sample. A 9.1 kg ± 0.1kg mass is dropped from a height of 61 ± 2.5 cm at the intersection of the bar and sample in a controlled manner using a near frictionless, vertical sliding track or channel with minimal drag on the falling mass. The vertical track or channel used to guide the falling mass is oriented 90 degrees from the horizontal supporting surface. The test sample is impacted with its longitudinal axis parallel to the flat surface and perpendicular to the longitudinal axis of the 15.8 mm ± 0.1 mm diameter curved surface lying across the centre of the test sample. Each sample is to be subjected to only a single impact.	UN - Manual of tests & criteria - Part III/38.3
Pack drop test	A package filled with cells or battery packs is dropped from a height of 1.2 m onto a concrete surface such that one of its corners hits the ground first	IEC 62281: 6.6.1
	Fully charged packs dropped from a height of 1.5 m onto smooth concrete for up to six repetitions on six sides (36 times); open circuit voltage monitored for evidence of internal shorts.	IEEE 1725.6.14.6
Free Fall	Each cell or battery is dropped three times from a height of 1 m onto a concrete floor	IEC 62133 4.3.3
Vibration test	Simple harmonic vibration applied to cells in three perpendicular directions; frequency is varied between 10 and 55 Hz; testing at 20°C (68°F); testing of fresh cells.	UL 1642, Sec 16 UL 2054, Sec 17 IEC 62133: 4.2.2

Test purpose	Description	Standards
Vibration test	Cells and batteries are firmly secured to the platform of the vibration machine without distorting the cells in such a manner as to faithfully transmit the vibration. The vibration is a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 minutes. This cycle is repeated 12 times for a total of 3 hours for each of three mutually perpendicular mounting positions of the cell. One of the directions of vibration must be perpendicular to the terminal face.	UN - Manual of tests & criteria - Part III/38.3
Venting	Requirement for a pressure relief mechanism on cells	IEC 62133: 2.2

During the various experimentations to which the device is submitted, the damages accumulated in the components and their interconnections are logged and investigated. A damage estimation model is then used to assess the risks of failure and their consequences to determine its robustness and safety of use. Manufacturers and certification bodies use these data and those from other sources to decide whether the apparatus can be sold or corrective measures need to be implemented to reinforce it. Note that the norms under which the apparatus has been tested must be indicated on it. Regarding this matter, it seems that no official test has been published regarding the capability of cell phones, laptops, and similar devices to withstand repeated exposures to hyperbaric conditions successfully. Note that the altitude simulation tests described for batteries are not sufficient as they are designed to control the ability of these objects to resist a depression instead of compression and that the maximum depression in the cargo of a plane is limited to less than 1 bar (787 mb) at 11,000 m altitude when the absolute pressure at 300 msw is 31 bar. Thus, we can say that the divers have improvised the pressure tests of the electronic devices they have transferred in chambers.

3.1.3.3 - Guidelines provided by the diving industry

Two organizations have published guidelines regarding using devices powered by batteries in hyperbaric chambers that can be taken into consideration:

- The well-known International Marine Contractor Association (IMCA), which is described in book #1 of this manual, and defends the interest of its members, has published the diving guidance IMCA D 041 “Use of battery-operated equipment in hyperbaric conditions”.
- QinetiQ, a multinational defense technology company, headquartered in Farnborough in England, has published a recommendation report called “A risk-based investigative study into the safety implications of using lithium-ion batteries in hyperbaric treatment chambers & saturation diving compression chambers”.

3.1.3.3.1 - IMCA D 041 “Use of battery-operated equipment in hyperbaric conditions” (October 2006)

This document updates and replaces the guidance AODC 62 “Use of battery-operated equipment in hyperbaric conditions”, published in 1993.

The authors of this document highlight the following risks and control measures:

- Items developing internal voltages over 30 volts DC can potentially be sources of electric shocks. However, the document's authors recognize that the battery-powered devices considered in this note use voltages significantly below the limit from which electric shocks are possible.
- The risks linked to battery-operated equipment in hyperbaric conditions are mostly overheating, fire, and leakage of toxic material, caused by partial or complete electrical short-circuits developing across the batteries. However, the authors of this document say that a mechanical accident is necessary to create such undesirable events from these low-energy devices. Also, even though it is theoretically possible that the ignition of the

materials that compose the device can then propagate in an oxygen-enhanced atmosphere, this combination of circumstances is improbable, and it can be minimized by limiting the power of the batteries.
The authors of this guidance conclude their analysis regarding fire risks by saying that measurements and trials would have to be carried out on each item and that if that is not possible, "any judgment on safety must be based upon the experience of the maximum size and type of battery that can be safely used under hyperbaric conditions to limit to a reasonably low level the energy available to cause serious overheating".

- There may be failure of the equipment during compression which may result in the collapse of the components or implosion in case of vacuum devices. The authors of the guideline suggest that such incident would not be a serious hazard to the chamber's occupant and the Life Support Technicians (LST).
- Helium may enter into the components during the saturation and cause the battery to explode during a rapid decompression in the medical lock. Also, it is said that another risk of explosion is linked to the possibility that the accumulated pressure in the battery may not be released sufficiently quickly during the ascent of the chamber. As control measures, the authors suggest that precaution must be in place when transferring such items through the medical lock with controlled and not too fast decompression and also ensuring that the devices transferred are designed to allow for equalization.
- Items, such as batteries, contain potentially toxic materials that can be released into the chamber atmosphere, causing pollution. The control measures suggested by the authors of the guidance are to limit the size of batteries to cells no larger than 'AA' size (1.5v) NiMH rechargeable or their physical equivalent in non-rechargeable form (500 mA/hr), and that items containing potentially toxic materials should not be permitted in chambers. In case of doubt about the composition of a battery, it should not be used until a competent person has assessed it. In addition, alternative solutions to batteries should be considered, and the authors of the document say that battery charging should never be performed in the chamber.
- It is also said that when some cells in a battery are exhausted, this places stress on the remaining cells, resulting in a reverse polarisation. For this reason, it is suggested that all batteries of a pack should be renewed at the same time. In addition, batteries can be affected by corrosion, and for this reason, they must be protected from humidity and immediately removed if the exposure to moisture has damaged them.

The document is completed by a table that classifies the battery-operated devices into those that are prohibited in a hyperbaric environment and those that can be used in such conditions following a relevant risk assessment. The authors of the document call this second category "potential problem".

- The prohibited devices are the following:
    - Rechargeable power tools
    - Batteries containing potentially toxic materials (mercury, lead-acid, lithium dioxide, lithium).
    - Mobile phones
    - Battery chargers
    - Cathode ray tube TV monitors
- The devices classified "potential problem" are the following:
    - LCD monitors/video players
    - Portable computers (laptops)
    - Rechargeable torches (not diver's type torch in a pressure housing)
    - iPod, Personal Digital Assistants (PDA)
    - Calculators
    - Cameras
    - Dictaphones
    - Digital analysers
    - Electronic clocks
    - Mini Disc players
    - Shavers
    - Toothbrushes

Note that this guidance has been published more than 15 years ago and should be updated:

- Portable computers and iPods, listed in the category "potential problem", are today energized by lithium-ion batteries due to the advantages provided by this technology. Also, the batteries of new devices are not removable. For this reason, they would be prohibited in hyperbaric chambers if this guideline would be applied.
- To complete what is said above, laptops and cell phones sold today are much more powerful than those available 15 years ago. As a result, the maximum power recommended in this guidance would be insufficient to energize them efficiently.
- Cathode ray tube TV monitors are no longer sold and replaced by Liquid Crystal Display (LCD) monitors.

These changes resulting from technological advancement are discussed further in the next points.

3.1.3.3.2 - QinetiQ - "A risk-based investigative study into the safety implications of using lithium-ion batteries in hyperbaric treatment chambers & saturation diving compression chambers" (July 2015)

QinetiQ says that the purpose of this report is to identify and assess the risks to the life of operators using Lithium-Ion battery (LIB) powered devices in saturation diving chambers and Deck Decompression Chambers (DDC) and to analyze

the International Marine Contractors Association's (IMCA) guidance D 041 on the use of lithium-ion batteries as power sources for consumer electronic devices in the hyperbaric environments.
This report leans on the fact that no incident record regarding the use of lithium battery-powered devices in hyperbaric chambers has been reported at the date of publication of the document, although a lot of diving contractors do not enforce the prohibition on the use of such devices recommended in IMCA D 041 and that many others consider it impossible to enforce an effective prohibition rule.

To identify and assess the risks of lithium battery-powered devices and publish relevant recommendations, QinetiQ has conducted a literature review and interviews with more than twenty Subject Matter Experts (SMEs) to gather the evidence necessary to construct a hazard analysis, perform a risk classification, and elaborate control measures.
As a result of this analysis, QinetiQ estimates the probability of a lithium-ion battery-powered device being involved in an energetic event is less than 1 in 21.3 million devices so that the probability of such an undesirable event is very low (as suggested by the aviation transportation report in point 3.1.3.2). So, the residual risk rating can be considered "acceptable", subject to implementing the recommended control measures and mitigation.
To conclude, QinetiQ says that using portable devices powered by lithium-ion batteries in hyperbaric chambers is safe as long as the recommendations indicated in the document are implemented. QinetiQ also says that the IMCA guidance D 041 should be updated at the earliest opportunity.

QinetiQ's recommendations are based on a risk assessment taking into account hazardous conditions arising from lithium-ion batteries used for portable electronic devices using reduced voltages such as MP3 players, digital cameras, hand-held games consoles, tablets, laptops, personal gas monitors, and other similar devices. We can summarize them as follows:

- *Recommendation 1:*
  The small scale hyperbaric cycling testing of a selected number of battery types from major manufacturers, in helium (to show that the batteries are resilient to both the pressure and the helium ingress) could be carried out in order to add confidence to the conclusion of this report.
    - Explanations and comments:
      QinetiQ says that people raised the concern that there may be a risk that helium diffuses into a battery during a heliox dive, which may cause this battery to expand and potentially burst during the relatively rapid decompressions that occur in medical locks, compared with the more gradual compressions/decompressions of the chambers containing diving personnel. It was felt that the likelihood of such an event might increase if these devices are exposed to saturation (Heliox) diving atmospheres for lengthy periods of time.
      To answer this concern, QinetiQ's Advanced Batteries Division said that the probability of this occurring during a short period is very limited. Also, even though helium penetration may occur over a long period of time, the quantity of gas that would enter the battery would not be sufficient to cause an undesirable event during decompression because the batteries are assembled with very little or no free space. Thus, this recommendation can be used to add confidence to this evaluation of the risk.
- *Recommendation 2:*
  All modified and non-Original Equipment Manufacturer (OEM) repaired devices to be prohibited from the chamber environment, only allowing OEM devices in original condition to be used.
    - Explanations and comments:
      QinetiQ considers that the batteries of small devices, such as mobile phones, are contained in hermetically sealed units that are considered sufficiently robust to withstand repeated hyperbaric compression & decompression cycles. This assumes that the batteries are compliant with recognized industry standards and are marked with relevant certification marks. However, QinetiQ considers that the integrity of non-OEM batteries cannot be guaranteed as their build quality is questionable. For this reason, QinetiQ says that the purchase of such batteries should be discouraged and not permitted for use within a chamber.
      QinetiQ also says that there are numerous replacement charging devices available for lost or damaged original devices. Some of these charging devices are untested and may not be safe enough to withstand the environmental hazards in a maritime workplace. For this reason, charging devices without recognized testing certification marks should not be permitted unless specifically authorized and certified.
- *Recommendation 3:*
  The operation of lithium-ion battery powered devices during both the initial compression to depth and the final stages of decompression (oxygen rich) should be limited to essential use only, i.e. the use of Lithium-ion battery entertainment devices is prohibited when in the "Fire Zone" as they cannot be deemed essential, as stated in the US Navy Diving Manual.
    - Explanations and comments:
      QinetiQ reminds us that a fire will not start when the oxygen percentage is below 6%, regardless of partial pressure. However, a spark is sufficient to ignite cotton overalls in an atmosphere where the oxygen percentage is 21%, but the partial pressure (PPO2) is over 700 millibar. The higher levels of oxygen percentage (>21%) during a saturation dive occur during the initial compression and the final stages of decompression. During most of the dive, the oxygen levels are below 6%. However, note that the Deck Decompression Chambers used for surface decompression and medical treatment are usually above 21% oxygen due to oxygen leaks during the decompression or the hyperbaric treatment.
- *Recommendation 4:*
  To prevent incidents occurring in an area of excessive dampness and humidity, the recommendation is to

damp conditions, such as the diving bell, and transfer chamber (transfer lock).

- Explanations and comments:
  QinetiQ explains that most electronic devices are not waterproof or capable of operating effectively or safely in the very humid atmospheres found in the bell or the transfer lock. For this reason, the authors of this recommendation consider it necessary to prohibit the use of these devices within those sections of a hyperbaric diving system unless the device is specifically designed for such conditions (i.e., splash or waterproof). Note that these waterproof devices will have to be opened during the phases of compression and decompression not to be crushed by the pressure or explode.

- *Recommendation 5:*
  It is recommended that certification marks (usually found on the exterior of lithium-ion batteries) should always be checked to ensure that they include the standards of test and that the applicable certification is in order. The aim is to establish the levels of compliance and safety of a device. Such a check would primarily be the responsibility of the personnel using the devices, but the dive supervisor can also check them prior to entry to the chambers. This will help establish if the devices are Original Equipment Manufacturer (OEM) equipment, are from reputable manufacturers and are built to internationally recognised standards.
  - Explanations and comments:
    This recommendation is a complement to recommendation #2. However, even though it was easy to implement it with the previous generation of cell phones (QinetiQ published this study in 2015), it is difficult or impossible to implement it with those currently sold. The reason is that batteries were accessible from the back of the devices with the previous generation of phones, so the users could easily access and remove them. That is not possible with the new phones and tablets as the batteries are embedded and glued inside them, so the devices' touch-screens have to be removed to access them, and the glue or the adhesive band must be taken off to detach them. As a result, only trained people can change these batteries. Of course, that does not eliminate the fact that non-Original Equipment Manufacturer (OEM) equipment can be installed in place of the original one by a phone technician.

Cell phone with removable battery (manufactured in 2012)

Tablet 7” with non-removable battery (manufactured in 2016)

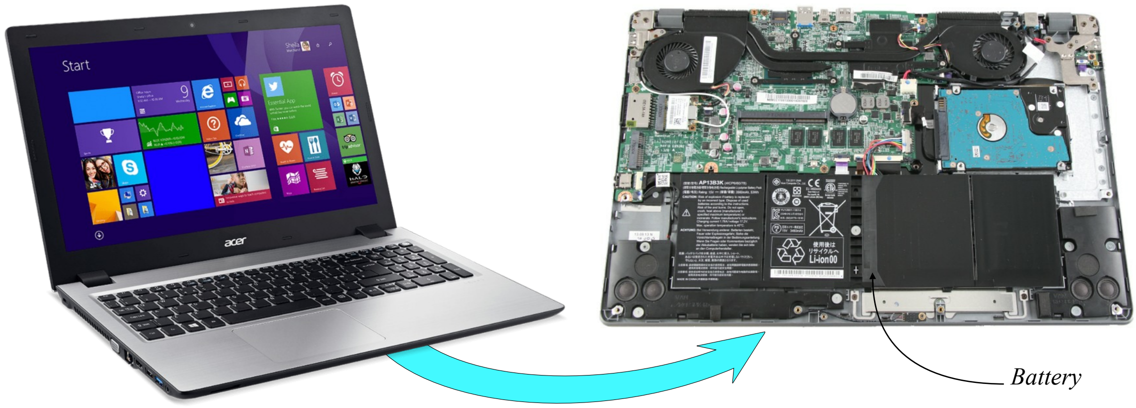
- *Recommendation 6:*
  We recommend procedures to ensure crew within the chamber are not developing and utilising elaborate techniques to conduct charging of equipment within the chamber, such as the using of the USB ports on a laptop and other devices with USB ports, or using aftermarket devices to provide a charging power supply.
  - Explanations and comments:
    Charging phones or tablets is considered a phase where the risks of fire are more elevated. For this reason, this activity should not be performed within chambers.
    QinetiQ says that charging devices within chambers is common today, with laptops and other USB sockets used to charge phones. Additionally, some divers use the bed lightings to charge the devices with an adaptor plugged into a bulb socket.
- *Recommendation 7:*
  We recommend that the Hazard Log is maintained and regularly reviewed to ensure that it still represents the current scenario.
  - Explanations and comments:
    QinetiQ says that to reduce the risks to a tolerable level, it is emphasized that the defined mitigations must be implemented as discussed in the meeting and documented in the Hazard Log (Hazard evaluation).
    QinetiQ also says that any deviation from these mitigations will invalidate this qualitative risk assessment.
    In addition, they say that the application of mitigations does not guarantee that a catastrophic event will never happen.
- *Recommendation 8:*
  It is recommended that this study is updated at least once every 3 years in order to understand the effects of new technology when used in diving chambers, and the impact of control measures implemented for the use of devices as a result of this report.
  - Explanations and comments:
    QinetiQ explains that there is a risk that the pace of technology advancement may rapidly change the size, shape, and power density of the batteries available for use in mobile phones and consumer electronic devices, rendering the findings of an investigation obsolete. It is what has happened to the document IMCA D 041 that has been written 15 years ago, which is like an eternity regarding electronic devices. It is also the case with this study, as demonstrated in the comments of recommendation #5.
- *Recommendation 9:*
  It is recommended that the total lithium-ion battery power density contained within a single device should be restricted to a maximum of 100 Wh to reduce the effective energy release in the event of a catastrophic lithium-ion battery failure.
  - Explanations and comments:
    QinetiQ says that a power density limit of 100 Wh is considered the best practice by the airline industry. Restricting the size of the battery to below 100 Wh will reduce the magnitude of an energetic event, potentially limiting an explosion to a fire scenario. This measure may not prevent a catastrophic event. Still, it can increase the crew's ability to escape safely and take remedial action against the fire.
    Note that electric charges of batteries are usually provided in milliamp-hours (mAh). To convert mAh to Watt hours (Wh), apply the following formula: Watt-hours = milliamp-hours × volts / 1000.
- *Recommendation 10:*
  It is recommended that a simple condition check of all devices taken into a chamber be conducted on entry.
  - Explanations and comments:
    QinetiQ considers that all batteries/devices built by reputable manufacturers are sealed units and are robust enough to withstand repeated hyperbaric cycling; however, this cannot be guaranteed. Hyperbaric cycling tests would need to be completed to assure their safety for use in chambers. Battery inspection (where access is possible) is vital to detect early signs of deterioration. Any batteries identified as defective should be removed and replaced with Original Equipment Manufacturer (OEM) approved replacements.
    This recommendation is a complement of recommendations #2 and #5. My comments are those of recommendation #5.
- *Recommendation 11:*
  It is recommended that the charging of lithium-ion battery powered devices or lithium-ion batteries within saturation diving chambers and deck decompression chambers is prohibited as this has been identified as the activity that presents the most risk of a catastrophic lithium-ion battery failure.
  - Explanations and comments:
    This recommendation is the complement of recommendations #2, #6 & #10.
    QinetiQ says that overcharging or a faulty charger could cause a failure in the battery leading to an energetic event. For this reason, it is preferable to refill the batteries outside the chamber.
    However, QinetiQ says that such an operation requires transferring the batteries/devices through the medical lock, increasing compression, and decompression cycles. Although QinetiQ considers that batteries and devices built by reputable manufacturers are sealed units robust enough to withstand repeated hyperbaric cycling, they say that this cannot be guaranteed and that hyperbaric cycling tests would need to be completed to ensure their safety for use in chambers.
    QinetiQ also says that battery inspection (where access is possible) is vital to detect early signs of deterioration. Also, any defective unit should be removed and replaced with an Original Equipment Manufacturer (OEM) approved replacement. The authors of the recommendation also suggest ensuring

that divers do not elaborate charging methods in the chamber.
My comments regarding the control of batteries are those of recommendation #6. Also, note that it is complicated to ensure that divers are not refilling their cell phones through laptops' USB ports. The only solution is to ensure that USB cables are not transferred within the luggage of the divers.

- *Recommendation 12:*
  It is recommended that suitable Personal Protective Equipment (PPE) is provided in all chambers where lithium-ion battery powered devices are used (i.e. heat and solvent resistant gloves to handle casualty batteries or devices; BIBS etc.).
  - Explanations and comments:
    A burning lithium-ion battery emits extreme temperatures in addition to pollutants. For this reason, it cannot be manipulated with classical gloves. "Polybenzimidazole" fiber gloves that can resist temperatures up to 700 Cº seem the most efficient currently sold. Also, tongs similar to those used by blacksmiths are antique efficient tools to manipulate burning items. Note that hyperbaric extinguishers and the Built-In Breathing System (BIBS) are supposed to be ready at all times.
- *Recommendation 13:*
  It is recommended that all relevant staff should be trained in the potential consequences of bad practices when using lithium-ion battery operated devices. It is imperative that adequate training is provided.
  - Explanations and comments:
    QinetiQ suggests organizing training for all hyperbaric and diving staff to address a lithium-ion battery fire situation that includes preventative procedures in the preparation and use of lithium-ion battery-powered devices within a chamber, in addition to emergency response techniques.
- *Recommendation 14:*
  It is recommended that a separate facility (external to and away from the vicinity of a saturation diving chamber or Deck Decompression Chamber) is established for the recharging of batteries remote from the chamber. This should prevent an energetic event from causing harm to personnel within the chamber.
  - Explanations and comments:
    QinetiQ highlight the fact that there is a risk that the adjacent area to a device being charged may be damaged from overheating or fire if a charger fault causes an energetic event.
- *Recommendation 15:*
  The provision of an alternative power supply within chambers and the attendant removal of device batteries (such as from laptops or medical equipment) as seen at Chichester hospital HTC is recommended.
  - Explanations and comments:
    QinetiQ refers to the Hyperbaric Treatment Chamber (HTC) of St Richards Hospital, Chichester (UK), in which operators actively prohibited the use of lithium-ion-powered devices at the date of publication of the report. The report says that medical handheld equipment used in the chamber was modified to run from a power supply that was pre-transformed externally and then supplied inside at the lower voltage/level. This arrangement was similar to the one on the photo below that shows a small laptop supplied by an external supply block that is working with the battery block removed. Thus, the external supply block is plugged into the 220 volt electrical supply, and the 19 volt DC output cable from the supply block supplies the laptop without passing through any battery. Thus, we can say that such a system is not difficult to implement, as the 19 volt supply could be transferred inside the chamber through a penetrator.

However, if making a laptop working without a battery and then adapt it to a hyperbaric chamber was easy with the models available before 2015; it was already not possible with the models of cell phones sold at this time that needed to have their lithium-ion battery in place to start and could not be started if the battery was damaged or discharged.
Based on the fact that the latest generations of laptops are built on similar designs to cell phones, making them work without a battery would be more complicated or impossible because their batteries are now embedded inside the devices. Of course, a trained technician can access such a battery by unscrewing the laptop's bottom cover, as we can see in the photo on the next page. Nevertheless, following discussions

with computer specialists, it appears that some of these portable computers might work without a battery after a modification and that some others will not start.



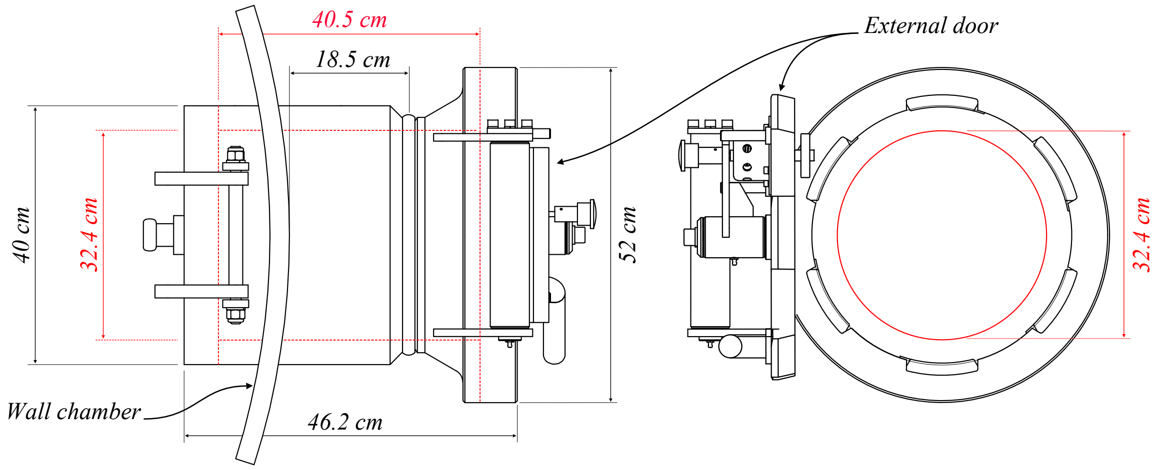
Based on what is said above, we can say that implementing such a process of modifications with the latest generations of multimedia equipment may result in unsuccessful attempts and limit the devices that can be transferred inside hyperbaric chambers to a few models specifically designed for this purpose. For these reasons, this solution can be considered only with devices belonging to the company.

- *Recommendation 16:*
  Where possible, the use of alternative types of battery (non-rechargeable) is recommended for all devices used within saturation diving chambers and deck decompression chambers (also called Hyperbaric Treatment Chamber), as this will completely remove any risk associated with lithium-ion batteries.
  - Explanations and comments:
    This procedure is also recommended in IMCA D 041. It would be complicated, or probably impossible, to implement it for the reasons already explained above (batteries of new generations of laptops and cell phones are not removable), the fact that alternative types of batteries would need to have shapes corresponding to the original slots of the devices they are supposed to energize. Also, batteries 2 or 3 times bigger than those originally designed for the devices would be necessary to provide the same working times depending on the models. As for the solution above, this option should be limited to devices belonging to the company if implemented.
- *Recommendation 17:*
  It is recommended the number of devices within the chamber complex is monitored and everything practicable is done to ensure that they are kept safe and used in accordance with the manufacturers' operating instructions, so that the safety of these devices is a priority at all times.
  - Explanations and comments:
    QinetiQ says there is a risk that a lithium-ion battery powered device may inadvertently be damaged within the hyperbaric chamber. As a control measure, it is proposed to make an inventory and monitor the devices using lithium-ion batteries within the chamber.
- *Recommendation 18:*
  It is recommended that all lithium-ion battery powered devices are switched off whilst not in use, with particular attention to transference through the medical lock.
  - Explanations and comments:
    QinetiQ specialists say that switching off the devices is a straightforward and effective way of securing them. The reason is that the batteries are isolated while switched off, which prevents the possibility of short circuits and further undesirable events whilst the device is unattended.
    In addition to what QinetiQ says in this report, a common practice was removing the batteries from the apparatuses. However, as previously explained, this is not possible with the devices of the latest generation.
- *Recommendation 19:*
  It is recommended that the total prohibition of all backlit Liquid Crystal Display (LCD) laptop screens within hyperbaric treatment and saturation diving chambers is strictly enforced. The prohibition of backlit LCD laptop screens should be included in the update of the guidance issued to IMCA members.
  - Explanations and comments:
    QinetiQ explains that the Liquid Crystal Display (LCD) screens of the very early laptops were prone to failure in hyperbaric conditions, resulting in short circuits in these devices.
    Regarding this recommendation, it must be highlighted that these portable computers are obsolete and no longer in service today.
- *Recommendation 20:*
  It is recommended that a suitable practicable maximum rate of compression / decompression is established and mandated for batteries and devices being transferred to and from the chamber.
  - Explanations and comments:
    QinetiQ says that despite their robustness, the structure of batteries may be affected by repeated fast compressions and decompressions. For this reason, it is expected that establishing maximum compression & decompression rates would prolong the life span and reliability of the batteries.
    Note that the authors do not indicate any specific descent or ascent rate.

- *Recommendation 21:*
  It is recommended that the use of the "hot box" is discontinued, on the grounds that the current 'hot box' could be introducing additional hazards. Personal protection Equipment (PPE) is required as part of the standard equipment needed to handle a casualty device (see Recommendation 12).
  - Explanations and comments:
    QinetiQ specialists say that some companies made steel boxes designed to transfer failing devices that may introduce additional hazards because they are not properly tested and approved for this purpose. They also say that IMCA members who took part in a hazard evaluation meeting considered that the best option is to don protective gloves and remove the malfunctioning device into the medical lock as quickly as possible.
    The comments we can make regarding protective gloves and tools that can be used are those already made for recommendation #12. However, I am not sure that transferring scalding items into the medical lock will not damage it. Thus cooling the device before this operation could be a better idea.
    This topic is also discussed in recommendation #22.
- *Recommendation 22:*
  The recommendation is that a blast resistant container, such as an ammunition box or similar box, which is specifically designed and tested to provide safe containment of potential energetic events, is used.
  - Explanations and comments:
    In complement to recommendation #21, QinetiQ specialists say that ammunition boxes can be used to contain the heat generated by an energetic event and transfer the device through the medical lock. They argue that these containers are not sealable or heatproof but are designed to contain all debris from an energetic event up to the United Nations explosives shipping classification system of 1.4 (minor explosion hazard). They also add that these boxes can be fitted with fire and heat resistant or insulating material that may help to contain the heat generated by an energetic event or filled with water.
    This solution can be considered suitable, provided that these boxes can contain the apparatus present in the chamber and can be transferred through the medical lock. As an example, the following ammunition boxes dimensions can be found on the Internet:

Ammunition	***Length***	***Height***	***Width***
5.56 mm NATO	30 cm	22 cm	16 cm
7.62 mm NATO	26 cm	16 cm	11 cm
12.7 mm NATO	28 cm	18.5 cm	16 cm
20 mm NATO	33 cm	34.5 cm	14 cm
40 mm NATO	44 cm	25 cm	16 cm

The medical locks of the saturation systems of UDS Lichtenstein and Picasso have an internal length of 40.5 cm and an internal diameter of 32.4 cm (see in red in the drawing below).



We can see that some of these ammunition containers cannot be used because they are too high or/and too long. It is the case of the boxes designed for calibre 20 mm and 40 mm. The other boxes of this list can be used for cell phones and tablets 10", but they are too small for most laptops. For example, devices with a 14" screen are approximately 32 cm long & 22 cm in width. That obliges to use smaller models with 10 or 11" screens whose external dimensions are approximately 25 cm long & 19 cm in width. So, even though this solution is efficient, it is not perfect. For this reason, a better solution is to provide fire containment battery bags designed to carry spare lithium batteries and portable electronic devices in aircraft and are promoted by the aviation industry. The configuration of these bags consists of high-temperature insulation & fire-resisting materials that are able to withstand the explosive release of energy and cell combustion as a result of a lithium-ion thermal runaway. These bags are sufficiently wide to contain laptops, so the only problem is to ensure that the device in the chamber can be transferred through the medical lock. Note that these bags can also be used to store the electronic apparatus when they are not used.

Additional QinetiQ recommendations for fire fighting:
In addition to the recommendations above, QinetiQ says that reputed safety organizations state that a water-based fire extinguisher is the most appropriate method for tackling a lithium-based fire because the water will cool the lithium and prevent the battery from rupturing and venting gases. In addition, it is considered that in the event of a battery rupture, water will help to contain any fluid leakage from the battery, and the water vapour in the air will help to reduce the risk of acidic gas. Regarding this guideline, note that the extinguishing agent of chamber extinguishers is an Aqueous Film Forming Foam (AFFF), which is suitable for any fires, including electrical fires up to 24 Volts.

QinetiQ completes its report by a risk assessment where the elements from the recommendation above are integrated to the fire fighting procedures and abandon saturation system procedures.

3.1.3.3.3 - To conclude with these guidelines

The reports IMCA and QinetiQ described in the previous point are more than 6 years old. Thus, they are outside the recommendations of QinetiQ, which suggests updating guidelines related to electronic apparatus every 3 years. That shows the difficulties of implementing such a process. However, both documents highlight potential hazards linked to the use of battery-powered portable electronic devices in hyperbaric chambers and suggest control measures that can be used for the assessment of the policy of the company. Other data from various professional associations, safety organizations, and certification bodies should also be used.
Note that the following facts that are also discussed in the comments of the recommendations of both documents have to be considered in the evaluation of risks and for the selection of the procedures:

- Lithium-ion batteries power today the totality of laptops and cell phones.
- Cell phones have replaced a lot of devices, including video games, clocks, calculators, and others.
- Since the publication of the QinetiQ report in 2015, the efficiency of lithium-ion batteries has been increased in terms of durability, energy storage capacity, and refilling speeds that are today two-three times faster than the units sold in 2015. That is linked to the fact that the electronic industry is a very competitive world where performances, innovations, and ease of use are essential to attract clients. For this reason, it may happen that despite the certification tests, some devices are not as robust as planned.

These facts demonstrate the importance of being aware of the industry's progress and implementing procedures for this.

3.1.3.4 - Evaluate the likelihood of occurrences

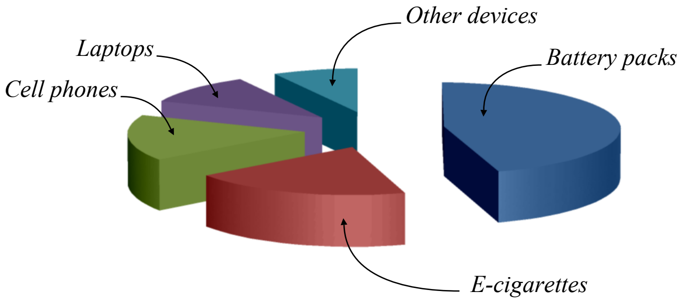
The investigation of occurrences must be based on reports from recognized organizations that precisely report facts. Thus, articles from the mainstream press, which are often insufficiently documented, are not reliable sources. Nevertheless, some of these articles highlight events to investigate further.

As said in point 3.1.3.3.2, QinetiQ estimated that the probability of a lithium-ion battery-powered device being involved in an energetic event was less than 1 in 21.3 million devices in July 2015. Considering the quality of this report, we can think that this estimation was based on reliable sources. This report also said that no incident happened in a hyperbaric chamber at its publication date. Regarding this fact, there is still no incident indicated in chambers by professional organizations such as IMCA, ADCI, and others since the date of publication of this QinetiQ report. However, the probability that such an event happens exists. For example, a few incidents are reported in the IMCA safety flashes, with some of them are from other organizations. They can be summarized as follows.

IMCA safety flash & Sources	*Description*
IMCA Safety Flash 29/18 / United States Bureau of Safety & Environmental Enforcement	Fire in the living quarters of a drill ship (March 2016): The fire was supposed to have started from a universal adapter plugged into a light fixture where a phone charger was plugged in and/or from a tablet left under the bunk's pillow.
IMCA Safety Flash 16/16 / Marine safety forum	Fire in a crew member’s cabin on a vessel caused by the overheating of a battery. The crew member who was not in his cabin at the time, had left a power bank charging and unattended.
IMCA Safety Flash 24/16	Fire in a vessel accommodation due to an overheating notebook computer. It appears that the notebook computer was inadvertently turned on whilst laying on a bunk bed, and this reduced the efficiency of the cooling fan which caused the computer to overheat.
IMCA Safety Flash 27/17	A laptop battery exploded and caught fire. The device was switched off at the time but was on charge at the mains.
IMCA Safety Flash 29/18 / United States Bureau of Safety & Environmental Enforcement	Fire in temporary living quarters that started from a cell phone charging on a mattress. The charger wire apparently failed, creating enough heat to ignite the bed sheet and mattress.
IMCA Safety Flash 29/18 / United States Bureau of Safety & Environmental Enforcement	Heat damage to the ceiling and lights of a room, as well as multiple mattresses. The possible cause of the fire was a tablet being charging on a bunk.
IMCA Safety Flash 18/18	A phone left charging caught fire that extended to the cabin and triggered the fire alarm.
IMCA Safety Flash 25/19 / Norwegian Maritime Authority or *Sjofartsdirektoratet*	A fire incident occurred in a seafarer’s cabin due to a faulty mobile phone charger. The charger was left plugged in while unattended and an electrical short circuit ignited some paper on a desk.

Note that of eight fire events indicated, seven were attributed to cell phones and tablet charging. However, there are not enough incidents reported in these safety flashes to edit relevant statistics. For this reason, these incident reports must be completed with more data.
For the moment, there is no database of such incidents from the diving industry. However, a reliable documented source is the air transportation industry that is more exposed to such events due to the high number of flights organized daily.
As an example, the Federal Aviation Administration (FAA), which regulates all aspects of civil aviation in the USA, regularly updates such incident records on a document called "Events with smoke, fire, extreme heat or explosion involving lithium batteries" that can be downloaded on the Internet:
This document indicates 247 spontaneous fires attributed to electronic equipment powered by Lithium-ion batteries in American airports and various planes (passengers & cargo) moving to or from these airports between January 2015 and June 2021.
Considering that more than 1.25 billion passengers and more than 60 million tonnes of cargo have been transported by air during this period from or to airports situated in the USA, we can say that the number of occurrences remains very low. However, we need more information than only this comparison that does not indicate the types of apparatus responsible for these spontaneous fires and the conditions that triggered these events.
This is possible with this document as it indicates a sufficient number of events to create statistics. As an example, the devices responsible for fires or associated occurrences can be classified as follows:

Items	***Nb of incidents***	***Percentage (%)***
Battery packs	112	45.3
E-cigarettes	48	19.4
Cell phones	40	16.2
Laptops	27	10.9
Other devices	20	8.1

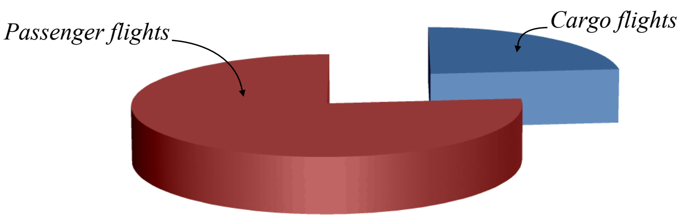


Clarifications regarding the classifications above:

- "Battery packs" are power banks for cell phones and tablets, but also ensembles of batteries for other applications such are medical equipment, cars and others. The incident classified "battery packs", involve these devices only.
- "Other devices" are apparatus, such as medical devices, gas analysers, entertainment equipment, etc.
- "Cell phones" includes cell phones and tablets.

Note that 64.7% of the incidents are from battery packs and e-cigarettes. Also, cell phone and laptop occurrences represent 27.1% of the total, but this point must be further detailed.
Smoking "E-cigarettes" is normally authorized only in the smoking room. However this report indicate that they may be sources of fire when not used. For this reason, strict control measures have to be implemented.
Another clarification process is to separate events that happened during passenger flights from those during cargo flights to provide rates for these events by the number of passengers and tonnes of goods transported:

Types of flights	***Nb of incidents***	***Percentage (%)***
Cargo flights	58	23.5
Passenger flights	189	76.5



Clarifications:

- "Cargo flights" consists of sudden fires events during loading and offloading phases and during the flights. Note that the incidents recorded between 01/01/15 and 30/06/21 happened during the preparation phase of cargos and offloading operations. Nothing is indicated during flights.
- "Passenger flights" consists of sudden fires happening during the flights and the boarding and disembarkation processes of the passengers in the airports.

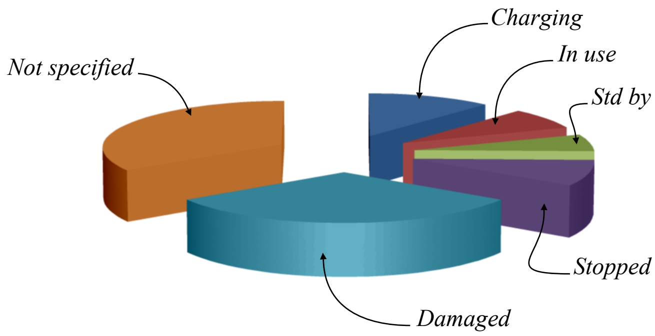
We can say that approximately 189 incidents are recorded for 1.25 billion passengers and that 58 incidents are recorded for 60 millions tonnes of cargo transported during the period of time considered.
Also, as battery packs are the most involved in fire events, it is interesting to see whether these incidents happened mainly with passengers or during cargo flights operations. The records of this document indicate 42 incidents liked to battery packs during cargo operations (37.5%), and 70 incidents linked to passengers flights and their embarkation & disembarkation processes (62.5%).

We can also say that only 59 incidents involve cell phones and laptops during passenger flights and their embarking and disembarking phases. However, other data should be extracted to understand better the reasons that have triggered spontaneous fires of cell phones and laptops. That can be done by classifying the status of the devices when the incident happened, as in the example below:

- "Device charging" is when it is indicated that the apparatus was connected to a battery pack or a charger. The device could have been stopped, started but not used, or in use (statuses are unclear in some reports).

- "In use on battery" is when the incident happened to a machine at work, but not charging
- "Standing by" is when the apparatus was open but not actively used and not connected to a charger. It is the status of cell phones during the major part of the day.
- "Stopped" is when the device was indicated as stopped and not connected to a charger.
- "Device damaged" is when the machine was not connected to a charger, and the fire spontaneously started immediately following a drop or damages to its structure.
- "Not specified" are the incidents where none of the above conditions is clearly indicated in the report. Thus it was possibly due to one of them but also several of them cumulated.

Items	*Nb of incidents*	*Percentage (%)*
Device charging	8	11.9
Device in use	5	7.5
Device standing by	4	6
Device stopped	6	9
Device damaged	21	31.3
Not specified	23	34.3



We can see that the most identified scenarios are from devices charging and damaged, which represent 43.2% of the cases if grouped.
Regarding the damaged cell phones and laptops, note that seven of the twenty-one events reported were units crushed between the passenger's armchair's seat and backrest, which is equal to 1/3 of the scenarios. Also, two laptops started to burn after receiving water accidentally spilled.
In addition, we must take into account that 34.3% of the sudden fires reported are not documented regarding the status of the apparatus when the event happened. That represents approximately 1/3 of the cases, which is a lot.

The incidents can be more studied by detailing them by type of apparatus and manufacturer brands. However, too much data may not provide additional exploitable information, and may push the investigation team outside the purpose of this process, which is to be aware of the frequency of incidents arising from the devices considered.
We must also consider that there are some uncertainties regarding some causes of incidents. For example, an apparatus that starts to burn may have been damaged several days before the event. In addition, we need to take into account that the status of the apparatus before the occurrence is often indicated by its owner to the cabin attendants who write the report. Also, the authors of this incident list say the following: *"These are events that the FAA is aware of and should not be considered a complete listing of all such incidents"*. These uncertainties demonstrate the difficulties of establishing a relevant database.
Despite the problems highlighted above, these incident records from FAA are sufficiently documented to say that undesirable events arising from portable battery-powered apparatus are infrequent. However, the following elements are to be taken into consideration to prepare a suitable response to such incidents:

- Battery packs (power banks) are the devices the most involved in fire scenarios.
- Fires often start from damaged apparatus, and these damages are not always visible. Thus, a dropped object can suddenly burn even though there is no external damage.
- Another noticeable fire scenario comes from devices in the charging phase. This point is confirmed by the reports of incidents from the safety flashes IMCA and other organizations.
- The thermal runaway of a lithium cell can start with stopped devices.
- Considering the data above, we can say that only 15 incidents are reported for cell phones, tablets, and laptops not damaged or under a refilling phase, plus 23 events where the statuses of the devices are not precisely documented. That is to be compared to the 1.25 billion passengers transported during the period indicated.

3.1.3.5 - Implement preventive control measures

In point 3.1.3.3.1, it is said that portable phones, tablets, and recent laptops cannot be transferred in the chamber if IMCA D 041 (Oct. 2006) is applied. Company managers are free to apply this IMCA guidance strictly. However, as explained in the report from QinetiQ described in point 3.1.3.3.2, a lot of companies, many of them are members of this organization, do not apply it.

According to the QinetiQ report taken as a reference and the evaluation of the likelihood of undesirable events from portable battery-powered apparatus above, we can admit that using these devices in hyperbaric chambers is safe as long as preventive and corrective control measures are implemented. The problem is that even though the likelihood of an incident is infrequent, the consequences of such an event could be catastrophic.
The purpose of the preventive control measures described in this point is to ensure that incidents from portable battery-powered apparatus in the chamber will be As Low As Reasonably Practical (ALARP) if it is decided to transfer such devices in the chamber. These safety precautions are to be implemented for each phase of the saturation dive.

The divers must be involved in assessing and implementing the control measures and then fully adhere to them.

3.1.3.5.1 - Select the cell phones, tablets, and computers allowed in chambers

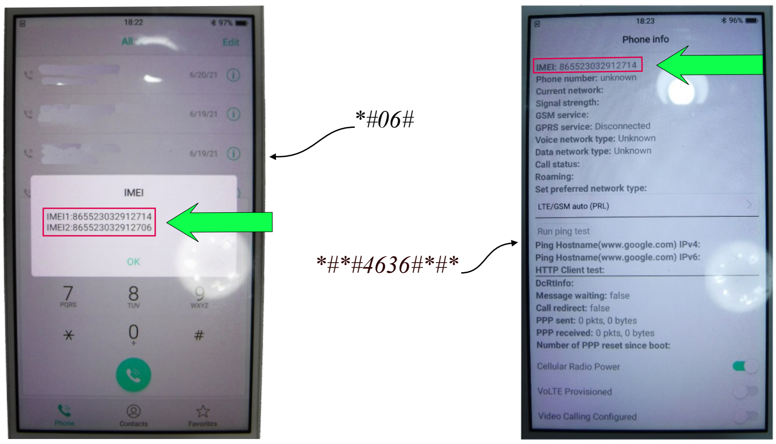
Cell phones, tablets, and laptops planned to be in the chamber must be checked to ensure safe use.
Two options can be implemented:

1 - The company supplies cell phones and laptops that have been tested suitable for use in chambers to the divers sufficiently in advance to let them set up the apparatuses with the software they like. At the end of the dive, the devices can be reset to the factory settings, reviewed, and reused by another diver. If the diver is working in rotation, the apparatus can be kept for his next saturation.
Despite its cost, this procedure has the advantage that the equipment transferred is fully under the company's control, and most QinetiQ recommendations are easy to put into practice.
However, as already commented in point 3.1.3.3.2, QinetiQ recommendations #15 and #16 (change the supply system) will be difficult to implement with the new generations of computers and probably impossible with most models and cell phones for the reasons already discussed.

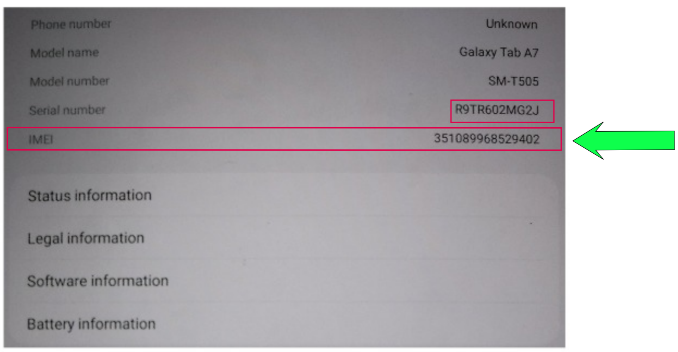
2 - The company authorizes the divers to use their personal devices. In this case, the team has to be organized to implement the recommendations as below:

- QinetiQ recommendations #15 and #16 are not applicable with personal computers of the latest generation as they require the opening and modification of devices that do not belong to the company. It is also the same case with phones that usually do not start without their original battery.
- As explained in the comments in point 3.1.3.3.2, recommendations #2 and #5 (checking batteries) were easy to implement with previous devices. Still, it is much more complicated with the latest generations because the batteries are today not accessible without opening the devices. However, it is possible to ensure that the batteries are original parts by limiting the age of the device agreed in chambers. This age can be controlled through code numbers sometimes displayed on the machine and always accessible through the operating system.

  The International Mobile Equipment Identity (IMEI) is a number attributed to each mobile phone and tablet that provides the name of the model, the name of the manufacturer, the year of fabrication, the serial number, the capacity of the battery, and much other information. If it is not indicated on the shell of the device, two methods can be used to obtain it:
  The 1st method consists of dialing *#06# or *#*#4636#*#* through the phone call program to display one of the two windows below.

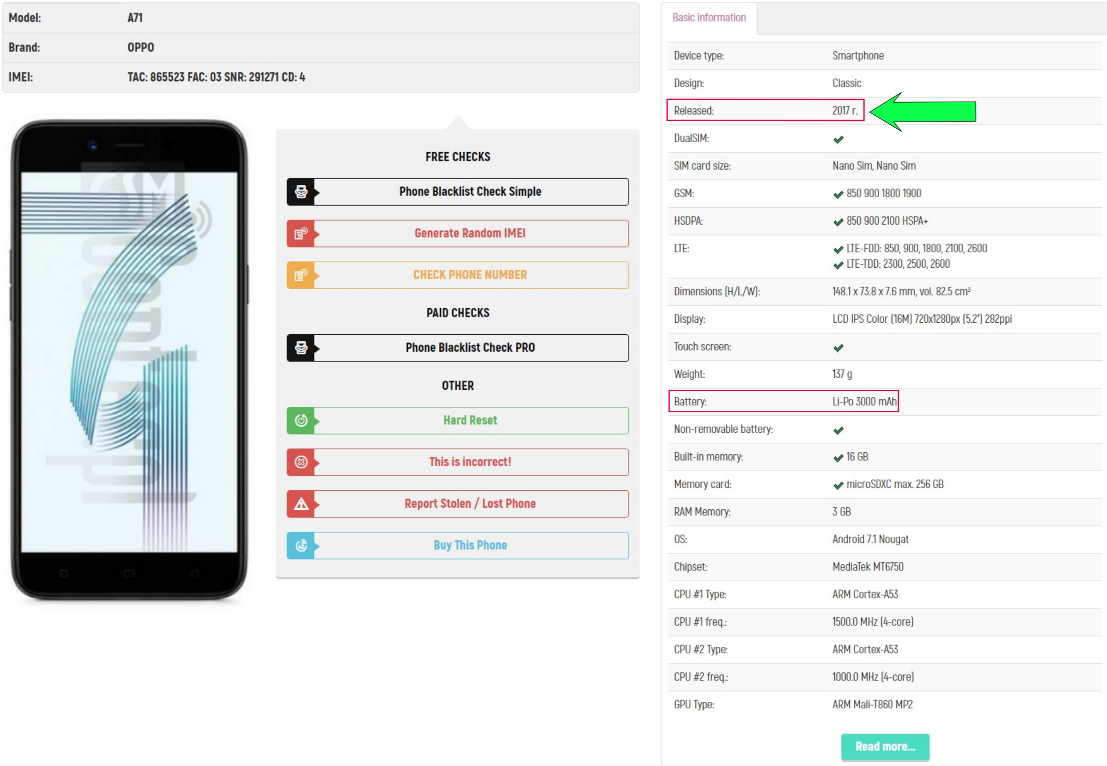


  The second method to access to the International Mobile Equipment Identity (IMEI) number is to do it through the function "settings" and then select "About tablet" or "About device". Usually that displays the required information as in the photo below. However, it is sometimes necessary to open the function "status" to access it. Note that the serial number is also displayed. This method can be used with Android tablets not provided with phone function.



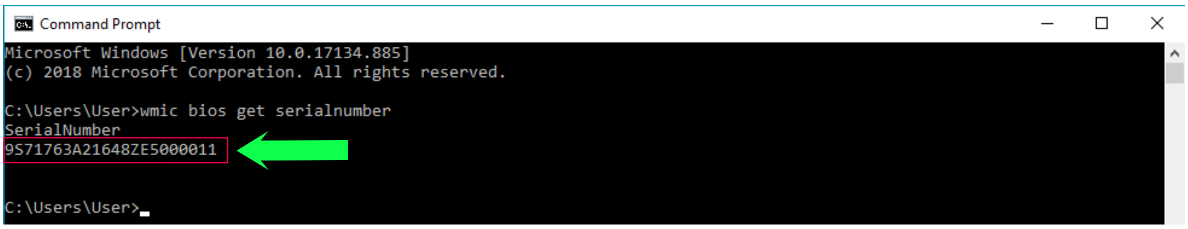
  IMEI code and serial number of I pads and other tablets Apple is possible using a similar process:
  From the home screen, tap the icon "Settings". Then, tap the icon "General". Then, tap the icon "About". Then, scroll down to view the serial number and IMEI.

When the IMEI code is obtained, connect to the website https://www.imei.info/ (or a similar site), compose the IMEI code in the dedicated slot and click “check”. The website then provides the characteristics of the phone or the tablet as displayed below.



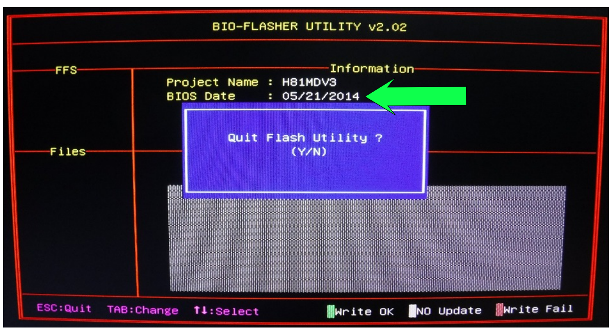
Note that some manufacturers provide the IMEI and serial number on the device's shell, but many of them (even the most reputed) do not do it. Also, a straightforward means of control is the invoice of the device where its IMEI code or/and serial number should be indicated.

IMEI system is not implemented for computers. However, laptop manufacturers using Windows and Linux OS also provide the serial number of the machines they sell on the device’s shell.
This serial number can be used to check the age of the computer through the online support system of the manufacturer or using the invoice of the machine.
When the serial number is not visible on the machine, it can be found through the functions of the operating system:
The 1st step consists of opening the “Command Prompt” by typing *“cmd”* into the search box of the task-bar beside the “Start menu”. The 2nd step consists of typing *“wmic bios get serialnumber”* and press the key “Enter”. Then the program displays the information as below:



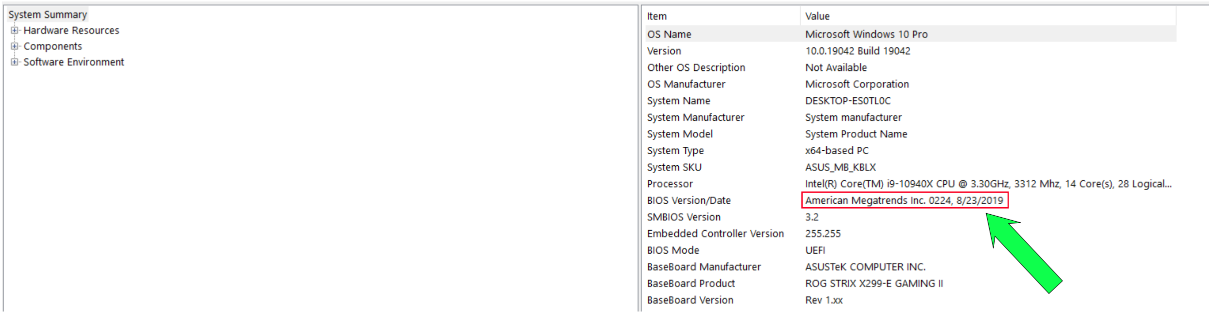
Note that attempts made with different brands’ support systems to check the age of laptops show that the manufacturers' websites do not always provide relevant information. Also, it is often required to open an account to access the support program. That can make difficult the investigation from the boat or a facility. For this reason, it seems that asking the divers to keep the invoice of the machine where the serial number of the device is clearly visible is a better procedure.

Another method to find the age of a laptop is to check the date of the Basic Input/Output System (BIOS). The BIOS is the program a computer's microprocessor uses to start the system after it is switched on and manage the data flow between the Operating System and the attached devices.
This method is based on the fact that people do not update the BIOS of their machine as long as it works.
The 1st method to access the BIOS is by pressing the key briefly indicated when the machine starts.
Then the computer displays the information aside:



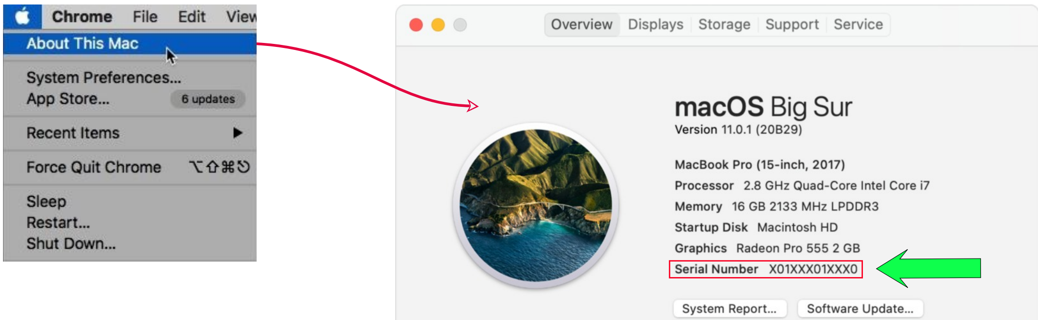
Hyperlink Table of contents

A second procedure that works with Windows OS to access the age of the bios in through the function "system information" . The 1st step consists of opening the window by typing *"system information"* into the search box of the task-bar beside the "Start menu". Normally the link to the program should appears in the window above the search box. Clicking on it should open the window below:



Note that the date of BIOS refers to the date of update. It is true that usually, this update remains the same all along with the life of the computer. However, the BIOS may have been updated if the machine has been repaired or if the machine's owner has knowledge in computing. In case of doubt regarding the age of a computer, and nothing is on-site that allows to check it using its serial number, the solution will be to unscrew its bottom shell to assess the battery.

The serial number of an Apple/Mac computer is often indicated on its shell. It can also be collected through the functions "About This Mac" and "System Information".
To access it, the operator clicks the icon "Apple menu" in the upper-left corner, and then opens "About This Mac", which provides an overview of the machine, such as in the picture below. To see more details, the operator can click the System Report button (below the serial number).



The serial number can then be checked on the website https://checkcoverage.apple.com/. However, as indicated above, using the bill from the reseller is maybe more straightforward.

- Limit the age of the devices in the chamber:
As said previously, the reason for checking the age of last generation computers and cell phones is to ensure that their embedded batteries are genuine parts. This procedure is based on the fact that batteries of new devices rarely fail. Note that it is possible to change the battery of an old apparatus. Still, in this case, the operation must be certified by relevant documents from the manufacturer or one of his registered subcontractors (QinetiQ recommendation #2).
Investigations regarding the maximum time a battery can last show that there is no officially published data that would allow us to evaluate such items' average life. Also, phone manufacturers avoid giving precise information regarding this matter for commercial and legal reasons.
Several consumer organization websites say that cell phones typically last for around 2-3 years. But their investigations seem not based on precise data, or their sources are kept hidden. However, the website https://storymaps.arcgis.com that describes "the life of an iPhone from its conception to the end of its life" says that an iPhone's typical lifespan is about 4 years & 3 months. This website explains that the main reason for 4 years & 3 months limit is planned obsolescence.
It seems that the renew frequencies indicated by consumer organizations are based on the same reasons and not on the real lifespan of batteries.
Of course, as previously indicated in point 3.1.3.2, the fact that these devices will be submitted to repeated compression and decompression is not taken into account by the manufacturers. Regarding this matter, we can refer to the report from QinetiQ that says that even though helium penetration may occur over a long period of time, the quantity of gas that would enter the battery would not be sufficient to cause an undesirable event during decompression. QinetiQ recommendation #1 says that tests can be organized with several batteries to ensure that the batteries withstand repeated compression and decompression. Nevertheless, we can also consider that divers transfer cell phones and laptops in chambers for years and that no incident is indicated for the moment. Thus we can say that such tests have already been empirically made.
Pressure tests may be useful on particular models that are indicated to have susceptibility to failures. However, the problem is to decide who performs these tests and how they are evaluated. It must be notified that for the moment, no diving organization has officially published the results of such tests, and none of them publish records of apparatus transferred in chambers.

Considering what is said above and the fact that many computers and phones continue to work satisfactorily past 5 years of age, we can say that limiting the age of devices transferred into chambers to 3 years appears reasonable. However, the method of control used must be taken into account:

- If the reference is the invoice, the date indicated is a valid reference.
- If the reference is the IMEI code and the date of the BIOS, more flexibility may be acceptable as the IMEI indicates only the year of production, and the update of the BIOS can have been done up to one year before the motherboard is activated.

- Set the maximum size of the battery
QinetiQ Recommendation #9 says that a device's total lithium-ion battery power density should be restricted to a maximum of 100 Wh, which is a logical restriction we should adhere to limit the effective energy released in case of a catastrophic event.
Regarding this matter, investigations through manufacturer websites prove that the most powerful laptops currently on the market remain below this limit.
- Appoint a competent person in charge of checking the devices:
Among people in charge of the dive system, the dive technicians are probably the most competent to check these appliances. However, they are usually very busy with the system, and it is not suitable to occupy them with operations that other people can easily do. For these reasons, they should be involved only when activities require technical knowledge to be performed, such as, for example, the opening of a laptop. If the procedures explained in the previous point are implemented, checking the IMEI codes and serial numbers do not require particular skills. Thus, a safety officer can be in charge of this operation. Checking these elements requires patience, imagination, and honesty.
- Record the devices accepted in the chamber:
The person in charge of the verifications must establish a clear list of the devices authorized in the chamber. This list should be accompanied by relevant folders that group copies of the invoices, detailed specifications of each device, photos, etc. A good system is to attribute a reference number to each device. This list and its attached documents should be sent to the Life Support Technician, the Diving superintendent, the safety officer (if the person checking the devices is someone else), and the Offshore manager. Also, it should be kept and shared for the follow-up of the machines registered for the next saturation.
To help the life Support Technicians to identify the devices during the operations, a self-adhesive sticker that displays the attributed reference number (thus, the proof that the device has been checked), and the name of the diver, can be provided on each apparatus agreed in the chamber.
- Cases of models susceptible to failure:
A particular model of phone or laptop may be more subject to sudden fires than the ensemble of apparatus taken into consideration for the likelihood of such events. These problems have been encountered with the most reputed brands and must be taken into account. However, they should be considered isolated events and not general events that may result in the divers suddenly not being allowed to transfer their devices in the chamber. For this reason, unless a study proves that the likelihood of such dangerous events has dramatically increased and affects the totality of devices, only the model affected must not be allowed in the chamber until further clarifications are provided. A note should be transmitted to the divers and the people in charge to ensure everyone is aware.
- Edit a database:
The list of devices in the chamber should be shared to establish a database. This database should be published so divers and people in charge are aware of it and enrich it.

3.1.3.5.2 - Set rules for other electrical and electronic devices

Rules must be established for other electrical and electronic devices and also charging devices of cell phones, computers, and other equipment:

- Small electrical and electronic devices:
As specified in IMCA D 041, small devices such as rechargeable torches, calculators, cameras, analysers, electronic clocks, shavers, toothbrushes, and similar small items do not represent any harm to the divers and can be transferred in the chamber.
- Electronic medical equipment:
These devices are allowed in the chamber provided that they comply with the specifications for cell phones, tablets, and laptops. Also, in case that their power supply is more elevated than these devices, it must be Direct Current (DC) less than 30 volts and the maximum voltage indicated on the hyperbaric extinguisher.
- Power-banks (battery packs):
Power banks, also called battery packs, are involved in the highest proportion of incidents reported in the document from the FAA taken as reference for analysing the likelihood of fires linked to Lithium-ion batteries. For this reason, and also because another recognized condition linked to sudden fires of cell phones and laptops is when they are charging, these items must not be allowed in the chamber.
- Cell phones, laptop or other equipment chargers:
As said above, a recognized condition linked to sudden fires of laptops and cell phones in the document from the FAA taken as reference for analysing the likelihood of fires linked to Lithium-ion batteries is when these devices are charging. For this reason, chargers must not be allowed in the chamber.

3.1.3.5.3 - Prepare the firefighting systems, tools, and procedures

Ensure that the fire fighting systems and tools are ready is essential to ensure that failures of electronic devices in the chamber will always be under control.

- Tools to control a battery powered apparatus burning must be provided:
  As already indicated in the comments of QinetiQ recommendation 22, "fire containment bags" designed to carry spare lithium batteries and portable electronic devices in aircraft must be provided with specific high temperature gloves to handle device starting a sudden fire.
  Note that these bags should also be used to store the electronic apparatuses when they are not used.
  The configuration of these bags consists of high-temperature insulation and fire-resisting materials that are able to withstand the explosive release of energy and cell combustion as a result of a lithium-ion thermal runaway.
  These bags are sufficiently wide to contain laptops, so the only problem is to ensure that the device in the chamber can be transferred through the medical lock.


  Among the manufacturers who can be contacted note: AVSax (http://avsax.com), and FEC Heliports equipment (www.heliportsequipment.com).
  As already commented, a burning lithium-ion battery emits extreme temperatures in addition to pollutants. For this reason, it cannot be manipulated with classical gloves. "Polybenzimidazole" fiber gloves seem the most efficient. Also, blacksmith tongs are antique but efficient tools for this purpose.
  There must be sufficient gloves available to manipulate the devices if a sudden battery fire scenario starts. Note that they should be some available outside the chamber.
- The deluge system, hyperbaric extinguishers, and the Built-In Breathing System (BIBS) are explained in point 1.2.2.2 "Living chambers and their entry lock". They must be ready at all times.
  It must be remembered that the extinguishing agent used in the hyperbaric extinguishers is an Aqueous Film Forming Foam (AFFF), which is suitable for fabrics, combustible solids, flammable liquids, and electrical fires up to 24 Volts. The operating process of the foam is that it makes a blanket that blocks oxygen supply and suppresses vapours. Also, the water content of the solution produces a cooling effect. Nevertheless, electrical devices in the chamber should be limited to the maximum voltage the extinguishing agent is designed for.
- Drills should be organized to train the team to throw an apparatus into a fire containment battery bag, transfer it outside the chamber through the medical lock, and remove it from the dive station. Scenarios where the fire extends to other items in the chamber, such as bedding, should be considered.
  Note that firefighting and abandon ship drills are mandatory for saturation teams.

3.1.3.5.4 - Organise the batteries charging station

As explained previously and demonstrated through the likelihood study, catastrophic lithium-ion battery failures that trigger sudden fires happen more often during the device's charging process than when the device is not connected. For this reason, the refilling of the apparatuses must not be done in the chamber, and a charging station must be organized. This is also in line with QinetiQ's recommendation #11.

- QinetiQ report 2015 suggested using Original Equipment Manufacturer (OEM) chargers. Regarding this point, note that recent cell phones use chargers 5 volts DC 1 to 2 amperes, which is the electricity supplied from the universal charging blocks found in hotels, cars, airports, offices, etc. The main difference is from the USB cords that are different whether the phone is an Apple or another brand. This is more complicated with laptops as the output voltage and amperage change from one model to another. For this reason, genuine chargers should be used with these devices.
- The charging station must not be organized at the direct proximity of the dive station, the vessel's machinery, the gasses, or a storage area. It must be in a place where people who may intervene quickly if a fire starts are present, and where a sudden fire has limited consequences and can be quickly solved. Means of fire fighting should be close to the devices with "fire containment battery bags" and high-temperature gloves.

3.1.3.5.5 - Set up safe practices in chambers

Implementing a suitable preventive safety also depends on the behaviour of people and the precautions in place in the chamber during the dive. For these reasons, strict rules must be established and implemented:

- Electrical and electronic apparatuses should be used for the tasks they are designed for only.
- Lithium battery-powered devices must be shut off and stored in their "fire containment bags" when they are not used. They should be stored in the lower parts of the chamber and away from flammable items.

- Devices that have fallen, are damaged, or are abnormally hot must be removed from the chamber. They may be allowed again after a close investigation of their condition.
- Devices should never be left unattended on flammable items such as bedding and similar.
- The divers should watch each other to avoid falling asleep with the apparatus open.
- Fire gloves and "fire containment bags"must always be available. It is also the case of the fire extinguisher.
- Recharging empty devices within the chamber must be strictly prohibited.
- Cell phones, tablets, and laptops must not be used in the moisten parts of the saturation complex, unless they are designed to withstand these conditions (waterproof phones).
- Electronic and electrical devices must not be used during the beginning of compression and the end of decompression phases, where the oxygen percentages are more elevated and may favor a fire. The green light to use them is given by the Life Support Supervisor (LSS) only.

3.1.3.5.6 - Implement precautions for the transfer of the battery powered devices through the medical lock:

The uncertainty regarding the effects of pressurization and depressurization processes on the devices transferred must be considered. Also, transfer locks operations imply some risks that must be taken into account, in addition to the fact they consume heliox. The following precautions should be in place:

- Transfers operations to and from the chamber should be limited to a minimum and organized at regular times. The divers should be encouraged to buy products with long autonomy to limit the need for transfer to a minimum. Note that recent cell phones, tablets, and laptops allow for more than 8 hours of battery life at work.
- Electronic devices transferred to the chamber must be logged, so the Life Support Supervisor is aware of the devices in the chamber and those that are charging or stored outside.
- Electronic devices should be stopped during the transfers. Relevant “fire containment battery bags” should also be transferred with the devices.
- Some models of cell phones are designed to be water-resistant (1 to 2 m depth maximum). They should be opened to allow for equalization and avoiding damage. Note that the study of likelihood discussed previously shows that fires often start with damaged devices.
- QinetiQ report recommends limiting the compression and decompression rates but does not provide any value. Thus, the reduction of the compression/decompression speeds is currently at the LSS discretion. Nevertheless, although no official rule is published, no incident has been officially reported for the moment.

3.1.3.5.7 - Last precautions before entering the chamber:

It is important to ensure that everyone understand and adhere to the rules discussed above.

- A tool-box talk must be organized to discuss the consequences of a fire in the chamber, the conditions that can trigger the thermal runaway of a lithium cell, and the reasons for the rules described above.
- The Life Support supervisor must ensure the conformity of the cell phones, tablets, and laptops planned to be transferred to the chamber with the list previously established. He must also ensure that no forbidden device is transferred in the chamber with the divers' belonging (including USB cords).

3.1.3.6 - Conclusion

It is impossible to publish permanent rules regarding the problems arising from battery-powered portable electronic apparatus because the products proposed by the manufacturers evolve and are quickly obsolete. Thus the problems posed by some devices can be quickly solved, but other issues can also happen.

Regarding the policy a diving company can select for electronic devices in hyperbaric chambers, we can see that other solutions than merely forbidding these apparatus can be selected. The best example comes from air transporters organizations such as the International Air Transport Association (IATA) that actively support new technologies for controlling fires and explosions resulting from the potential thermal runaways of these devices. The “fire containment bags” and high-temperature gloves described in the previous points result from these actions.

Based on the facts indicated above, even though the QinetiQ report and this evaluation say that using lithium-ion battery-powered apparatuses and other small electrical and electronic devices is possible in chambers as long as relevant control measures are in place, the diving team must prove that this problem is properly managed. For this reason, a risk assessment that considers recent incident records, the newly available control measures, and the apparatuses planned in the chambers must be done before starting the diving project.

3.1.4 - Precautions before transferring the divers to chambers

As already said in point 3.1.1.2, pathogens and fungus can be transported in chambers by the occupants. Also, if introduced onboard the boat, a virus can be transmitted very quickly throughout the entire vessel. Examples of persons affected by diseases such as the flu who transmitted it to the entire ship have been reported, and in some cases, the diving operations had to be stopped, and the vessel quickly sent to the shore with sanitary assistance.
Thus, the recent events linked to "COVID 19" that have pushed the majority of the planet into a panic should not be considered a single case scenario, as there are numerous viruses and other pathogen infections that can put the entire vessel out of order if basic precautions are not implemented. Also, pathogens proliferate faster in a chamber since divers in saturation live under a partial pressure of oxygen that is roughly the double of the normal one, and are grouped in a very small space where it is impossible to be isolated.
For these reasons, divers should never be compressed as soon as they arrive. Instead, there should be a period of observation before boarding them and committing them to saturation. The duration of this observation period should be decided by the diving medical specialist in charge of the divers for the company. More information regarding this point is provided in Book #4 "Saturation diving accidents".
Also, some medications are based on drugs, and so a diver under medication or drug abuse can be dangerous to himself and his colleagues. Thus, this point is also to be considered, and medical treatments have to be indicated to the diving medical specialist, who is the only person qualified to decide whether the diver can be authorized to dive or not.
Regarding drug abuse, the common policy is zero tolerance, and the divers should be tested. Note the diving study CCO Ltd "Implement a drug and alcohol abuse policy" that can be downloaded free of charge on the website "Diving & ROV Specialists" gives guidelines on how such a policy has to be organized and the people affected taken in charge.

Taking the elements above into consideration, before being committed to saturation, the divers should:

- Inform those in charge of any potential or declared infections, illness, and on going medical treatments.
- Be examined by the on board medic.
- Be clean…
- Wear clean cotton clothes
- Present their belongings to the chamber operator.

The chamber operators should:

- Reject items forbidden in chamber such as: Suspicious electronics, perfumes, powders, nylon clothes, and other elements that can be source if fire or pollution of the chamber atmosphere.
- Identify and mark the personnel equipment to be used in the chamber such as under suits, personal hat liners, boots and other.
- Assign and mark diving equipment (dive suits, boots, hat liners, harness…).
- Store the personal belongings not carried in the chamber in a safe place.

Prevention of ear infection:

During saturation, divers should systematically use preventive ear drops. The preventive drops present an effective barrier for bacteria thriving within the ear canal. The drops should contain neither antibiotics nor steroids. One well know brand "Domeboro Otic" consists of a mix of 2% acetic acid in an aluminium acetate solution.
Each diver should be issued with 2 bottles marked with his name. In addition, one should be marked LEFT and the other RIGHT and used for the respective ear without confusion. The brand and frequency of application should be decided by the diving medical specialist *(Common practice with "Domeboro Otic" is 6 drops each ear four times daily. However, new practices have been tested by the US Navy to prevent side effects of this medication. See "Acute otitis externa" in book #4 "diving accidents").*

3.1.5 - Last preparation

The instruction to commit the divers to saturation is given by the diving superintendent.

Prior to instructing the LSS to start the compression, the diving superintendent should ensure that:

- There is sufficient personnel to perform the operations safely.
- The checks lists have been completed and no defect is reported.
- The checklists have been completed less than 6 hours before the pressurization. Note that this rule is an old rule and a lot of companies accept a longer time due to the complexity of the systems, and based on the fact that only appointed persons can access the system.
- Sufficient quantities of gas are available (in conformity with IMCA D 050).
- Appropriate gasses are online.
- The saturation plan is ready (Storage, excursions, decompression…)
- Diving and technical manuals are in the saturation and dive controls.
- The emergency decompression procedures are ready.
- The number of occupants does not exceed the maximum capacity of the saturation system. Also, when the system is able to accommodate more divers than the "Hyperbaric rescue unit" (HRU), the maximum of divers in the complex should be the maximum the "hyperbaric rescue unit" can welcome.
- The stand by rescue vessel is at proximity, ready to intervene if required.
- The HRU evacuation plan has been explained and a drill has been performed satisfactorily (see in abandon ship procedures).
- Divers and the support team have been examined by the appointed medic and are medically fit for their functions.
- 23. After the system is cleared from the main complex and the sea fastenings are removed, the team installs tag lines in the corners of the HRC.
- The diving medical specialist is informed of the beginning of the operations. *(The satellite phone of the saturation control should have been tested).*
- Sufficient diver medics are inside and outside the complex. Regarding this point, The Diving Medical Advisory Committee (DMAC) says the following:
  - One trained diver medic must remain outside the chamber at all times for purposes of communications and provision of equipment. This role can be met by a rig medic or nurse or by a member of the dive team with medic training.
  - A minimum of two trained diver medics should be at pressure in the chamber system. A lower level of provision could result in the situation where the only trained diver medic is the casualty.
  - Where a saturation system is operating with chambers at different depths, all divers must retain rapid access to a trained diver medic.

The medical kit DMAC 15 is in the chamber.

- The Medical equipment capable of measuring: blood pressure, temperature, heart rhythm, SPO_2, and able to transmit this information from the inside of the chamber to a doctor remote from the worksite, such that the information can be viewed in real time *(system vitalink or similar)* is working.
- If the vessel is under contract, the client representative is informed and agrees for the beginning of the saturation. Note that it often happens that the divers are committed in saturation before the arrival to the client's field, and the beginning of the contract.
- The Offshore Construction Manager and the Offshore Manager are informed.

Prior to commit the divers in the system, the Life support supervisor should ensure that:

- The BIBS are ready to be online, supplied by appropriate mixed gas, and the therapeutic mixes are ready to be online.
- The names of the divers conform with the list given by the superintendent.
- When there are several teams to commit, they should be clearly identified and accommodated in the relevant chambers.
- In cases of different storage depth, the system should be checked for any risk of accidental equalisation of the chambers. IMCA D 022 says that separation between chambers should be ensured by bleeding the trunking between the chambers to surface.

3.2 - Pressurisation to the 1st storage depth and elements to control during the saturation

Note: *The procedure to calculate the chamber atmosphere is explained in the previous chapter*

3.2.1 - Initial seal and beginning of pressurization

The procedure consists to establish an initial seal, then pressurize the chamber to 10 msw, and stop the descent at this depth for a minimum of 20 minutes. During this time, checks must be performed. *(NORSOK standards U-100 point 8232)*

When the checks are completed the chamber can be compressed according to the procedure selected.
The options already explained point 2.2.6 *"Make up the gas atmosphere"* can be used to pressurise the system:

1. A single gas to storage depth sometimes called an "ideal gas".
2. A rich mix to an initial depth then a lean mix (also called "poor mix") to storage.

- IMPORTANT:

The divers should be on BIBS at least during the first 10 m.
Also, the LSS and the diving superintendent can decide to keep the divers on BIBS for a longer time if they consider it suitable. *(IMCA D 022)*

Clean fresh gasses should be used for compression.

As a reference, note that NORSOK standard says that Reclaimed gas should not be used for pressurisation unless the nitrogen content is within the acceptable Hyperbaric Exposure Limits (HEL): 1,5 bar (150 KPa) with a maximum of 3,5 bar (350 KPa). These limits are explained in point 2.3.1.2.
Note that mixes treated using the "Helipure" system in addition to the "Gas Pure" system would normally conform to these requirements, provided that the cartridges have been replaced on time.

The Environmental Control Unit and scrubber should run during pressurisation to assist in mixing of the chamber atmosphere. The divers can help in the homogenisation, by shaking towels or similar action.

In the early stages of a pressurisation, divers should not lie on their bunks. They should sit or stand so that the LST can see clearly that they are well and conscious.

3.2.2 - Gas percentages and compression rates

3.2.2.1 - Procedures for standard saturations

3.2.2.1.1 - Gas parameters

PP O2: 0.4 to 0.57 bar (400 to 570 mbar) - *570 mbar is acceptable only at the arrival at the storage level*
PP CO2 : < 0.005 bar (< 5 mb)

3.2.2.1.2 - Compression rates and stabilization prior to starting the diving operations

Saturation area	***Maximum compression speed***	***Stabilization stops in the initial compression***
0 to 100 metres	1 msw/minute	- Two hours at 100 m or proportional time to the depth between the surface and 100 m, calculated by the expression: *Stabilization time (min) = 2 x 60 x depth (m)/100*
101 to 180 metres	1 msw/minute	- 1st stabilization stop for 2 hours at 100 m - 2nd stabilization stop at the arrival at depth, calculated by the expression: *Stabilization time (min) = 2 x 60 x (depth - 100)/100*

3.2.2.2 - Procedures for deep saturations

3.2.2.2.1 - Gas parameters

PP O2: 0.4 to 0.57 bar (400 to 570 mb) - *570 mbar is acceptable only at the arrival at the storage level*
PP CO2 : < 0.005 bar (< 5 mb)

3.2.2.2.2 - Compression rates and stabilization prior to starting the diving operations

Saturation area	Maximum compression speed	Stabilization stops
181 to 240 metres	- Surface to 100 m: 2 minutes/msw *(0.5 msw/minute)* - From 100 to 200 m: 4 minutes/msw *(0.25 msw/minute)* - From 200 to 240 m: 6 minutes/msw *(0.166 msw/minute)*	- 1st stabilization stop for 2 hours at 100 msw - 2nd stabilization for two hours at 200 msw - 3rd stabilization of at least 6 hours at the saturation depth
241 to 300 metres	- Surface to 100 m: 2 minutes/msw *(0.5 msw/minute)* - From 100 to 200 m: 4 minutes/msw *(0.25 msw/minute)* - From 200 to 300 m: 6 minutes/msw *(0.166 msw/minute)*	- 1st stabilization stop for 2 hours at 100 msw - 2nd stabilization for two hours at 200 msw - 3rd stabilization of least 12 hours at the saturation depth

3.2.2.3 - Procedures for exceptional saturations

3.2.2.3.1 - Gas parameters

PP O2: 0.4 to 0.57 bar (400 to 570 mb) - *570 mbar is acceptable only at the arrival at the storage level*
PP CO2 : < 0.005 bar (< 5 mb)

3.2.2.3.2 - Compression rates and stabilization prior to starting the diving operations

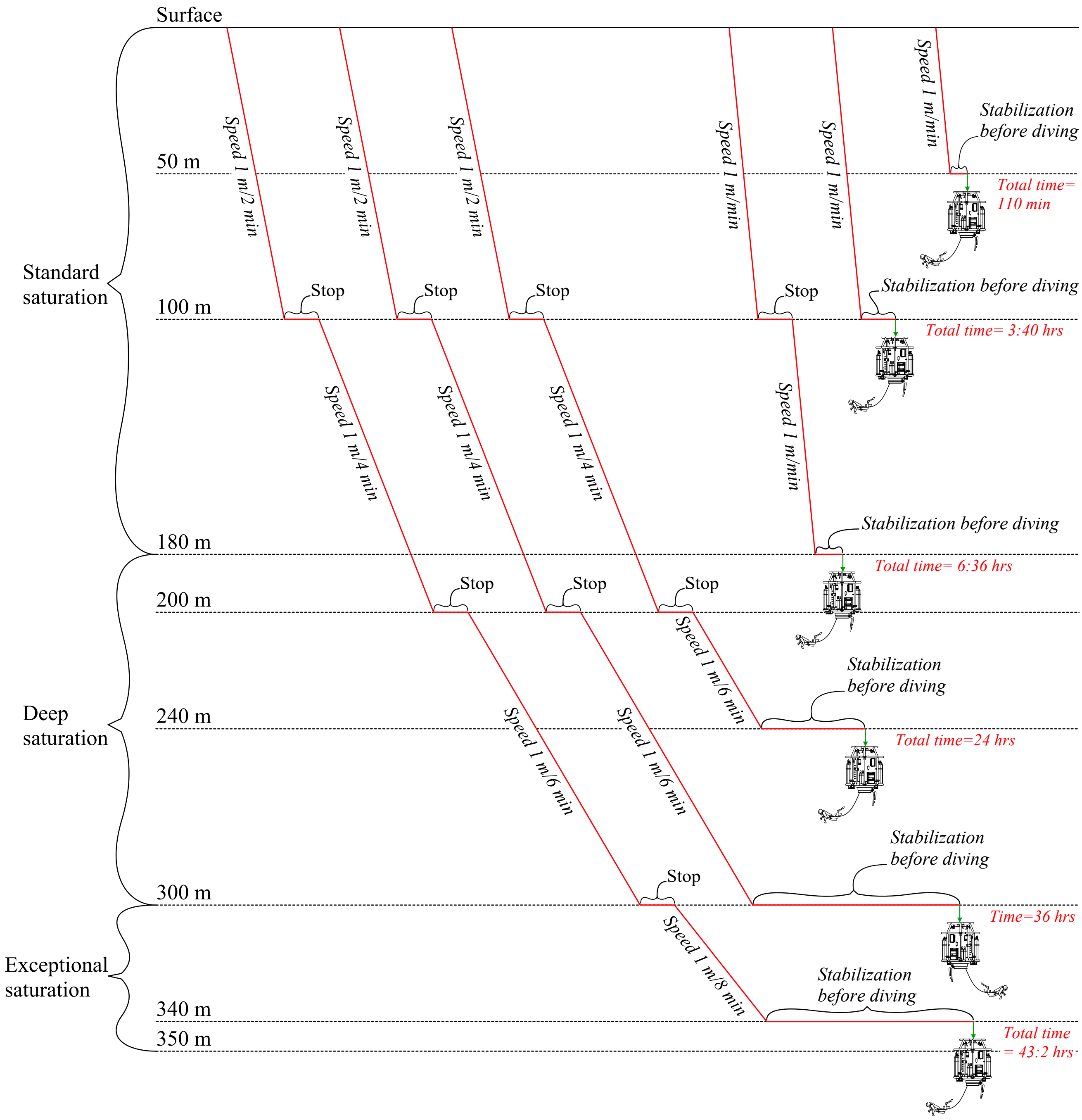
Saturation area	Maximum compression speed	Stabilization stops
300 to 350 metres	- Surface to 100 m: 2 minutes/msw *(0.5 msw/minute)* - From 100 to 200 m: 4 minutes/msw *(0.25 msw/minute)* - From 200 to 300 m: 6 minutes/msw *(0.166 msw/minute)* - From 300 to 350 m: 8 minutes/metre *(0.125 msw/minute)*	- 1st stabilization stop for 2 hours at 100 msw - 2nd stabilization stop for 2 hours at 200 msw - 3rd stabilization stop for 2 hours at 300 msw - 4th stabilization stop of least 12 hours at the saturation depth

3.2.2.4 - Descents rates and procedures implemented to control the effects of High Pressure Nervous Syndrome (HPNS)

Reduced compression speeds and stabilization stops are organised to control the High Pressure Nervous Syndrome (HPNS). Note that the descent speeds to the final storage depths below 180 metres are seriously slowed down with several intermediates stops and longer stabilization periods at the final depths. These rest periods should take place at the exactly planned depths.

The drawing below shows the descent curves from the surface to the maximum depths of the areas described in points 3.2.3.1, 3.2.3.2, and 3.2.3.3. Note that the curves do not integrate the leak test at 10 m.

Depth *(metres)*	***surface to 1st stop***	***Stab. at 1st stop***	***1st stop to 2nd stop***	***Stab. at 2nd stop***	***2nd stop to 3rd stop***	***Stab. at 3rd stop***	***3rd stop to final depth***	***Stab. at final depth***	***Total time***
50 m	50 min	–	–	–	–	–	–	60 min	***1:50 hours***
100 m	100 min	–	–	–	–	–	–	120 min	***3:40 hours***
180 m	100 min	120 min	80 min	–	–	–	–	96 min	***6:36 hours***
240 m	200 min	120 min	400 min	120 min	240 min	–	–	360 min	***24 hours***
300 m	200 min	120 min	400 min	120 min	600 min	–	–	720 min	***36 hours***
340 m	200 min	120 min	400 min	120 min	600 min	120 min	320 min	720 min	***43:2 hours***



HPNS, which is explained more in the document “Diving accident” of this saturation manual can be summarized as follows:

- It usually appears at depths somewhat greater than 150 m (500 fsw).
- It involves primarily the central nervous system, and its symptoms are manifested as neuromuscular disturbances (incoordination, fasciculation, tremors) or as disturbances of higher cerebral functions (disorientation, micro-sleep, convulsions in animals).
- These neurological aberrations can be correlated to some degree with changes in electroencephalograms.
- These symptoms normally disappear when the diver returns to pressures above 150 m.
- The development and intensity of the HPNS are augmented by rapid compression to depth.

  Experiences have demonstrated that slow compression rates and stabilization stops reduce the risks of HPNS or limit its effects. In addition, it has been demonstrated that the use of anticonvulsant may offer some degree of protection against this phenomenon.
- Experiences have also proved that the use of trimix mixtures (He + O_2 + H_2) give good results.

Note that the descent rates indicated in this chapter can be slowed down and the compression rates can be lengthened without any limitation in the case of severe HPNS.

3.2.2.5 - Aborting the pressurization

When pressurizing the saturation diving system, a leak test at 10 m is usually organized to ensure the system works satisfactorily and that the pressurization to the storage depth can be safely undertaken. However, the pressurization may have to be stopped for many technical and physiological reasons not seen during this observation period.
Depending on the duration of pressurization and the depth reached, two procedures can be applied to return the divers to the surface.

- The classical saturation decompression procedure explained in point 3.6 allows a safe return to the surface from any depth, whatever is the bottom time. However, this decompression process is slow. For example, 24 hours are necessary to recover divers from 16 m and 55 hours from 50 metres.
- If the depth reached and the time of exposure allows for, the procedure promoted in chapter 2 of IMCA D 022 can be applied. This procedure, based on the procedure of the US Navy diving manual, consists of selecting a surface orientated heliox table that provides an appropriate bottom time and partial pressure of heliox. However, it is limited by the depths and bottom times provided by such tables. The procedure for selecting the decompression procedure is as follows:
  1. Calculate the partial pressure of the helium of the mix used to pressurize the divers. As an example, if the depth reached is 70 m, and the oxygen partial pressure is 0.4 bar, the partial pressure of helium is 8 bar minus 0.4 bar, so 7.6 bar.
  2. Select a table with a depth and a partial pressure of helium superior or equal to those reached during the pressurization. As an example, using the closed bell tables MT92-2019:

     72 m with 16% O 2 = 8.2 bar x percentage helium (100 - 16 = 84) /100 = 6.89 bar is not suitable.
     75 m with 16% O 2 = 8.5 bar x percentage helium (100 - 16 = 84) /100 = 7.14 bar is not suitable.
     78 m with 16% O 2 = 8.8 bar x percentage helium (100 - 16 = 84) /100 = 7.39 bar is not suitable.
     81 m with 16% O 2 = 9.1 bar x percentage helium (100 - 16 = 84) /100 = 7.64 bar is suitable.
     78 m with 12% O 2 = 8.8 bar x percentage helium (100 - 12 = 88) /100 = 7.74 bar is suitable.
  3. Ensure that the bottom time is suitable. As an example, if the planned storage depth was 100 m, the Normam-15’s descent rate is 1 m per minute, to which the time of the leak test at 10 m (20 minutes) and the time lost to select the table and implement it must be added.
  4. Ensure that the first decompression stop is above the depth the divers are at. As an example, with the tables 81 m /16% O 2 & 78 m /12% O 2 above, the first stop starts at 57 m and 60 m, so above the divers’ depth.

Important points:

In case the compression has to be stopped, the diving medical specialist must be contacted and be kept informed of the procedures implemented and the divers' condition.

The saturation chamber atmosphere is heliox. For this reason, surface orientated heliox tables that use air stops to speed up the decompression must not be used. The reason is that breathing air through a mask in a chamber filled with heliox can induce high tissue gas supersaturation levels and greater susceptibility for bubble formation and decompression illness *(see chapter “Isobaric inert gas counter-diffusion” in Book #4)*. Note that the tables below are suitable:

- Closed bell tables MT92-2019 are in chamber decompression procedures in heliox atmosphere for dives between 30 and 120 metres and bottom times up to 120 minutes. These tables are available in the appendix.
- USN navy wet bell heliox tables provide exceptional bottom times of 120 minutes for depths between 18 and 115 metres. These tables use heliox mixes and oxygen. However, the depths of these tables are designed in feet instead of metres. They are also available in the appendix.

Shallow depth exposures may result in the table corresponding to the storage depth does not exist and that the first depth available asks for deeper stops than the divers' storage depth. In this case, contact the diving medical specialist to decide on the recovery procedure.

3.2.3 - Parameters to control during the saturation operations

3.2.3.1 - Parameters to check

The following parameters should be measured, displayed, and logged and retained on a continuous basis starting from compression to the end of the saturation:

- Time
- Divers depth
- Partial pressure O_2 and partial pressure CO_2 in the diver's breathing gas
- Hot water temperature and flow, or heating power to the bell
- Bell internal and external pressure
- Bell internal partial pressure O_2 , partial pressure CO_2 and temperature
- Chamber internal pressure, humidity, partial pressure O_2, partial pressure CO_2 and temperature (+ SPHL)
- Habitat internal and external pressure
- Habitat internal partial pressure O_2, partial pressure CO_2, and temperature
- Wet bell/diving basket: gas supply pressure surface/on-board
- Hot water temperatures in the bell and in the diver's suit
- Hot water flow, or heating power, to the diver in the bell

The following shall be measured and logged (not required on-line) on a routine basis:

- Potentially toxic gases in the hyperbaric environment
- Bacterial growth/content in all critical places including fresh water, hot water, BA sets, rebreather
- For saturation/living compartments at least CO and N_2 - Others to be considered
- For saturation/living compartments daily sensory check for odour/smell
- Biological samples when justified

Alarms should be installed for the following gases

- Oxygen in the diver's breathing gas
- CO2 in the diver's breathing gas
- Hydrocarbons,Hg and H_2S in the bell
- Oxygen in control/gas storage rooms when justified

3.2.3.2 - Parameter at the initial storage depth

3.2.3.2.1 - Gas parameters

Oxygen: 0.38 to 0.45 bar (380 to 450 mb)

NOTE: It is accepted that the final chamber PPO2, can exceed 0.450 bar and reach up to 0.570 at the end of an initial pressurisation. No corrective action is required as the excess chamber oxygen will be depleted by diver's consumption.

Carbon dioxide: < 0.005 ATA (< 5 mb)
Argon: 50 kPa (0,5 bar)
Nitrogen: 150 kPa (1,5 bar)
Carbon monoxide: 0,5 Pa (5 µbar)

See point 2.3.1.2 *"Acceptable gas values"*

3.2.3.2.2 - Temperatures

Depth (msw)	Temperature range (C°)
0- 50	22 - 27
50 - 100	25 - 29
100 - 150	27 - 30
150 - 200	28 - 31

Depth (msw)	Temperature range (C°)
200 - 250	29 - 31
250 - 300	30 - 32
300 - 350	31 - 33

3.2.3.2.3 - Humidity

High humidity associated with heat provides an ideal environment for infections. Also, it impairs sweat evaporation and restricts the resistance to heat. As a result, dehydration and hyperthermia may occur.

- Ideal percentage should be 50 to 70% for depths shallower than 180 msw and 40 to 60% for deeper depths
- Extremes percentage can be 30 to 80% for short periods.

3.2.4 - Hygiene in chamber

During the course of the saturation, the divers should:
- Maintain personal hygiene.
- Use preventive drops.
- Make sure that the chamber is kept clean.
- Respect the rest of others.
- Follow the instructions.

3.2.4.1 - Personal hygiene

Normal hygiene rules must be observed stringently so as to avoid the cross infection of bacteria from one individual to the next. Therefore divers should:

- Take a shower per day:
    - Divers should avoid taking too many showers; one after each bell run is recommended, or daily otherwise. Divers taking a shower should follow a « head to toes » procedure in order to avoid self contamination by transferring bacteria from one part of the body to another.
    - The skin, especially the ears, must be kept as dry as possible. Nothing is to be put in ears except drops. Q-tips, ear washing or scratching are absolutely forbidden in the chamber.
    - Soap destroys bacteria membranes and prevents infection. Unfortunately, many commercial brands contain perfumes or additional agents which can be a problem in saturation. Thus, divers are invited to use a specific liquid disinfecting soap for their personal hygiene. Aggressive detergents or soap must not be used.
- Never share toilet items such soaps, razors, towels.
- Take drops to prevent ear infection. The divers should ensure that:
    - There are two bottles, and each one corresponds to one ear.
    - If the end of the drop counting touches anything else other than the internal of the ear, it should be thrown away, and be replaced.
- Report health problems
    - Minor health problem must be reported, noticed and treated.
    - Also, minor injuries must be reported and treated immediately.

3.2.4.2 - Clothes and bedding

- Personal clothing must be changed every day, and machine washed at 85°C with any commercial washing agent
- Towels and pillows must be changed everyday, and machine washed at 85°C with any commercial washing agent,
- Bedding sheets should be changed every 3 days, and machine washed at 85°C with any commercial washing agent,
- When a new occupant arrives in the chamber, the bedding sheets, towel and pillow must be changed. Also, when beds are swapped between two occupants the bedding must be renewed.
- Following a dive, diving suits must be rinsed in freshwater at first, and then washed in 50°C water with normal soap (1 spoon per bucket), and then rinsed in freshwater and dried for the next shift.
- Hat liners should be washed as well.
- Diving masks/helmets should be rinsed with fresh water, and swabbed with disinfectant after the bell run and prior to the next bell run.

3.2.4.3 - Chamber cleaning

- Water in wet chambers should be drained after each dive or after each shower.
- Chamber system walls and toilet areas should be washed twice a week using hot water (60-70°C, locked from outside) and soft soap. The bilge should not be washed during saturation because this area is generally so polluted that any contact with it will unavoidably contaminate the diver.
- Toilet facilities, shower tray, wash basin, and toilet bowl should be cleaned after use, and disinfected. The DMAC says the following regarding disinfectant cleansers:
    - Several agents are in use or recommended. These include amphoteric surface active agents (e.g. Tego 2000) and potassium peroxymonosulfate (e.g. Virkon, Oxone). Various other products may also be suitable including dish-washing liquid solutions. Dichlorophen (Panacide M) is now less used than previously because of its undesirable properties of strong odour and skin irritation. The amphoteric surface active agent products combine good anti-microbial properties with relatively few disadvantages, e.g. they are odourless and less likely to be an irritant to the skin
    - The prime requirements of the cleaning agents is that they should be very effective against the microbes known to flourish in the chamber environment and be non-toxic to man. Additionally, the cleansers should be odourless, non-volatile, and be free from irritant and sensitising properties.
    - All chamber disinfectants should be used at the appropriate dilution, skin contact should be minimised by the

use of personal protective equipment, and they should be applied by cloth or sponge to avoid the formation of an airborne aerosol.

- All the washing gear should be locked out after use to avoid contamination (bucket, sponge, rag, gloves).
- Swabs should be taken from the chamber walls and toilet area twice a week. Depending on the result of their analysis some parts of the chamber may have to be cleared/disinfected more than twice a week.
- Reading material should not be allowed to accumulate as they constitute a large stock of flammable material and a nest for bacteria. Some print inks vapours can also be toxic in a confined space.
- Remains of meals should not be allowed to linger or accumulate in the chamber.

3.2.4.4 - Food

- Food can be a source of contamination in the chamber:
  Pathogens can develop quickly with poor quality ingredients and poor hygiene. For this reason, the kitchen where the food is prepared and quality of the ingredients should be regularly monitored by the onboard medic:
  - Kitchens and restaurants must be fully cleaned and disinfected daily.
  - Swabs should be taken from the walls, floors, tables, and cooking tools twice a week.
  - The temperatures and internal condition of the fridges (< 5 C°) and freezers (< -18 C°) should be regularly checked. Note that these temperatures must be kept while transferring food from delivery containers.
  - There should be a means of traceability for the ingredients used.
  - The hygiene and physical condition of the personnel working in the kitchen should be monitored, and they should wear hygienic barriers that are renewed every shift.
- There should be regular meals:
  Hypoglycemia is an abnormally low blood sugar (glucose) level. Severe exercise on an empty stomach can occasionally bring on symptoms even in an individual who ordinarily has no abnormality in this respect.
  The possibility of hypoglycemia increases during long diving operations. Personnel have a tendency to skip meals or eat haphazardly during the operation. For this reason, attention to proper nutrition is required.
  Prior to long dives, divers should be encouraged to load up on carbohydrates. In addition, snacks and drinks should be available in the bell. The daily needs of the divers will vary as a function of:
  - Sex
  - Age
  - Weight and musculature
  - Activity

  An average daily ration indicated by nutritionists is given for 37 calories/kg + 10 calories/hour effort.
  The daily meals should be equilibrated, and their composition should be monitored by the onboard medic (in addition to the hygiene).
  In addition, the divers should make use of common sense: For example; a huge meal shortly before diving is not dangerous itself, but if vomiting takes place for any reason, the effect can be catastrophic in a diving helmet. On the other hand, as indicated above, it is important to not be starved at the beginning of a dive.

3.2.4.5 - Respect the rest of the divers

In saturation diving, bell runs should not last more than eight hours from seal to seal, and the divers must then have 12 hours of unbroken rest *(AODC 48; DMAC 20; IMCA D 022 point 7.19).*

- The teams should be accommodated in a way that they will not disturb each other, particularly during the shift changes and meals.
- The divers should ensure to not disrupt their neighbours.
- The chambers should be isolated from external noise. NORSOK standards U-100 suggest 60 dB maximum in a sleeping chamber and 65 dB in a living chamber.

3.3 - Transfer under pressure (TUP)

3.3.1 - Purpose and principles of safety

3.3.1.1 - Purpose

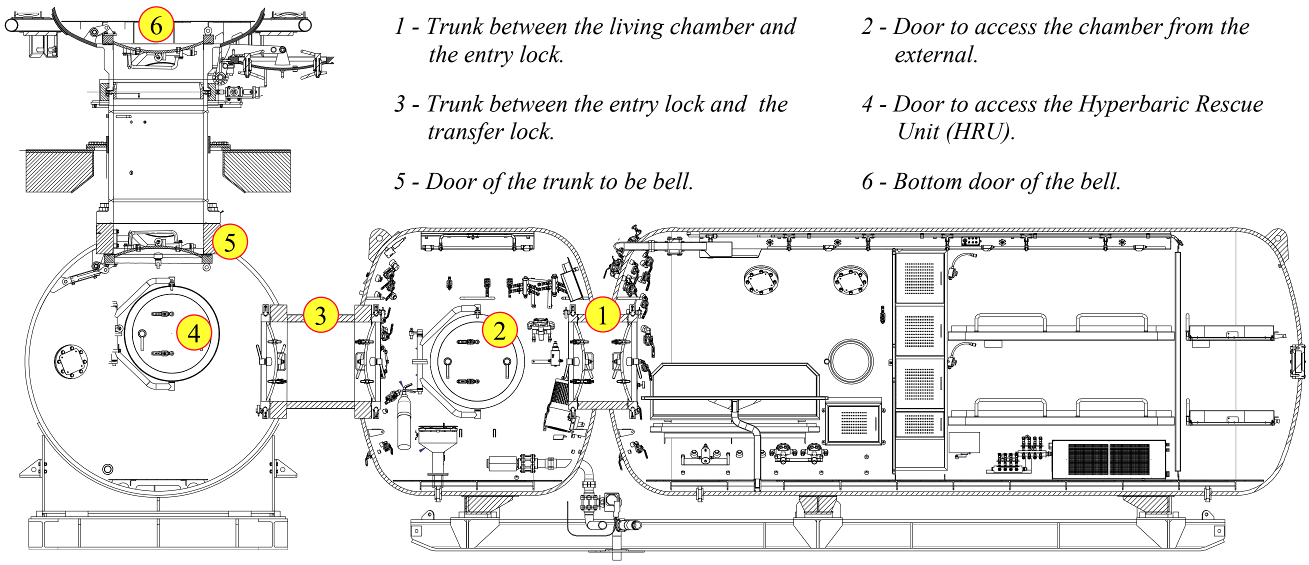
During the project, divers have to transfer into or from the bell before its launching and after it reconnection. This phase is one of the most critical as an error can have fatal consequences, such as the Byford Dolphin accident in 1983 where the full team in saturation and the operator of the clamp were killed as a result of an accidental opening of the clamp *(see explosive decompression in Book #4 "Diving accidents")*. For this reason, the transfer under pressure (TUP) requires precautions, organization, and discipline, and the potential for human errors has to be watched.

3.3.1.2 - Principles of safety

- When the saturation system is under pressure, all the doors should be closed to ensure that a pressure loss in a compartment will not have an effect to the other compartments. The doors should be opened only for transfer, and the time a door is opened should be reduced to a minimum.
- The team must be familiar with the dive system, and there should be good communication. Only well trained personnel should operate or monitor clamps and be on a headset with dive control only at all times.
- The transfer can take place only when the diving supervisor and the LSS/LST are at their control panels and ready. The decision to proceed is given by the diving supervisor and no action should be undertaken without his authorisation.
- The doors to the transfer lock should stay closed at all times unless divers are entering or leaving the lock.
- The doors to the bell trunk should stay closed at all times unless divers are moving between the bell and the chamber.
- The equalization valves on the internal chamber doors have to be kept closed and all valves on the doors in the TL kept open. When equalization valves are used, they must be returned to their initial position when the door is open.
- The diving supervisor and the life support supervisor must check the status of the doors and the pressures in the bell and the chambers before and during the transfers.
- During the transfer into the bell, a diver in the transfer lock should control the trunk's door and ensure that all the doors in the transfer lock are closed.
- There should be pressure interlocks to prevent the trunk from being opened under pressure.

3.3.1.3 - Transfer in the bell and locking off (LSS/LST side)

Note: In this example, the bellman enters the TL first, nevertheless it is considered acceptable that the other member(s) of the team enter the TL at the same time. This is depending on the decisions from the diving supervisor and the LSS. One rule to always remember is that transfer doors should be closed at all times.



1 - Trunk between the living chamber and the entry lock.

2 - Door to access the chamber from the external.

3 - Trunk between the entry lock and the transfer lock.

4 - Door to access the Hyperbaric Rescue Unit (HRU).

5 - Door of the trunk to be bell.

6 - Bottom door of the bell.

- The LSS/LST transfers the diving suits and small tools to the transfer lock using the tool lock.
- Before transferring, the diving supervisor checks the atmosphere in the the transfer lock and the bell and ensures it is breathable. He makes sure the transfer lock and the bell are at storage depth.
- The Diving supervisor and LSS/LST ensure there are no leaks and it is safe for the bellman to transfer to the transfer lock and enter the trunk to the bell.
- Upon confirmation that it is save to proceed, the bellman transfers into the the entry lock and closes the living chamber doors behind him *(see #1 in the drawing above)*. He then transfers to the transfer lock and also close the doors behind him *(see #3 in the drawing above)*. He recovers the diving equipment and small tools in the tool lock, checks his personal diving equipment, and dress.

- When the bellman is ready to go, the LSS/LST makes a last check to the trunk to the bell and if the condition is suitable for the transfer, tells the bellman that he can open the internal TL door to the bell trunk *(see #5 in the drawing)*.
- The bellman enters the bell (alone), closes the internal door *(see #6 in the drawing)*, and checks that the scrubber is running. Note that the door between the trunk and the transfer lock should be closed as well. Then, the checklist is started under the direction of the diving supervisor.
- Meanwhile, if they are not already transferred in the TL, the other divers standby in the chamber. They may be informed of additional tools that have been sent through the equipment lock. Also, complimentary documents of the task plan may be sent to them through the medical lock.
- At completion of the bell check the diving supervisor tells the LSS/LST he is ready for the divers to come to the bell.
- If they have not been transferred in the TL before *(As said above, the divers may be already in the TL)*, on instruction from LSS/LST, the divers enter the entry lock and close the doors behind them, and then the TL and also close the doors behind them.
- When they are in the transfer Lock, the divers confirm the LSS/LST that all the doors are closed. Then, they check their personal diving equipment and start to dress. When they are dressed, and the additional tools (if any) are transferred, they notify the LSS/LST that they are ready to go in the bell.
- The LSS/LST notifies the diving supervisor that the divers are ready to open the door of the trunk and come through to the bell.
- On diving supervisor "go ahead", the LSS/LST sends the diver(s) to the bell. The last diver, in the bell, closes the equalization valves and the isolation door of the trunk to the TL (if the door is hydraulic, it is closed by the LSS/LST), and then the bell door.
- The bell man reports to the dive supervisor that they are ready for a seal on the trunk.
- The diving supervisor contacts the saturation control and tells the LSS/LST that he is ready to take a seal on the bell trunk.
- On confirmation from the LSS/LST that it is "good to go" he vents off the trunk 1.5 to 3 m.

  Note: The divers in the bell push on the door for a good seal. The LSS/LST might require assistance of a diver to seal the trunk door in the TL.
- Upon confirmation from the bellman and the LSS/LST that they have got a seal and it is holding, the diving supervisor tells the LSS/LST that he will vent the trunk to surface.

  Note that depending on the system, this operation may be performed by the LSS/LST on duty. In this case:
  - After authorization from the diving supervisor to proceed, the LST vents off the trunk 1.5 to 3 m (*as indicated above, divers in the bell and the transfer lock may be asked to push on the doors for a good seal).*
  - Upon confirmation that the trunk is sealed, and it is holding, the operator vents the trunk to the surface.
- When the diving supervisor gets confirmation from the clamp operator and the LSS/LST that the trunk is at "0 - by gauge" and the interlock is disengaged he tells the clamp operator to open the clamp. At this point, the LSS/LST ceases to be involved in the bell launching *(The procedure for the diving supervisor is in Book #3)*.

3.3.1.4 - Locking on, and transfer from the bell

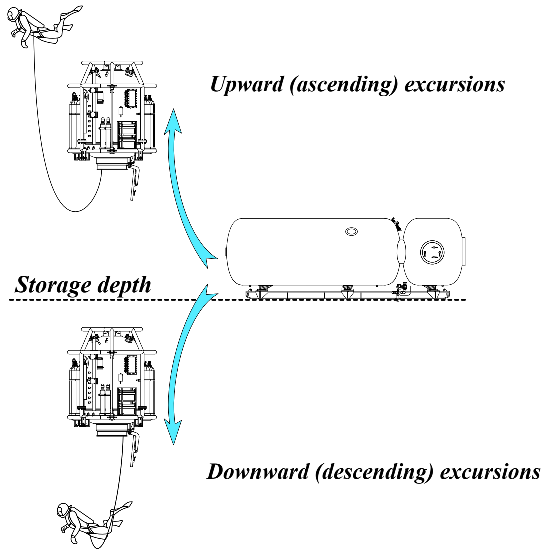
- The diving supervisor notifies the LSS/LST that the bell is coming up. The LSS/LST ensures nobody is in the TL, except for a person, if needed, for assistance. LSS/LST ensures that all the doors are closed.
- The bell is manoeuvred smoothly into contact with the flange and the clamp closed.
- The Diving Supervisor informs the LSS/LST, the divers are in the bell that the clamp is closed, secured and that the trunk is ready to be pressurized 1.5 - 3 m on chamber mix.
- The diving supervisor tells the clamp operator to check for leaks. Then, the clamp operator confirms that there are no leaks and the interlock is fully engaged.
- When the diving supervisor/LSS/LST confirms on their gauges that the pressure is holding, the trunk can be taken down 10 feet shallower than the storage depth.
- After the leak tests, on diving supervisor's order, the internal bell depth can be adjusted to the storage depth, then the diving supervisor tells the divers to open their door equalization valve. Note that the document NORSOK U-100 recommends 10 m/min (33 feet/min).
- Once the internal bell door is open to the trunk, the divers transfer to the TL on instruction from the diving supervisor who inform the LSS/LST that they are coming through.
- The bellman stays in the bell to clean up, get rid of old soda-lime and trash. He ensures the bell is ready for the next team (cleans and disinfect helmets) and does minor maintenance as needed. He reports technical problems to the diving Supervisor. During this time, the other team members send their diving suits, clothes, and tools to the surface through the tool lock. They also help to transfer the rubbish outside the chamber.
- Once the bellman has completed his checks he closes the internal door and equalization valve and transfers to the TL.
- In the TL he closes the door, the equalization valve, and reports to the LSS/LST that they can take the bell trunk away (if needed). His diving suit and clothes are sent to the surface through the tool lock.
- The procedure to return to the living chamber is the procedure to transfer to the bell performed in reverse.

3.4 - Excursions during the bell runs

3.4.1 - Types of excursions

3.4.1.1 - Ascending and descending excursions

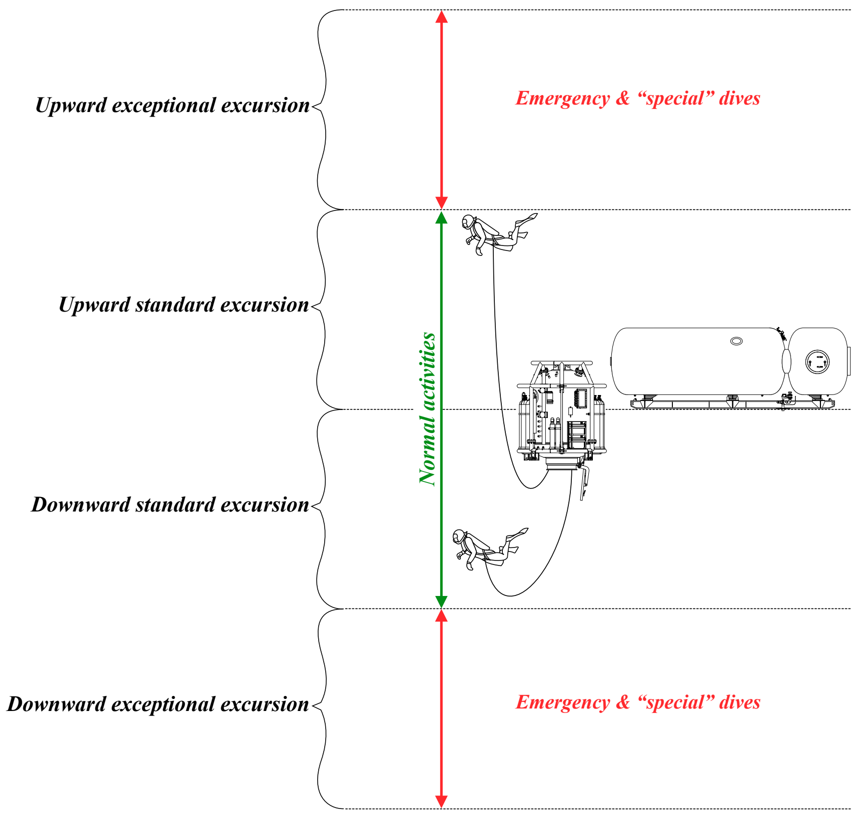
- Ascending excursions, also called upward excursions, are dives performed at depths shallower than the "storage depth", also called "life level".
- Descending excursions, also called downward excursions, are dives performed at depths deeper than the storage depth.



3.4.1.2 - Excursion depths range

Excursions are characterised by the pressure difference existing between the storage depth and the working depth which is called the excursion depth range or the excursion depth amplitude. There are two types of excursion depth ranges:

- Standard excursions allow moderate amplitudes. These excursions are those to be used for normal diving operations undertaken during underwater construction or inspection projects. Depending on the storage depth, they allow from 2 to 15 m amplitude.
- The exception excursions allow greater distances than standard excursions. However, these excursions should not be scheduled as routine and should be employed only in special or emergency situations.



3.4.2 - Stabilization periods before excursions

3.4.2.1 - Excursions upon arrival at the storage depth

Excursions upon arrival at the storage depth are not possible.
Prior to undertaking excursions, the pre-dive stabilization periods explained in point 3.2.2, must be completed.
After this initial stabilization period, upward and downward excursions are possible regardless of the depth in which the saturation is.

3.4.2.2 - Excursion after a previous excursion

Normam-15 says that after an excursion the diver should observe a stabilization period before going on another excursion according to the table below:

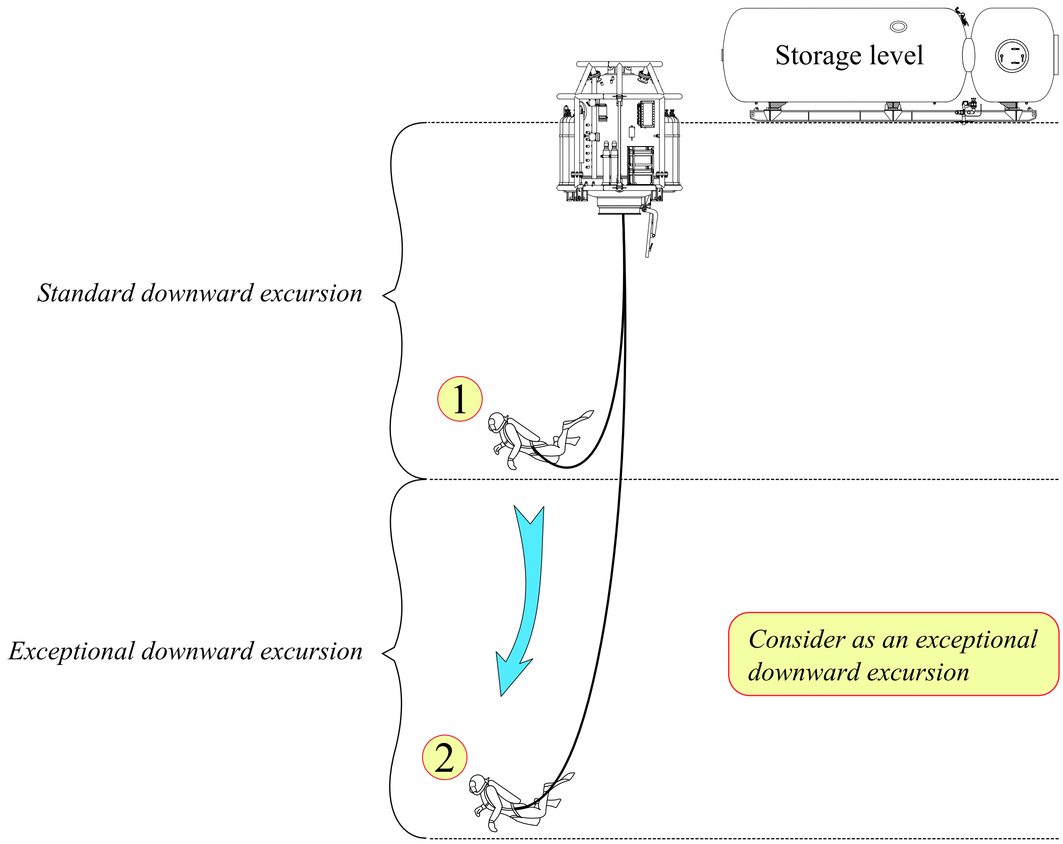
Stabilization period	***After a standard downward excursion***	***After a standard upward excursion***	***After an exceptional downward excursion***	***After an exceptional upward excursion***
Before a standard downward excursion	None	None	None	12 hours
Before a standard upward excursion	None	None	12 hours	12 hours
Before an exceptional downward excursion	None	None	48 hours	48 hours
Before an exceptional upward excursion	12 hours	None	48 hours	48 hours

Fundamental rule:
A saturated diver can perform only two exceptional excursions per saturation.
As a reminder, the maximum duration of a saturation dive is 28 days.

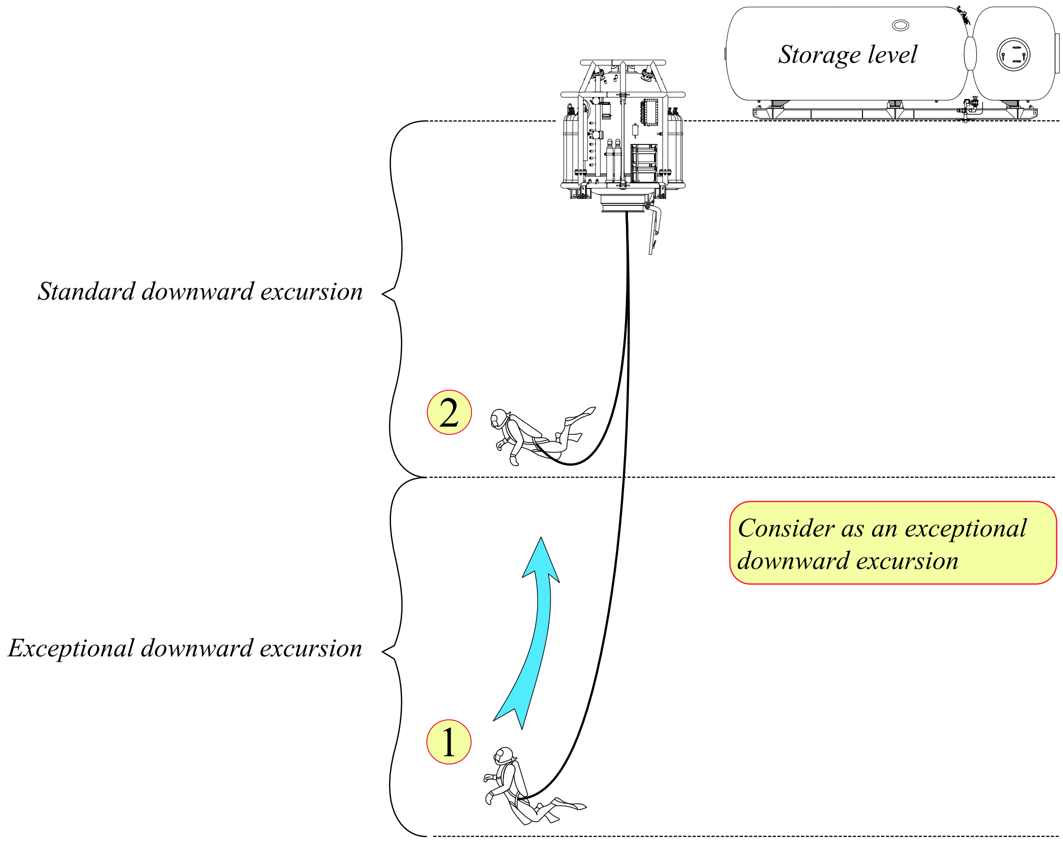
3.4.3 - Combinations allowed for excursions with no break

Combinations of standard and exceptional downward and upward excursions may have to be performed. The possible combinations are recorded below and should be done according to the criteria established in the previous point.

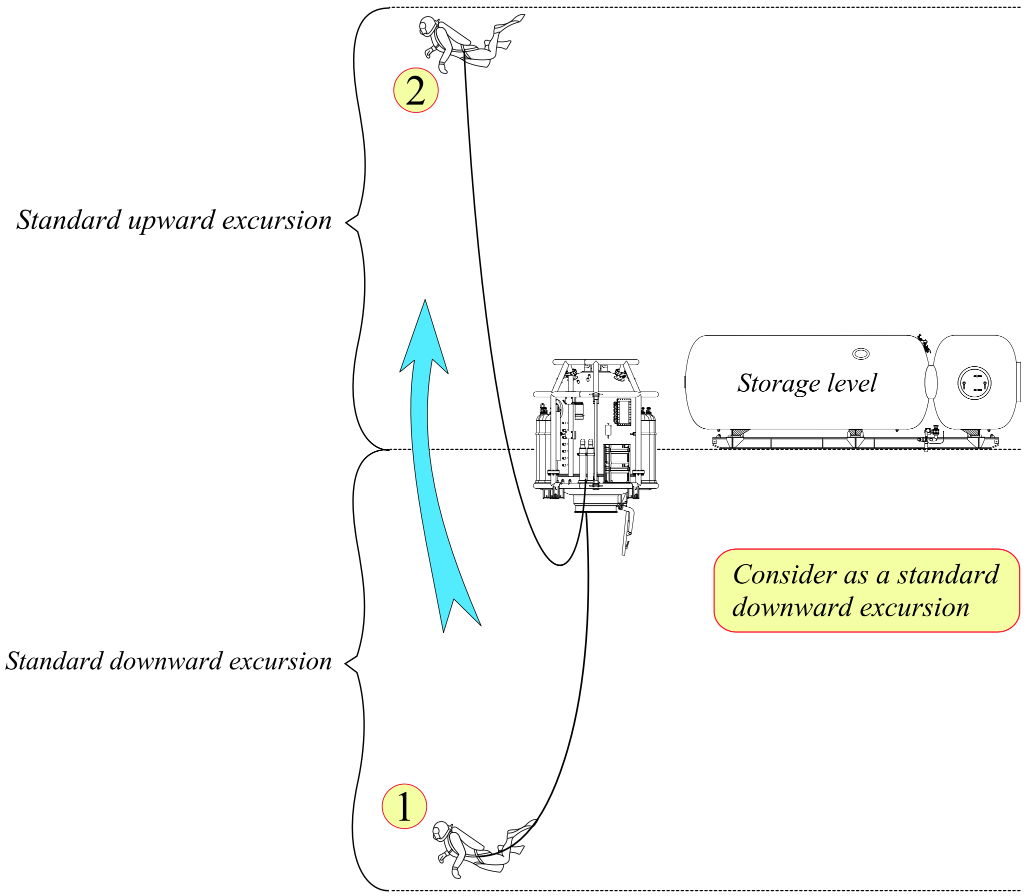
3.4.3.1 - Standard downward excursion followed by exceptional downward excursion



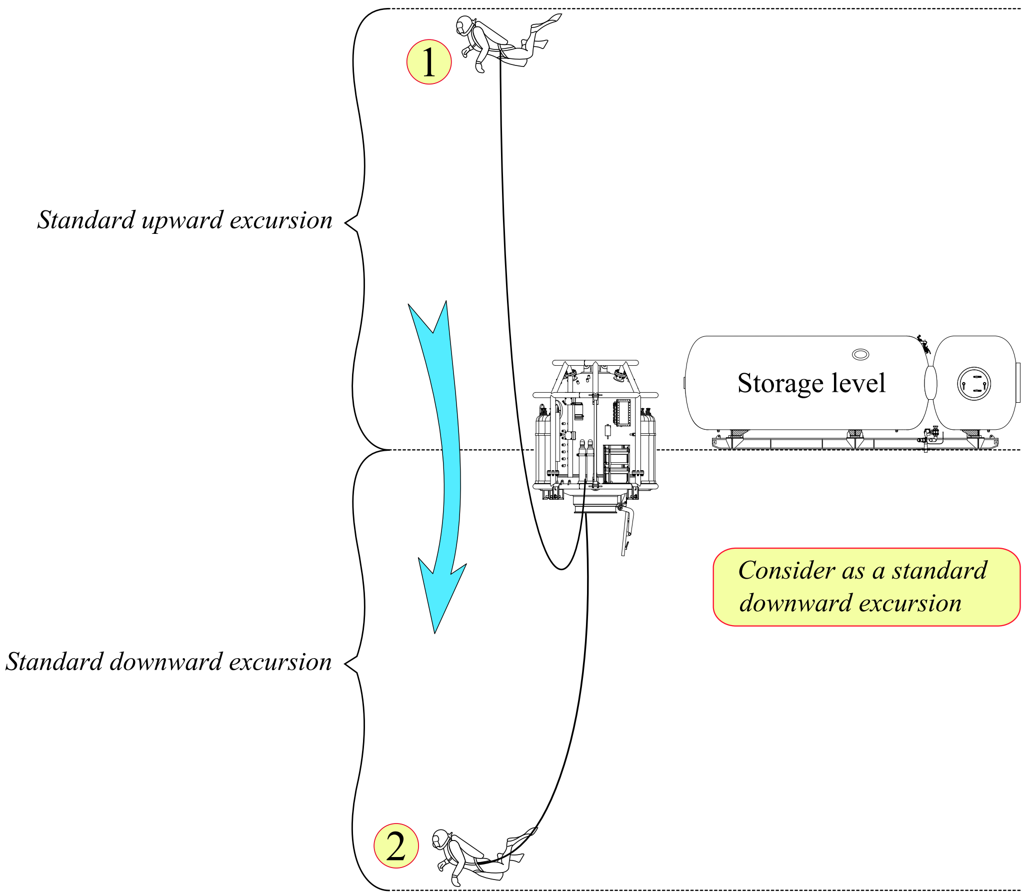
3.4.3.2 - Exceptional downward excursion followed by a standard downward excursion



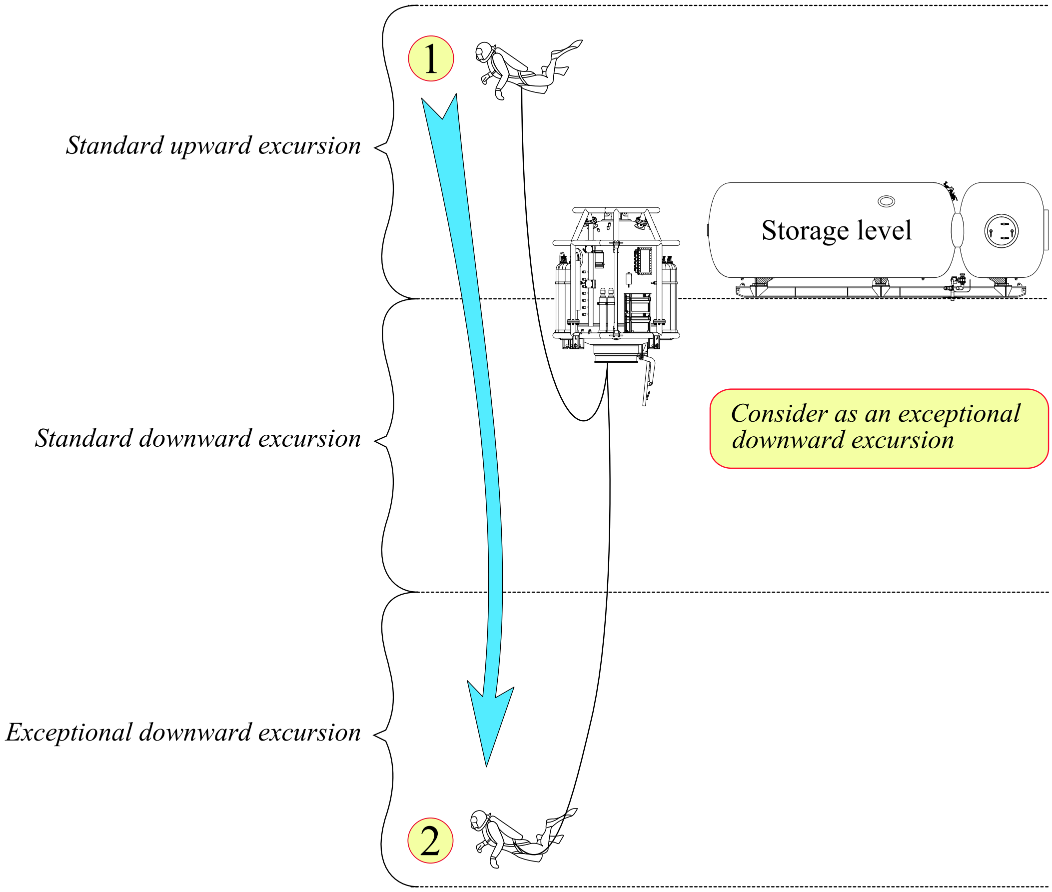
3.4.3.3 - Standard downward excursion followed by standard upward excursion



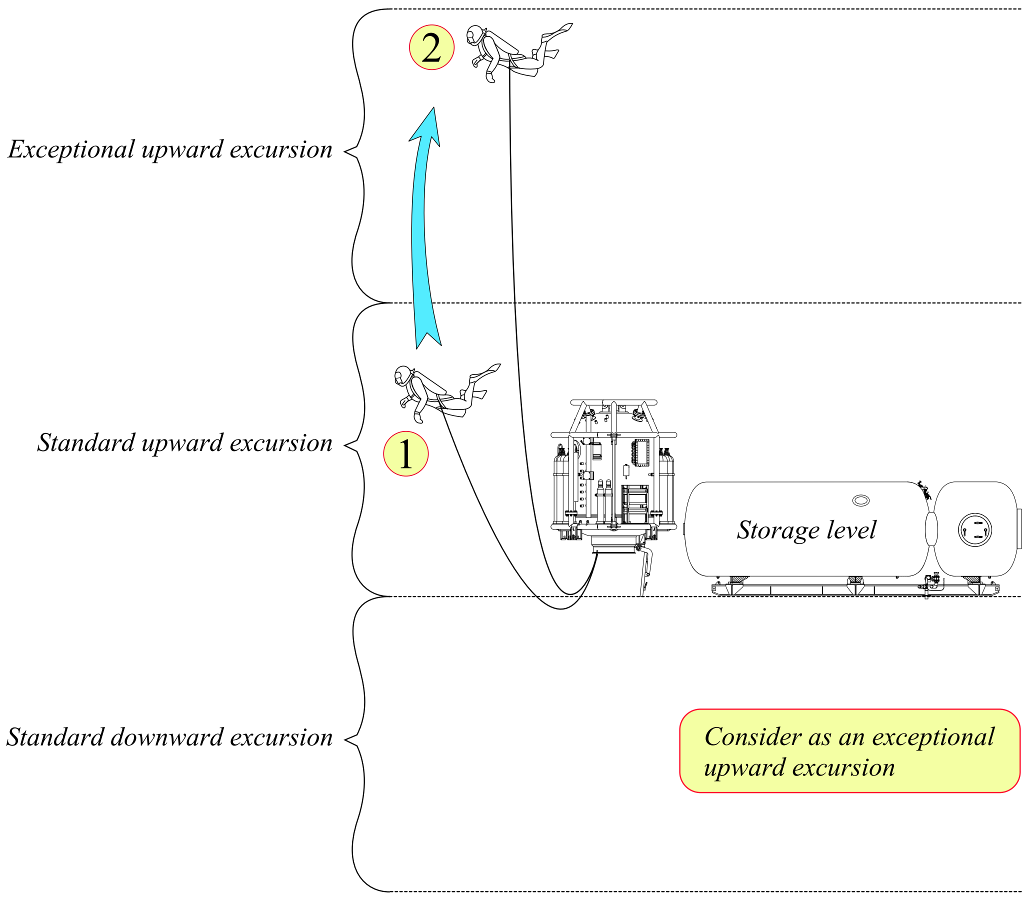
3.4.3.4 - Standard upward excursion followed by standard downward excursion



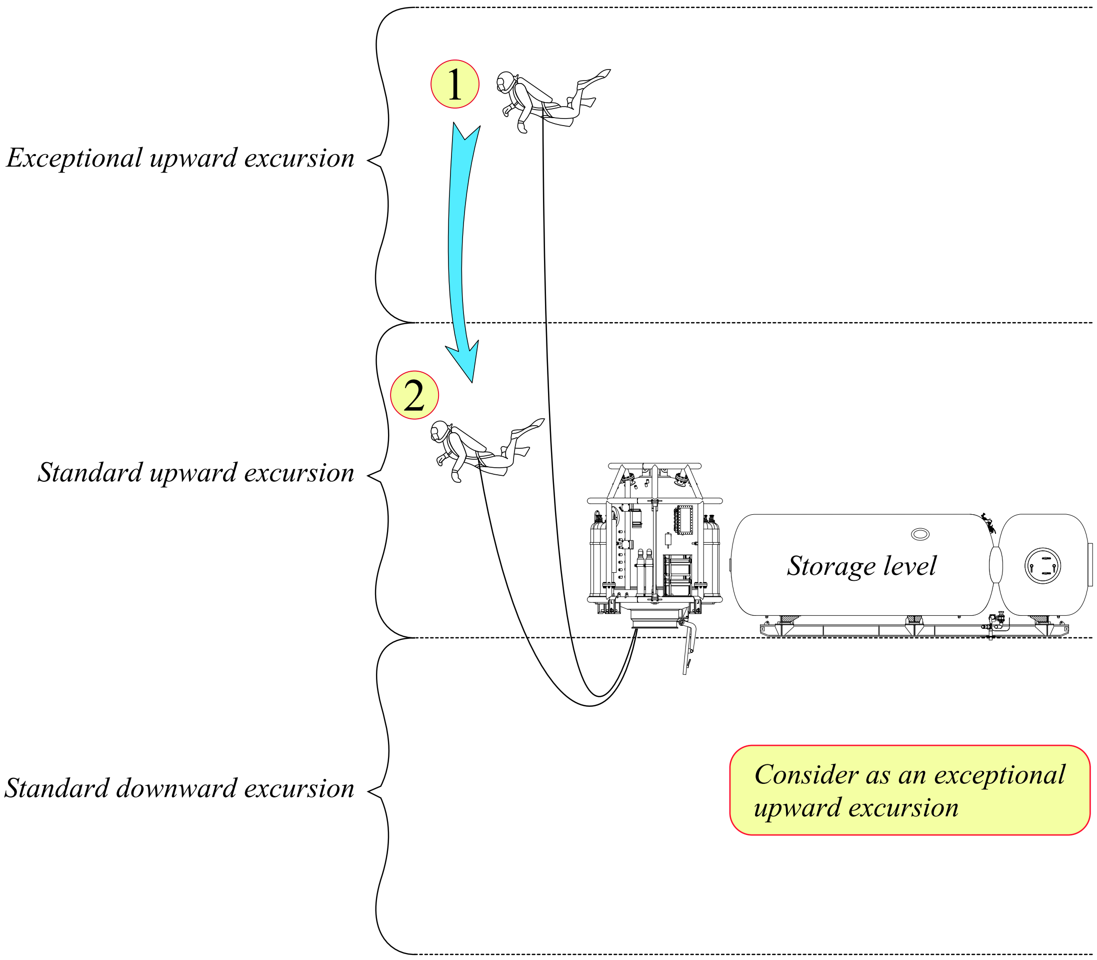
3.4.3.5 - Standard upward excursion followed by exceptional downward excursion



3.4.3.6 - Standard upward excursion followed by exceptional upward excursion



3.4.3.7 - Exceptional upward excursion followed by a standard upward excursion



3.4.4 - Recommendations for organizing bell runs and excursions *(NORSOK & French decree 15th of May 92)*

The working times should be organized in a way that the divers have regular rotations, so the working time and recovery times happen at the same hours every day. This point is very important to allow the divers a full recovery of their efforts.

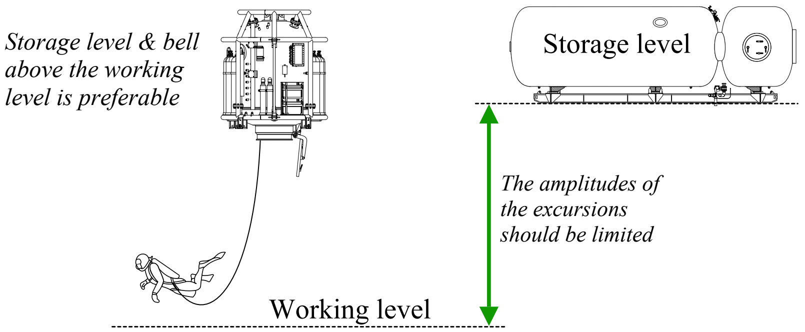
For a given bell run, the preferred choice should be:

- Descending excursions rather than ascending ones. It is preferable to have the storage level (chamber) and the bell above the working level.
- Standard excursions rather than exceptional ones.
- The work planning to be arranged so as to avoid repeated ascents for the divers.
- The living depth that is as close to the working depth as possible.

When adjusting the bell:

- The depth of the bell must be kept within the limits of "standard excursion" dives.
- A bell depth equal to or deeper than the storage level is preferable.

The storage level should be as close to the working depth as possible to limit the amplitudes of the excursions.



3.4.5 - Duration of bell runs

The bell run durations are given "seal to seal" *(from bell locked off the system to bell locked on the system)*.
Note that these durations are the maximum allowed by NORMAM-15 for 24 hours and that there must be at least 12 hours of full rest between 2 bell runs. The bell runs can be shortened according to the real time spent in the water.

The bell runs and times in the water should be organised as follows:

Depth	***0 - 210 m***	***211 - 260 m***	***261 - 300 m***	***301 - 350 m***
Maximum duration bell run	8 hours/24 hours	8 hours/24 hours	8 hours/24 hours	6 hours/24 hours
Maximum time in the water	6 hours/24 hours	5 hours/24 hours	4 hours/24 hours	3 hours/24 hours
Resting time 30 min or diver change *	At mid-dive	At mid-dive	At mid-dive	Not specified *(At mid dive)*

Resting time 30 min or diver change * :
The diver who goes into the water can at his own discretion and with the authorization of his supervisor, be replaced by the emergency diver.
If he is not replaced, he should have a resting period inside the diving bell where he can remove his diving helmet, eat, and re-hydrate. It is recommended that this resting period is to be up to thirty minutes.
Diver change or the rest period should be organized at the halftime of the time to be spent in the water.

Note that NORSOK U-100 says the following:

- The total in water time shall not exceed 5:30 hours and the break in the bell must be logged. During a two-man bell-run, total time in water during a 12 h period shall not exceed 4 h for each diver.
- Each diver shall be given a dry day as bell-man every third day
- The diving supervisor shall have a rest period from the direct communication control after a period of 4 h. The rest period shall be at least 30 min. The total time for this function shall be limited to 8 h in the course of a 12 h period. The workload should determine the length of the rest periods. Inside a 24 h period supervisory personnel should normally have a 12 h period of continuous rest.

Table of contents

3.4.6 - Excursion tables

The excursion tables displayed below and on the next pages indicate the maximum excursion depths and distances metre by metre from 10 msw to 350 msw.

To read the table, select the depth in the column on the left side and follow the horizontal line to read the corresponding maximum distances and depths of the downward or upward standard or exceptional excursions.

In the case of a storage depth between two levels:

- For an upward excursion, select the depth immediately deeper. As an example, for a depth between 20 & 21 msw, select 21 m. It is also possible to calculate the excursion using the “upward distance”.
- For a downward excursion, select the depth immediately shallower. As an example, for a depth between 20 & 21 msw, select 20 m. It is also possible to calculate the excursion using the “downward distance”.

Life depth (metres)	*Standard excursions*				*Exceptional excursions*			
	Downward distances	*Downward depths*	*Upward distances*	*Upward depths*	*Downward distances*	*Downward depths*	*Upward distances*	*Upward depths*
10	3	13	2	8	Forbidden	–	Forbidden	–
11	3	14	2	9	Forbidden	–	Forbidden	–
12	3	15	2	10	Forbidden	–	Forbidden	–
13	3	16	2	11	Forbidden	–	Forbidden	–
14	3	17	2	12	Forbidden	–	Forbidden	–
15	3	18	2	13	Forbidden	–	Forbidden	–
16	3	19	2	14	Forbidden	–	Forbidden	–
17	3	20	2	15	Forbidden	–	Forbidden	–
18	4	22	4	14	Forbidden	–	Forbidden	–
19	4	23	4	15	Forbidden	–	Forbidden	–
20	4	24	4	16	Forbidden	–	Forbidden	–
21	4	25	4	17	Forbidden	–	Forbidden	–
22	4	26	4	18	Forbidden	–	Forbidden	–
23	5	28	5	18	10	33	Forbidden	–
24	5	29	5	19	10	34	Forbidden	–
25	5	30	5	20	10	35	Forbidden	–
26	5	31	5	21	10	36	Forbidden	–
27	5	32	5	22	10	37	Forbidden	–
28	5	33	5	23	10	38	Forbidden	–
29	5	34	5	24	10	39	Forbidden	–
30	6	36	6	24	12	42	Forbidden	–
31	7	38	7	24	14	45	14	17
32	7	39	7	25	14	46	14	18
33	7	40	7	26	14	47	14	19
34	7	41	7	27	14	48	14	20
35	7	42	7	28	14	49	14	21
36	7	43	7	29	14	50	14	22
37	7	44	7	30	14	51	14	23
38	7	45	7	31	14	52	14	24
39	7	46	7	32	14	53	14	25
40	8	48	8	32	16	56	16	24
41	8	49	8	33	16	57	16	25
42	8	50	8	34	16	58	16	26
43	8	51	8	35	16	59	16	27
44	8	52	8	36	16	60	16	28

Life depth (metres)	Standard excursions				Exceptional excursions			
	Downward distances	Downward depths	Upward distances	Upward depths	Downward distances	Downward depths	Upward distances	Upward depths
45	8	53	8	37	16	61	16	29
46	8	54	8	38	16	62	16	30
47	8	55	8	39	16	63	16	31
48	8	56	8	40	16	64	16	32
49	8	57	8	41	16	65	16	33
50	8	58	8	42	16	66	16	34
51	8	59	8	43	16	67	16	35
52	8	60	8	44	16	68	16	36
53	8	61	8	45	16	69	16	37
54	8	62	8	46	16	70	16	38
55	8	63	8	47	16	71	16	39
56	8	64	8	48	16	72	16	40
57	8	65	8	49	16	73	16	41
58	8	66	8	50	16	74	16	42
59	8	67	8	51	16	75	16	43
60	9	69	9	51	18	78	18	42
61	9	70	9	52	18	79	18	43
62	9	71	9	53	18	80	18	44
63	9	72	9	54	18	81	18	45
64	9	73	9	55	18	82	18	46
65	9	74	9	56	18	83	18	47
66	9	75	9	57	18	84	18	48
67	9	76	9	58	18	85	18	49
68	9	77	9	59	18	86	18	50
69	9	78	9	60	18	87	18	51
70	9	79	9	61	18	88	18	52
71	9	80	9	62	18	89	18	53
72	9	81	9	63	18	90	18	54
73	9	82	9	64	18	91	18	55
74	9	83	9	65	18	92	18	56
75	9	84	9	66	18	93	18	57
76	9	85	9	67	18	94	18	58
77	9	86	9	68	18	95	18	59
78	9	87	9	69	18	96	18	60
79	9	88	9	70	18	97	18	61
80	10	90	10	70	20	100	20	60
81	10	91	10	71	20	101	20	61
82	10	92	10	72	20	102	20	62
83	10	93	10	73	20	103	20	63
84	10	94	10	74	20	104	20	64
85	10	95	10	75	20	105	20	65
86	10	96	10	76	20	106	20	66
87	10	97	10	77	20	107	20	67
88	10	98	10	78	20	108	20	68

Life depth (metres)	Standard excursions				Exceptional excursions			
	Downward distances	Downward depths	Upward distances	Upward depths	Downward distances	Downward depths	Upward distances	Upward depths
89	10	99	10	79	20	109	20	69
90	10	100	10	80	20	110	20	70
91	10	101	10	81	20	111	20	71
92	10	102	10	82	20	112	20	72
93	10	103	10	83	20	113	20	73
94	10	104	10	84	20	114	20	74
95	10	105	10	85	20	115	20	75
96	10	106	10	86	20	116	20	76
97	10	107	10	87	20	117	20	77
98	10	108	10	88	20	118	20	78
99	10	109	10	89	20	119	20	79
100	11	111	11	89	22	122	22	78
101	11	112	11	90	22	123	22	79
102	11	113	11	91	22	124	22	80
103	11	114	11	92	22	125	22	81
104	11	115	11	93	22	126	22	82
105	11	116	11	94	22	127	22	83
106	11	117	11	95	22	128	22	84
107	11	118	11	96	22	129	22	85
108	11	119	11	97	22	130	22	86
109	11	120	11	98	22	131	22	87
110	11	121	11	99	22	132	22	88
111	11	122	11	100	22	133	22	89
112	11	123	11	101	22	134	22	90
113	11	124	11	102	22	135	22	91
114	11	125	11	103	22	136	22	92
115	11	126	11	104	22	137	22	93
116	11	127	11	105	22	138	22	94
117	11	128	11	106	22	139	22	95
118	11	129	11	107	22	140	22	96
119	11	130	11	108	22	141	22	97
120	12	132	12	108	24	144	24	96
121	12	133	12	109	24	145	24	97
122	12	134	12	110	24	146	24	98
123	12	135	12	111	24	147	24	99
124	12	136	12	112	24	148	24	100
125	12	137	12	113	24	149	24	101
126	12	138	12	114	24	150	24	102
127	12	139	12	115	24	151	24	103
128	12	140	12	116	24	152	24	104
129	12	141	12	117	24	153	24	105
130	12	142	12	118	24	154	24	106
131	12	143	12	119	24	155	24	107
132	12	144	12	120	24	156	24	108

Life depth (metres)	Standard excursions				Exceptional excursions			
	Downward distances	Downward depths	Upward distances	Upward depths	Downward distances	Downward depths	Upward distances	Upward depths
133	12	145	12	121	24	157	24	109
134	12	146	12	122	24	158	24	110
135	12	147	12	123	24	159	24	111
136	12	148	12	124	24	160	24	112
137	12	149	12	125	24	161	24	113
138	12	150	12	126	24	162	24	114
139	12	151	12	127	24	163	24	115
140	13	153	13	127	26	166	26	114
141	13	154	13	128	26	167	26	115
142	13	155	13	129	26	168	26	116
143	13	156	13	130	26	169	26	117
144	13	157	13	131	26	170	26	118
145	13	158	13	132	26	171	26	119
146	13	159	13	133	26	172	26	120
147	13	160	13	134	26	173	26	121
148	13	161	13	135	26	174	26	122
149	13	162	13	136	26	175	26	123
150	13	163	13	137	26	176	26	124
151	13	164	13	138	26	177	26	125
152	13	165	13	139	26	178	26	126
153	13	166	13	140	26	179	26	127
154	13	167	13	141	26	180	26	128
155	13	168	13	142	26	181	26	129
156	13	169	13	143	26	182	26	130
157	13	170	13	144	26	183	26	131
158	13	171	13	145	26	184	26	132
159	13	172	13	146	26	185	26	133
160	13	173	13	147	26	186	26	134
161	13	174	13	148	26	187	26	135
162	13	175	13	149	26	188	26	136
163	13	176	13	150	26	189	26	137
164	13	177	13	151	26	190	26	138
165	13	178	13	152	26	191	26	139
166	13	179	13	153	26	192	26	140
167	13	180	13	154	26	193	26	141
168	13	181	13	155	26	194	26	142
169	13	182	13	156	26	195	26	143
170	13	183	13	157	26	196	26	144
171	13	184	13	158	26	197	26	145
172	13	185	13	159	26	198	26	146
173	13	186	13	160	26	199	26	147
174	13	187	13	161	26	200	26	148
175	13	188	13	162	26	201	26	149
176	13	189	13	163	26	202	26	150

Life depth (metres)	Standard excursions				Exceptional excursions			
	Downward distances	Downward depths	Upward distances	Upward depths	Downward distances	Downward depths	Upward distances	Upward depths
177	13	190	13	164	26	203	26	151
178	13	191	13	165	26	204	26	152
179	13	192	13	166	26	205	26	153
180	15	195	15	165	30	210	30	150
181	15	196	15	166	30	211	30	151
182	15	197	15	167	30	212	30	152
183	15	198	15	168	30	213	30	153
184	15	199	15	169	30	214	30	154
185	15	200	15	170	30	215	30	155
186	15	201	15	171	30	216	30	156
187	15	202	15	172	30	217	30	157
188	15	203	15	173	30	218	30	158
189	15	204	15	174	30	219	30	159
190	15	205	15	175	30	220	30	160
191	15	206	15	176	30	221	30	161
192	15	207	15	177	30	222	30	162
193	15	208	15	178	30	223	30	163
194	15	209	15	179	30	224	30	164
195	15	210	15	180	30	225	30	165
196	15	211	15	181	30	226	30	166
197	15	212	15	182	30	227	30	167
198	15	213	15	183	30	228	30	168
199	15	214	15	184	30	229	30	169
200	15	215	15	185	30	230	30	170
201	15	216	15	186	30	231	30	171
202	15	217	15	187	30	232	30	172
203	15	218	15	188	30	233	30	173
204	15	219	15	189	30	234	30	174
205	15	220	15	190	30	235	30	175
206	15	221	15	191	30	236	30	176
207	15	222	15	192	30	237	30	177
209	15	224	15	194	30	239	30	179
210	15	225	15	195	30	240	30	180
212	15	227	15	197	30	242	30	182
213	15	228	15	198	30	243	30	183
214	15	229	15	199	30	244	30	184
215	15	230	15	200	30	245	30	185
216	15	231	15	201	30	246	30	186
217	15	232	15	202	30	247	30	187
218	15	233	15	203	30	248	30	188
219	15	234	15	204	30	249	30	189
220	15	235	15	205	30	250	30	190
221	15	236	15	206	30	251	30	191
222	15	237	15	207	30	252	30	192

Life depth (metres)	Standard excursions				Exceptional excursions			
	Downward distances	Downward depths	Upward distances	Upward depths	Downward distances	Downward depths	Upward distances	Upward depths
223	15	238	15	208	30	253	30	193
224	15	239	15	209	30	254	30	194
225	15	240	15	210	30	255	30	195
226	15	241	15	211	30	256	30	196
227	15	242	15	212	30	257	30	197
228	15	243	15	213	30	258	30	198
229	15	244	15	214	30	259	30	199
230	15	245	15	215	30	260	30	200
231	15	246	15	216	30	261	30	201
232	15	247	15	217	30	262	30	202
233	15	248	15	218	30	263	30	203
234	15	249	15	219	30	264	30	204
235	15	250	15	220	30	265	30	205
236	15	251	15	221	30	266	30	206
237	15	252	15	222	30	267	30	207
238	15	253	15	223	30	268	30	208
239	15	254	15	224	30	269	30	209
240	15	255	15	225	30	270	30	210
241	15	256	15	226	30	271	30	211
242	15	257	15	227	30	272	30	212
243	15	258	15	228	30	273	30	213
244	15	259	15	229	30	274	30	214
245	15	260	15	230	30	275	30	215
246	15	261	15	231	30	276	30	216
247	15	262	15	232	30	277	30	217
248	15	263	15	233	30	278	30	218
249	15	264	15	234	30	279	30	219
250	15	265	15	235	30	280	30	220
251	15	266	15	236	30	281	30	221
252	15	267	15	237	30	282	30	222
253	15	268	15	238	30	283	30	223
254	15	269	15	239	30	284	30	224
255	15	270	15	240	30	285	30	225
256	15	271	15	241	30	286	30	226
257	15	272	15	242	30	287	30	227
258	15	273	15	243	30	288	30	228
259	15	274	15	244	30	289	30	229
260	15	275	15	245	30	290	30	230
261	15	276	15	246	30	291	30	231
262	15	277	15	247	30	292	30	232
263	15	278	15	248	30	293	30	233
264	15	279	15	249	30	294	30	234
265	15	280	15	250	30	295	30	235
266	15	281	15	251	30	296	30	236

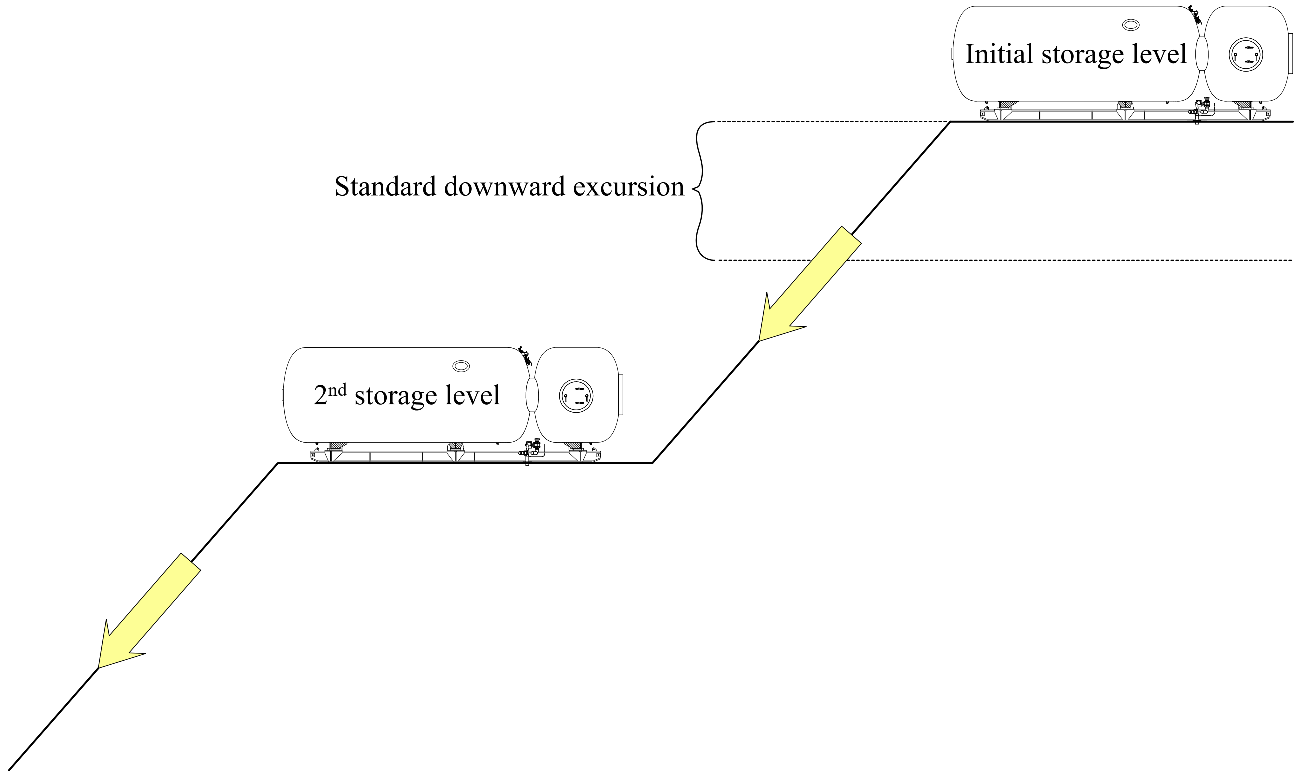
Life depth (metres)	Standard excursions				Exceptional excursions			
	Downward distances	Downward depths	Upward distances	Upward depths	Downward distances	Downward depths	Upward distances	Upward depths
267	15	282	15	252	30	297	30	237
268	15	283	15	253	30	298	30	238
269	15	284	15	254	30	299	30	239
270	15	285	15	255	30	300	30	240
271	15	286	15	256	29	300	30	241
272	15	287	15	257	28	300	30	242
273	15	288	15	258	27	300	30	243
274	15	289	15	259	26	300	30	244
275	15	290	15	260	25	300	30	245
276	15	291	15	261	24	300	30	246
277	15	292	15	262	23	300	30	247
278	15	293	15	263	22	300	30	248
279	15	294	15	264	21	300	30	249
280	15	295	15	265	20	300	30	250
281	15	296	15	266	19	300	30	251
282	15	297	15	267	18	300	30	252
283	15	298	15	268	17	300	30	253
284	15	299	15	269	16	300	30	254
285	15	300	15	270	15	300	30	255
286	14	300	14	272	14	300	25	261
287	13	300	13	274	13	300	25	262
288	12	300	12	276	12	300	25	263
289	11	300	11	278	11	300	25	264
290	10	300	10	280	10	300	25	265
291	10	301	10	281	Forbidden	–	25	266
292	10	302	10	282	Forbidden	–	25	267
293	10	303	10	283	Forbidden	–	25	268
294	10	304	10	284	Forbidden	–	25	269
295	10	305	10	285	Forbidden	–	25	270
296	10	306	10	286	Forbidden	–	25	271
297	10	307	10	287	Forbidden	–	25	272
298	10	308	10	288	Forbidden	–	25	273
299	10	309	10	289	Forbidden	–	25	274
300	10	310	10	290	Forbidden	–	25	275
301	10	311	10	291	Forbidden	–	Forbidden	–
302	10	312	10	292	Forbidden	–	Forbidden	–
303	10	313	10	293	Forbidden	–	Forbidden	–
304	10	314	10	294	Forbidden	–	Forbidden	–
305	10	315	10	295	Forbidden	–	Forbidden	–
306	10	316	10	296	Forbidden	–	Forbidden	–
307	10	317	10	297	Forbidden	–	Forbidden	–
308	10	318	10	298	Forbidden	–	Forbidden	–
309	10	319	10	299	Forbidden	–	Forbidden	–
310	10	320	10	300	Forbidden	–	Forbidden	–

Life depth (metres)	*Standard excursions*				*Exceptional excursions*			
	Downward distances	*Downward depths*	*Upward distances*	*Upward depths*	*Downward distances*	*Downward depths*	*Upward distances*	*Upward depths*
311	10	321	10	301	Forbidden	–	Forbidden	–
312	10	322	10	302	Forbidden	–	Forbidden	–
313	10	323	10	303	Forbidden	–	Forbidden	–
314	10	324	10	304	Forbidden	–	Forbidden	–
315	10	325	10	305	Forbidden	–	Forbidden	–
316	10	326	10	306	Forbidden	–	Forbidden	–
317	10	327	10	307	Forbidden	–	Forbidden	–
318	10	328	10	308	Forbidden	–	Forbidden	–
319	10	329	10	309	Forbidden	–	Forbidden	–
320	10	330	10	310	Forbidden	–	Forbidden	–
321	10	331	10	311	Forbidden	–	Forbidden	–
322	10	332	10	312	Forbidden	–	Forbidden	–
323	10	333	10	313	Forbidden	–	Forbidden	–
324	10	334	10	314	Forbidden	–	Forbidden	–
325	10	335	10	315	Forbidden	–	Forbidden	–
326	10	336	10	316	Forbidden	–	Forbidden	–
327	10	337	10	317	Forbidden	–	Forbidden	–
328	10	338	10	318	Forbidden	–	Forbidden	–
329	10	339	10	319	Forbidden	–	Forbidden	–
330	10	340	10	320	Forbidden	–	Forbidden	–
331	10	341	10	321	Forbidden	–	Forbidden	–
332	10	342	10	322	Forbidden	–	Forbidden	–
333	10	343	10	323	Forbidden	–	Forbidden	–
334	10	344	10	324	Forbidden	–	Forbidden	–
335	10	345	10	325	Forbidden	–	Forbidden	–
336	10	346	10	326	Forbidden	–	Forbidden	–
337	10	347	10	327	Forbidden	–	Forbidden	–
338	10	348	10	328	Forbidden	–	Forbidden	–
339	10	349	10	329	Forbidden	–	Forbidden	–
340	10	350	10	330	Forbidden	–	Forbidden	–
341	9	350	10	331	Forbidden	–	Forbidden	–
342	8	350	10	332	Forbidden	–	Forbidden	–
343	7	350	10	333	Forbidden	–	Forbidden	–
344	6	350	10	334	Forbidden	–	Forbidden	–
345	5	350	10	335	Forbidden	–	Forbidden	–
346	4	350	10	336	Forbidden	–	Forbidden	–
347	3	350	10	337	Forbidden	–	Forbidden	–
348	2	350	10	338	Forbidden	–	Forbidden	–
349	1	350	10	339	Forbidden	–	Forbidden	–
350	Forbidden	–	Forbidden	–	Forbidden	–	Forbidden	–

3.5 - Intermediate compressions

3.5.1 - Explanations

The 1st storage depth may be the final life level from which the operations are organized. Nevertheless, it often happens that the chamber has to be readjusted to a depth that allows reaching a workplace that is beyond the range permitted by the downward excursions from the initial storage level.
The relocation of the chamber cannot be undertaken at the speed of 10 metres/minute used by the divers during excursions and a procedure similar to the one used for the 1st pressurization must be implemented.
Two scenarios may happen that are explained in this chapter: Pressurization of the chamber during a rest period and pressurization of the chamber during a bell run.



3.5.2 - Pressurization of the chamber during a rest period

3.5.2.1 - Procedures for compressions starting within the standard saturation range

3.5.2.1.1 - Gas parameters

PP O2: 0.4 to 0.57 bar (400 to 570 mb)

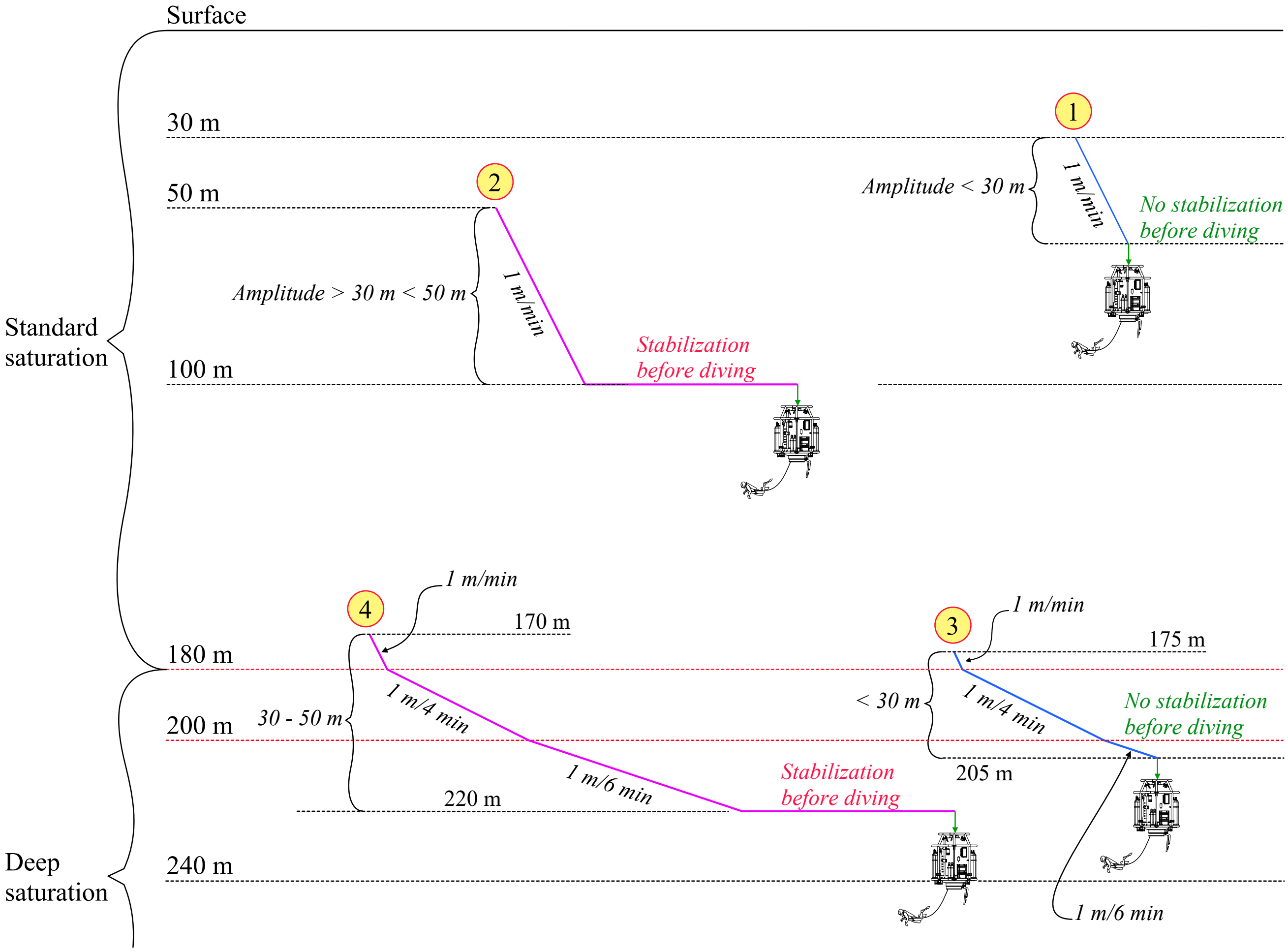
PP CO2 : < 0.005 bar (< 5 mb)

3.5.2.1.2 - Pressurization speeds and stabilization stops

Amplitude of the pressurization	***Maximum compression speeds***	***Stabilization stops***
< 30 metres ***Range:*** from 10 m to above 210 m	- From 10 to 180 m: 1 minutes/metre - From 181 to 200 m: 4 minutes/metre - From 201 to 210 m: 6 minutes/metre	- No stabilization required, even in the case of transition to a deep saturation *(below 180 m).*
30 to < 50 metres ***Range:*** from 10 m to above 230 m	- From 10 to 180 m: 1 minutes/metre - From 181 to 200 m: 4 minutes/metre - From 201 to 230 m: 6 minutes/metre	- 2 hours stabilization when reaching the new saturation depth, not stopping at 200 m in case of a transition to a deep saturation *(below 180 m)*.
> 50 metres ***Range:*** from 10 m to above 350 m	Apply the same procedure as for an initial compression: - From 10 to 180 m: 1 minutes/metre - From 181 to 200 m: 4 min/metre - From 201 to 300 m: 6 min/metre - From 301 to 350 m: 8 minutes/metre	Apply the same procedure as for an initial compression: - Depending on the final depth, apply the stabilization criteria of a standard or a deep saturation indicated in points 3.2.2.1, 3.2.2.2, and 3.2.23. - Start from the storage depth where the chamber is and apply the procedure from this point to the next depth .

The drawing below shows possible scenarios for compressions inferior to 30 m and from 30 m to less than 50 m described in the tables 6212:

- Curve #1: Compression with an amplitude less than 30 m within the limits of a standard saturation
- Curve #2: Compression with an amplitude between 30 & < 50 m within the limits of a standard saturation
- Curve #3: Compression with an amplitude less than 30 m transiting from standard saturation to deep saturation
- Curve #4: Same scenario as the curve #3 for a compression more than 30 m and less than 50 m



3.5.2.2 - Procedures for compressions starting within the deep saturation range

3.5.2.2.1 - Gas parameters

PP O2: 0.4 to 0.57 bar (400 to 570 mb)

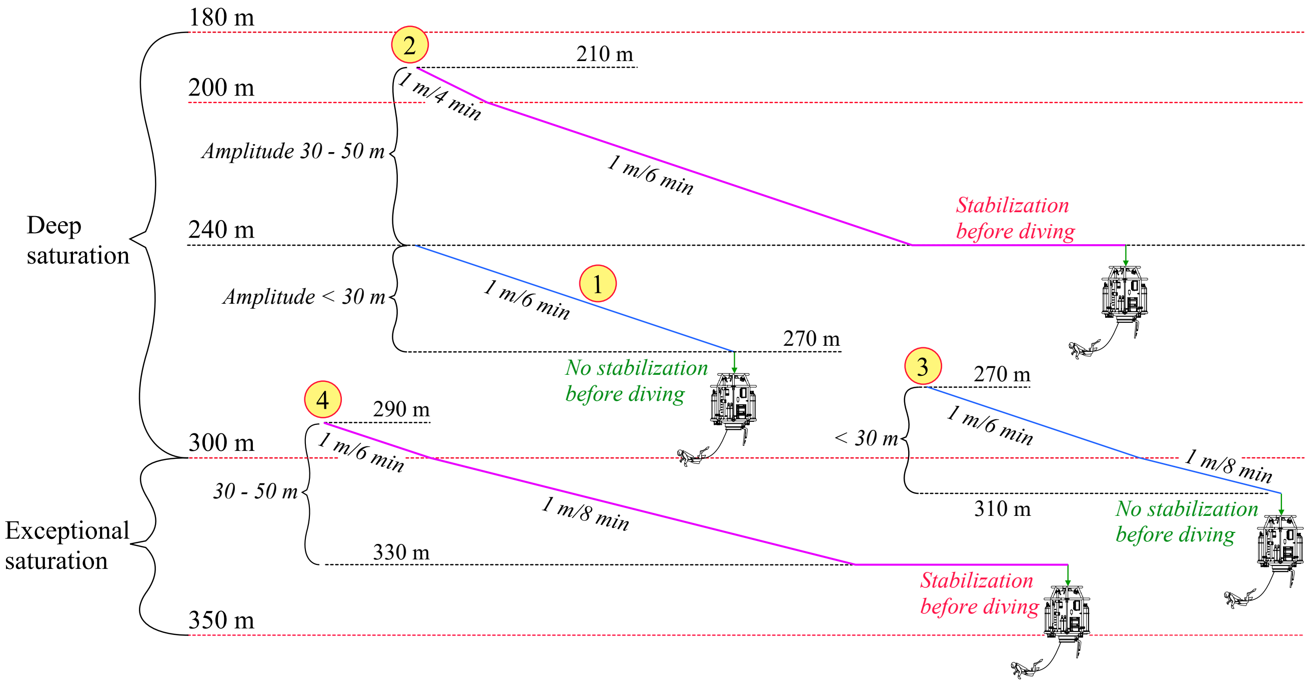
PP CO2 : < 0.005 bar (< 5 mb)

3.5.2.2.2 - Pressurization speeds and stabilization stops

Amplitude of the pressurization	***Maximum compression speed***	***Stabilization stops***
< 30 metres ***Range:*** from 181 m to above 330 m	- From 181 to 200 m: 4 minutes/metre - From 200 to 300 m: 6 minutes/metre	- No stabilization required.
31 to 50 metres ***Range:*** from 181 m to above 350 m	- From 181 to 200 m: 4 minutes/metre - From 200 to 300 m: 6 minutes/metre	- Two hours of stabilization when reaching the new saturation depth.
> 50 metres ***Range:*** from 181 m to above 350 m	Apply the same procedure as for an initial compression, but starting below 180 m: - From 181 to 200 m: 4 minutes/metre - From 200 to 300 m: 6 minutes/metre - From 300 to 350 m: 8 minutes/metre	Apply the same procedure as for an initial compression, but starting below 180 m: - Depending on the final depth, apply the stabilization criteria of a deep saturation indicated in points 3.2.2.2, and 3.2.2.3. - Start from the storage depth where the chamber is and apply the procedure from this point to the next depth .

The drawing below shows possible scenarios for compressions inferior to 30 m and from 30 m to less than 50 m described in the tables 6222:

- Curve #1: Compression with an amplitude less than 30 m within the limits of a deep saturation
- Curve #2: Compression with an amplitude 30 & < 50 m within the limits of a standard saturation
- Curve #3: Compression with an amplitude less than 30 m transiting from deep saturation to exceptional saturation.
- Curve #4: Same scenario as the curve #3 for a compression more than 30 m and less than 50 m



3.5.2.3 - Procedures for compressions starting within the exceptional saturation range

3.5.2.3.1 - Gas parameters

PP O2: 0.4 to 0.57 bar (400 to 570 mb)

PP CO2 : < 0.005 bar (< 5 mb)

3.5.2.3.2 - Pressurization speeds and stabilization stops

Intermediate compressions should not be done in dives with storage depth (life level) between 300 and 350. However, if it is necessary for safety reasons, the speed for pressurization and the procedures for stabilization stops should be those of the initial pressurization that can be found in point 3.2, or the table below:

Compression rates and stabilization in the initial compression prior to start the diving operations

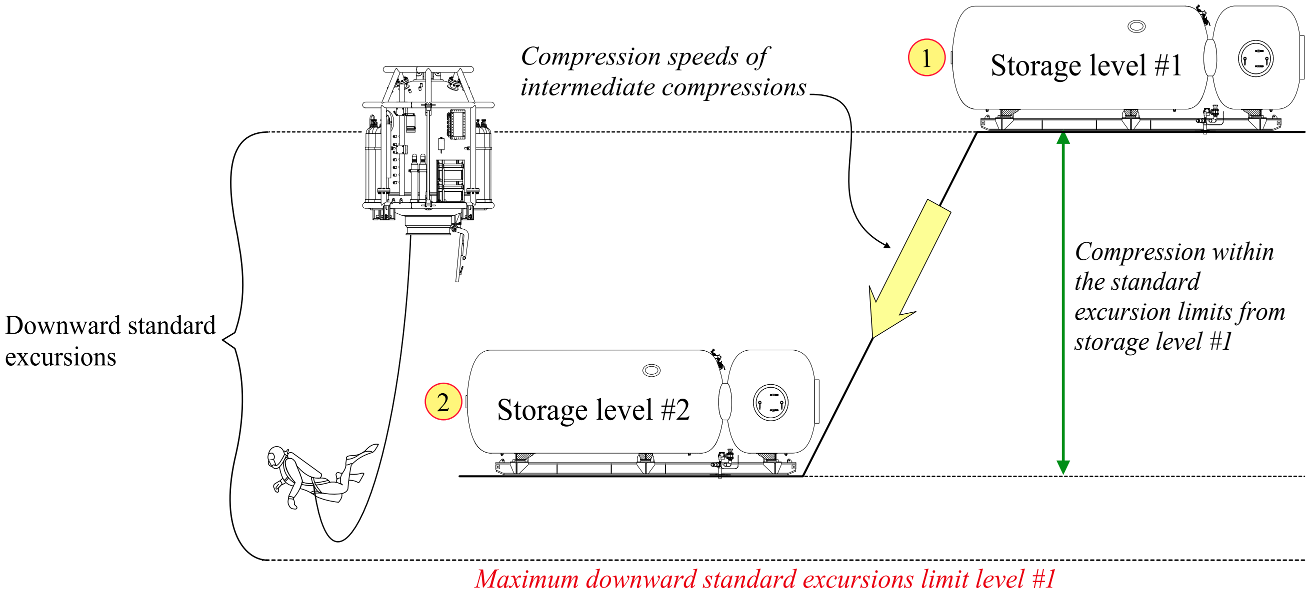
Saturation depth	Maximum compression speed	Stabilization stops
300 to 350 metres	- From 300 to 350 m: 8 minutes/metre (0.125 m/minute)	Stabilization stop of least 12 hours at the saturation depth

3.5.2.4 - Excursions upon arrival at the storage depth

Prior to undertaking excursions, the stabilization periods for compression distances superior to 30 m that can be read in the tables in point 3.2.2 must have been completed. After this initial rest period, upward and downward excursions are possible regardless of the depth in which the saturation is.

3.5.3 - Pressurization of the chamber during a bell run

It may happen that small readjustments of the chamber have to be performed during a bell run.
Change the chamber storage level to a deeper depth during a bell run is possible only if the new depth of the chamber is within the standard excursion limits of the divers at work.
Also, the divers at rest in the chamber must not have performed an exceptional upward excursion within the previous 12 hours.
The change of level must be performed at the compression speeds indicated in point 3.5.2.



3.6 - Decompression procedures

3.6.1 - Decompression of the chamber during normal operations

The standard procedure for decompression is the same for standard, deep and exceptional saturations.

3.6.1.1 - Gas values

From the beginning of decompression up to the depth in which the oxygen percentage in the chamber reaches 21%, the partial oxygen pressure of 0,48 and 0,5 bar should be kept.
From this depth, the oxygen partial pressure should decrease so that the oxygen percentage in the respiratory mixture used in the chamber is as close as possible to 21% due to the fire risk. Note that variations up to 23% maximum are acceptable for reduced periods (23% is the oxygen percentage indicated in IMCA D 022).

3.6.1.2 - Level from where the ascent starts

NORSOK standard U 100 says in point 8.2.3.3 that a decompression shall not start with a pressure reducing (upward) excursion. This is also confirmed in the French decree of may 1992. For these reasons, we can consider that starting the decompression from the life level is the only acceptable option.

3.6.1.3 - Stabilization prior to start the ascent

There is no stabilization period before the ascent mentioned with NORMAM-15. However, this procedure is today suggested by several national safety organizations and applied by most reputed companies. For these reasons, a minimum of eight hours of stabilization before starting the ascent is recommended.

Also, note the following:

- NORSOK U 100/point 8.2.3.4 says: *"There shall be a minimum 8 hours hold at living depth prior to decompression after an excursion. This hold period is to be considered as part of the decompression and not the stay at living depth".*
- French decree of 15th May 1992 / page 361/ point 5.3 says: *"There should be a 12 hour hold at living depth prior to decompression at living depth after a "maximum excursion"*

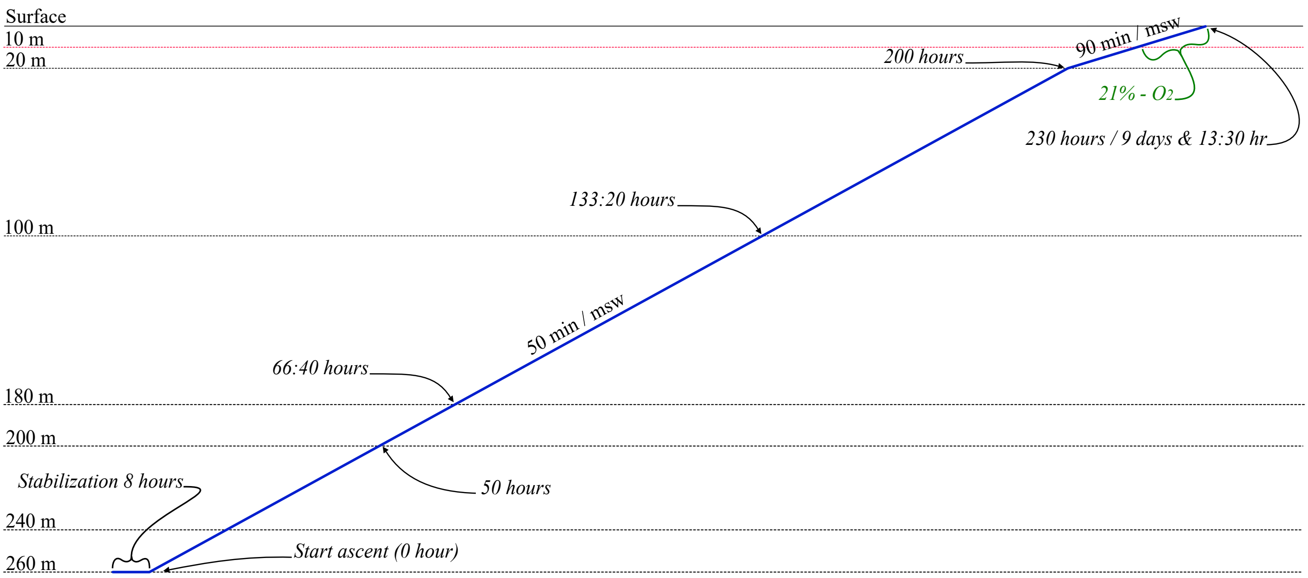
3.6.1.4 - Ascent speeds and profile

The decompression procedure NORMAM-15 is designed with a continuous ascent *(without stops).*
Continuous slow ascent profiles give smooth decompressions that are appreciated by a lot of Life Support Technicians (LST), diving supervisors, and divers. The procedure proposes 2 two methods:

- Continuous speed where the gas is bleeding continuously
- Step by step, where the chamber is decompressed metre by metre

The speeds established for the different depth ranges should be met as applicable.

Depth range	*Continuous speed*	*Going up through steps*
350 to 20 msw	50 minutes/msw *(1.2 msw/hour)*	Go up 1 msw every 50 minutes
20 msw to surface	90 minutes/msw *(0.67 msw/hour)*	Go up 1 msw every 90 minutes



3.6.1.5 - Decompression times from various storage depths

Notes:
- The durations in days are indicated in days + decimals.
- The times below do not include the stabilization period prior to decompression.

Depth in metres	Deco. in hours	Deco. in days	Depth in metres	Deco. in hours	Deco. in days	Depth in metres	Deco. in hours	Deco. in days
10	15:00	0.625	***41***	47:30	1.979	***72***	73:20	3.056
11	15:30	0.688	***42***	48:20	2.014	***73***	74:10	3.09
12	18;00	0.75	***43***	49:10	2.049	***74***	75:00	3.125
13	19:30	0.813	***44***	50:00	2.083	***75***	75:50	3.16
14	21:00	0.875	***45***	50:50	2.118	***76***	76:40	3.194
15	22:30	0.938	***46***	51:40	2.153	***77***	77:30	3.229
16	24:00	1	***47***	52:30	2.188	***78***	78:20	3.264
17	25.3	1.063	***48***	53:20	2.222	***79***	79:30	3.299
18	27:00	1.125	***49***	54:10	2.257	***80***	80:00	3.333
19	28:30	1.188	***50***	55:00	2.292	***81***	80:50	3.368
20	30:00	1.25	***51***	55:30	2.326	***82***	81:40	3.403
21	30:50	1.285	***52***	56:40	2.361	***83***	82:30	3.438
22	31:40	1.319	***53***	57:30	2.393	***84***	83:20	3.472
23	32:30	1.354	***54***	58:20	2.431	***85***	84:10	3.507
24	33:20	1.389	***55***	59:10	2.465	***86***	85:00	3.542
25	34:10	1.424	***56***	60:00	2.5	***87***	85:50	3.576
26	35:00	1.458	***57***	60:50	2.535	***88***	86:40	3.611
27	35:50	1.43	***58***	61.4	2.569	***89***	87:30	3.646
28	36:40	1.528	***59***	62:30	2.604	***90***	88:20	3.618
29	37.3	1.563	***60***	63.2	2.639	***91***	89:10	3.715
30	38:20	1.597	***61***	64:10	2.674	***92***	90:00	3.75
31	39:10	1.632	***62***	65:00	2.708	***93***	90:50	3.785
32	40:00	1.667	***63***	65:50	2.743	***94***	91:40	3.819
33	40:50	1.701	***64***	66:40	2.778	***95***	92:30	3.854
34	41:40	1.736	***65***	67:30	2.813	***96***	93:20	3.889
35	42:30	1.771	***66***	68:20	2.847	***97***	94:10	3.924
36	43:20	1.806	***67***	69:10	2.882	***98***	95:00	3.958
37	44:10	1.84	***68***	70:00	2.917	***99***	95:50	3.993
38	45:00	1.875	***69***	70:50	2.951	***100***	96:40	4.028
39	45:50	1.91	***70***	71:40	2.986	***101***	97:30	4.063
40	46:40	1.944	***71***	72:30	3.021	***102***	98:20	4.097

Depth in metres	Deco. in hours	Deco. in days
103	99:10	4.132
104	100:00	4.167
105	100:50	4.201
106	101:40	4.236
107	102:30	4.271
108	103:20	4.306
109	104:10	4.34
110	105	4.375
111	105:50	4.41
112	106:40	4.444
113	1107:30	4.479
114	108:20	4.514
115	109:10	4.549
116	110:00	4.583
117	110:50	4.618
118	111:40	4.653
119	112:30	4.688
120	113:20	4.722
121	114:10	4.757
122	115:00	4.792
123	115:50	4.826
124	116:40	4.861
125	117:30	4.896
126	118:20	4.931
127	119:10	4.965
128	120:00	5
129	120:50	5.035
130	121:40	5:069
131	122:30	5.104
132	123:20	5.139
133	124:10	5.174
134	125:00	5.208
135	125:50	5.243
136	126:40	5.278
137	127:30	5.313
138	128:20	5.347
139	129:10	5.382
140	130:00	5.417
141	130.5	5.451
142	131:40	5.486
143	132:30	5.521
144	133.2	5.556
145	134:10	5.59
146	135:00	5.625
147	135:50	5.66
148	136:40	5.694
149	137:30	5.729
150	138:20	5.764
151	139:10	5.799
152	140:00	5.833
153	140:50	5.868
154	141:40	5.903
155	142:30	5.938
156	143:20	5.972
157	144:10	6.007
158	145:00	6.042
159	145:50	6.076
160	146:40	6.111
161	147:30	6.146
162	148:20	6.181
163	149:10	6.215
164	150:00	6.25
165	150:50	6.285
166	151:40	6.319
167	152:30	6.354
168	153:20	6.389
169	154:10	6.424
170	155:00	6.458
171	155:50	6.493
172	156:40	6.528
173	157:30	6.563
174	158:20	6.597
175	159:10	6.632
176	160:00	6.667
177	160:50	6.701
178	161:40	6.736
179	162:30	6.771
180	163:20	6.806
181	164:10	6.84
182	165:00	6.875
183	165:50	6.91
184	166:40	6.944
185	167:30	6.679
186	168:20	7.014
187	169:10	7.049
188	170:00	7.083
189	170:50	7.118
190	171:40	7.153
191	172:30	7.188
192	173:20	7.222
193	174:10	7.257
194	175:00	7.292
195	175:50	7.326
196	176:40	7.361
197	177:30	7.396
198	178:20	7.431
199	179:10	7.465
200	180:00	7.5
201	180:50	7.535

Depth in metres	Deco. in hours	Deco. in days	Depth in metres	Deco. in hours	Deco. in days	Depth in metres	Deco. in hours	Deco. in days
202	181:40	7.569	***235***	209:10	8.715	***268***	236:40	9.861
203	182:30	7.604	***236***	210:00	8.75	***269***	237:30	9.896
204	183:20	7.639	***237***	210:50	8.785	***270***	238:20	9.931
205	184:10	7.674	***238***	211:40	8.819	***271***	239:10	9.965
206	185:00	7.708	***239***	212:30	8.854	***272***	240:00	10
207	185:50	7.743	***240***	213:20	8.889	***273***	240:50	10.035
208	186:40	7.778	***241***	214:110	8.924	***274***	241:40	10.069
209	187:30	7.813	***242***	215:00	8.958	***275***	242:30	10.104
210	188:20	7.847	***243***	215:50	8.993	***276***	243:20	10.139
211	189:10	7.88	***244***	216:40	9.028	***277***	244:10	10.174
212	190:00	7.917	***245***	217:30	9.063	***278***	245:00	10.208
213	190:50	7.951	***246***	218:20	9.097	***279***	245:50	10.243
214	191:40	7.986	***247***	219:10	9.132	***280***	246:40	10.278
215	192:30	8.021	***248***	220:00	9.167	***281***	247:30	10.313
216	193:20	8.056	***249***	220:50	9.201	***282***	248:20	10.347
217	194:10	8.09	***250***	221:40	9.236	***283***	249:10	10.382
218	195:00	8.125	***251***	222:30	9.271	***284***	250:00	10.417
219	195:50	8.16	***252***	223.2	9.306	***285***	250:50	10.451
220	196:40	8.194	***253***	224:10	9.34	***286***	251:40	10.486
221	197:30	8.229	***254***	225:00	9.375	***287***	252:30	10.521
222	198:20	8.264	***255***	225:50	9.41	***288***	253.2	10.556
223	199:10	8.299	***256***	226:40	9.444	***289***	254:10	10.59
224	200:00	8.333	***257***	227:30	9.479	***290***	255:00	10.625
225	200:50	8.368	***258***	228:20	9.514	***291***	255:50	10.66
226	201:40	8.403	***259***	229:10	9.549	***292***	256:40	10.694
227	202:30	8.438	***260***	230:00	9.583	***293***	257:30	10.729
228	203:20	8.472	***261***	230:50	9.618	***294***	258:20	10.764
229	204:10	8.507	***262***	231:40	9.653	***295***	259:10	10.799
230	205:00	8.542	***263***	232:30	9.688	***296***	260:00	10.833
231	205:50	8.576	***264***	233:20	9.722	***297***	260:50	10.868
232	206:40	8.611	***265***	234:10	9.757	***298***	261:40	10.903
233	207:30	8.646	***266***	235:00	9.792	***299***	262:30	10.938
234	208:20	8.681	***267***	235:50	9.826	***300***	263:20	10.972

Depth in metres	Deco. in hours	Deco. in days	Depth in metres	Deco. in hours	Deco. in days	Depth in metres	Deco. in hours	Deco. in days
301	264:10	11.007	***316***	276:40	11.528	***331***	289:10	12.049
302	265:00	11.042	***317***	277:30	11.563	***332***	290:00	12.083
303	265:50	11.076	***318***	278:20	11.597	***333***	290:50	12.118
304	266:40	11.111	***319***	279:10	11.632	***334***	291:40	12.153
305	267:30	11.146	***320***	280:00	11.667	***335***	292:30	12.188
306	268:20	11.181	***321***	280:50	11.701	***336***	293:20	12.222
307	269:10	11.215	***322***	281:40	77.736	***337***	294:10	12.257
308	270:00	11.25	***323***	282:30	11.771	***338***	295:00	12.292
309	270:50	11.285	***324***	283:20	11.806	***339***	295.5	12.326
310	271:40	11.319	***325***	284:10	11.84	***340***	296:40	12.361
311	272:30	11.354	***326***	285:00	11.875	***341***	297:30	12.396
312	273:20	11.389	***327***	285:50	11.91	***342***	298:20	12.431
313	274:10	11.424	***328***	286:40	11.944	***343***	299:10	12.465
314	275:00	11.458	***329***	287:30	11.979	***344***	300:00	12.5
315	275:50	11.493	***330***	288:20	12.014	***345***	300:50	12.535

3.6.2 - Decompression during a bell run, control of the divers during decompression, and excursions after an intermediate decompression

3.6.2.1 - Decompress the chamber during a bell run

It may happen that small upward readjustments of the chamber have to be performed.

However, we must keep in mind that NORSOK standard U 100 says that “a decompression shall not start with a pressure reducing (upward) excursion”, and that this point is also confirmed in the French decree of May 1992.
For these reasons, the chamber should never be decompressed during a bell run.

3.6.2.2 - Control the divers during the decompression

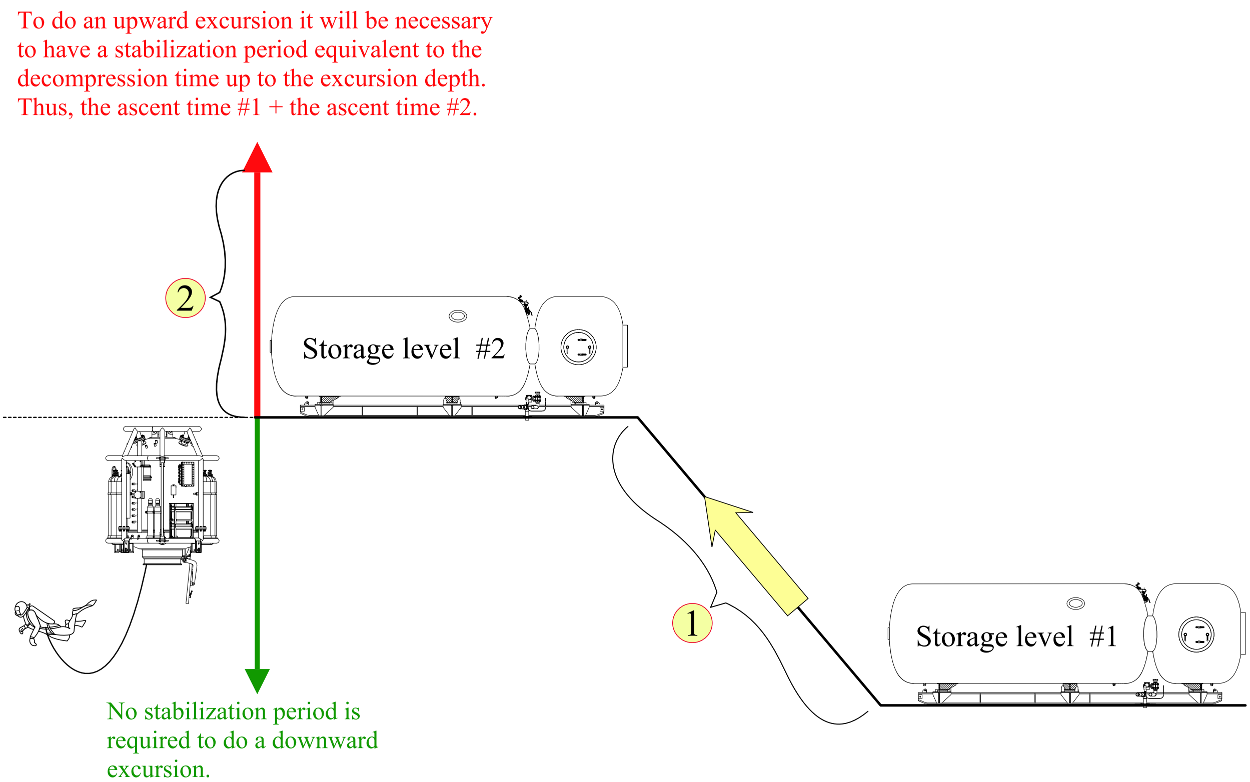
The controls to be in place during the saturation operations that are listed in point 3.2.3 must continue until the full completion of the dive. The following points should be kept in mind

- The divers should be encouraged to perform some light physical activity and report any suspicious event.
- BIBS should be available with the relevant gas at any time.
- Remember that facilities such as toilets cannot be used when the chamber arrives close to the surface.

3.6.2.3 - Excursions after an intermediate decompression

NORMAM-15 says:

After an intermediate decompression, no stabilization period is required to do a downward excursion upon arrival at the new depth.
However, to do an upward excursion, it will be necessary to have a stabilization period equivalent to the decompression time up to the excursion depth. In other words, the stabilization period must be equal to time needed to reach the shallower storage level (level #2) at an ascent speed of 50 minutes/metre (or 90 min/metre above 20 m) plus the time that should be necessary to reach the upper level of the planned excursion at the same speed.



Notes:

- After an ascent to a new storage depth, there is an increased risk of a decompression accident which will last several days. Thus, the upward excursions should be avoided or minimised for several days.
- As indicated in point 3.4.5 “*Recommendations for organizing bell runs and excursions*”, it is preferable to establish a shallower storage depth rather than perform a series of repetitive upward excursions.

3.6.3 - Accelerated decompression

As for all saturation procedures, the recommended decompression process of NORMAM-15 is slow. For this reason, a Hyperbaric Rescue Unit (HRU) which is the means for escaping the system, described in chapter 4.5 of this Book, is usually connected to the system and ready to accommodate and evacuate the divers. The divers and the supporting team must be regularly trained to launch this system and recover it on the accompanying boat, which will transfer it to Hyperbaric Reception Facility where the decompression will be undertaken in the best manner. However, it may happen that in some extreme situations, the use of the hyperbaric rescue chamber is not possible. For this reason, ultimate methods of decompression have been thought to recover the divers to the surface when a critical situation has happened that has resulted that the team in saturation having to be retrieved from the system as soon as possible, or being stuck in it without any possibility of escape. Of course, these methods should be used only when the diving team is dealing with a life-or-death situation and should never be used in another condition.
Two documents that describe suitable procedures have been published that should be taken into account to plan for an efficient response to such undesirable events:

- DMAC 31 *"Accelerated emergency decompression (AED) from saturation"*, published by the Diving Medical Advisory Committee (DMAC).
- *"A review of accelerated decompression from heliox saturation in commercial diving emergencies",* published by Jean-Pierre Imbert, and doctors Jean-Yves Massimelli, Ajit Kulkarni, Lyubisa Matity, and Philip Bryson.

3.6.3.1 - About DMAC 31

DMAC 31 has been published in March 2013, and is based on the conclusion of a workshop held on 13 April 2011 in London (UK), to consider the issues involved in rapid decompression from saturation. This paper, called *"Accelerated emergency decompression from saturation in commercial diving operations"* is available free of charge with DMAC 31 on DMAC's website (https://www.dmac-diving.org/guidance/).
The DMAC says that the knowledge underlying the guidance is limited, that the objective of this guidance is to reduce mortality, and it is recognized that there may be a high risk of injury.
The DMAC also says the following:

- A risk evaluation exercise should be conducted in any circumstance in which the safety of divers in a decompression chamber system is put at risk as a result of fire or mechanical damage to the vessel or chamber system, which may result in loss of the vessel (sinking) or inability to provide continued support to the divers under pressure. Such circumstances have the potential to result in multiple fatalities amongst the divers.
- The chances of an emergency situation resulting in fatalities may range from a possibility to an absolute certainty. Both level of risk and the timescale of progression of an emergency situation are difficult to assess but prediction of the outcome is likely to be more accurate as time progresses.
- Actions to remove the divers to safety need to be considered at the earliest stage possible.
- Emergency decompression will carry a relatively lower risk when storage depth is shallow, divers have made no recent excursions (i.e. within 24 hours) and when there is a longer time window of opportunity in which to conduct the decompression.
- In using an accelerated decompression it will always be safer to reduce the rate of decompression (or stop and recompress) in the event that the emergency resolves, than to speed up the rate of decompression if the emergency scenario progresses more rapidly than anticipated.
- Regarding chamber decompression issues:
    - The decompression should be planned to take place at the slowest rate consistent with a safe evaluation of the emergency timescale.
    - In planning a rapid decompression the selection of either a linear decompression or commencing with an upward excursion (1 msw per minute) should take into account the divers' recent excursion dive (pressure profile) exposure.
    - During the decompression a high PPO_2 in the divers' breathing gas is advantageous.
    - The level of PPO_2 selected will depend on anticipated duration of exposure. At deeper depths, the chamber PPO_2 could be raised to 1.0 - 1.5 ata.
    - Use of a built-in breathing system (BIBS) would be required for higher PPO_2 mixtures and at shallow depths.
    - Decompression rates as fast as 10 - 20 msw per hour using a high PPO_2 may be possible with divers who have not done any excursion in the previous 24 hours.
    - Breathing a high PPO_2 gas mixture before starting decompression may be helpful if the opportunity exists without reducing total time available for decompression.
    - All attempts should be made to obtain assistance from another dive vessel with chamber facilities for the recompression of divers completing decompression at the earliest available opportunity.
    - Maintaining adequate hydration is considered important. This will require an adequate oral fluid intake. Some advocate the administration of higher volumes of fluid by mouth or by intravenous route if practical.
    - The volumes taken or administered will be dependent on the duration of the decompression, but oral intakes as high as 1 litre per hour might be reasonable during a short decompression.
    - For oral hydration water or oral rehydration mixture should be locked into the chamber shortly before use.

- Thermal control of the chamber should be maintained.
- If environmental control is compromised, this may increase the risk of the procedure.
- Where practical, divers should be encouraged to move around but not undertake vigorous exertion during the decompression.
- There is no human evidence that any drug would offer benefits but analgesia may be valuable. “Glyceryl trinitrate”, “non-steroidal anti-inflammatory agents”, and “clopidogrel” may all offer some advantage in protection against decompression illness and can be used in the case of an accelerated decompression.
  - “Glyceryl trinitrate” is a nitrate used for chest pain associated with angina. It is also sold under the names of various registered brands.
  - “Non-steroidal anti-inflammatory agents” (NSAID) are a group of medicines that relieve pain and fever and reduce inflammation. They are used to treat mild-to-moderate pain that arises from a wide range of conditions such as headaches, menstruation, migraines, osteoarthritis, or rheumatoid arthritis, sprains and strains, and toothache. Note that the well known “Aspirin” is a NSAID that is also used in small doses to lower the risks of having a heart attack or a stroke caused by a blood clot.
  - “Clopidogrel” prevents platelets in the blood from sticking together to form an unwanted blood clot that could block an artery. Clopidogrel is used to lower the risk of having a stroke, blood clot, or serious heart problem after a heart attack, severe chest pain (angina), or circulation problems.
- Access to analgesia, antiemetics *(drugs that are used against vomiting and nausea)*, surface oxygen therapy, and a re-compression facility should be in place.

As suggested above, ascent rates of 10 and 20 msw/h are extreme. As a comparison, an ascent from 100 m at 10 msw/hour should take only 10 hours, while the decompression from a heliox dive at this depth using the MT92 heliox 10-12% closed bell decompression table 102 m/120 minutes, displayed in the appendix of this handbook, requires 22:35 hours decompression, and that 10:57 hours is the decompression time using the same set of tables for 45 minutes exposure at this depth.

3.6.3.1 - About the paper “A review of accelerated decompression from heliox saturation in commercial diving emergencies”

This paper, which has been published through the National Library of Medicine/Diving and Hyperbaric Medicine - Volume 52 (https://www.ncbi.nlm.nih.gov/pmc/journals/3469/) the 4th of December 2022, assesses the benefit of emergency decompression, and provides guidelines, using a collection of data from the authors’ direct experience and networks, providing witness or first-hand information. It can be downloaded from our website (click here) and offers detailed step-by-step descriptions of the events summarized below.

- Bell evacuations with emergency decompression:

- “Discovery one”, Comex, Nigeria - 1975 *(Source: Michel Plutarque - Comex)*:
  This case discusses 2 divers decompressing in the diving system following a bell bounce dive to 90 msw. Due to the barge abandonment following a drilling incident, they were transferred to the bell, which was fully disconnected from the system, and hanged under a supply boat The bell was recovered on deck one day later, and the decompression of the divers was completed in the bell at Port Harcourt.
- “Taipan one”, Comex, Gabon - 1982 *(Source: Archives Comex)*:
  Discusses the story of a bell dropped to the bottom at 30 m depth after a fire onboard the barge. The bell was recovered 24 hours later and reconnected to a saturation system where the divers were decompressed normally.
- “Garupa PGP-1 Platform”, Comex - Marsat, Brazil - 1985 *(Source: J. F. Irrmann - Comex)*:
  The “Garupa PGP-1 Platform” had to be abandoned following a gas leak, and only essential personnel remained on site with four divers at 126 msw in the saturation system. The divers’ evacuation was organized by wet transfer from bell to bell with a nearby DSV equipped with a saturation system.

- Bell emergency evacuations with accelerated decompression:

- “Norjarl Semi Sub”, Oceaneering, North Sea - 1981 *(Source: Dr Philip James)*:
  The “Norjarl barge” started to list following a collision with a supply boat. Four divers were in the dive system at a storage depth of 87 msw. It was decided to accelerate their decompression using a chamber PO2 of 75 kPa and an ascent rate three times faster than the standard company procedure while the barge was towed to the shore. During the transfer, a storm threatened the safety of the barge, and it was decided to reach 18 msw and finish the decompression with a US Navy Table 6. Fortunately, the weather improved, and the decompression was completed without applying the USN table 6.
- “Sedco Phillips Semi Sub”, Oceaneering, Ekofisk Field, North Sea - 1981 *(Source: Dr Philip James)*:
  In November 1981, the semi-sub barge “Sedco Phillips” was operating with Oceaneering in the Ekofisk field with eight divers in saturation at a depth of 70 msw. A storm hit the barge, and the situation became critical. As the Hyperbaric Rescue Unit (HRC) could not be launched, it was decided to decompress the divers using the same principle of accelerated decompression as the Norjarl event described above.
- “Transworld 58 Semi Sub”, Argyll Field, North Sea - 1981 *(Source: Dr Philip James)*:
  During the same November 1981 storm, the “Transworld Rig 58” broke all anchor lines and drifted for several hours. Four divers in saturation at 30 msw were decompressed in an emergency, starting with an upward excursion to 18 msw at 6 msw/min. The decompression then proceeded at 1.2 msw/h to the surface with a progressive gas switch from heliox to air.

- “DLB 269”, McDermott, Mexico - 1995 *(Source: Michael Krieger)*:
The Barge "DLB 269" was doing a tie-in at 48 msw depth when a tropical storm that turned into a hurricane hit it. The barge master decided to face the storm with two tugs pulling the barge to maintain position. The divers' decompression was initiated with standard procedures. Then, as the weather worsened, the divers were decompressed via an emergency procedure (Ascent rate of 1.5 m/h). The divers surfaced in the middle of the storm without any symptoms. The following day, the hurricane hit the barge again and sank it, resulting in six fatalities.

Norjarl emergency decompression		
Depth (msw)	***Gas breathed***	***Ascent rate***
63 to 49.5	*Chamber: 0.8 bar PO_2*	*7.8 m/h*
49.5 to 18	*Chamber: 0.8 bar PO_2*	*3.6 m/h*
18 to 0	*Chamber: 23 % O_2*	*1.8 m/h*
Note: *The authors provide the partial pressures in kilo Pascals (kPa).* *For convenience, I have displayed these values in bar: 1 bar = 100,000 Pascals = 100 kPa*		

DLB 269 emergency decompression			
Depth (msw)	***Gas breathed***	***Ascent rate***	***comments***
30 to 20	*Chamber: HeO_2 - 0.6 bar PO_2*	*1.2 m/h*	*Normal deco. 16 h ascent per day*
20 to 10	*BIBS periods 20/5 BIBS: HeO_2 - 50% O_2*	*1.5 m/h*	*Starting accelerated decompression*
10 to 3	*BIBS periods 20/5 BIBS: 100 % O_2*	*1.5 m/h*	
3	*Chamber atmosphere*	*Hold*	*110 min. Stop*
3 to 0	*BIBS continuous BIBS: 100 % O_2*	*Unknown*	*Described as a slow ascent*
Surface	*BIBS periods 10 min 100% O_2/20 min air for 6 hours*	*Hold*	

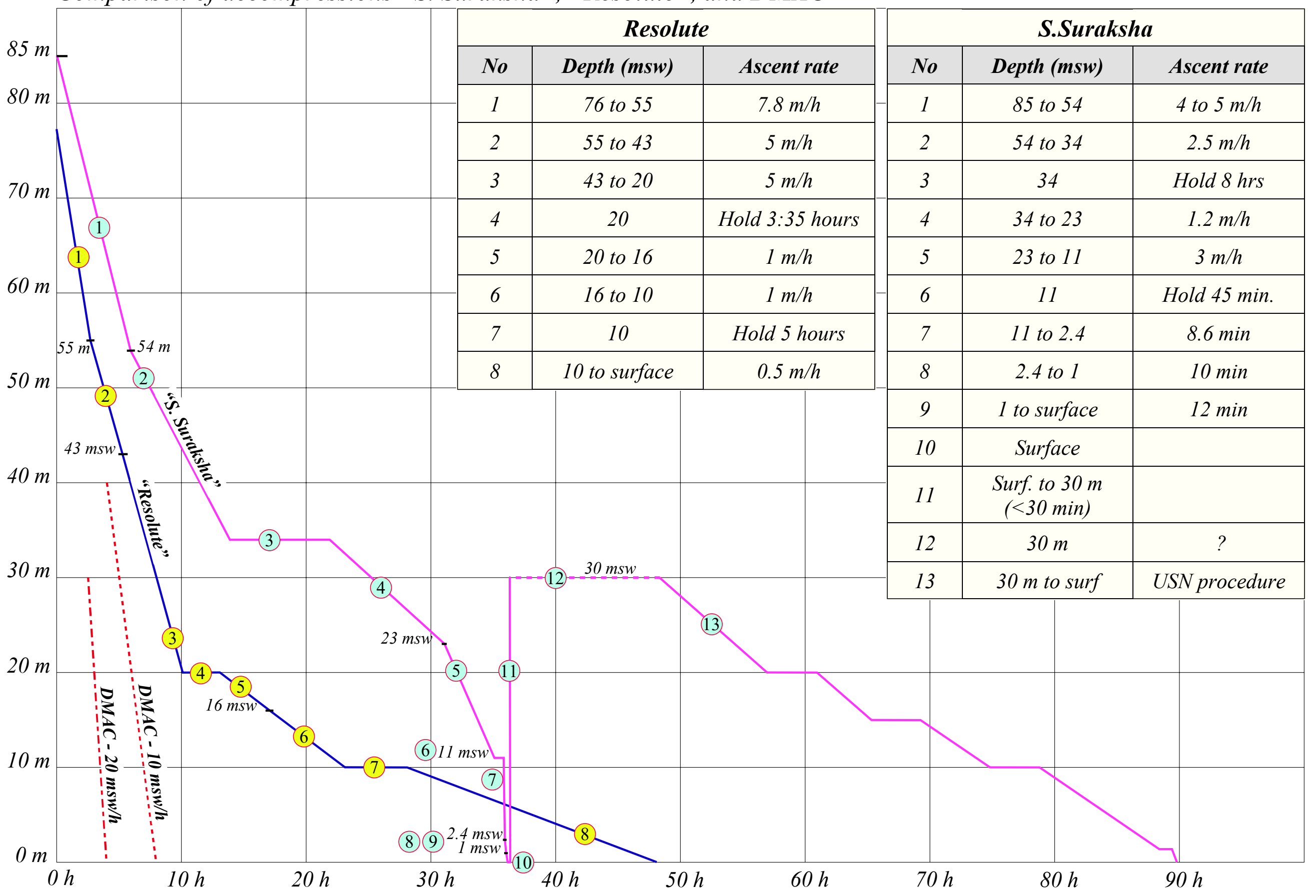
- “S. Suraksha”, Bombay High Field, India - 2005 *(Source: Dr Ajit Kulkarni)*:
During the transfer of a cook who cut his finger to a platform by basket, the "S. Suraksha" hit a riser resulting in the platform and the vessel catching fire. Six divers who were in saturation at 28 & 42 msw were pressurized to 85 msw, the deepest depth of the field, to be evacuated with the Self Propelled hyperbaric Lifeboat (SPHL). Nevertheless, the SPHL was found in flames, and the power supply of the chamber failed. As a result of the fire progressing, the supporting team was forced to abandon the vessel, and the divers, provided with fluids and food, managed to decompress themselves to 54 msw using the bilge valve. When the fire calmed down during the night, the diving support team of another vessel, the “S. Prabha”, which had been fighting the fire, boarded the S. Suraksha and managed the divers' decompression and food. The decompression continued until 23 msw when the supportive team had to abandon the vessel again. The divers were instructed to decompress at 3 msw/h. The supporting team returned on board when possible, organized the divers' recovery to the surface, and transferred them to 30 msw in the saturation system of the “S. Prabha”, where a standard decompression was performed according to the US Navy procedures. It is not indicated whether a stabilization period has been performed at 30 msw prior to the final decompression.

Sequence No	***Depth (msw)***	***Gas breathed***	***Ascent rate***	***comments***
0	*0 to 85 msw*			*Two separate teams of divers compressed to the deepest operating depth in the area*
1	*85 to 54*	*Chamber: HeO_2 6% O_2 (uncertain)*	*4 to 5 m/h*	*Empirical decompression carried out by the divers*
2	*54 to 34*	*Chamber: HeO_2 8% to 12% O_2*	*2.5 m/h*	*Decompression during the night, under the control of the LSTs on site. No power, no scrubber, divers on emergency rebreather*
3	*34*	*Chamber: HeO_2 12% O_2*	*Hold*	*Eight hour hold decided by Dr Kulkarni*
4	*34 to 23*	*Chamber: HeO_2 16% O_2*	*1.2 m/h*	*Standard decompression performed by LSTs*
5	*23 to 11*	*Chamber: 0.6 bar PPO_2*	*3 m/h*	*Decompression performed by the divers*
6	*11*	*Chamber: HeO_2 20% O_2*	*Hold*	*Decision to transfer. Stop for 45 min waiting on the S. Prabha to prepare for divers’ reception*
7	*11 to 2.4*	*BIBS: 100% oxygen*	*1 m/min*	*8.6 min from 11 to 2.4 msw*
8	*2.4 to 1*	*BIBS: 100% oxygen*	*0.16 m/min*	*10 min from 2.4 to 1 msw*
9	*1 to surface*	*BIBS: 100% oxygen*	*0.08 m/min*	*12 min from 1 msw to surface*
10	*Surface*			*Divers transferred to the S. Prabha*
11	*0 to 30 m*			*Recompression to 30 m - One case of knee pain in one diver relieved on arrival at 30 msw. Decompression according to USN procedure.*

- Barge Resolute, East Java, Indonesia - 2013 *(Sources: Doctors Bryson and Massimelli)*:
This case is also taken as a reference for fast emergency decompression and displayed in this point. Due to adverse weather conditions, the resolute barge lost anchors while six divers were stored at 45 msw and three others under compression were at 28 msw. These three divers were in the Hyperbaric Rescue Unit (HRC) used as a living chamber. Containers and heavy gas cylinders had been wiped out by the waves and were crushing other deck equipment. The dive control station was flooded. While the rest of the barge's crew were already at the muster station preparing to abandon ship. All the divers were transferred in the HRC that was compressed to 80 msw (76 msw after cooling) and prepared for launching. However, it appeared that the launching of the HRC was impossible. When the barge's condition has been stabilized following the intervention of an anchor handler, the HRC has been reconnected to the system. An emergency decompression has been initiated after 4 - 5 hours of hold. The divers arrived on deck without signs of DCS.

Sequence No	*Depth (msw)*	*Gas breathed*	*Ascent rate*	*comments*
1	*76 to 55*	*Chamber: HeO2* *0.6 bar oxygen*	*7.8 m/h (average)*	*Ascent of 21 msw performed in 2 h 42 min*
2	*55 to 43*	*Chamber: 0.6 bar oxygen* *BIBS heliox: 20% O2*	*5 m/h*	*Decompression* *5 BIBS sessions 20/5*
3	*43 to 20*	*Chamber: 0.6 bar oxygen* *BIBS heliox: 35% O2*	*5 m/h*	*Decompression* *2 BIBS sessions 20/5* *7 BIBS sessions 25/5*
4	*20*	*Chamber: 0.6 bar oxygen* *BIBS heliox: 50% O2*	*Hold*	*3 h 35 min hold* *2 BIBS sessions 25/5*
5	*20 to 16*	*Chamber: 0.6 bar oxygen*	*1*	*Decompression*
6	*16 to 10*	*Chamber: HeO2* *23% oxygen*	*1*	*Decompression*
7	*10*	*Chamber: 23% oxygen* *BIBS gas: 100% O2*	*Hold*	*5 h hold* *3 BIBS sessions 25/5*
8	*10 to surface*	*Chamber: 23% oxygen*	*0.5*	*Decompression* *After 4 h on chamber gas 20 min on BIBS 100% O2 every 2 h to surface.* *No DCS symptoms reported*

Comparison of decompressions "S. Suraksha", "Resolute", and DMAC



Resolute		
No	*Depth (msw)*	*Ascent rate*
1	*76 to 55*	*7.8 m/h*
2	*55 to 43*	*5 m/h*
3	*43 to 20*	*5 m/h*
4	*20*	*Hold 3:35 hours*
5	*20 to 16*	*1 m/h*
6	*16 to 10*	*1 m/h*
7	*10*	*Hold 5 hours*
8	*10 to surface*	*0.5 m/h*

S.Suraksha		
No	*Depth (msw)*	*Ascent rate*
1	*85 to 54*	*4 to 5 m/h*
2	*54 to 34*	*2.5 m/h*
3	*34*	*Hold 8 hrs*
4	*34 to 23*	*1.2 m/h*
5	*23 to 11*	*3 m/h*
6	*11*	*Hold 45 min.*
7	*11 to 2.4*	*8.6 min*
8	*2.4 to 1*	*10 min*
9	*1 to surface*	*12 min*
10	*Surface*	
11	*Surf. to 30 m (<30 min)*	
12	*30 m*	*?*
13	*30 m to surf*	*USN procedure*

The authors also made a review of the following accelerated decompression procedures. The texts below are those of the guideline:

- Early COMEX saturation decompression procedures:
  In the early 1970s, decompressions that were considered as standard procedures appear today as excessively fast ascents.
  Unfortunately, the procedures at the time were a mixture of bounce and saturation diving and cannot be directly translated into modern practice. However, some profiles provide useful references to what can be done in terms of rapid decompression.
  In 1974, Comex published their first set of original heliox saturation procedures that were used until 1979. The ascent could be initiated by a 10 msw upward excursion depending on the last dive interval. Decompression was continuous over 24 hours. Chamber oxygen was controlled to a PO_2 of 60 kPa when deeper than 15 msw, and then adjusted to an inspired fraction (FO_2) of 24% when shallower. It took five days and 16 hours to decompress from 280 msw storage depth to surface (see the table below).
  The overall safety performance based on data from the Comex database indicated a DCS risk of 5 to 10%; all symptoms were related to joint pain occurring in the last 10 msw of ascent.

Depth (msw)	*Chamber gas*	*Ascent rate (min per msw)*	*Ascent rate (Msw per hour)*
280 to 240		*20*	*3*
240 to 160		*25*	*2.4*
160 to 80	*PO_2 = 0.6 bar (60 kPa)*	*30*	*2*
80 to 20		*35*	*1.7*
20 to 15		*40*	*1.5*
15 to 10		*40*	*1.5*
10 to 5	*FO_2 = 24%*	*45*	*1.3*
5 to surface		*50*	*1.2*

- US Navy 2016 emergency abort procedures:
  Revision 7 of the US Navy diving manual, 12 paragraph 13.23.7.2, provides a specific procedure for emergency abort decompression, defined for serious life-threatening emergency, however, no information is provided on its validation. The emergency ascent includes several phases: an initial upward excursion, a hold, and an accelerated decompression (see below this table converted in metric).
  The ascent rates are defined according to the starting depth, which decides the chamber PO2. These ascent rates appear very slow compared to the emergency situations studied and seem of little practical use.
  Note: The authors also say that they could not find any instance when these procedures were used.

Depth (msw)	*Chamber gas*	*Ascent rate or duration*
Decompression from 306.4 to 83.7 msw with 0.6 bar (60 kPa) chamber PO_2		
306.4 to 61.3	*PO_2 = 0.6 bar (60 kPa)*	*1.53 msw·h*
61.3 to 16.1		*0.88 msw·h*
16.1 to 1.2	*FO_2 = 23%*	*0.88 msw·h*
1.2 to surface		*4 min*
Decompression from 83.4 to 62.5 msw with 0.7 bar (70 kPa) chamber PO_2		
83.4 to 61.3	*PO_2 = 0.7 bar (70 kPa)*	*1.67 msw·h -*
61.3 to 20.4		*0.97 msw·h*
20.4 to 1.2	*FO_2 = 23%*	*0.97 msw·h*
1.2 to surface		*1.02 msw·h*
Decompression from ≤ 62.2 msw with 0.8 bar (80 kPa) chamber PO_2		
62.2 to 61.3	*PO_2 = 0.8 bar (80 kPa)*	*1.67 msw·h*
61.3 to 24.8		*1.02 msw·h*
24.8 to 1.2	*FO_2 = 23%*	*1.02 msw·h*
1.2 to surface		*4 min*

- Italian accelerated decompression procedures:
  An accelerated decompression procedure can be found in the Italian UNI 11366 diving regulations. The procedure has continuous decompression varying with depth and constant chamber PO2 until 18 msw when the chamber is flushed with air to change from helium to nitrogen (see below).
  Note: As for the US Navy procedures, the authors say: *"We could not find any instance when these procedures were used"*.

Depth (msw)	***Chamber gas***	***Ascent rate (msw * h)***
180 to 90		*3*
90 to 30	*PO_2 = 0.65 bar (65 kPa)*	*2.4*
30 to 18		*1.2*
18 to surface	*Air flushing to never exceed an FO_2 of 23.5%*	*0.6*

- COMEX emergency decompression procedure
  In the 1994 revision of its diving manual, COMEX introduced an accelerated decompression procedure that provided three options depending on the starting depth. These procedures were based on a higher level of chamber PO_2, and thus allowed faster ascent rates. Considering pulmonary oxygen toxicity as the limiting factor, the PO_2 selected controlled the maximum decompression time, and therefore the depth of use. Three depth ranges were proposed: 70 msw, 90 msw and 130 msw, with their respective chamber PO_2. For an emergency deeper than 130 msw, the only possibility was to decompress the divers to 130 msw using standard saturation decompression and then consider the possibility of using an accelerated decompression to the surface.
  An option was available where decompression could be further accelerated by putting the divers on a higher FO_2 via the built-in breathing system (BIBS) during the last 10 msw of the ascent to the surface. The ascent rate could be increased to 60 min per msw.
  Note: The authors also say: *"To our knowledge, these procedures have never been used by COMEX"*.

Depth (msw)	***Chamber gas***	***Ascent rate (msw * h)***
	Decompression from not deeper than 130 msw	
130 to 16	*PO_2 = 0.6 bar (60 kPa)*	*1.4*
16 to surface	*FO_2 23%*	*0.6*
	Decompression from not deeper than 90 msw	
90 to 20	*PO_2 = 0.7 bar (70 kPa)*	*1.6*
20 to 15	*FO_2 23%*	*1.2*
15 to surface	*FO_2 23%*	*0.6*
	Decompression from not deeper than 70 msw	
70 to 25	*PO_2 = 0.8 bar (80 kPa)*	*1.7*
20 to 15	*FO_2 23%*	*1.2*
15 to surface	*FO_2 23%*	*0.6*

The authors say the following about the events and procedures presented above:

- The events:
  The weather was clearly a critical factor in four out of the six incidents discussed. It prevented the evacuation via a Hyperbaric Rescue Chamber (HRC) in the Sedco Phillips SS, the Transworld 58, the DLB 269, and the Resolute cases. Accurate planning and preparedness are critical in risk management.
  It is notable today that HRCs are not accepted in the UK or Norwegian sectors of the North Sea and other regions due to their limitations of life support and seaworthiness.
- The options:
  Faced with an event requiring an emergency decompression, a commercial diving company will mobilise its safety response network and involve the diving medical advisor in the decision-making process. The decisions will be made on information received via telecommunication systems, generally with limited real time knowledge of the actual situation and its evolution. The circumstances are often dramatic and changeable, with emotional pressure to manage. History has shown that decisions often must be revised promptly according to the development of the situation.
  Upon deciding whether to use an emergency decompression, the first consideration will be the depth of the divers. An accelerated decompression is only useful if the divers are close enough to the surface and the time

scale allows them to be brought to safety. If these criteria are fulfilled, then methodological options for the rescue would be:

- To decide on a starting depth. The situation may require the recompression of a team in decompression or at a different storage depth to a deeper depth.
- To perform a rapid large excursion to get the divers closer to the surface. However, too great an excursion might cause DCS and impair further decompression.
- Decompress with increased ascent rates. However, too rapid an ascent rate might cause DCS.
- Decompress with an increased PO2 to allow faster ascent rates. However, too high an oxygen exposure might induce oxygen toxicity.
- Possibly store the divers at a depth close to the surface waiting for the best time to evacuate.
- A combination of the above.

The decision is therefore a balance between the time left to decompress to surface and the accepted risk of DCS and/or oxygen toxicity. This may lead to a graded response where two levels of emergency could be considered:

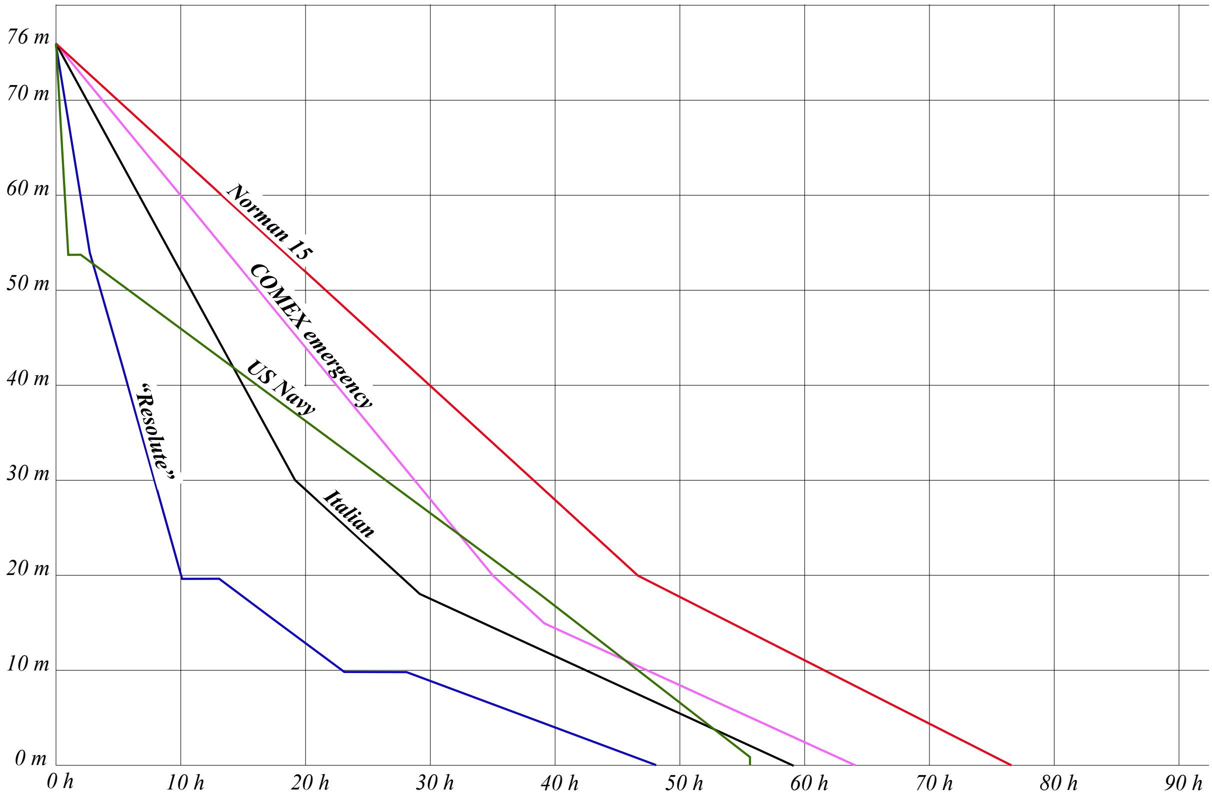
- A ‘level one emergency’ where time is available and a fast, but still reasonable ascent rate could be employed to minimise the DCS risk.
- A ‘level two emergency’ where the immediate integrity of the system is at risk and a life-threatening situation involves the whole saturation team. This could justify an aggressive ascent protocol and the acceptance of a higher risk of DCS and oxygen toxicity.

Finally, operational constraints must be evaluated:

- Feasibility:
  - Are communications reliable enough to direct the decompression?
  - Is the diving support vessel a safe place to decompress, and for how long?
  - Are Life Support Technicians (LST) present?
- Acceptability:
  - Can the divers be informed of the options and involved in the decision?
- Control of decompression:
  - Is the chamber atmosphere breathable?
  - Can a breathing mix be supplied on BIBS?
  - Is the chamber temperature within limits?
- Treatment options:
  - In case of DCS, would it be possible to treat a diver during the emergency decompression or would the diver have to wait until he is evacuated to a hyperbaric facility?
  - How long would it take to take the divers to a nearby vessel of opportunity or a shore-based facility equipped with a saturation diving system?

- Initial excursion:
  In several recorded instances, the immediate strategy was to perform a rapid upward ascent or excursion to bring the divers closer to surface. This protocol is described in the US Navy diving manual (paragraph 13–23, revision 7) that allows the start of a final decompression to begin with an upward excursion. The excursion amplitude can be quite significant, for example, a 30 msw ascent from 120 msw to 90 msw.
  Diving companies have become more cautious about upward excursions. This is because the data from the Comex diving database, the Hades database from Seaways, and the US Navy have all shown that too great an excursion may induce vestibular DCS symptoms, which could have a dramatic impact on the rest of the emergency management.
  One way of controlling the risk of DCS is to perform this initial ascent at a slower rate, as during the Resolute case (approximately 7.8 msw·h). Alternatively, the divers may be kept at constant depth for a while after the excursion, as per the US Navy abort decompression procedure, which requires a two hour hold before any further ascent.
- Final excursion:
  Another documented emergency decompression strategy consists of decompressing the divers to a depth close to surface and keeping the divers at this depth until the situation is controlled. The ‘holding’ depth was 10 msw during the Resolute case, 3 msw during the DLB 269 case, and 11 msw during the S. Suraksha case. This hold has the advantage of stabilising the divers in terms of decompression, providing a higher PO_2 on BIBS (if required for a DCS treatment) and still permitting a rapid escape to surface if needed. The S. Suraksha case showed that divers could ascend from 11 msw to surface in 30 minutes and then be recompressed to 30 msw in a nearby vessel system, with only one case of DCS (pain only) among six saturated divers.
- Faster ascent rates:
  During decompression, the ascent rate and the inhaled PO_2 are closely related. This relationship is linear, according to Vann’s model. 16 With the use of data from commercial saturation decompressions, a regression line has been established between the safe rate of ascent and chamber PO_2 in the deeper part (> 60 msw). This is the design principle of the US Navy and Comex emergency procedures that propose three values of chamber PO_2 associated with three different ascent protocols. To control oxygen toxicity, each decompression PO_2 is associated with a time limit, translated into a limitation in starting depth.
  To compare emergency protocols, we first considered the Resolute case and displayed its actual depth/time

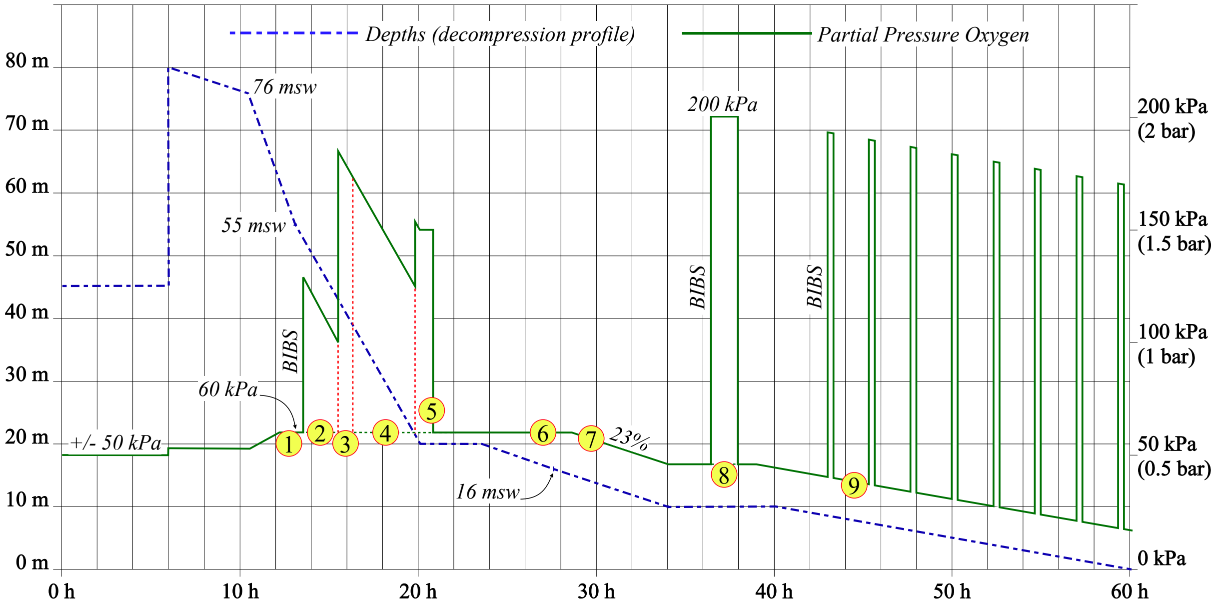
profile. We then added the profiles of the US Navy, Italian and Comex emergency decompressions, for the same starting depth. The Norsok profile was also added to provide a reference associated with a standard and conservative saturation decompression. *Note: For consistency with this manual, the Norsok profile has been replaced by the Norman 15 procedures.*



Two strategies emerge from this figure:
The US Navy and Comex procedures have relatively slow decompression rates (1.5 to 1.8 msw·h and are adapted to the evacuation of a diver with an injury or an illness, where the risk of DCS must be controlled. These situations we class as Level 1 emergencies.
The figure shows that ascent rates can be significantly increased in a life-threatening situation. On board the Resolute, the decompression was initiated with an upward excursion at approximately 7.8 msw·h from 76 msw to 55 msw and then continued at 5 msw·h from 55 msw to 20 msw. This situation represents a Level 2 emergency, and these are imbued with a higher risk of DCS and oxygen toxicity, which are accepted given the circumstances.
Estimation of DCS risk is a key decision factor. For standard saturation decompressions not exceeding 200 msw, a study using data from the Comex database, based on 60 kPa chamber PO_2, showed that DCS cases were associated with pain symptoms alone, which occurred in the last part of the ascent. Therefore, with Level 1 emergency decompression, the risk seems to be limited to mild DCS.
For deeper dives, three cases of vestibular symptoms have been reported during historical deep experimental dives with an initial rapid decompression. These included: a Comex PLC I dive made in 1968, from 335 msw, with an initial ascent rate at 3.5 msw·h; in 1971, a Royal Navy RNPL 457 msw (1500 feet of seawater) dive, varying ascent rates starting at 12 Msw·h; and in 1974, a Comex Physalie VI dive, 610 msw, initial ascent rate at 2.4 msw·h.
With Level 2 emergency decompressions, a tangible risk is vestibular symptoms associated with DCS. Current experience and algorithms do not allow the control of this risk.

- Central Nervous System (CNS) oxygen toxicity:
Increasing the PO_2 allows the ascent rate to be accelerated. However, oxygen toxicity may lead to convulsions, which are dangerous due to their sudden onset and limited warning signs that are either difficult to recognise or absent. The simplest way of managing CNS toxicity is to consider it as a matter of threshold and set limit values to the PO_2.
During immersion, the limit for pure oxygen breathing is set to 175 kPa (1.75 bar). In the dry environment of a deck decompression chamber, the PO_2 is set to 220 kPa (2.2 bar) during normal bounce diving, and can reach up to 280 kPa (2.8 bar) during treatment (US Navy table 6 for instance).
Data from animal studies have documented that oxygen breathing interruptions delay CNS oxygen toxicity.
In practice, BIBS sessions are associated with interruptions, generally five minutes 'off BIBS', then 25 minutes 'on BIBS'. These breaks in oxygen breathing provide divers with the possibility to rest, talk and drink. It is believed that they also allow a recovery from CNS toxicity. Arieli's oxygen toxicity model suggests that a five-minute break after a 25-minute exposure can reduce the CNS toxicity dose by 67%, for this range of PO_2 breathed. If Arieli's model is applied to the Resolute case scenario, a detailed PO_2 profile can be derived, whereby the index computed for CNS toxicity reaches a score of 80 during the BIBS sessions, but is almost zero by the end of the decompression.

Our review has shown that in several instances, the people managing the emergency did not hesitate to provide the divers with high PO_2 in the BIBS breathing mix, but with interruptions to allow a safe, rapid decompression.
Based on the Resolute case, it seems that sessions of 200 kPa PO_2 on BIBS can be managed over a two–three day decompression (*see the scheme below*). It all depends on the interruptions and the expected recovery process, which is difficult to estimate. Interruptions also assume that the chamber atmosphere remains breathable, and this might not always be the case (as in the S. Suraksha event). Finally, we note that during the DLB 269 case, the BIBS sessions were continued out at surface pressure for six hours after the end of the decompression. This may be operationally difficult in some circumstances but certainly helps to protect the divers from developing DCS symptoms, especially if the divers omitted significant decompression.



The scheme above represents the various sequences of oxygen uptake by the divers during the "Resolute barge incident". The depths in msw are indicated on the left side,the PO2 on the right side, and the times in hours on the bottom side. Refer to the reference numbers of the sequences in the table below for the description of the procedures used.

Sequence No	*Depth (msw)*	*Gas breathed*	*Ascent rate*	*comments*
1	*76 to 55*	*Chamber: HeO_2 0.6 bar oxygen*	*7.8 m/h (average)*	*Ascent of 21 msw performed in 2 h 42 min*
2	*55 to 43*	*Chamber: 0.6 bar oxygen BIBS heliox: 20% O_2*	*5 m/h*	*Decompression: 5 BIBS sessions 20/5*
3	*43 to 20*	*Chamber: 0.6 bar oxygen BIBS heliox: 35% O_2*	*5 m/h*	*Decompression: 2 BIBS sessions 20/5*
4	*43 to 20*	*Chamber: 0.6 bar oxygen BIBS heliox: 35% O_2*	*5 m/h*	*Decompression: 7 BIBS sessions 25/5*
5	*20*	*Chamber: 0.6 bar oxygen BIBS heliox: 50% O_2*	*Hold*	*3 h 35 min hold - 2 BIBS sessions 25/5*
6	*20 to 16*	*Chamber: 0.6 bar oxygen*	*1*	*Decompression*
7	*16 to 10*	*Chamber: HeO_2 - 23% oxygen*	*1*	*Decompression*
8	*10*	*Chamber: 23% oxygen BIBS gas: 100% O_2*	*Hold*	*5 h hold: 3 BIBS sessions 25/5*
9	*10 to surface*	*Chamber: 23% oxygen BIBS 100% O_2*	*0.5*	*Decompression: After 4 h on chamber gas 20 min on BIBS 100% O_2 every 2 h to surface*

In relation to CNS oxygen toxicity, benzodiazepines could, in theory, be used as secondary prevention agents *(note: Benzodiazepines are a class of drugs primarily used for treating anxiety)*. However, their prophylactic effect remains unknown. In fact, the respiratory depressant effects of these drugs could potentially lead to CO_2 retention, which would increase the risk of CNS oxygen toxicity. They would also introduce sedation into an unfolding emergency, which could have disastrous consequences. For these reasons, pre-emptive use of such drugs during emergency decompression to mitigate the risk of CNS oxygen toxicity is not justified.

- Pulmonary oxygen toxicity:
  Another recognised type of oxygen toxicity affects the lung (pulmonary oxygen toxicity). The symptoms include coughing, chest pain and dyspnoea. Extreme exposures may lead to pulmonary oedema.

The difficulty is setting the upper PO_2 limit to avoid severe pulmonary toxicity. One study exposed 12 subjects for 48 h at PO_2 = 105 kPa (1.05 bar) during a simulated air saturation dive. Pulmonary oxygen toxicity symptoms occurred, and pulmonary function changes consisted of significant decrements in vital capacity, flow rates and diffusing capacity for carbon monoxide. Subjects showed a complete recovery in both symptoms and pulmonary function in about eight days. In 1979, Comex conducted a deep saturation dive with eight divers to 450 msw. Decompression lasted 10 days and 5 h (corresponding to an average 44.1 msw per day), using 70 kPa chamber PO_2 from 314 msw to surface pressure. No DCS or pulmonary oxygen toxicity of note was reported (Imbert JP, personal communication 2022).

These data suggest that PO_2 may be raised significantly in the event of an emergency, but a mathematical tool is required to evaluate this limit.

Several mathematical models can be used to estimate the pulmonary toxicity dose: the unit pulmonary toxic dose (UPTD) calculation from Clark and Lambertsen; the oxygen tolerance model from Harabin; and the more recent oxygen toxicity index from Arieli. However, these models do not translate well to data drawn from conditions different from their validation. Their weakness is multiple injury pathways and the obvious individual variability that may confound models.

The simplest model is the UPTD, which provides an immediate dose evaluation in an emergency. However, it has well-known limitations. First, it was validated with a PO_2 higher than 152 kPa and its prediction curves were extrapolated to the lower range of PO_2; it tends to overestimate toxicity in saturation diving. Second and more importantly, it does not account for any recovery. The computation of UPTD on emergency dive profiles generally leads to doses higher than 1,000 UPTD that far exceed the daily limit of 625 UPTD set for a 5% decrement in vital capacity.

Arieli's toxicity index offers a new alternative, accounting for recovery. It provides a more relevant dose/limit indication, but its calculation might not be practical during an emergency. We applied both models over the Resolute PO_2 profile and obtained a dose of 1,265 UPTD and a cumulative value of 36 with the Arieli's pulmonary index.

This overall 1,265 UPTD dose is not regarded as excessive; in the early Comex experimental dives it was documented that a dose of 1,300 UPTD was acceptable during saturation based on vital capacity measurements. The index computed with Arieli's model for pulmonary toxicity reached a maximum value of 566 during the BIBS sessions but was very low by the end of the decompression. This would indicate that divers' vital capacity decrement reached 7.5% but a recovery took place.

Pulmonary oxygen toxicity remains the limitation of accelerated decompression. A high chamber PO_2 accelerates the decompression but can only be tolerated for a few days. Therefore, efficient accelerated decompressions can only be carried out from depths shallower than 100 msw.

- Divers' hydration:
  There is a considerable literature suggesting the importance of hydration during or after immersion. Immersion exposes the diver to heat and cold, exercise, dry gas breathing and modifies cardiac function. In particular, it has been shown that hydration before immersion reduces the level of circulating venous gas emboli post-dive. However, these situations are not pertinent to saturation decompression, where the divers are in a dry environment with controlled humidity and temperature. We could not find studies on divers' hydration during saturation decompression. However, one study showed a diminution of the plasma volume and haemoconcentration *(increased proportion of red blood cells)* between pre-and post-saturation measurements. There is a general assumption that if vascular volume is maintained, it will optimise perfusion and help to eliminate dissolved gases during decompression, thus reducing bubble formation. The DMAC report on emergency decompression from saturation recommends encouraging divers to drink as much as they can. Plain water or oral rehydration mixtures are preferred. DMAC guidance note 31 mentions possible additional treatments, such as analgesics and non-steroidal anti-inflammatory agents but acknowledges that there is no human evidence that such drugs would offer benefits *(see in the previous point "About DMAC 31")*.
- Inert gas switching:
  Inert gas sequencing (helium, nitrogen and argon) was developed in the sixties by Dr Bühlmann to accelerate gas exchange during deep bounce decompressions. He reported decompression time of 22 h after a 6 h bottom time at 100 msw and 40 h decompression time after 6 h at 150 msw.
  Another study reported 62–64 h decompression time from 220 msw with 66–68 h bottom time using an inert gas switch from 30 msw.
  Based on the same principle, chambers were flushed with air at around 10 msw by the end of the heliox decompression
  during the Predictive Study experimental dives at the University of Pennsylvania. A gas switch was introduced by slowly venting the chamber with air during the 1981 Transworld incident. An air switch is also prescribed in the Italian accelerated decompression procedures.
  The difficulty with an inert gas switch is the control of the dynamics of the gas exchange, which depends on the physical properties of the gas and the depth of switch. When the technique is performed under controlled conditions and the decompression is previously validated, inert gas sequencing allows the design of efficient bounce tables (as for instance, historical Comex Cx 70 or Oceaneering bell bounce tables with transfer to an air-filled deck chamber). In case of an emergency, if the divers have already been subjected to an accelerated decompression, it is difficult to assess the gas kinetics without a complex mathematical model. In fact, the University of Pennsylvania stopped using inert gas switches because of the occurrence of specific DCS symptoms that were difficult to treat. In practice, inert gas switching should not be recommended in an

emergency as it would add complexity to an already difficult situation, for example, at which depth should the change occur, what decompression rate after the change, and how to treat associated DCS?

- Emergency response and responsibility for decisions:
  Diving companies have based their emergency response on a supportive network, that includes all their departments in addition to their medical advisor. In an ideal case, all parties involved cooperate and share the decision. In real cases, the operational personnel are often in the front line before reliable communication can be established with shore-based resources. In most of the cases reviewed, the medical advisor, once contacted, had to take the decision on the emergency decompression. The authors believe that the duty of the medical advisor is too often perceived as exclusively focussed on the responsibility of making therapeutic decisions as an event is unfolding. Ideally, medical advisors should be involved from the earliest stage of project design and elaboration of diving procedures, until project completion. We noted, however, that in several cases, the divers were instructed on the available options and shared the decision on the accelerated decompression (DBL 269) or took the decision themselves (S. Suraksha). The diving industry needs optimised guidance on what can be achieved, depending on the saturation depth and the level of emergency. This guidance must be developed with the involvement of the diving teams themselves.

3.6.1.3 - Additional comments regarding the two procedures presented

It must be noted that three authors of the study *"A review of accelerated decompression from heliox saturation in commercial diving emergencies"*, doctors Massimelli, Matity, and Bryson, are members of the DMAC. Also, Jean Pierre Imbert was one of the participants of the workshop on accelerated decompression organized by the DMAC on 13 April 2011 in London. Thus, the relationship between the two documents presented is more than evident. Note that this document is also available on DMAC's website.

It is essential to consider that many cases discussed in this document finished positively because the catastrophic events that were triggered were finally under control. For example, in the case of the Resolute incident, the weather calming down allowed the marine crew to regain control of the barge. as a result, the Life Support Technicians could slow down the decompression to normal values. Regarding the S. Suraksha incident, the recovery of the divers was possible because the 2nd vessel with a saturation system was on site (and also due to the courage of the diving team of this vessel). These two events highlight that except in areas with a high density of ships equipped with a saturation system that can accommodate the diving team, installing the Hyperbaric Reception Facility on a vessel is more desirable than onshore.

Another essential point for a diving team is ensuring that the emergency decompression can be managed appropriately. For example, the decompression profiles of the "Resolute" and "S. Suraksha" show that the teams adapted the ascent rate and gas values according to the events. Reliable communications with the diving medical specialist and the person competent to provide guidelines are essential. However, communications can be lost, and in such a scenario, the diving support team must be sufficiently skilled to manage an accelerated decompression. We can see that for such scenarios, expertise is more suitable than an established procedure.

Note:
Doctor Philip Bryson is the corresponding author of the study *"A review of accelerated decompression from heliox saturation in commercial diving emergencies"*. He can be contacted through this address:

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- Website: https://my.internationalsos.com/ukhealth_contactus

Other point of contact can be phone through our website:

- On the home page, click on the tile "logistics" in the navigation bar. Then click the button "Doctors and clinics"
- It is also possible to directly access to the lists through this link: https://diving-rov-specialists.com/doctors.htm

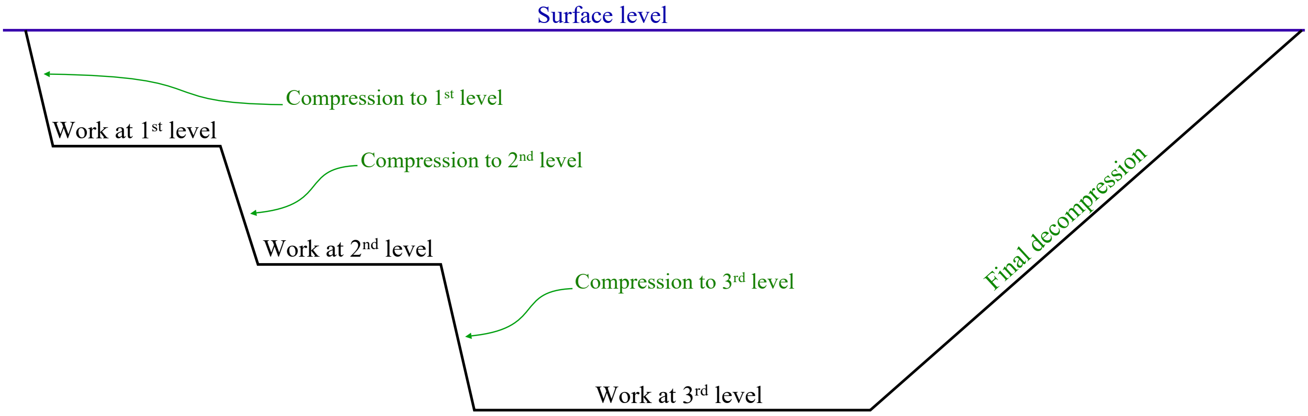
3.7 - Storage depth and saturation profile

There are no rules of saturation profiles indicated in NORMAM-15.
Also, the literature regarding this aspect of the operations is limited. However, the following guidelines published by NORSOK and in the French regulations can be taken as references:

- The dive planning should be based on a minimum change of living depth and excursion exposures. *(NORSOK U-100 point 8.2.3.5)*
- The living depth should be as close to the working depth as possible, based on a total evaluation of all safety aspects. *(NORSOK U-100 point 8.2.3.5)*
- Living depth changes are permitted, but it is not allowed to compress, decompress, and then recompress. *(NORSOK U-100 point 8.2.3.5)*
- When storage depths modifications are necessary, it is preferable to select :
  - A change of storage depth by intermediate pressurisation rather than by decompression, or by planning working levels of increasing depths rather than decreasing depths. *(French decree of 15th May 1992 / page 362/ point 7)*
  - A complete intermediate decompression rather than a shorter one followed by an ascending excursion. *(French decree of 15th May 1992 / page 362/ point 7)*

3.7.1 - Ideal saturation profiles

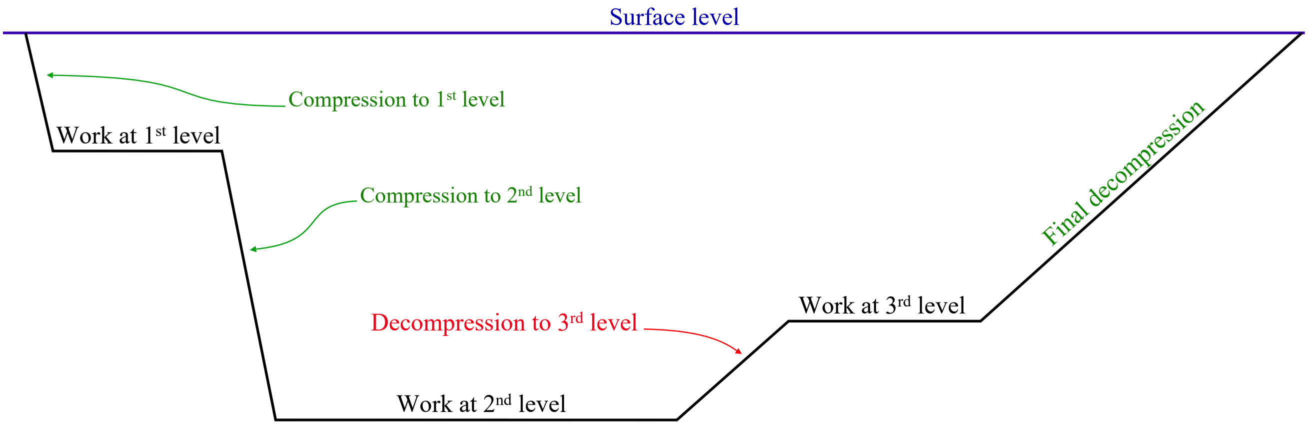
According to the recommendations above, the ideal profile is a U profile, with the change of storage depth by intermediate pressurisation rather than depressurization.



Remember that:

- Downward excursions are preferable.
- It is recommended to limit the change of living depth and excursions exposures.

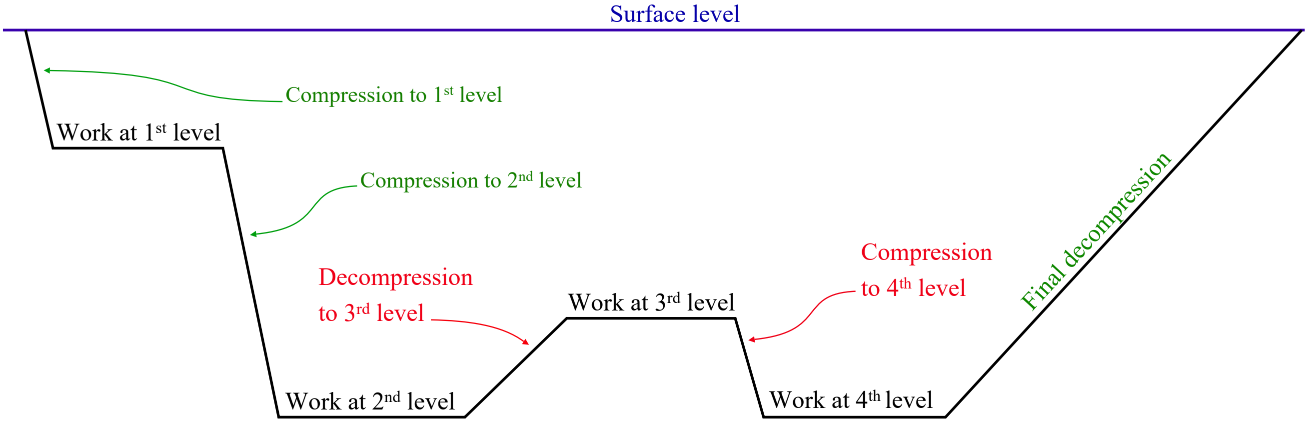
Despite efforts to organize the dives according to the ideal profile, it may happen that last minute changes or an emergency oblige the team to perform operations at a shallower level.
In this case, work periods after a decompression to a shallower level is considered acceptable. Note that as indicated in the French decree of 15th May 1992 / page 362/ point 7, it is preferable to perform a complete intermediate decompression rather than a shorter one followed by an ascending excursion.



3.7.2 - "W" profiles and other profiles

3.7.2.1 - "W" profiles

According to the recommendations above, diving teams should be encouraged to perform U profiles. Nevertheless, it may happen that, due to special circumstances, the ideal profile cannot be applied and that a decompression followed by recompression (W profile) is needed.



"W" profiles may result in two possible scenarios:

1) As indicated in the texts from NORSOK standards, only U profiles are permitted in some countries such as Norway. Also, NORSOK standards may have been adopted by some clients and companies. As a result, depending on the country where the project is performed, the policy of the client and the company regarding such profiles, the diving superintendent in charge of the project has to apply for a dispensation and obtain the approval from the organizations and the people listed below for implementing such procedures:
    - The company
    - The client (oil company)
    - The divers involved
    - The diving medical specialist
    - The legal authorities of the country if they forbid such procedures.

2) A lot of clients and countries allow for W profiles. It is also said that W profiles are considered industry standard. Nevertheless, what is called industry standard in the diving word are practices that are applied by some companies but not recognised by an official body. Also, we can see that some organizations reject such practices.
   For these reasons, and because there is currently no study issued by recognized competent bodies that describe the effects of such procedures on the health of the divers, the diving managers of a company commonly performing such profiles should edit rules that should be strictly followed.
   Note that for the reasons explained before, the principle of precautions should prevail and a W with an exaggerated amplitude should be avoided. These rules should be approved by the diving medical specialist of the company. In addition, to cover the company on the legal point of view, the divers should be informed that such practices may have to be applied. For this reason, it should be clearly indicated in their contracts of employment or in another document they sign before starting the operations.

3.7.2.2 - Other profiles

As indicated above, W profiles can be applied in special circumstances.
For safety purposes, other profiles should be considered unsafe and never be applied.

3.8 - Precautions to be in place during and after the dive regarding decompression sickness

3.8.1 - Decompression sickness during the operations

3.8.1.1 - Purpose

Decompression sickness may occur during a saturation dive as a result of an upward excursion or as a result of a decompression. The decompression sickness may manifest itself as musculoskeletal pain (Type I) or as the involvement of the central nervous system and organs of special sense (Type II).
Due to the subtleness of decompression sickness pain, all divers should be questioned about symptoms when it is determined that one diver is suffering from decompression sickness. Also, treatment procedures must be available at all times during the saturation and until the end of the post "dive bend" watch period *(see explanations in the next point)*.
Note that the classification of the symptoms into type 1 or type 2 categories is done for convenience but that there is no real border between the categories and that a decompression sickness classified type 1 first may quickly become a type 2.

The therapeutic tables to be used during the saturation or a problem happening during the post dive observation period are to be selected by the Diving medical specialist of the company. Note that such accidents, and the procedures to solve them are more explained in Book #4 "Diving accidents".

3.8.1.2 - Therapeutic tables COMEX

NORMAM-15 does not publish guidelines in the case of decompression sickness during the saturation. However, the procedures developed by COMEX that are well known and commonly used in the industry are applicable and recommended by numerous diving doctors. Therapeutic procedures COMEX are efficient alternatives to US Navy tables. They are designed for air and heliox surface supplied diving, and air and heliox saturation diving. Some tables are initially designed for therapeutic use of heliox, and the set proposed is composed as follows:

- ***Cx 12*** (oxygen) can be used for treatment of "type 1" accident of an air, nitrox or heliox dive.
- ***Cx 18*** (oxy.) can be used for treatment of "type 1" accident after no relief or worsening of symptoms in Table Cx 12.
- ***Cx 30*** (heliox + oxygen) can be used for treatment of "type 2" accident of an air, nitrox or heliox dive.
- ***Cx 30 saturation*** (heliox + oxygen) can be used for treatment of "type 2" accident of an air, nitrox or heliox dive. after no relief or worsening of symptoms in Table Cx 30
- ***Cx B*** (heliox + oxygen) can be used for treatment of "type 1" accident during normal decompression or after a blow-up from deeper than 9 m in an heliox bounce dive or air/heliox saturation
- ***Cx SB*** (heliox + Oxygen) can be used in case of failure of Table "Cx B" during normal decompression or after a blow-up from deeper than 9 m in an heliox dive or air/heliox saturation.
- ***Cx N*** (heliox + oxygen) can be used for treatment of "type 2" accident during normal decompression or after a blow-up from deeper than 9 m in an heliox dive or an air/heliox saturation.

These tables are available in Book #4 "Diving Accidents"

3.8.1.3 - Therapeutic gasses

Therapeutic gasses that must be available are already explained in point 2.4.2.3.
As a reminder, their recommended oxygen partial pressure should be between 1.5 and 2.8 ata *(1 ata = 1.013 bar)*. Their percentages and quantities should be calculated according to a gas consumption of 20 litres per minute per diver at the surface. What is important is always to have a therapeutic gas available for the depth the divers are.

The table below indicates the depths with 2.8 bar and 1.5 bar PP O_2 for various oxygen percentages

Percentage oxygen	*Depth in metres with 1.5 bar PP O_2*	*Depth in metres with 2.8 bar PP O_2*	*Percentage oxygen*	*Depth in metres with 1.5 bar PP O_2*	*Depth in metres with 2.8 bar PP O_2*
100 %	5	18	***13 %***	105	205
70 %	11	30	***12 %***	111	223
60 %	15	36	***11 %***	126	244
50 %	20	46	***10 %***	140	270
40 %	27	60	***9 %***	156	301
30 %	40	83	***8 %***	177	340
20 %	65	130	***7 %***	204	390
15 %	90	179	***6 %***	240	456
14 %	125	190	***5 %***	270	550

3.8.2 - Precautions to be in place after the dive

3.8.2.1 - Observation time following the completed diving operation

After surfacing, the divers are still at risk from decompression sickness.
For this reason, they must be kept at the direct proximity of the chamber for 2 hours. Then, they should have a minimum rest period of 24 hours at less than 30 minutes from the therapeutic re-compression facility that is organized with immediate access (NORSOK U-100). Note that other competent bodies such as US Navy prolong the observation time after surfacing to 48 hours.

- It should be emphasized to all divers that:
  - They should not perform hard physical activities
  - Any symptom should be reported as soon as possible, and before departure from the dive location.
  - Treatment begun soon after the onset of symptoms is often relatively straightforward but the treatment which has been delayed for a while after the onset of symptoms may be difficult because the condition has become less responsive.

3.8.2.2 - Standby time before flying

As no recommendations are proposed by NORMAM-15, those from the Diving Medical Advisory Committee (DMAC 7) should be implemented.
Note that it is a common practice that a medical check up of the divers is organized prior to sending them back home. This checkup is mandatory in the case of a decompression accident during or following the dive.

- DMAC 7 says:

The times recommended have never been tested and in commercial diving the interval between diving and flying is commonly longer than that recommended in the guidelines.

In most situations flying involves exposure to reduced barometric pressure (altitude). After diving, exposure to altitude always carries a risk from decompression illness *(DCI)*, in particular if the diver has any symptoms (see later). This together with our evaluation of the existing experimental evidence and experience is the basis of the revised recommendations. Unfortunately there is no evidence relating to repeated exposure to altitude.

For the purposes of these guidelines, it was considered that diving could be divided into two categories:

1. Air and nitrox diving;
2. Mixed gas diving.

Two maximum cabin altitudes are considered:

a) A maximum altitude of 2000' *(600 m)*, provided that the flight plan has been checked – consistent with a helicopter flight from an offshore platform or vessel;

b) A maximum altitude of 8000' *(2400 m)* – all other flights. 2400m is widely used as the maximum cabin altitude in commercial passenger flights.

Caution

The times given below are minimum times: longer time intervals are recommended, in particular if the planned journey involves a number of take-offs. Journeys involving multiple flights are common and are likely to carry an increased risk. Shorter times may be considered but only after the advice of a qualified medical diving physician.

Flying *(or any altitude exposure including road travel)* in the presence of even minor symptoms of decompression illness carries a considerable risk of provoking serious neurological illness.
For those who want to increase the standby time before flying, note that US Navy manual recommends 72 hours after a saturation.

<table>
<tr><th rowspan="2">Table 1:
Diving without decompression illness problems or any symptoms</th><th colspan="2">Minimum times before flying at cabin altitude</th></tr>
<tr><th>2000 feet (600 m)</th><th>All other flights</th></tr>
<tr><td>1.1 - No stop dives.
Total time under pressure less than 60 minutes within the last 12 hours</td><td>2 hours</td><td>18 hours (24 hours)*</td></tr>
<tr><td>1.2 - All other air and nitrox diving, heliox and mixed gas bounce diving
(less than 4 hours under pressure)</td><td rowspan="2">12 hours</td><td rowspan="2">24 hours</td></tr>
<tr><td>1.3 - Heliox saturation (more than 4 hours under pressure)</td></tr>
<tr><td>1.4 - Air, nitrox or trimix saturation (more than 4 hours under pressure)</td><td>24 hours</td><td>48 hours</td></tr>
</table>

** 18 hour time applies to short flights (less than 3 hours). For longer flights the time is extended to 24 hours*

Residual risks will be reduced by giving 100% oxygen during the flight. Following landing the diver should be assessed by a diving medical specialist.

- DCI in Flight

In most circumstances, the medical decisions concerning an air passenger who develops symptoms of decompression illness during flight will be the responsibility of the air crew and airline.

The following guidance may be helpful.

- Where the diver's symptoms consist only of pain in a limb, the diver should be treated with analgesics, oral fluids, and oxygen if available. Advice should be sought from a diving medical specialist. It may be possible for the plane to continue to its destination without diversion or adjustment of altitude, but the risk of development of more serious symptoms, the duration of flight and route need to be considered.
- When the diver has any other symptoms, immediate advice should be sought from a diving medical specialist. The diver should be given 100% oxygen and oral fluids. Reduction in cabin altitude and diversion to an airport where further treatment can be given may be necessary.

Table 2: ***Following therapy for DCI, advice must be sought from a diving medical specialist***	***Minimum time from completion of therapy (completion of recompression treatment)***	
	2000 feet (600 m)	***All other flights***
2.1 - Immediate and complete resolution of symptoms on first recompression	24 hours	72 hours
2.2 - Cases without immediate response or with residual symptoms must be decided on an individual basis by a diving medical specialist. Generally wait as long as practical	Consult a diving medical specialist	

3.8.3 - Duration of saturation exposures and surface intervals following saturations

In addition to the daily working time, the duration of the saturation exposures and the interval between two hyperbaric exposures can influence the organisation of the manning levels.

NORMAM-15 has emitted guidelines which specifies the maximum duration of the divers in saturation and the interval between 2 saturations or hyperbaric exposure that are more stringent than those published in the DMAC 21. These guidelines should be applied in place of those from DMAC 21.

3.8.3.1 - Standard and Deep Saturations

- Using the saturation technique, the maximum one can stay under pressure is 28 days.
- The minimum interval between two saturations will be the same as the saturation time, and it cannot be below 14 days.
- The maximum time one can stay under saturation in a period of 12 consecutive months cannot be over 120 days.
- Until completion of the recommended surface interval (as specified above) after a saturation dive, a diver should not undertake any diving or be exposed to any pressure greater than atmospheric unless cleared to do so by the relevant diving contractor's medical adviser who will take all circumstances into account, including the duration and depth of the previous saturation exposure and the proposed diving.
- Following deep saturation dives, the surface interval should not be less than the duration of the saturation and preference should be given to a surface interval of at least 28 days.

3.8.3.2 - Exceptional Saturations

- The diver will only be allowed two saturations per year in this depth range, with a minimum interval of 6 months between them and as long as he has not done saturation deeper than 300 m during this interval.
- In case the diver has already done a saturation between 300 and 350 m, he can only perform another up to 300 m during the 4 months after the end of the previous saturation, and he cannot exceed 77 saturated days in the interval of 12 months, counting from the beginning of the saturation between 300 and 350 m.
- The maximum period one can stay under pressure is 21 days.

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Table of contents

4) Chamber emergency procedures

4.1 - Fire fighting

4.1.1 - Fire in chambers

4.1.1.1 - Description

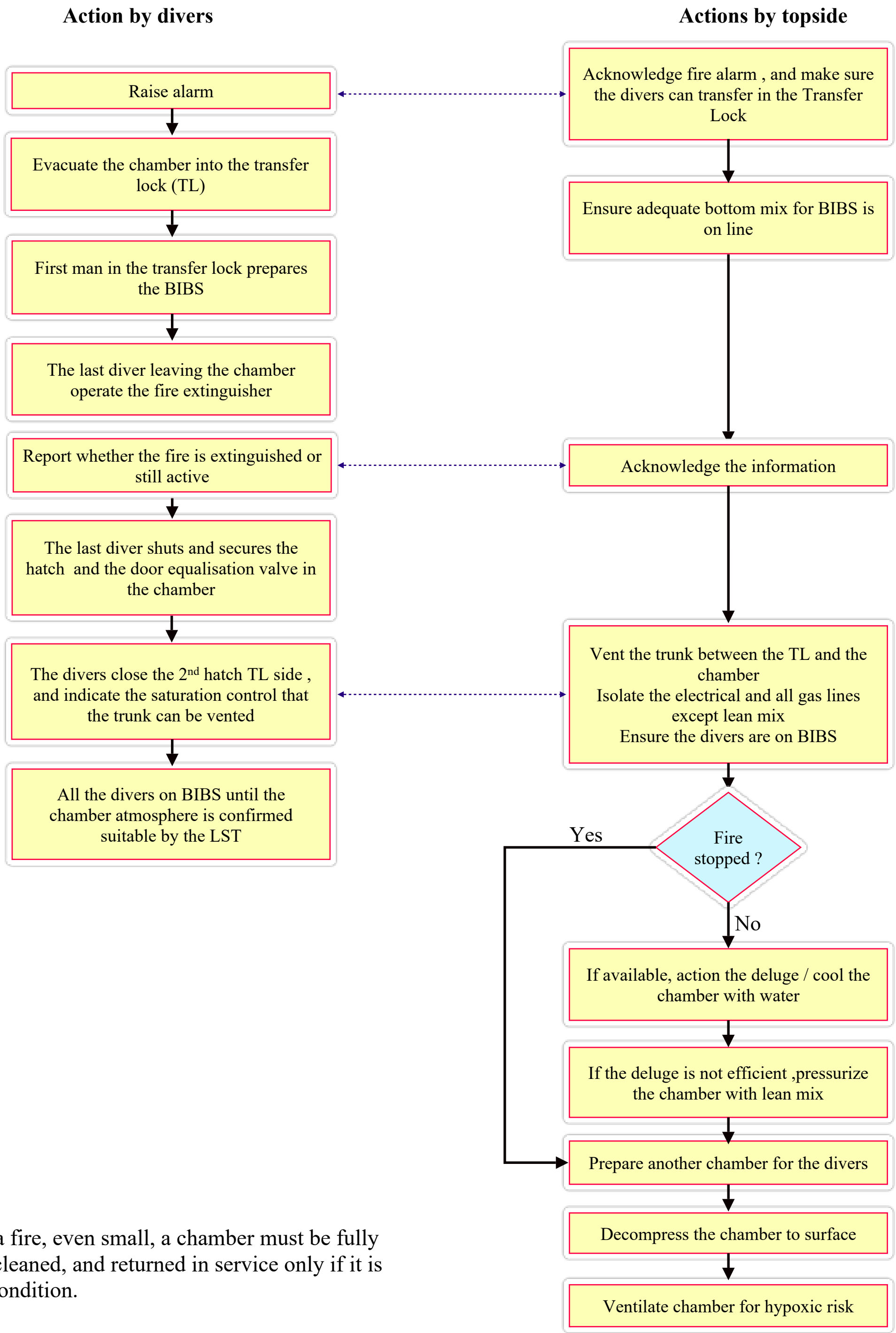
Fire in the chamber is a serious danger the divers may have to face:

- They cannot escape the diving system and can be incapacitated and injured by the smoke and the heat.
- The fire can lead to other dangers such as massive gas leaks due to the seals and view ports being damaged.

Firefighting systems for chambers are described in point 1.2.2.2. Also, note that a flame is not likely with bottom mixes, particularly those with less than 6% O2, but is very likely with mixes above 21% Oxygen.

4.1.1.2 - Procedure with chambers not equipped with automatic fire detection and deluge system.

With systems not equipped with automatic fire detection and internal deluge system, The response is based on a perfect synchronisation of the actions by the divers in the chamber, and the actions of the LSS/LST.

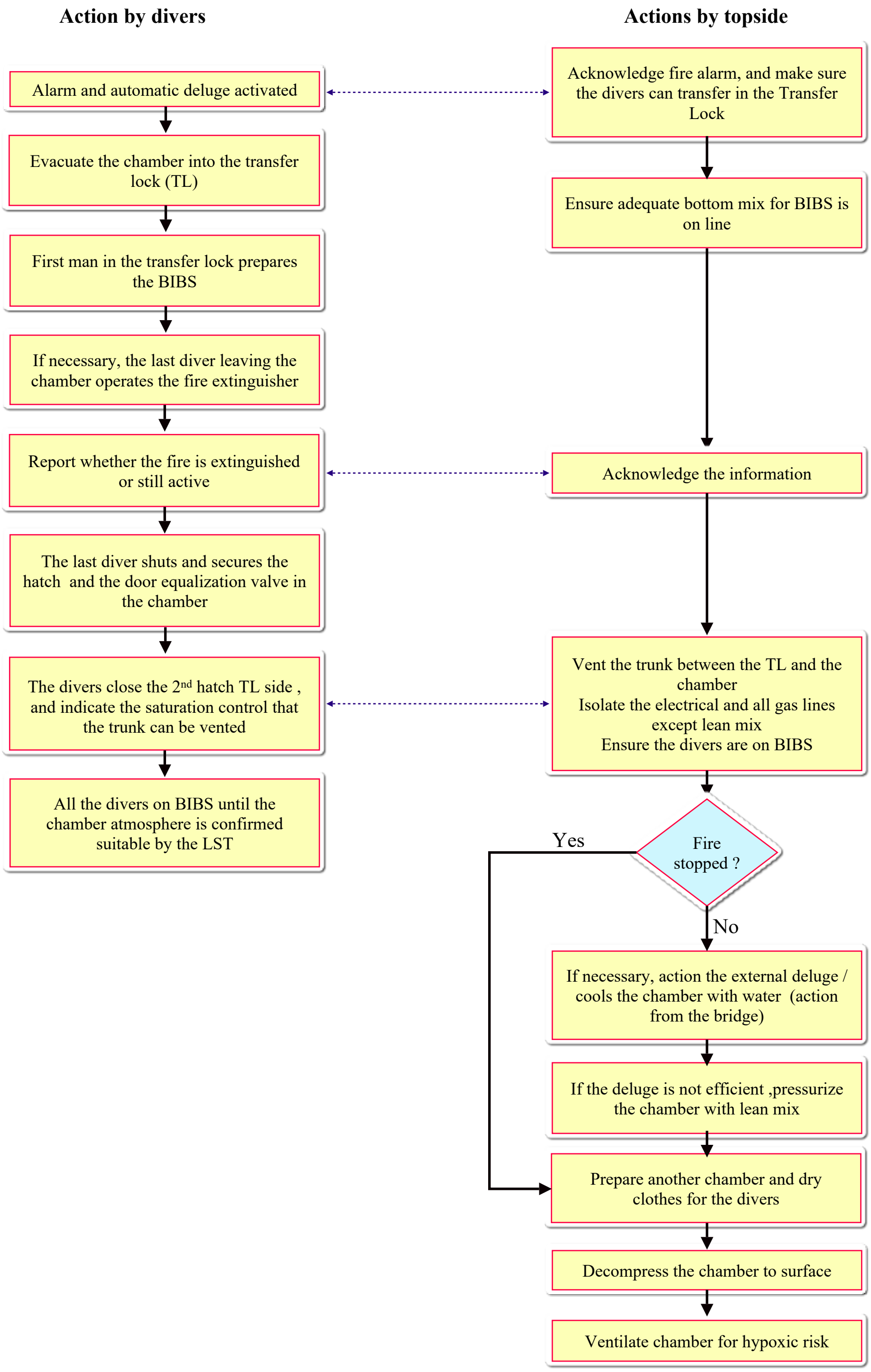


Important

Following a fire, even small, a chamber must be fully inspected, cleaned, and returned in service only if it is in perfect condition.

4.1.1.3 - Procedure with chambers equipped with automatic fire detection and deluge system.

As already said, fixed water deluge extinguishing systems are highly recommended in chamber compartments that are designed for manned operations. Also, these systems that consist of water supplied to the chamber through a number of spray nozzles are mandatory in many countries. Most modern systems are equipped with an automatic activation, and should be designed to prevent unintended activation. In addition, manual activation/deactivation controls should be located at the operator’s console in the saturation control room and in the chamber.
In case the system is equipped with an automatic activation of the chamber, the procedure chart becomes as follows.



4.1.1.4 - Prevention

Cotton clothes and towels should be provided. Also, paint and bedding should be fireproof, and precautions to ensure that combustible materials are not introduced in the chamber should be in place. Among these materials note:

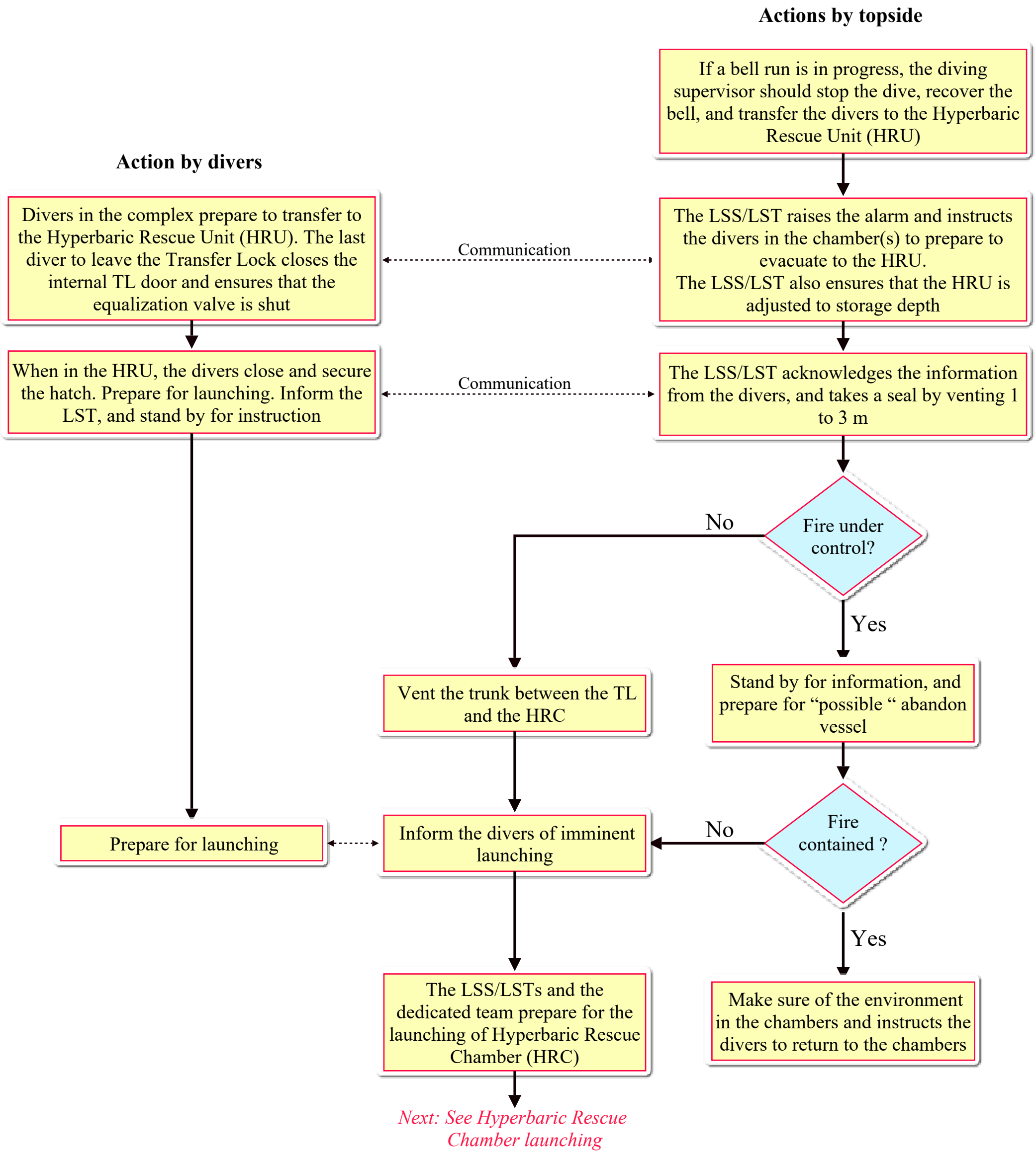
- Cigarettes, matches, lighters
- Alcohol
- Talcum powder, foot powder
- Suspicious electrical appliances
- Grease, dirty clothes

4.1.2 - Fire near the saturation chambers

4.1.2.1 - Description

External firefighting means must be provided to protect and cool the chambers. Built-in systems are protected by fire detection, extinguishers, and a water deluge system that is usually controlled by the bridge and the chamber control room. These internal firefighting systems are requested by SOLAS (International Convention for the Safety of Life at Sea). However, some portable systems, designed to be installed on the deck of a vessel of opportunity, are not provided with external fire detection and deluge systems. In this case, the fire fighting system consists of extinguishers, and the water lances available on deck.

A fire near the saturation system may have catastrophic consequences, and if it cannot be contained, it is necessary to escape the complex using the “hyperbaric rescue Unit” (HRU). Such evacuation has to be triggered as a precaution as soon as the fire is detected, and the divers must be kept ready for launching in the HRU as long as the fire is not stopped. Note that the decision to evacuate the vessel is with the master. As for a fire in the complex, the response is based on a perfect synchronization of the divers' actions in the chamber and the actions of the LSS/LST.
The flow chart below indicates actions to implement before the decision to launch (or not) the Hyperbaric Rescue Unit. Note that another detailed procedure indicates the launching of the HRU.



4.1.2.2 - Precautions

They are those discussed in the previous chapters:

- Flammable gas should be stored in ventilated areas, and not in the direct vicinity of the chambers.
- Hot works at the proximity of the dive station during the diving operations.
- The fire fighting systems described above and in the description of the saturation system must be ready for use. Also, fire detectors should be installed at strategic points, whatever the system.
- The access to the dive station should be restricted to the personnel involved only.

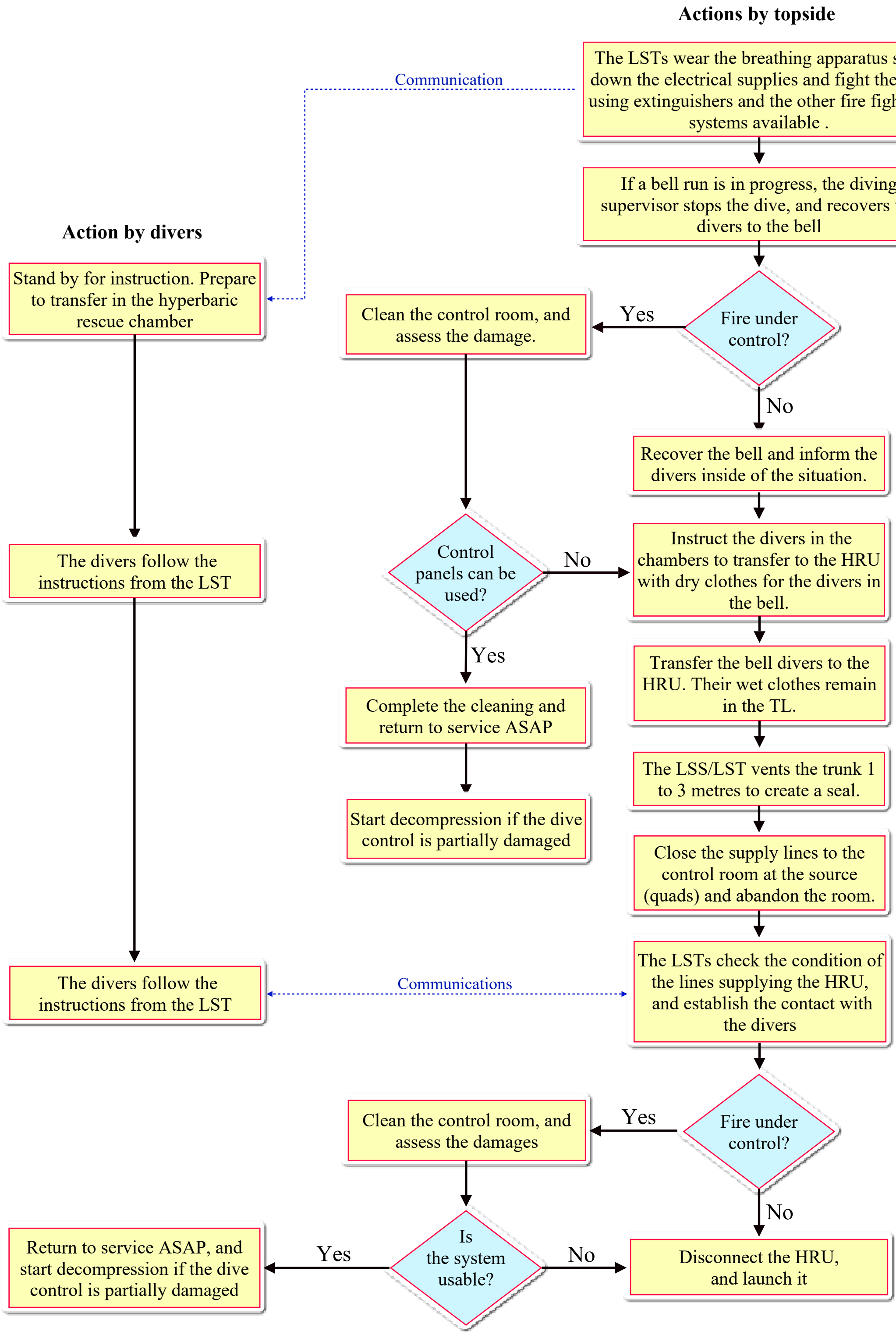
4.1.3 - Fire in the saturation control

4.1.3.1 - Description

Firefighting systems of the saturation control room are explained in point 1.2.8.11. Note that sets of breathing apparatus with communication must be available to allow the life support crew to continue operating the system if the room becomes filled with fumes.

Saturation controls of built in systems are provided with automatic fire detection and firefighting that may trigger as soon as the fire is detected. When fighting the fire, the precaution is to shut down the electrical and the gas supplies.
If it becomes necessary to evacuate the control room, all gas supplies to chamber control should be closed off at the source (quads). The divers should be instructed to transfer to the HRU and close the doors.
It is of utmost importance to keep in contact with the divers and recover the control of the saturation system. Control of a part of the saturation system should be possible through the hyperbaric rescue unit.
If a bell run is in progress, the bell must be recovered, and the divers transferred in the HRU. They must be aware of the situation and that communication in the transfer lock may be lost.

If the control room is damaged and cannot be used, the hyperbaric evacuation procedures should be implemented. Also, diving operations cannot be continued with a system partially damaged.



Note that electrical and electronic components can short- circuit if water (deluge system) and extinguishing agents such as powder have been used. As a result, they must be fully cleaned, dried, and checked before being returned to service.

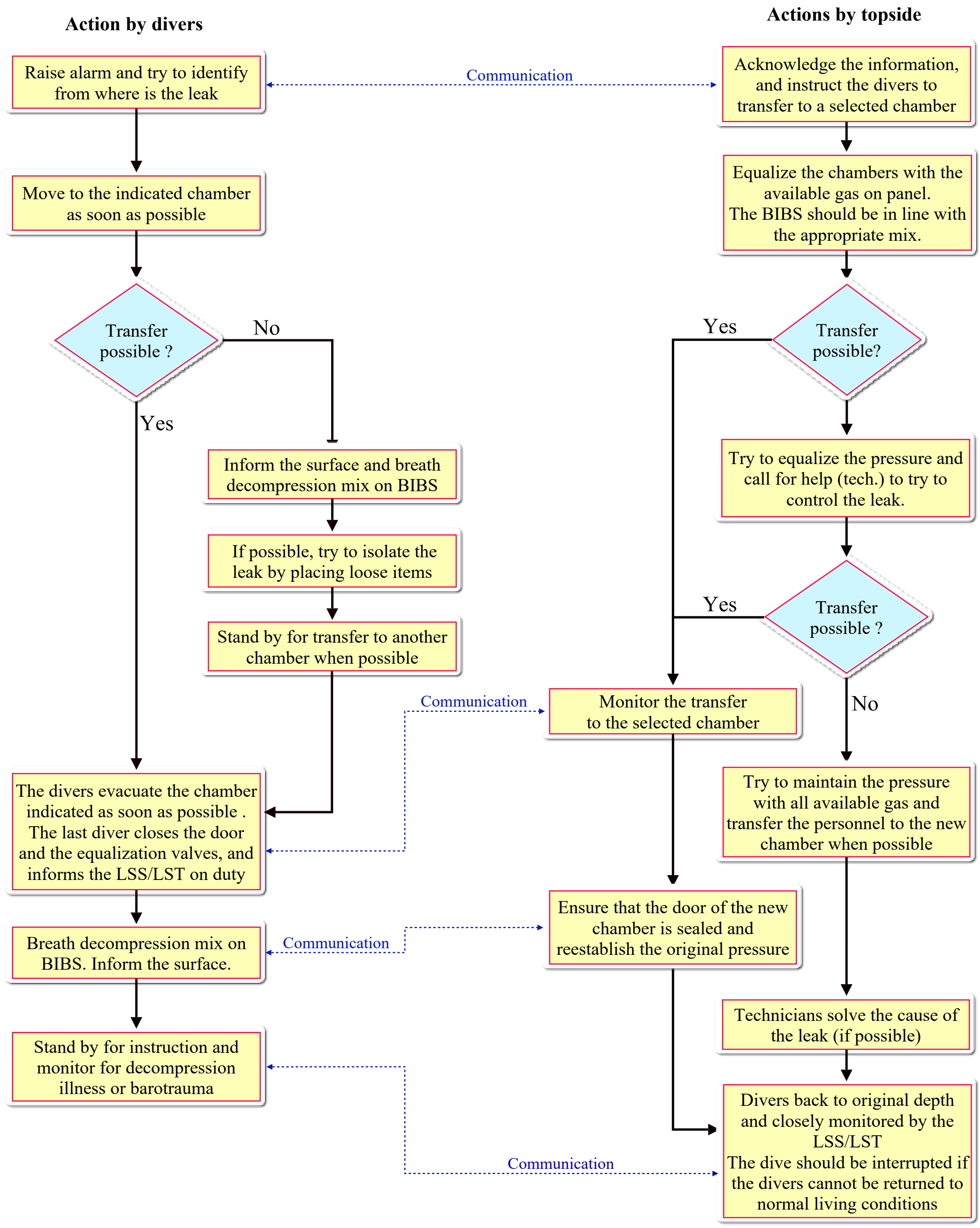
4.1.3.2 - Precautions

Precautions are similar to those described in “Fire near the saturation chamber”. Also, electric systems that are present in the room must be regularly checked.

4.2 - Pressure loss

Pressure loss in the chamber can lead to decompression illness, or worse, explosive decompression, which means the instantaneous death of the inhabitants of the chamber. Such an event can happen without notice in every type of chamber. One indicator of a massive loss of pressure is the atmosphere becoming suddenly foggy.

The procedure is based on the immediate evacuation of the chamber in depression to the nearest chamber, whatever its function. Note that in such a situation, the faster the evacuation, the better it is. Waiting too long a time may result in an evacuation that is problematic or impossible. For this reason, perfect synchronization of the actions of the divers and the LSS/LST is necessary, and drills should be regularly organized. The chamber can be returned in service only when confirmed 100% safe unless the leak is solved immediately and is not due to a technical failure. If the chamber's return to service is not possible and the divers cannot be back to normal living conditions, or too many quantities of gas have been lost to control the situation, the dive must be stopped.



4.3 - Loss of control of the chamber's atmosphere

Loss of control of the chamber's atmosphere includes loss of oxygen and carbon dioxide levels control, chamber atmosphere contamination, and temperature control loss.
In most cases, there will be some warning about the problem. If the situation cannot be quickly returned to normal values, The divers should evacuate the chamber and close the doors. They should go onto BIBS immediately in the new chamber.
The divers' whereabouts in the system should be checked, and analysis of all the chambers' atmosphere should be made *(see in* *point 1.2.8.4* *"Means for gas analysis")*.
If it is impossible to evacuate the chamber, the divers should go onto BIBS until the chamber atmosphere has been thoroughly flushed. According to IMCA D 050, there should be enough gas on-board to keep all the divers in the chamber supplied on BIBS for a minimum of four hours, but a lot of companies double this value as a minimum.

4.3.1 - Loss of gas parameters

4.3.1.1 - Loss of oxygen control

Diving accidents resulting from exposure to too high or too low partial pressure of oxygen are explained in Book #4 "Diving Accidents" in the following topics:

- Acute O2 poisoning
- Chronic O2 poisoning
- Diseases resulting from long exposures to hyperoxia
- Hypoxia - Anoxia

Divers can be safely exposed to oxygen partial pressures between 0.20 and 1.5 bar in chamber. However, efforts should be implemented immediately to correct the problem and reestablish normal oxygen levels recommended by the table. The table below lists the chamber oxygen values, and the exposure limits during the bell run excursions of Normam 15:

Action	*Partial pressure oxygen*	*Duration*
Storage	0.38 to 0.45 bar	28 days minus the ascent time to the surface
Arrival at storage depth after initial or intermediate decompression	0.4 to 0.57 bar	Until the normal value is reached by natural depletion of the oxygen in excess by the respiration of the divers
Decompression	0.48 to 0.5 bar	Up to the depth in which PPO_2 is 23%. Then % O_2 between 21 to 23%
Exceptional exposures (excursion values during bell runs)	0.5 to 0.8 bar	0 - 210 m: 6 hours/24 hours 211 - 260 m: 5 hours/24 hours 261 - 300 m: 4 hours/24 hours 300 - 350 m: 3 hours/24 hours

Hypoxia (PPO_2 < 0.16 bar) during pressurization may occur because of inadequate mixing or because of accidental flushing.

- If only some of the divers are affected, the others may be able to render assistance. They should all go onto BIBS until the atmosphere is returned to normal.
- If all the divers are incapacitated, the life support technician should flush the chamber with a rich oxygen mix and get the surface crew members into the chamber as quickly as possible.
- Personnel entering the chamber should take precautions to avoid being overcome by hypoxia. This type of incident can occur very close to the surface.

Incorrect oxygen partial pressure may result from an incorrect mix in line, a problem with the automatic oxygen addition system, or an incorrect setup of the analyser. If they are correctly setup the analysers should warn the chamber operator sufficiently early to solve the problem. Note that most analysers are provided with an alarm in case of a failure.

- For an oxygen partial below 0.38 bar, the normal oxygen addition system can be used to adjust the oxygen level to the requested value. The operator can also flush the chamber with a correct mix to speed up the return to normal parameters.
- For an oxygen partial pressure above the recommended partial pressure, it may be necessary to secure the oxygen addition system and allow the divers to breathe the oxygen in excess to obtain a normal level. Note that the concept of "Unit Pulmonary Toxicity Dose" can be used for managing chronic oxygen poisoning in the case of repeated or long exposures. This concept is explained in Book #4 "Diving accident"/"Chronic O2 Poisoning". As above, the operator may flush the chamber with a correct mix to speed up the return to normal parameters.
- If the automatic injection system cannot be controlled, the control is to be performed manually, or the divers are to be evacuated to another chamber.

4.3.1.2 - Loss of CO_2 control

The effects of carbon dioxide on divers are explained in the chapter "Hypercapnia" of Book #4 "Diving accidents".

When the DDC's hyperbaric regeneration system loses its ability to absorb carbon dioxide, the level of carbon dioxide inside the chamber rises at a rate depending on the chamber size and the carbon dioxide production rate of the divers, which is usually calculated at 30 litres per hour per diver *(Note that a completely inactive person can survive for a time on less than 100 Mb)*.
The normal maximum value of carbon dioxide should always be less than 5 millibars. However, several competent bodies admit more than 15 minutes of exposure at 10 millibars and up to 15 minutes exposure at 30 millibars. Regarding this point, note that there is no visible symptom with 10 millibars, which is considered an acceptable value in an emergency. Slight hyperventilation should happen with 20 millibars, and shortness of breath associated with headaches is probable with 40 millibars.

When the chamber carbon dioxide level exceeds the normal value, the LST on duty should ask the technician to ensure the carbon dioxide absorbent status and switch to a fresh pot. If the value in the chamber is already high, the divers should be on BIBS until returning to the normal situation, and the LST should flush the chamber with fresh clean gas. Also, the gas values and calibration of the analyser should be checked. Note that the reading of the online analyser can be confirmed by using another unit.
If the level of carbon dioxide of the chamber cannot be lowered, the divers should be transferred into a new chamber where they should go onto BIBS immediately until the atmosphere of the new chamber is confirmed below 5 millibars. If it is not possible to evacuate the divers, they should be on BIBS, and the LST should flush the chamber atmosphere until it returns a normal value, and the technicians solve the problem.
Note that an increasing carbon dioxide level may result from the exhaustion of the carbon dioxide absorbent or inadequate gas flow through the carbon dioxide absorbent canister. If the carbon dioxide level still cannot be brought under 5 millibar following the carbon dioxide absorbent canister change, the technician should check the flow through the canister that may be inadequate.

4.3.1.3 - Atmosphere contamination

The effects of atmosphere contamination on divers' health are discussed in the following points of Book #4 "Diving accidents":

- Hydrocarbons
- Hydrogen sulphide
- Cleaning fluids

If an abnormal odour is detected or if several divers report symptoms of eye or lung irritation, coughing, headache, or impaired performance, contamination of the chamber atmosphere should be suspected. This contamination could be detected by the analysers (Hypergas Analox or similar).

- The divers should move to another chamber, close the doors and go on BIBS in the new chamber.
- The suspected chamber should be isolated, and analysis of the atmosphere of the chambers where the divers are should be performed . The divers stay on BIBS until instructed to remove the BIBS and breathe normally.
- Gas samples from suspected sources must be checked for contaminants. Special attention should be given to possible introduction of hydrocarbons or other substances following a dive or during maintenance. For example, clothes not sufficiently cleaned before returning in the bell. Also, recently changed and cleaned piping sections, gas hoses, which may contain residual cleaning solvents. The filtration of the reclaim may also be deficient.
- If the source is identified in a chamber (or the bell), it should be surfaced and thoroughly ventilated with air or a breathable helium-oxygen mixture (to prevent hypoxia in maintenance personnel), inspected, and thoroughly scrubbed down to remove residual contaminants.
- An inspection of the regeneration system should be performed, the filters changed, and the piping cleaned
- The chambers which have been cleaned can then be compressed to depth using a gas bank that is free of contaminants.
- The divers can be transferred to a cleaned chamber, and the surface cleaning process can be repeated on the remaining chamber(s) if the rest of the complex is affected. Test of the chamber atmosphere should be performed after the intervention of the technician and prior to authorizing the divers to return.
- After cleaning and compression to depth, the chamber should be checked periodically for recurrence of the contamination.

Note that if the problem cannot be satisfactorily solved, the dive must be interrupted.

4.3.1 - Loss of temperature and humidity control

Loss of temperature control slightly above or below the comfort level may lead to severe thermal stress of the divers.

- When the chamber temperature falls, hypothermia develops unless rapid and aggressive measures are taken to correct the problem. Divers may be provided with insulated clothing, blankets, and sleeping bags. External electric heaters and additional insulation of the chambers may help to reduce the effect of the helium in cold conditions. Nevertheless, the best of these insulators are of limited effectiveness within the helium-oxygen environment and will provide marginal protection until the problem can be corrected.
- If the chamber is exposed to the sun in tropical areas, it will become very hot, and the divers will become overheated rapidly. A cold water sprinkler system over the chambers can minimize, but not solve the problem.

In case of loss of temperature control, the only acceptable solution is to solve the technical problem as soon as possible, and if the problem cannot be solved, the divers must be moved to another chamber, or the saturation dive must be stopped.

Loss of humidity control should be minimised by restricting the use of shower, and Silica gel may be added to the soda lime in the back up scrubber of the chamber, but the only acceptable solution should be the repair of the system. If the humidity cannot be controlled, the divers must be move to another chamber, or the dive must be stopped if this solution is not applicable.

4.4 - Infection during saturation

4.4.1 - Infection in chamber

DMAC 26 “Saturation diving hygiene” says:
Infection is the most frequent medical problem encountered during saturation diving. The closed environment, temperature, humidity, hyperoxia and helium environment contribute to enhanced microbial growth. Superficial infections, especially of the external ear canal and of soft tissues following minor wounds, are particularly common. The sources of microbial contamination of the chamber include the divers themselves, equipment, food, materials introduced into the chamber, the fresh water supply, and seawater. Control of microbial growth within the chamber is important in minimising episodes of infection.

DMAC 26 provides numerous guidelines regarding the description and the prevention of infection. Also, additional guidelines have been edited regarding the prevention of Covid-19. Such precautions should be extended to other microbes, because as already said, Covid-19 is a particular case of the numerous possible infections. However, despite these precautions, a diver may be infected and transmit the microbes responsible to all divers at his direct proximity. In case an infection is detected in the chamber, the following control measures should be implemented:

- The dives should be interrupted and the other teams isolated from the infected team. So, each team should stay in his living chamber and entry-lock.
- The diving medical specialist must be informed, and investigations regarding the disease's nature should be launched according to his recommendations. Such an investigation usually involves sampling and data transmission of symptoms and medical status of divers affected to the doctor using the appropriate equipment. In this case, the infected team needs to access the medical data transmission system, usually situated in the transfer lock.
- The other teams should be kept under close observation. Depending on the disease and the decision of the doctor, tests may have to be performed to ensure they are not contaminated.
- Note that it may be necessary to assign a diver medic if those of the infected team cannot work. In this case, precautions to avoid him from contracting the infection should be implemented. That could be the use of isolating clothes and other barriers.
- The decompression of the infected divers should start as soon as possible. It should also be the case for the other teams unless the doctor considers it unnecessary.
- The transfer lock(s) should be returned to the surface and disinfected. It is also the case of trunks, medical and tool locks, and the bell. The piping of these chambers should also be disinfected. Specific protection should be provided to people performing such cleaning and also the transfer of food and medication. Dishes should also be cleaned and disinfected before being returned to the kitchen.
- Clothes and linen must be changed regularly. Precautions should be in place to disinfect them and not contaminate those of others during the cleaning process.
- A medical team should be ready to assist the infected team at his arrival to the surface. The treatment facility should be organized at the proximity of the recompression chamber during the bend watch.
- When the infected team has been evacuated, the chambers' full disinfection should be undertaken using the precautions indicated above. This disinfection should extend to the Hyperbaric environment Regeneration System (HERS), and reclaim system which could nest microbes.

Important point to highlight:
Recover divers in saturation to the surface takes time. As indicated in point 3.5.1.5, recovering divers saturated at 16 metres takes 1 day, and 11 days will be necessary to ascent from 301 metres. This point and the procedures discussed above highlight the difficulties of assisting them if they become infected. For this reason, it is of ultimate necessity to implement the precautions described in points 3.1.1 & 3.1.3 of this book and Book #4 “Diving accidents”.

4.4.2 - Infection on the diving support vessel, but not yet in chambers

If despite precautions, an infection arrives on the vessel, it may quickly affect the divers and the people in charge of their life support, who may become incapacitated to fulfill their duties. For this reason, the dive should be interrupted, and the vessel should head to the closest location where hospital facilities are available.

- As soon as cases are detected, they should be quickly evaluated by the doctor in charge and isolated in rooms that can be secured and do not share their air conditioning systems with other rooms. These points are important as cases where the infection has spread throughout the vessel through the air conditioning system and rooms communicating have been reported.
- The life support personnel should be examined for symptoms and isolated from the rest of the team. Also, access to the dive system should be restricted to only these people. The same procedure should apply to the cooks and other personnel working in the kitchen, which access should also be restricted.
- Elements provided to the chambers must be disinfected.
- As soon as the vessel arrives in port, the people infected should be taken in charge by a medical team, evacuated to adequate treatment facilities, and the vessel disinfected.

4.5 - Abandon vessel using "hyperbaric evacuation systems"

This chapter discusses the way evacuation procedures can be organized, depending on the means available on site. Note that the means of evacuation are described in point 1.2.7 "means for hyperbaric evacuation", Life Support Package (LSP) is described in point 1.2.9, and Hyperbaric Reception Facility (HRF) in point 1.2.10 of this document The same texts are also available in the document "Description of a saturation system" that can be downloaded free of charge.

4.5.1 - Elements to take into account for selecting the procedure

Hyperbaric evacuation and reception systems allowing to evacuate the divers in saturation in case of vessel abandonment are today compulsory with most professional organizations and clients, so this point is not to be discussed further.

It is the duty of the employer to organize the evacuation of the divers according to the best practices to provide them the best possible protection. Several solutions may be proposed, among which the project team has to select the most appropriate. Note that the most appropriate does not mean the cheapest. Among the guidelines published by official organizations and professional associations, IMO A 692 and IMCA D 52, D 051, and D 053 are the most relevant.

4.5.1.1 - Hyperbaric Rescue Unit

The advantages and inconveniences of the Hyperbaric Rescue Unit (HRU) available should be highlighted. Note that the Hyperbaric Rescue Unit is part of the saturation system and cannot be replaced without complex modifications. Thus except if the entire diving system is changed, the team must organize according to the HRU available. That has an impact on the procedures and the way the HRU should be assisted.

Items	*SPHL*	*HRF*
Gas supply autonomy	72 hours minimum	72 hours minimum
Propulsion	Yes	No
Equipped to sail alone to a distant location	Yes (72 hours minimum)	No
Equipped with Global Maritime Distress & Safety System (GMDSS)	Yes	Yes
Active protection against external fire	Yes (sprinklers above the boat)	No
Radio communication & satellite phone	Yes	No (usually)
External management of the chamber parameters	Yes	No
Chamber heating & cooling system	Yes	No
Toilets	Yes	No
Onboard support team	2 sailors, 1 supervisor/LSS & 1 LST	No
Launching	Controlled descent by davits. Crane & float off if the davits cannot be used.	Free falling, controlled descent on a slope or by davits, crane, and float off.
Lifting & towing	Pre-installed rigging ready for use	Pre-installed rigging ready for use

4.5.1.2 - Hyperbaric reception facilities

Several types of Hyperbaric Reception Facility (HRF) can be available such as:

- A permanent unit is shared by several companies working in the area installed onshore at the direct proximity of a jetty or in an industrial estate.
- A unit is temporarily installed onshore at the direct proximity of a jetty or in an industrial estate for the project's duration and is not shared by other companies.
- A unit is permanently installed on a rescue vessel, standing by in the working area and shared by several companies.
- A unit is installed on the rescue vessel and is standing by at the diving support vessel's direct proximity.

4.5.1.3 - Elements regarding the transfer to the Hyperbaric Reception Facility

Regarding the transfer to the Hyperbaric Reception Facility (HRF), the faster the divers can be transferred into it, the better it is for the following reasons:

- Divers evacuating a dive system in an emergency are stressed and need to be calmed down and decompressed as soon as possible. Keeping them too long at sea increases their worries, which is not a favourable condition for an adequate decompression. Also, that may negatively influence their mood, and their response to instructions can be altered as a result.

- A long travel on a seat without moving due to the limited space in the congested chamber, favours a poor blood circulation and the risk of developing blood clots and pulmonary embolisms. Regarding this point IMCA says: *"Prolonged immobility can lead to serious medical conditions. Deep vein thrombosis (DVT) in the blood vessels of the lower leg may result from pooling of the blood in the lower limbs. The pooling may occur because there is no muscle activity around the venous system to assist the conduit of blood through the veins back towards the heart. The restriction in venous return can be made worse by compression of the veins over the edges of seating in the HRU. The circulation may be further compromised by dehydration (heat stress and vomiting) causing increased viscosity of the blood. Clots that detach from blood vessel walls can be carried in the venous return to the heart and passed through to the pulmonary circulation where they cause pulmonary embolism".*
- A long trip in the HRU increases the problems of seasickness since the inner ears of the divers inside the chamber detect changes in the vessel's motion and accelerations, resulting in the condition of the sea, where their eyes register a stable scene. As a response to such incongruity, their brains produce stress-related hormones that lead to nausea, vomiting, and vertigo. Acid effluences from vomit often affect those who are not affected first who may vomit in turn. Seasickness tablets allow controlling the problem partially.
- Linked to the above and the use of toilets, people in a congested chamber will be quickly contaminated by dirt, bad odours, etc. That will be increased by the fact that the use of toilets medical lock should be restricted due to limited gas reserves. As an example toilets should be limited to 3 flushes per day in a SPHL 18 divers.
- The assistance of injured divers in the chamber is difficult as there is no medical support and no means of treatment other than those provided by the medical kit DMAC 15. DMAC 15 medical kit is normally designed for emergencies and short periods of support only and may be insufficient in case of prolonged periods.

4.5.1.4 - Reasons for transferring the Hyperbaric Rescue Unit onboard the rescue vessel

IOGP 411 "Diving recommended practices" states in Appendix 8 that a towing/reception vessel designed to support the hyperbaric evacuation and a Life Support Package are mandatory. This point is also agreed by most companies and diving organizations and should not be discussed. As an example IMCA D 052 says in point 2.4.3 "The availability of a suitable vessel within a reasonable timescale should be considered as part of the planning process".

Transfer the Hyperbaric Rescue Chamber (HRF), or the Self Propelled Hyperbaric Lifeboat (SPHL) onboard the rescue vessel is preferable to towing them or letting the SPHL sailing for the reasons listed below. It is the reason that we say that such an operation must be planned and performed as soon as possible. Note that the transfer of the HRU onboard the rescue vessel is explained in point 1.2.7.9 of this document.

- Towing the HRU affects the manoeuvrability of the rescue vessel and obliges her to sail at reduced speed (< 3 knots). Also, that obliges the team to regularly check the towing rope that may be quickly damaged by frequent sudden pulls resulting from bad sea conditions, and exaggerated wear at the friction points.
- Note that some organizations pretend that towing Hyperbaric Rescue Units at 5 - 6 knots is possible. However, several experiences have proved that they tend to submerge at speeds above 4 knots. Also, even though Self Propelled Hyperbaric Lifeboats are given to maximum sailing speeds of 5 to 6 knots, they cannot maintain such a speed by bad weather, and an unexpected breakdown is possible.
- When the Hyperbaric Rescue Unit (HRU) has been transferred to her deck, the rescue ship can cruise faster than when towing or protecting the SPHL sailing at 6 knots maximum by flat sea. Depending on the ship, speeds between 10 and 20 knots are common.
- The rescue vessel is more visible than a small unit, particularly in bad weather. This is essential at the proximity of port facilities where the risks of collision are increased. Also, the means of communication of the rescue vessel are considerably more powerful than those of the HRU. The rescue ship is also equipped with radars that allow detecting vessels at sea from far, calculating their direction, and avoiding a collision.
- Transferring the HRU to the rescue vessel deck allows the team to safely connect the Life Support Package that provides a more comfortable means of control and sufficient gas to keep the divers in more normal conditions. Although it is not recommended, the LSP may also be used to decompress the divers if needed.
- As a result of the increased stability when onboard the rescue vessel, the seasickness problems of the divers in the chamber are diminished. Also, recovering the HRU onboard the rescue vessel should make them confident in the rescue procedure.

4.5.1.5 - Recommended maximum travel time in the Hyperbaric Rescue Unit, and why having the Hyperbaric Reception Facility onboard the rescue vessel could be preferable

Hyperbaric Rescue Units are provided with 72 hours of autonomy. However, IMCA D 052 says that the arrival to the safe haven should be as soon as possible and that planning should be based on arrival at the safe haven within 75% of the HRU designed endurance. That means 54 hours, which can be considered too-long a trip for the reasons already indicated above. To understand the problem posed by long trips, people in charge of organizing the rescue procedure should compare the time passed in the chamber with a flight trip. Note that a trip of 54 hours in the chamber represents more than two consecutive flights from London to Melbourne in the economy class, whose duration is more than 24 hours each without moving from the seat. Discussing this point with some people, none of them agreed to perform such long trips of 24 hours on a seat without at least a few days to recover between the two. So, conditions no one would accept for

him/herself or his/her family should not be considered suitable even in an emergency. For this reason, a maximum time at sea of approximately 12 hours should be the recommended option to people organizing the procedure, taking into account that it is usually the sailing duration of supply boats from far facilities.
The 72 hours of autonomy of the HRU should be considered a backup in case it is lost at sea, or unable to reach the rescue vessel or the safe haven within the planned time for technical reasons or others.

Another point to consider as a part of the travelling when the Hyperbaric Reception Facility is situated onshore is the transfer by crane from the rescue vessel to the facility or the truck that will transfer the HRU to the HRF. In case that a truck is used because the Hyperbaric Reception Facility is not directly on the jetty, a 2nd crane transfer is to be planned in addition to the travel by truck. Regarding transfer by road, several elements are to be taken into account that may delay the operations, such as traffic jams and difficult roads as a result of a lack of maintenance or seasonal conditions. Note that road transfer increases the risks of accidents during this critical phase. So, third party interventions may have to be organized to protect the chamber and speed up the transfer. Also, the jetty's immediate availability from where the chamber is to be transferred is another problem that must be solved, as some port facilities are very congested.

Note that these problems can be eliminated or diminished if the Hyperbaric Rescue Chamber is installed on the rescue vessel, as this solution can provide the following advantages:

- The connection of the HRU to the HRF is performed as soon as possible when the unit is transferred on board. Thus, the decompression can be undertaken when the divers have completed their stabilization period after their transfer. There is no time lost by transfer at sea to the facility and then transfer by road.
- In addition to saving time, this system allows for more flexibility because the vessel can head to any suitable location without affecting the launching of the divers' decompression.
- The personnel for the management of the decompression is available and ready to operate. Regarding this point, most companies plan for a transfer of the Life Support technicians (LST) onboard the SPHL or onboard the rescue vessel to activate the Life Support Package. However, that is an optimistic scenario as nothing says that the LSTs and diving supervisors on the diving support vessel will be capable of reaching the Self Propelled Hyperbaric Lifeboat or the craft planned to transfer them to the rescue vessel in case of a catastrophic event such as a massive fire, explosion, or quick sinking. Thus, having the Life Surface Technicians ready to operate onboard the rescue vessel is an advantage. Note that this procedure is imposed by some clients.
- It is said that installing the Hyperbaric Reception Facility on board the rescue vessel is more expensive. It may be true when minimal means of evacuation are planned, and people consider that long trips in uncomfortable conditions before reaching the shore are suitable. However, because most clients request a rescue vessel at the proximity of the Diving Support Vessel, and that recovering the HRU on board is advantageous and recommended, the difference of price is minimal, considering that for a unit situated onshore, expenses are to be planned for the transfer and the installation of the facility, the renting of the area where it is installed and of the facilities where the LSTs in charge are accommodated, and the payment of the crane and truck on standby. Thus, we can consider that the cost should be close for better efficiency.

4.5.1.6 - Availability of shared Hyperbaric Reception Facilities

The availability of the Hyperbaric Reception Facilities shared between several companies is based on the probability that accidents happening during the same period in the same area is very low. However, the probabilities for such events in the area and the availability of chambers if an accident happens are to be analysed. Note that in the case of divers stored at several depths that are too far to allow a rapid compression, and thus must be evacuated in separated units at two different depths as explained in point 1.2.7.7 (remember that the compression from 100 m to 300 m takes 32:20 hours), sufficient number of chambers must be available in the reception facility. Also, the dives must be interrupted if the shared reception facility is in use, and the chambers required are no more available.

4.5.1.7 - Ensure of a means of escape from the Hyperbaric Reception Facility

IMCA D 052 says:
When using an HRF it may be possible to surface the HRU and thoroughly clean it out. The HRU can, if required, be re-mated to the HRF chamber, blown down to the chamber depth and provide an additional area for the divers to improve the comfort of the decompression. The additional chamber on the HRU would be beneficial for longer decompression times, such as depths greater than 150 m.
Before it can be re-mated and blown down it needs to be clarified that the HRF is adequately supported, has adequate environment control unit capacity, appropriate umbilicals and sufficient gas supplies.
Regarding this point, the rule should be to always reconnect the Hyperbaric Rescue Unit (HRC or SPHL) to the Hyperbaric Reception Facility, to provide a refuge and a means of escape in case of an incident such as those discussed previously (gas leak, fire, wrong gas, abandon of the facility). An exception to this rule is possible only if the facility is onshore and has sufficient chambers where the divers can be transferred in case of an incident.

4.5.1.8 - Decompression in the Hyperbaric Rescue Unit

Hyperbaric Rescue Units (HRU) are not designed to perform optimal decompression for the reasons already indicated above. As a result, safety organizations and most clients require that the decompression is organized in the Hyperbaric Reception Facility, which is designed for this purpose. Note that one day is necessary to ascent from 16 metres and 11 days from 301 metres. Thus, such long decompressions are not to be envisaged with people nailed on their seats and should be considered only when an undesirable event results that the Hyperbaric Reception Facility is no more available.

Regarding the possible health problems that may arise if such decompression is organized, please, refer to what is said in point 4.5.1.3.

A lot of companies organize their rescue decompression in the HRU because they consider that the risk of abandoning the vessel is improbable and that the cost of the Hyperbaric Reception Facility is too high. For several years clients indeed diminish the envelopes assigned to diving projects. As a result, people in charge provide risk assessments stating that decompression is possible in the Hyperbaric Rescue Unit to avoid paying for a hyperbaric Reception Facility.
Also, IMCA D 052 is insufficiently directive regarding this point and says in point 2.3: *The reception site is the place where the evacuated divers are in safe environmental conditions and transfer can be made to a decompression facility or where decompression can be carried out (or completed) in the HRC or SPHL using external life support facilities (LSP).*
This sentence opens the gate to the condition indicated above. Also, it is in opposition with the health problems highlighted previously, and point 5.5 of the same guideline where it is said that the Hyperbaric Reception Facility needs to meet the following:

- *Have the ability to lock in/out medical personnel.*
- *Provide facilities for at least 50% of the maximum number of occupants to lie down comfortably.*
- *Have the ability in terms of life support, toilets, etc. to support the maximum number of occupants without recourse to the HRU which may or may not remain mated to it;*

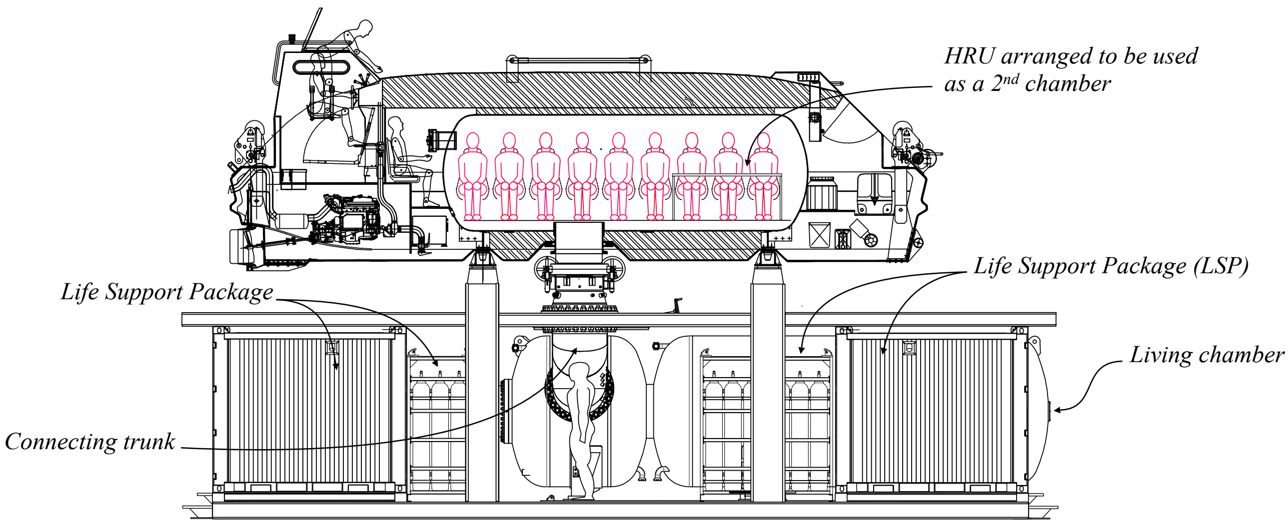
Thus, we can consider a decompression in the HRU if the above conditions or similar are in place. That means that the chamber cannot be full, must provide sufficient space to install beds and means for washing in addition to toilets. Also, note that these chambers' diameter may be less than 1.8 m, limiting the ability to stand up in them. As a result, even though the conditions above can be met, only decompressions from shallow depths should be planned.

Regarding those that, despite these arguments, say that decompression in the HRU is suitable, we can answer that people who calculated the number of Titanic lifeboats also considered the risk that this ship would sink in less than two hours was extremely improbable. Note that DMAC says that accelerated decompression procedures must not be used.

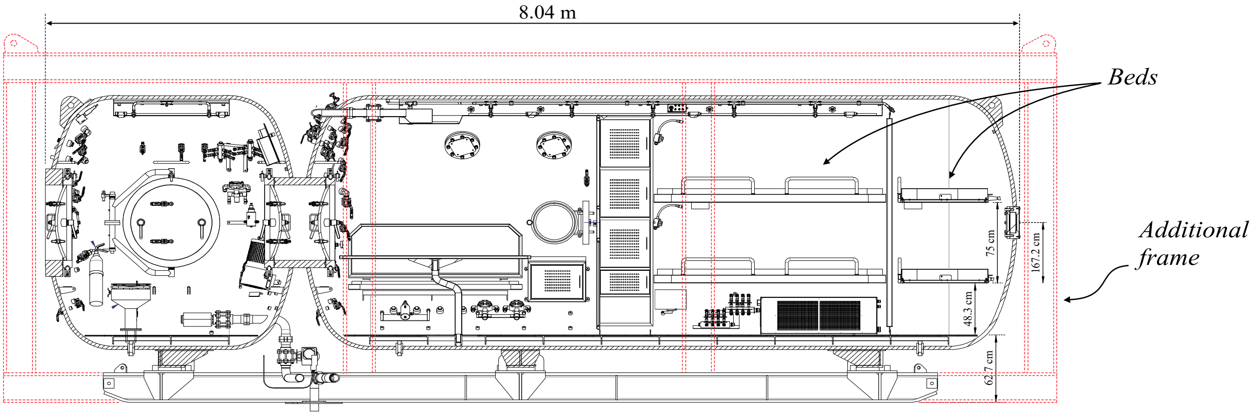
4.5.1.9 - Decompression in small Hyperbaric Reception Facilities

Several studies have been made to investigate how costs of Hyperbaric Reception Facilities could be reduced to banish decompression in Hyperbaric Rescue Units definitively.
As explained in the previous point, the system currently proposed is considered too expensive and complicated by numerous companies. IMCA and IOGP plan to impose it through international organizations such as IMO. However, they should keep in mind that too costly diving operations will result in the implementation of other means of intervention and in the study of systems that can be operated without divers.
The response, to this problem can be Hyperbaric Reception Facilities that are composed of small chambers and which size can be adapted to the needs of the projects, as diving systems are rarely full.

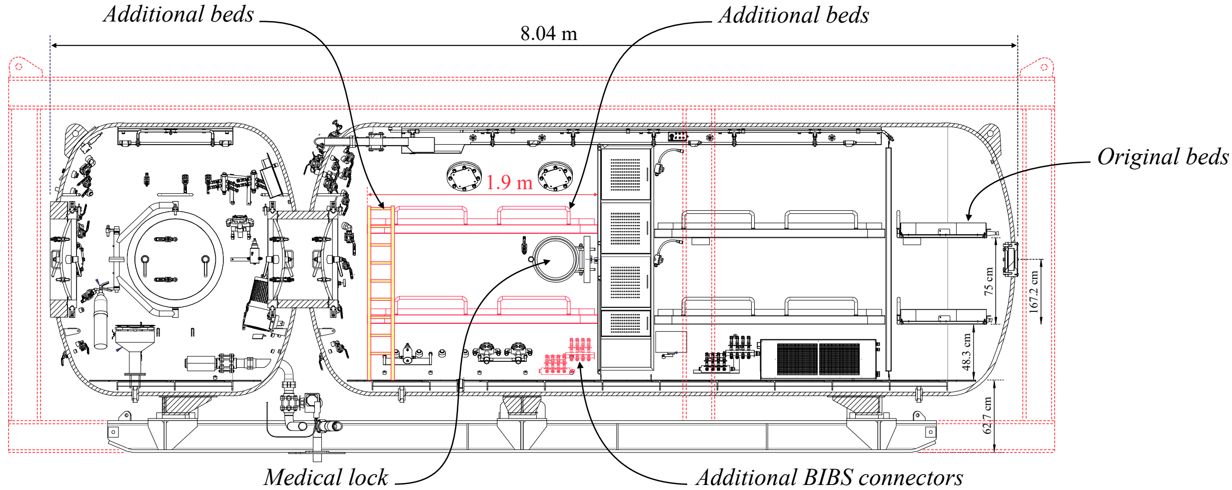
Another study called “Reflection regarding the improvement of hyperbaric reception facilities", published during a hyperbaric doctor meeting at Kuala Lumpur in October 2018 by CCO Ltd, can be considered to find solutions to diminish hyperbaric Reception facilities’ costs. It is based on sleeping periods of 8 hours per diver instead of the 12 hours recommended by IMCA. Eight hours is the average sleeping period of adults from 18 to 65 years old, according to data published by medical organizations such as the "Sleep Foundation" (https://www.sleepfoundation.org/). Another point that is retained in this study is that the HRU is used as a part of the decompression facility. The difference with what IMCA promotes is that with bed rotations of 8 hours, instead of 12 hours the number of bunks necessary to accommodate the divers is only a third of the maximum occupants instead of half with 24 divers, which allow for a smaller chamber.
The concept is based on a dormitory organized in a saturation chamber *(they are commonly fabricated in small series)*, and the arrangement of the Hyperbaric Rescue Unit (HRU) to offer a place where the divers in saturation can relax, take their meals, and chat without disturbing those who are sleeping.
The entry lock of the saturation chamber is used as a means of connection between the chamber and the HRU and of course as toilets and bathroom. Depending on the cost, the connection between the HRU and the entry lock is made by a trunk similar to those used to connect the SPHL to the saturation system on board the vessel or a flange installed on the top of the entry lock.



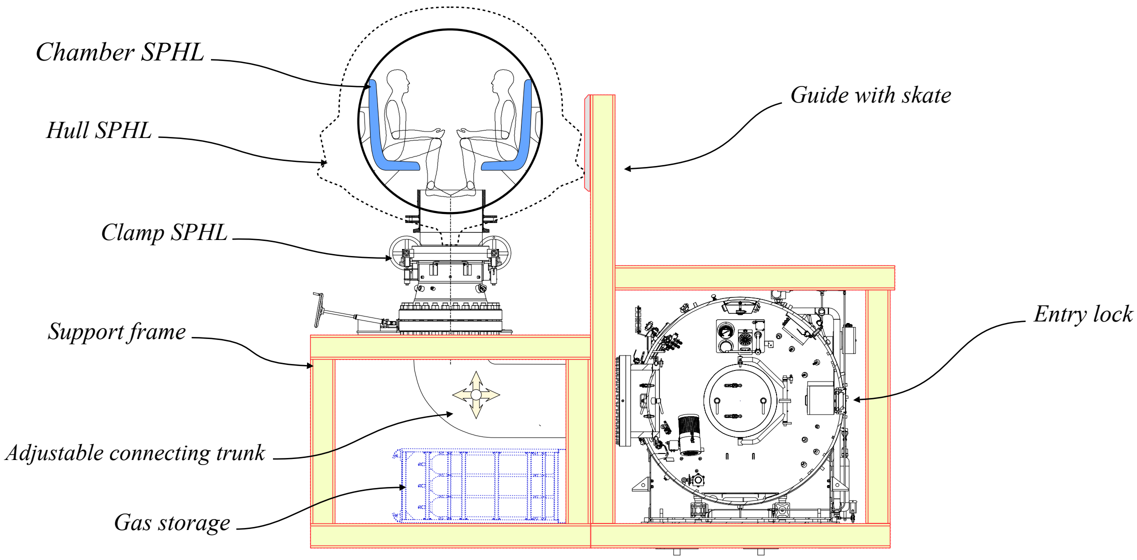
The model of chamber taken as an example is a 6 bunks chamber similar to those described in point 1.2.2 of this document. As for portable saturation systems, a frame (see red in the drawing below) is added to protect it, and support the elements necessary for the connection of the HRU. Note that this chamber can be a 2nd hand unit. Thus, the principle is to perform minimum modifications to limit costs.



The use of the standard living chamber as a hyperbaric dormitory is done by replacing the table and the seats of the chamber with beds that can be transformed into seats. However, the medical lock may not be accessible or be vulnerable if a bed is at its proximity. In this case, only three or two bunks can be installed. That allows a minimum of 8 hours of sleep/day with 24 divers. Note that no change is necessary for a dive system designed for 18 divers.

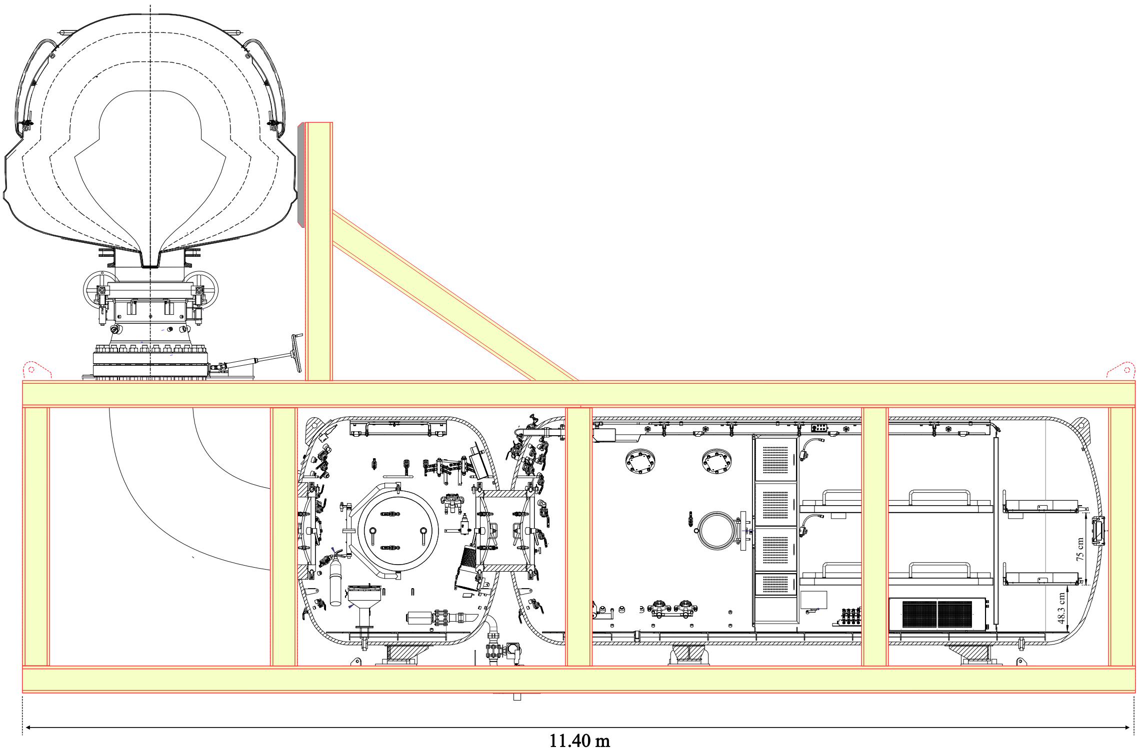


A problem posed by this configuration is the necessary transfer from the HRU to the chamber through the entry lock and vice versa that may oblige to open and close the doors of the trunks often. Also, depending on the number of divers, this entry lock may be often occupied by divers who need to wash and go to toilets. As a result, a strict organization of the activities should be implemented. Toilets of the HRU (if fitted with) may be used; however, in addition to bad odours, contamination may occur. The chamber can also be very congested when all the divers are in it, and the gas regeneration system has to be reinforced accordingly.
Another problem is the transfer and the connection of the HRU to the chamber. As indicated, this study looks for solutions to avoid costly modifications of existing chambers used as Hyperbaric Reception facilities. For this reason, the 1st solution proposed is a trunk similar to those used to transfer from the transfer lock to the HRU.



A robust frame should support the connecting trunk to which the hyperbaric Rescue Unit is transferred from the water if the connection is to be on the bottom of this unit, which is usually the case with Self Propelled Hyperbaric lifeboats (SPHL). Note that the weight of the 18 divers units installed on Lichtenstein is 20 tonnes and that the Safe Working Load of their davits is 24 tonnes.

An inconvenience of the arrangement proposed on the previous page is that the connecting trunk must be perfectly adjusted. That may not be easy to perform when the system comprises several modules to be adjusted side by side during the installation on site. That can be corrected if the connecting trunk is integrated with the same frame as the chamber. Of course, the result may be a longer or larger frame, except if the trunk is installed on the top of the entry lock, which is the 2nd solution. However, this solution would oblige to modify the hull of the chamber, which may be more expensive, except if the connection is already in place. Note that a modification of a chamber includes a full dismantling of the elements, the installation of the flange and the test of the welds, a full pressure test, and the reinstallation of all the components of the chamber.



If such Hyperbaric Reception Facility is installed on the rescue vessel, the methods of transfer can be those discussed in point 1.2.7.9 of this document. Note that if the frame is correctly calculated, davits or an A-frame can be installed on the top of it.

The procedure proposed for the transfer of the divers is as follows:

1. The Hyperbaric Rescue Unit (HRU) is recovered from the sea and connected to the chamber.
2. The divers transfer into the chamber through the entry lock where they wash and disinfect. New clothes and individual sleeping bags are provided. The divers standby in the chamber.
3. he HRU is returned to the surface, and the lateral chamber door opened. If there is no lateral door, the HRU is disconnected and lifted to allow the persons in charge of cleaning access inside the chamber through the trunk.
4. The SPHL is fully cleaned and disinfected. Then, the door is closed, or the HRU is reconnected to the trunk, and the supplies and controls from the Life Support Package are connected. The HRU is then pressurized to the depth of the divers.
5. The divers who are not sleeping are transferred in the SPHL, then the doors are closed as usually in a saturation system.
6. Sleeping periods and meals are then organized according to the number of divers to decompress.

The advantages of the system proposed can be listed as follows:

- The chambers used are fabricated in small series and should be less expensive than chambers built specifically. Also, 2nd hand chambers can be used for this purpose, which can reduces the price of the unit.
- The HRU is used as a 2nd chamber, which reduces the footprint of the ensemble. Also, the divers sleeping are fully separated from those awake with no risk of being disturbed during their rest time.
- Depending on its conception, a chamber originally designed for 6 beds can be conditioned to accommodate 8 to 9 beds. Thus such a chamber can be used for 24 divers
- As the chambers are not too voluminous and heavy, their installation does not require specific cranes (a crane 30 tonnes should be sufficient). Also, they can be installed in less broad areas or smaller vessels than most existing Hyperbaric Reception Facilities.
- As every HRF, a bathroom and toilets are provided, in addition to beds, and it is possible to transfer diver medics inside. Also, there is the possibility to transfer the divers to the safe chamber in case of a problem.

The system proposed also has some inconveniences:

- The chamber is too small to provide beds to 50% of the divers, as recommended by IMCA. However, using 8 hours of sleep per diver instead of 12 hours is a key element of this procedure.
- If all the divers planned in the chamber taken as an example (24 people) are in it, the rule of 8 hours sleep per diver cannot be applied due to the lack of space to deploy all the bunks. Thus, in such a case, it is essential to have the HRU connected to offer 8 hours of sleep to each diver.
- In the case of a reconditioned chamber, the installation of additional bunks and the new function of the chamber will oblige to reclassify it as it was initially designed for fewer divers and another function. This point is to be discussed with the classification society to be selected for this task.

Conclusion:
As demonstrated above, such a chamber does not provide the level of comfort of large Hyperbaric Reception Facilities and does not fully comply with what IMCA D 052 promotes.
However, the authors of IMCA D 052 are in contradiction when they say that decompression in the HRU can be undertaken, and at the same time, promote strict procedures for the design of the reception facility and the procedures of decompression that cannot be applied if decompressing in an HRU.
Instead of encouraging long decompressions in the HRU in response to a lack of budget, we can consider that it is preferable to look for solutions that diminish the cost of these facilities that are not used in normal conditions but must be ready in case of undesirable events. It is the aim of this study CCO Ltd, which concludes that instead of sticking to rules that many people do not apply, mainly for money reasons, it is better to soften these rules to obtain a system that, despite it is not perfect, can allow for correct decompressions.

4.5.1.10 - Rented and owned Hyperbaric Reception Facilities

Depending on the location and how the project is planned, the contractor may choose between owned and rented Hyperbaric Reception Facilities (HRF).

The advantage of rented units is that the companies who rent them usually provide competent personnel to install, maintain, and manage them. As a result, the contractor can focus only on the evacuation plan of the Hyperbaric rescue unit. Also, he does not need to spend time and money on the maintenance of the system.
The main problem of such a solution is its price if the unit is not shared and the availability of the facility if it is shared with other companies.

The advantage of owned facilities is that they can be installed everywhere, even in locations that are not be covered by companies renting units such as isolated oilfields at the end of the world. Their availability does not depend on external companies, and depending on the conditions, it often happens that a facility is assigned to only one diving system during the operations. Such a solution is often used in the case of a diving system permanently at work.
However, the contractor must organize to maintain the structure and appoint technicians & LSTs in charge of it.
Note that plans that consist of sending Technicians and LSTs at the last minute if an accident happens are valid only in places where such people are immediately available, which is usually not the case in most areas other than some North sea places. Thus, it is preferable to have a minimum team ready to operate and maintain the system when needed.

4.5.2 - Organize the teams

4.5.2.1 - People involved and their duties

The organization of the teams depends on whether the vessel is on hire in the fields of the client or not yet under contract. Note that if the boat is not under contract the support teams of the client are not to be considered. For convenience, the description below includes the client's teams. Also, the organization of the teams depends on the organization of the companies, so there may be some differences regarding the organization of the Emergency Response Teams than discussed below.

4.5.2.1.1 - Client's onshore Emergency Response Team (ERT)

The client's Emergency Response Team (ERT) is a group of people whose function is to organize adequate responses to emergencies in the client's oilfields and premises. Regarding marine emergencies, it is composed or liaise with , but not limited to, the following people who may be represented by assigned specialists:

- The Standby officer is a management or senior staff member in charge of the organization of the emergency responses, and the initial contact person in an emergency. He is also usually the chairman of the Emergency Response Team.
- The marine manager is in charge of controlling the marine activities undertaken on the oilfields, wind farms or other marine premises of the client.
- The diving manager is in charge of controlling the diving & ROV activities of the client.
- The HSE manager is in charge of controlling all Health, Safety, and Environmental aspects of the client's activities.
- A specialist in communication is in charge of transmitting information through the company staff and controlling the press and other media.
- Depending on the emergency, other specialist may be invited to be part of the team.
- Some representatives of the contractor may be members of the client's Emergency Response Team (ERT). However, it happens that the client rejects this option. The people assigned and their functions are usually discussed during the preparation of the project.

Note that, to avoid false news or events badly exploited by the press or other media, the client's Emergency Response Team usually works in a close circuit and communicates only through the nominated communication specialist. A specific room is often assigned to the team from which he can contact the people offshore and organize responses to the problems encountered.

The project manager is in charge of the project on behalf of the client and thus responsible for ensuring that the evacuation plan is suitable and that all people in charge are adequately informed of their duties and chain of reporting. He reports to the topside management of the company on site. Depending on the client's organization, he may or may not be a member of the Emergency Response Team.

4.5.2.1.2 - Contractor's onshore Emergency Response Team (ERT):

The contractors' Emergency Response Team (ERT) is organized according to the same scheme as the client's team, and depending on the project, it is usually composed of , but not limited to the following people:

- A senior manager who is the point of contact for the company and lead the Emergency Response team.
- The HSE manager or his representative.
- The Diving Medical Specialist of the company
- The marine manager (if the company has a fleet).
- The diving & ROV manager of the company.
- The project manager has the same duties as the client's project manager for the contractor, and similarly may or may not be a member of the Emergency Response Team.

4.5.2.1.3 - Client's offshore team

This team is composed of the people who manage the client's facility and the company representatives onboard the vessel.

- The Offshore Installation Manager (OIM) is in charge of the oilfield (or wind farm, or structure) and the point of contact of the Diving Support Vessel (DSV). He is often assisted by a marine officer who manages the boats on and around the field and is the point of contact of the DSV on behalf of the OIM. The OIM directly liaise with the Emergency Response Team, and organize the rescue operations on site.
- The Company Diving Representative represents the client onboard the DSV. He makes sure that the abandonment procedure is in place and liaise with the OIM and the Emergency Response Team.

4.5.2.1.4 - Contractor's offshore management team

This team consists of the people on board the DSV, or on the facility where the diving system is installed.

- The vessel Master is responsible for the ship and the person who orders to abandon it.
- The Chief mate assists the master and is usually in charge of ensuring that the elements for the abandon ship are in place. He replaces the master if, as the result of the event, this one is incapacitated or missing.
- The Diving superintendent makes sure that the diving team understands the abandon ship procedure and is regularly trained. He orders the Diving supervisors and the Life Support Supervisor on duty to transfer the

divers to the Hyperbaric Rescue Units and to be prepared to abandon ship. He then coordinates the evacuation of divers in saturation.
In the event of any vessel general alarm or situation that may endanger the lives of the divers in saturation, he liaises with the offshore construction manager, the vessel masters (diving support vessel & rescue vessel), and the client's representative to ascertain the safest action.

- The Offshore Construction Manager is responsible for the project for the contractor onboard the diving vessel. He ensures with the diving superintendent and the master that the teams are appropriately trained, and the abandonment procedure is in place.
- Diving supervisors are responsible for their teams. They organize the launching of the HRU they are responsible when instructed to proceed by the diving superintendent. One of them replaces the diving superintendent if, as the result of the event, this one is incapacitated or missing. Their functions are usually organized as follows:
    - The on-shift supervisors recover the bell (if deployed), and stay in contact with the diving superintendent and the Life Support Supervisor to ensure the transfer of the divers to their assigned HRU. When two supervisors are on duty for the same diving bell *(see point 3.1.5.4 in Book #1)*, one of them can be assigned to the launching of the Hyperbaric Rescue Unit.
    - The off-shift diving supervisors are usually in charge of the launching of the Hyperbaric Rescue Units. If the HRU is a Self Propelled Hyperbaric Lifeboat, they go on board to manage the chamber and link with the Emergency Response Team.
- Life Support Supervisors (LSS) work with the diving supervisors to train the diving team, ensuring that LSTs know their function. They are also responsible for the preparation of the HRUs.
The on-shift Life Support Supervisor is in charge of alerting the divers and transferring them to the HRUs. He is also responsible for ensuring that the doors isolating the connecting trunks are closed, the trunks to the HRUs are vented, and the diving system is secured.
The off-shift Life Support Supervisor usually goes into one of the SPHL
- The Senior dive technician is responsible for maintaining the Hyperbaric Rescue Unit diving equipment in peek condition. He works closely with the chief engineer. With the technicians under his responsibility, he assists the supervisor in recovering the bell and launching the hyperbaric rescue Units.
- The chief engineer is responsible for the maintenance of the marine parts of the Hyperbaric Rescue Unit. He works closely with the senior diving technician and the nominated coxswain.

4.5.2.1.5 - Hyperbaric Rescue Units launching team

The size of the team depends on the type of Hyperbaric Rescue Unit and the procedure of launching selected.

- Launching a Self Propelled Hyperbaric Lifeboat using davits requires limited personnel:
    - 1 technician should be assigned to the removal of the securing slings and the opening of the clamp.
    - 1 technician should be assigned to the disconnection of the connections to the saturation system and manage the davits and the launching winch. Note that the winch can be monitored from the craft with modern units.
    - The diving supervisor ensures that the divers are in the HRU, that the unit is disconnected, the LST and the sailors are onboard the SPHL, the trunk is vented and opened, The SPHL is ready to be deployed and lowered to the water. He informs the bridge when the SPHL is ready for launching and goes on board when the instruction to launch it is given by the vessel master.
- Launching a Hyperbaric Rescue Chamber (HRC) using a slope *(see the description in point 1.2.7.8)* requires more people (approximately 6 persons in this example).
    - 1 diving supervisor should be assigned to the management of the operation.
    - 1 technician should be assigned to remove the sea fastenings of the Hyperbaric Rescue Chamber and the opening of the clamp.
    - 1 person should be assigned to the lateral winch that pulls the Hyperbaric Rescue Chamber away from the dive system and aligns it with the slope, then disconnect this winch and operate the pulling winch that approaches the HRC to the edge of the vessel.
    - 1 person should be assigned to the holdback winch that retains the HRC.
    - 1 person should be designated to disconnect the pulling line when the HRC arrives at the balance point.
    - 1 person should be designated to launch the buoy with the pulling line to the rescue boat and then cut the hold-back line.

4.5.2.1.6 - Self Propelled Hyperbaric Lifeboat team

The team of 4 people should be organized so that one member of the team can rest while the others continue their duties if, for any reason, the boat is obliged to sail a long distance. As an example, it is improbable that a person can fully perform his duties 48 hours without a few hours of recovery. Taking this point into account, the team should be composed of:

- A coxswain who is responsible for the maintenance of the boat, the safe navigation, marine issues, managing the fuel, and the communications with the surrounding vessels and the rescue boat.
- A Life Support Technician who is responsible for the support of the occupants of the chamber. He controls the parameters of the chamber, the gas consumption, and elements such as toilet and medical lock use.
- A technician/sailor who is in charge of small repairs of the boat or the chamber and helping the coxswain regarding marine issues and navigation.

- A diving supervisor or Life Support Supervisor who has the overall responsibility for the occupants of the chamber and its associated life support equipment and liaises with the Emergency Response Team to manage the delivery of the SPHL to the meeting point and indicate any program change. He also manages the food and the water and replaces the LST on the panel to allow him to rest.

4.5.2.1.6 - Hyperbaric Rescue Unit recovery team

If the recovery is performed on the rescue vessel, the recovery team is usually composed of riggers who are members of the vessel's crew. It is judicious to ensure that the crane or A-frame operator and the banks man are present.

If the recovery is to be performed in port, the crane operator, banks man, and riggers (at least 2 persons) are to be planned. Also, there should be a truck driver and a 2nd lifting team if the Hyperbaric Reception Facility is not on the jetty.

4.5.2.1.7 - Decompression team

IMCA D 052 says that the following personnel need to be available:

- A diving technician supervisor.
- A diving mechanical technician.
- A diving electrical technician.
- Two Life Support Supervisors
- Two Life Support Technicians
- Assistant Life Support Technicians /tender equivalents to support the life support team.
- A superintendent acting as designated senior company representative

4.5.2.2 - Organize for clear communication process

Communications are part of the emergency response plan that usually conforms with the processes of the client when the vessel is on his oilfields or at the proximity of his premises, as the assistance is organized by the Emergency Response Team of the client and the Offshore Installation Manager.
When discussing the evacuation plan, clients usually prefer a limited number of points of contact to avoid having the communications unnecessarily occupied for not essential purposes, which may disturb the teams intervening. Also, too many communications may be the source of confusion and undesirable leaks to external.

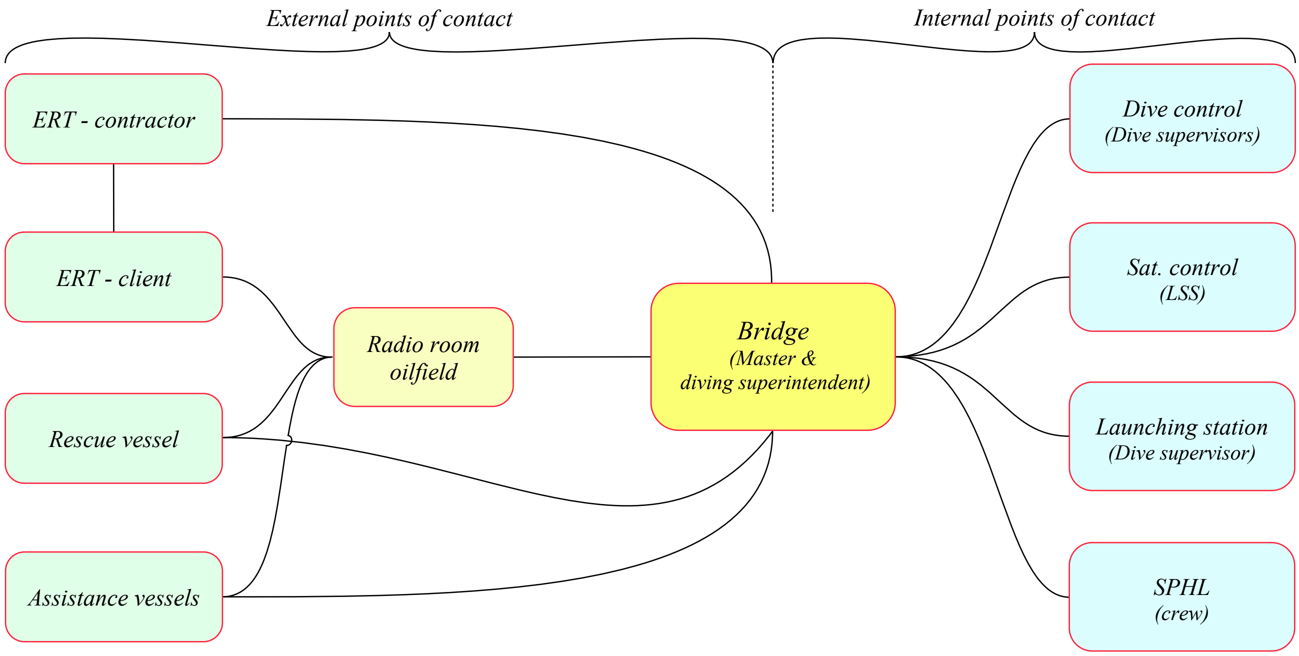
The bridge is the point of contact of the DSV for the communications inside the boat and the communications to the Emergency Response Team that organises the assistance of the vessel.

Internal point of contacts of the bridge for the evacuation of the divers in saturation are:

- The dive control room (wired communications and very high-frequency radio)
- The saturation control room (wired communications)
- The launching station (wired communications and radio)
- The Self Propelled Hyperbaric Lifeboat (very high-frequency and marine radios)

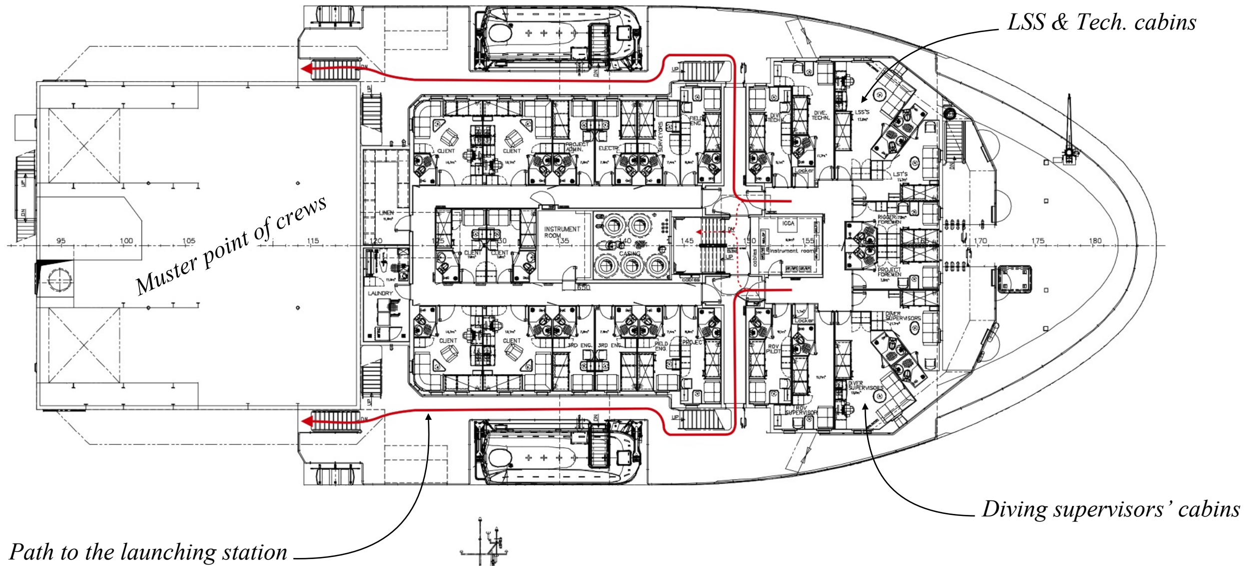
External points of contacts to and from the bridge are:

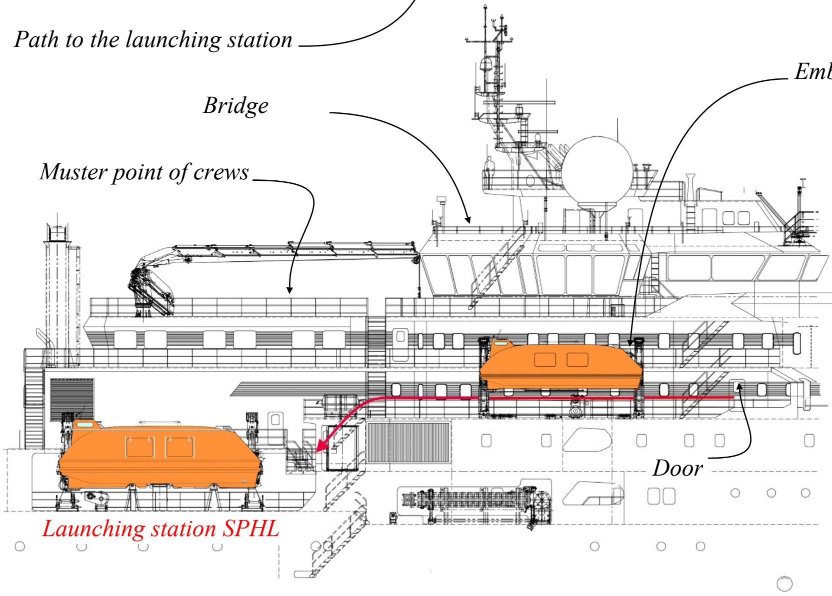
- The Radio room of the field or the facility (marine Radio, satellite phone, Global Maritime Distress & Safety System (GMDSS), SSB radiotelephone).
- The client's Emergency Response Team (marine Radio, GMDSS, SSB, & satellite phone).
- The rescue boat of the HRU (marine Radio & satellite phone, GMDSS, SSB).
- Other rescue boats warned by the Radio room of the field and the client's Emergency Response Team
- The contractor's Emergency Response Team (satellite phone & SSB radiotelephone)



4.5.2.3 - Ensure that people involved in the launching can reach their position and be replaced

In the case of vessel abandonment due to a sudden catastrophic event, people can be delayed or incapacitated to reach their planned position due to the access obstructed or because they are injured or killed. For this reason, it is essential to ensure that the people in charge of the launching of the HRU can easily reach their position and can be replaced if needed. For this reason, an assessment should be performed, taking into account the characteristics of the surface support and the diving system and the travel people may have to do.
Main and backup means of access of people on shift, and those who are at rest to their assigned positions must be highlighted. Regarding this point, it may be prudent to select paths where people accessing their position will not be disturbed by people moving to their muster station. As an example, cabins of key people should be situated not far from the launching station, so diving supervisors, LSTs, and technicians off-shift can be quickly in position.





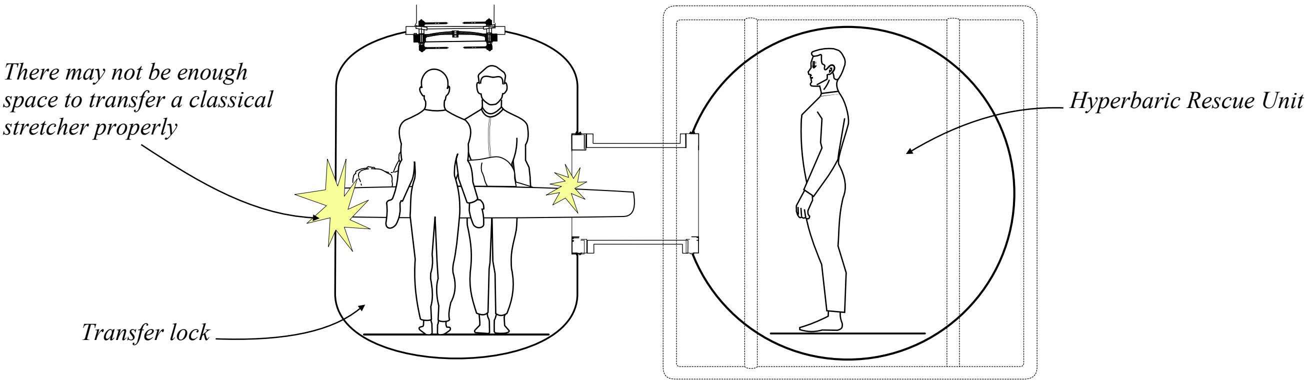
In this example, the cabins of the Diving supervisors, Life Support Supervisors, and dive technicians are arranged such that they have easy access to the Self Propelled Hyperbaric Lifeboats through the external paths which passe underneath the crew's lifeboats. These paths must not be congested in case of an alert, so they must not conflict with the ways to the muster points.
Note that if a way is obstructed, people can go to their launching station through the other side or by the paths inside the boat. Cabins of Life Support Technicians, system technicians, divers, and riggers involved in the launching should be arranged in the same manner.

As the launching of the Hyperbaric Rescue Unit must be completed as soon as possible, it is essential to ensure that the operation is started without delay. For this reason, there is no time lost waiting for a nominated person for a function who is delayed or incapacitated to reach the station. Thus each function should be attributed to a main nominated person and one or two other persons who can take over this function to ensure that whatever happens the positions will be adequately filled and the Hyperbaric Rescue Unit will be launched on time. As a result, as soon as the persons planned for a function are in place, they should inform the diving superintendent or his replacement, and the operation should starts immediately when all the necessary positions are filled.
The list of nominated persons is established, taking into account the people planned for the project. As a result of this list, it may happen that the team is being reinforced.

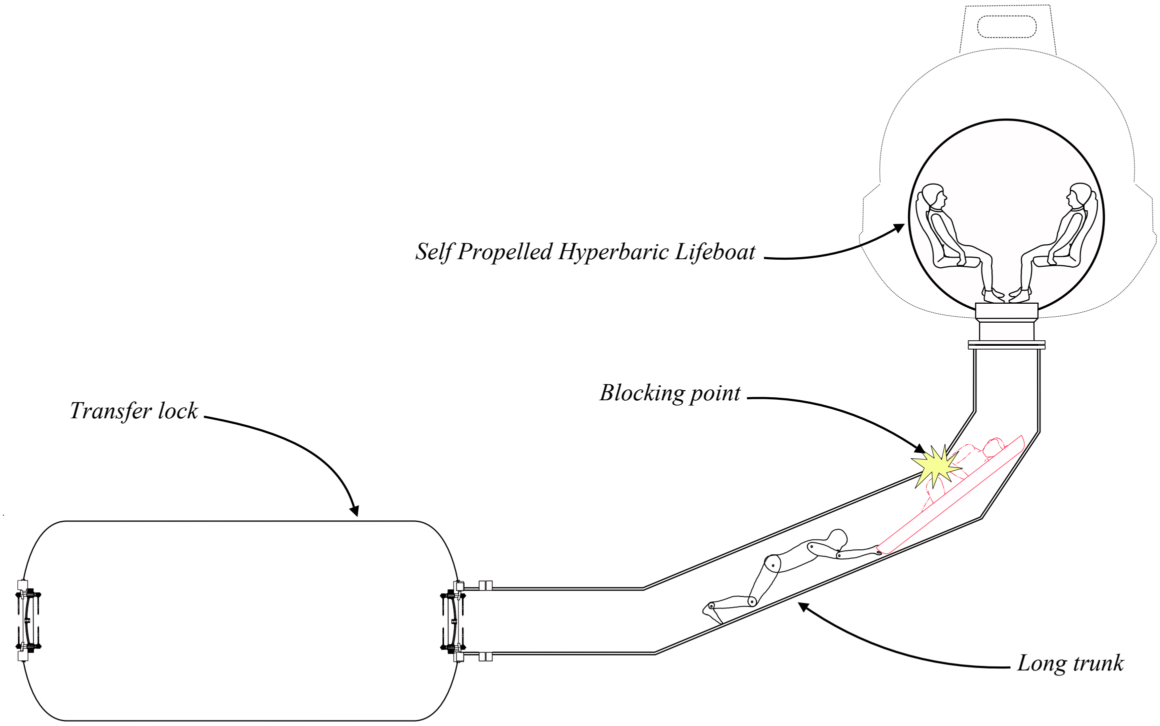
4.5.3 - Organize an efficient transfer of the divers to the Hyperbaric Rescue Unit

4.5.3.1 - Ensure that injured divers can be easily transferred to the HRU

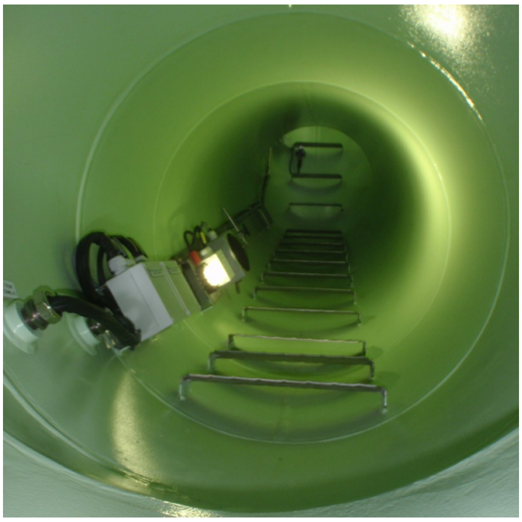
One or several divers may be injured and must be transferred on a stretcher. This transfer can be problematic if there is not enough space to deploy and handle a classical stretcher. That can happen with narrow transfer locks such as those that can be found with some old portable systems.



It may also happen if the transfer to the HRU is done through a very long trunk with sharp turns such as the one that is below (which is the drawing of an existing model).



Another problem arising from long trunks to transfer to Self Propelled Hyperbaric Lifeboats (SPHL) is that they are provided with rungs or steps to allow the divers to climb up to the chamber situated at the upper level. These rungs or steps may be very uncomfortable to the casualties if the stretcher is not designed to absorb the shocks they may cause while the casualty is pulled along *(see in point 1.2.7.3)*.



To limit and control the inconveniences linked to the limited space, specific stretchers that are in use for rope access jobs and works that are performed in places where the access is difficult can be used.
Such stretchers provide spinal immobilization, head support and protect the back of the casualty from shocks while the legs can be slightly moved to pass where a classical stretcher cannot pass *(See below)*.

Because the casualty may have pelvis injuries or fractures, pelvis stabilization devices similar to the one that is visible on the left side below can be used. Because such an accident may happen anytime, it is recommended to have at least one unit onboard.
Note that if there is sufficient space to use them, stretchers that immobilize the back and the legs are preferable *(see on the right side below)*. Note that the limbs can be immobilized using classical splints.

Pelvis stabilization device

Drills based on the scenarios indicated above (but not limited to) are recommended to select the best equipment for casualty transfer. These drills should be witnessed by a medic familiar with rescue procedures.

- A realistic safety training dummy corresponding to a casualty of 1.90 m height for 100 kg weight should be used to represent the worst-case scenario. Nevertheless, if there are divers who are more corpulent, the dummy should correspond to these divers.
- Following each drill, the procedure implemented should be discussed to ensure that it is appropriate or whether it can be improved. The devices that are jugged the best to secure and transfer casualties should be adopted and stored near the medical table in the transfer lock.

Transfer of a casualty through a long trunk can take a long time, which must be minimized during the ship's abandonment. For this reason, the team must be familiar with the procedures and be able to solve problems that may arise. The process can be as follows:

- Two divers (preferably diver medics) prepare the casualty for transferring from the dive system to the Hyperbaric Rescue Unit (HRU) while the divers who are not incapacitated transfer to the HRU.
- When the divers who are not necessary to transfer the casualty have been transferred to the HRU, they prepare the place where the casualty will be secured. The diver in charge of the winch deploys the traction cable while an assistant transfers the cable's end to the transfer lock, ensuring it is not stuck.
- When the assistant arrives in the transfer lock, the cable is connected to the stretcher. Then, the assistant comes back into the trunk to guide the casualty and the cable.
- The casualty is then introduced into the trunk, and the cable is recovered gradually. Simultaneously, the assistant guides the front of the stretcher, making sure that the cable is not stuck and that the casualty is as comfortable as possible.
- When possible, one of the remaining divers enters into the trunk and helps the diver who is already in the trunk to control the casualty. The last diver medic follows when it is possible to do so and closes the trunk door.
- When he arrives in the HRU, the casualty is secured at the dedicated place (it should be on the floor), the traction cable is disconnected, and the bottom door is closed.

Note that, depending on the events, there may be several casualties.

4.5.3.2 - Problems linked to the transfer through very long trunks

Very long trunks to the Hyperbaric Rescue Unit (HRU) may slow down the transfer of divers. It must be considered that they may create a “funnel effect” similar to those that can be observed when several roads converge to only one during rush hours. Note that such an effect may be increased if some divers are very slow to move in for physical or psychological reasons. Precautions such as those described below should help to solve these problems:

- Divers should be regularly trained to transfer as fast as possible to the HRU. Divers who have difficulties transferring through the trunk should not be selected.
- In case of an alert, the divers should be transferred as a precaution as soon as a risk of abandoning the ship is detected. If there are casualties, they should not be transferred immediately but prepared to be transferred as fast as possible if the ship's abandonment is confirmed.
- When there is the possibility of selecting the diving system, solutions with short trunks should be preferred. Note that long trunks tend to disappear with last generation systems. For example, UDS Lichtenstein and Picasso's connecting trunks are less than 4 m long, with a slope limited to 25%.

Another problem is that it may happen that connecting trunks are passing through rooms that are not used by the saturation system. As indicated in point 1.2.7.3, safety evaluation must be performed, and control measures must be implemented to address the hazards that may be present. The crossed rooms must also be kept at this assessment's original statement and not be reorganized for another purpose. To prevent such conditions from happening, regular inspections should be performed.

4.5.4 - Hyperbaric Rescue Unit launching

As indicated in points 1.2.7, and 4.5.2.1.5, the methods vary with the system of Hyperbaric Rescue Unit used.
Note that it is considered that the Hyperbaric Rescue Unit (HRU), Life support package (LSP), and Hyperbaric rescue Facility (HRF) have been checked for compliance prior to launch the operations as indicated in point 3.1.2, and according to the elements indicated in points 1.2.7; 1.2.9; and 1.2.10 of this book.

4.5.4.1 - Hyperbaric Rescue Chamber (HRC) launching

Four classical methods are described for deploying a Hyperbaric Rescue Chamber (HRC) in addition to davits, which is a less common procedure with such units and for this reason, is described in the next point for the deployment of a self Propelled Hyperbaric Lifeboat:

1. Controlled descent on a slope, also called "pull off"
2. Free falling
3. Liftoff
4. Float off

Note that "float off" procedure is not applicable if the diving system is installed on a facility.

4.5.4.1.1 - Controlled descent / Pull Off

The principle of this procedure is described in point 1.2.7.8. As a reminder:

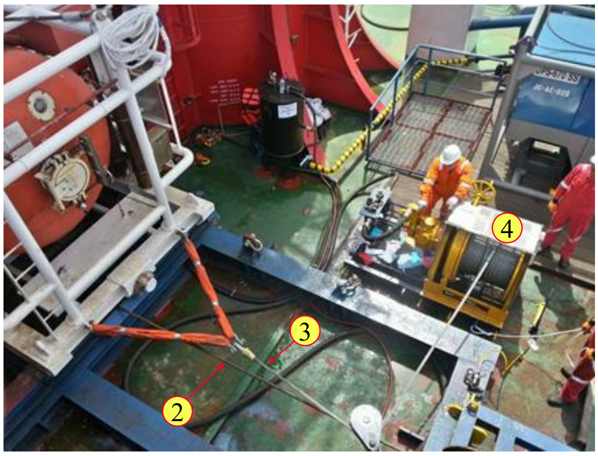
- A slope extension is installed overboard to support and guide the HRC until it reaches the water.
- A dedicated winch is utilized to haul the HRC over the stern or the side of the vessel. The winch wire passes through a sheave that is secured to the chassis of the launching platform at the edge of the surface support and is connected to the dedicated pulling points of the hyperbaric rescue chamber. It is disconnected when the HRC is ready to slide down on the slope extension.
- To control the descent and avoid potential damage/injury on equipment/personnel due to the impact with the surface of the sea, a hold-back tugger is attached to the HRC.
- Once cleared to the sea and free of tension the hold back wire is cut with a hydraulic cutter and the rescue boat tows it away. Note that if established the towing line must not be used during the descent.

- Skid launch to sea sequences

1. As soon as the alarm is triggered, the diving superintendent instructs the diving supervisor and the LSS to prepare to abandon the vessel. Also, the rescue vessel is instructed to move to the proximity of the diving support vessel or facility. The LSS/LST asks the divers in the chamber(s) to prepare.
2. The divers in saturation prepare for immediate transfer to the HRC. They prepare clothes for those in the bell.
3. The on-shift supervisor recovers the bell if it is in the water.
4. The off shift nominated personnel for the launching of the HRC goes to the launching station. Those who are not attributed to a task go to the muster point.
5. At the launching station, the diving supervisor in charge of the launching station, or his replacement checks the list of people and reports to the bridge by radio.
6. The LSS/LST on-shift in the saturation control blows the shallower chambers to the deeper storage level, and ensures that the depth of the HRC is at this level.
7. The divers in the system transfer to the HRC and carry out the internal check list.
8. When the bell is recovered and clamped, the divers transfer directly to the HRC. The last diver out of the diving bell, closes the internal bell door equalization valve and holds the door to obtain a seal.
9. The on-shift diving supervisor ensures he gets a seal on the door (5 -10 feet).
10. Then, the last diver who leaves the bell closes the door of the trunk and the equalization valves, and goes to the HRC. The on-shift diving supervisor closes the valves of the dive control, and ensures that the transfer of the divers is ongoing. He informs the diving superintendent that the bell is secured and the divers are transferring to the HRC. According to the situation he can move to the launching station or to the Saturation control to help the LSS/LST if needed.
11. The last diver who leaves the transfer lock closes the door and the equalization valves of the trunk and goes to the HRC.
12. When the last diver arrives in the HRC, he closes and holds the door for a seal.
13. The LSS/LST in the saturation control vents the trunk about 1.5 m (5 feet), and confirms he has a good seal with the divers inside the HRC. The divers in the HRC prepare for launching, and take seasick tablets.
14. When the seal is confirmed, the LSS/LST in the saturation control vents the trunk to the surface.
15. The divers in the HRC confirm that all valves are set according to internal launch check list.
16. The nominated person for the final checklist of the HRC (or his replacement) secures the external valves according to the checklist.
17. The nominated person for the final checklist of the HRC disconnects all the gas whips from the HRC, and secures the connectors.
18. The supervisor in charge of the launching station orders to remove the sea fastenings rigging of the HRC.

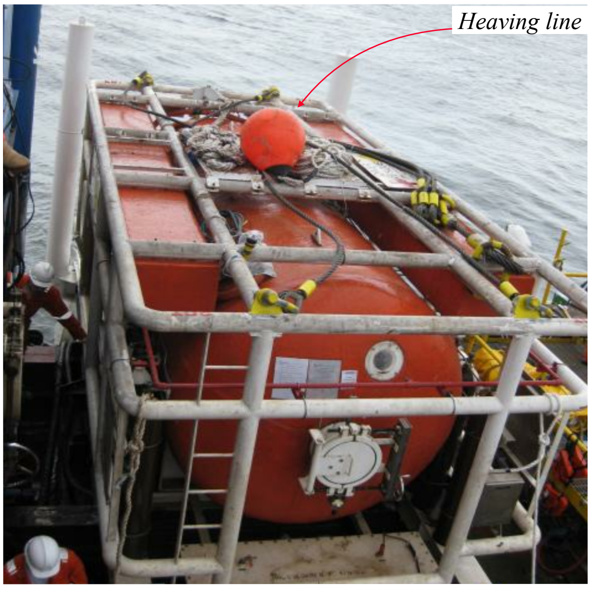
19. The LSS/LST in the saturation control room confirms to the supervisor in charge of the launching station that the trunk is vented (0-by gauge).
20. The supervisor in charge of the launching station confirms that the trunk is vented using his gauge and opens the clamp.
21. Using the hydraulic jacking system or the dedicated lateral winch, the HRC is pushed away from the clamp of the transfer lock and aligned with the launch skid. The hauling and holdback lines are connected to the HRC.
22. The supervisor in charge of the launching station ensures that the hauling and holdback lines are secured and in slight tension. Then, he orders to release the jacking system or the lateral winch from the HRC.

1= pulling winch - 2= Pulling line - 3 = holdback line



2= Pulling line - 3 = holdback line - 4 = holdback winch

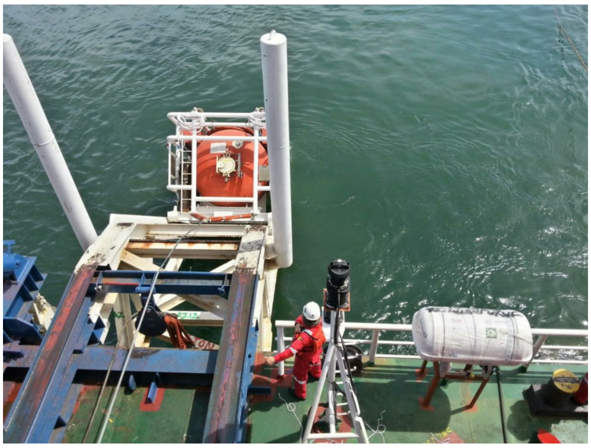
23. Using simultaneously the hauling and holdback winches, the HRC is approached next to the edge of the boat. Then, the team secures the winches, and waits for the final order to launch.
24. On instruction from the vessel master, the rescue vessel (RV) approaches closer, and the heaving line of the towing line is passed across.



25. Once the towing line is across and secured to the rescue vessel, the supervisor in charge of the launching station confirms with the diving superintendent that it is all clear to launch.
26. On confirmation from the diving superintendent, the supervisor in charge of the launching station orders the winch operators to pull on the HRC to move it to the final launching slope.
27. Once the HRC has passed the “balance point” and is ready to slide to the water by gravity, the pulling line is disconnected or cut.
28. When the pulling line is removed, the HRC is gradually lowered to the water by gravity using the holdback winch to control it *(see the pictures on the next page)*.
29. Once the HRC is in the water, the rescue vessel slowly takes up tension on the towing bridle. The supervisor in charge of the launching station cuts the holdback line and confirms that the HRC is ready for towing.
30. On confirmation from the Supervisor in charge of the launching station that the HRC is freed, the rescue vessel tows the HRC away from the vessel or the installation slowly.
31. If necessary (not sufficient people to start the deco), off-shift crews, diving supervisor, LSS, LST, and 2 technicians transfer to the rescue vessel. The remaining personnel goes to the muster point to evacuate the vessel.
32. Before sailing to its destination, the master of the rescue vessel confirms with the radio room of the field and the bridge of the diving support vessel:
    - The names of the divers inside the HRU.

- Whether the HRU is transferred onboard or towed.
- The saturation holding depth in the HRU.
- The names of support personnel transferred to the Rescue Vessel.
- The time of departure of the rescue vessel to the designated haven.
- The estimated time of arrival at the haven.

This information is transmitted to the Emergency Response Team, who organizes to assist the rescue vessel and prepares for having the decompression performed the soonest.



33. The rescue vessel tows the HRC at a reasonable speed to the nearest safe haven, or the HRC is recovered onboard as soon as possible, and the vessel sails to the haven at full speed, which is the recommended option. If the Hyperbaric Reception Facility is onboard (preferred option), the HRU is connected to it as soon as possible.

4.5.4.1.2 - Free falling procedure

This procedure is also explained in point 1.2.7.8 and consists of dropping, the chamber to the water from the height of the deck where it is stored using a launching platform that is lifted at the extremity opposite to the edge of the surface support to create a slope that allows the HRC to fall to the sea by gravity. Thus pulling and holdback lines are not used to control the HRC that falls in the water as a stone.

The process of launching is similar to the controlled descent until step #20, and continues as follows:

21. When the clamp is opened, the HRC is pushed away from the clamp of the transfer lock and aligned with the launch skid using the hydraulic jacking system or the dedicated lateral winch.
22. The supervisor in charge of the launching station orders to release the jacking system or the lateral winch from the HRC. Then, the team waits for the final order to launch.
23. On instruction from the vessel master, the rescue vessel approaches nearby the Diving Support Vessel.
24. On confirmation from the diving superintendent, the supervisor in charge of the launching station orders to raise the jacks at the extremity of the launching slope to launch the HRC by gravity.

25. Once the HRC is in the water, the Rescue boat approaches to pickup the towing line.
26. When the towing line is secured, the rescue vessel tows the HRC away from the vessel or the installation slowly.
27. If necessary (not sufficient people to start the deco), off-shift crews, diving supervisor, LSS, LST, and 2 technicians transfer to the rescue vessel. The remaining personnel goes to the muster point to evacuate the vessel.
28. Before sailing to its destination, the master of the rescue vessel confirms the following with the radio room of the client (OIM) and the bridge of the diving support vessel:
    - The names of the divers inside the HRU.
    - Whether the HRU is transferred onboard the rescue vessel or towed.
    - The storage depth in the HRU.
    - The names of support personnel transferred to the Rescue Vessel.

- The time of departure of the rescue vessel to the designated haven.
- The estimated time of arrival at the haven.

This information is transmitted to the Emergency Response Team, who organizes to assist the rescue vessel and prepares for having the decompression performed the soonest.

29. The rescue vessel tows the HRC at a reasonable speed to the nearest safe haven, or the HRC is recovered onboard as soon as possible, and the vessel sails to the haven at full speed, which is the recommended option. If the Hyperbaric Reception Facility is onboard (preferred option), the HRU is connected to it as soon as possible.

4.5.4.1.3 - Liftoff procedure

This method consists of lifting the HRC using the dedicated lifting straps installed on its top. Once the HRC is in the water, the crane's hook is detached from the HRC rigging using a quick release hook that should be provided to aid in a safe release from the crane.

This procedure depends on the capacity to connect the rigging and the vessel motions to slew the HRC safely. Thus, it cannot be used if the surface support is unstable or tilted, or the weather conditions are not favourable as the crane may increase the vessel's instability.

Also, the crane is usually energized by the generators of the ship or the installation and may not be available.

For these reasons, this procedure should never be considered the main option and can be used only as a backup if the preferred procedure cannot be implemented.

Liftoff sequences

1. The diving superintendent instructs the diving supervisor and the LSS to prepare to abandon the vessel. Also, the rescue vessel is instructed to move to the proximity of the diving support vessel or facility. The LSS/LST asks the divers in the chamber(s) to prepare.
2. If diving operations are on the way, the on-shift supervisor recovers the bell.
3. The off shift nominated personnel for the launching of the HRC goes to the launching station. Those who are not attributed to a task go to the muster point.
4. The on-shift crane operator (or his replacement) to HRC's muster station. Subject to suitable lifting conditions, the crane driver inspects the crane and prepares to lift the HRC.
5. At the launching station, the diving supervisor in charge of the launching station, or his replacement checks the list of people and reports to the bridge by radio.
6. The LSS/LST on-shift in the saturation control blows the shallower chambers to the deeper storage level, and ensures that the depth of the HRC is at this level.
7. The divers in the system transfer to the HRC and carry out the internal check list.
8. The divers transfer to the HRC, last man in closes the internal TL door equalization valve to HRC trunk.
9. When the bell is recovered and clamped, the divers transfer directly to the HRC. The last diver out of the diving bell, closes the internal bell door equalization valve and holds the door to obtain a seal.
10. The on-shift diving supervisor ensures he gets a seal on the door 1.5 to 3 m (5 -10 feet).
11. Then, the last diver who leaves the bell closes the door of the trunk and the equalization valves, and goes to the HRC. The on-shift diving supervisor closes the valves of the dive control, and ensures that the transfer of the divers is ongoing. He informs the diving superintendent that the bell is secured and the divers are transferring to the HRC. According to the situation he can move to the launching station or to the Saturation control to help the LSS/LST if needed.
12. The last diver who leaves the transfer lock closes the door and the equalization valves of the trunk and goes to the HRC.
13. When the last diver arrives in the HRC, he closes and holds the door for a seal.
14. The LSS/LST in the saturation control vents the trunk about 1.5 m (5 feet), and confirms he has a good seal with the divers inside the HRC. The divers in the HRC prepare for launching (helmets, seatbelt, etc.), and take seasick tablets.
15. When the seal is confirmed, the LSS/LST in the saturation control vents the trunk to the surface.
16. The divers in the HRC confirm that all valves are set according to internal launch check list.
17. The nominated person for the final checklist of the HRC (or his replacement) secures the external valves according to the checklist.
18. The nominated person for the final checklist of the HRC disconnects all the gas whips from the HRC, and secures the connectors.
19. The supervisor in charge of the launching station orders to remove the sea fastenings rigging of the HRC.
20. The LSS/LST in the saturation control room confirms to the supervisor in charge of the launching station that the trunk is vented (0-by gauge).
21. The supervisor in charge of the launching station confirms that the trunk is vented using his gauge and opens the clamp.
22. Using the hydraulic jacking system or the dedicated lateral winch, the HRC is pushed away from the clamp of the transfer lock on the launch skid. The jacking or pulling system is then released from the HRC.
23. After the system is cleared from the main complex and the sea fastenings are removed, the team installs tag lines in the corners of the HRC.

24. The crane is deployed above the HRC, and the pre-installed lifting bridle is attached to the vessel crane with the use of the dedicated quick release hook in order to allow ease of release from either the sea or the rescue vessel.
25. The supervisor in charge of the launching station informs the bridge that the team is ready to transfer the HRC overboard and waits for the final confirmation to carry on.
26. The master of the diving support vessel ensures that the rescue vessel is ready to take the HRC on its deck or pick up its towing line if it is planned to tow it.
27. When the master instructs the team to carry on, the HRC is lifted and slewed overboard by the crane and lowered into the water or onto the rescue vessel, where the hook is disconnected from the master link of the rigging. Then, the crane is recovered to the vessel.

28. If necessary (not sufficient people to start the deco), off-shift crews, diving supervisor, LSS, LST, and 2 technicians transfer to the rescue vessel. The remaining personnel goes to the muster point to evacuate the vessel.
29. Before sailing to its destination, the master of the rescue vessel confirms the following with the radio room of the client (OIM) and the bridge of the diving support vessel:
    - The names of the divers inside the HRU.
    - Whether the HRU is transferred onboard the rescue vessel or towed.
    - The storage depth in the HRU.
    - The names of support personnel transferred to the Rescue Vessel.
    - The time of departure of the rescue vessel to the designated haven.
    - The estimated time of arrival at the haven.

    This information is transmitted to the Emergency Response Team, who organizes to assist the rescue vessel and prepares for having the decompression performed the soonest.

4.5.4.1.3 - Float off method

This option is an extreme procedure that allows the HRC to float off as the Diving Support Vessel is sunk. It will only be an option if an incident is so severe that the vessel sinks very rapidly.
In this instance, once the HRC is free, and away the rescue vessel would approach and recover the buoyed end of the towing bridle in preparation for a tow to the closest “Safe Haven” or recovery on deck.

In the event of a catastrophe where no time is available for evacuation of the HRC, the LST should blow down the system to at least 9 m (30 feet) deeper than bottom depth. The divers should be instructed to close all internal valves. When this has been done, the LSS should OPEN blow down, exhaust, BIBS supply, and oxygen make-up, and hand over control of the system to the divers

The sequences are similar to the liftoff procedure, except the chamber is blown down 9 m below the bottom depth, the valves prepared as indicated above, and no crane is connected when the chamber is freed from the system. So, when the level of the water reaches it, the chamber floats. However, freeing the chamber does not mean it should automatically float independently from the vessel that may capsize and catch it in a superstructure or other elements. It is the reason the chamber is secured deeper than the expected depth of the shipwreck, so that the divers should not be drowned and be recovered later on to the surface by a rescue team.

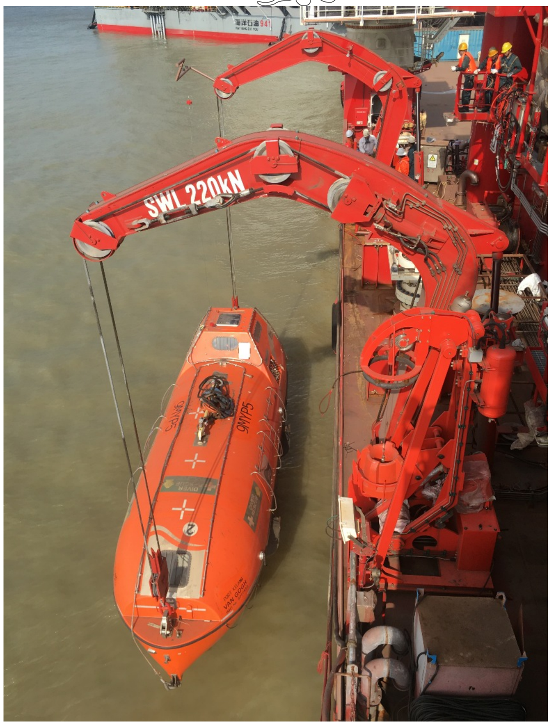
4.5.4.2 - Self Propelled Hyperbaric Lifeboat (SPHL) launching

As indicated in point 1.2.7.2, these units can be lowered using their standard hydraulic marine davit system driven by a Hydraulic Power Unit or by back-up stored energy Hydraulic Accumulators. Therefore, an SPHL can be launched with or without electrical power supply from the DSV. When the descent is performed by gravity, brakes are used to control the descent speed.
Also, their lifting slings can be released automatically or manually once the lifeboat reaches the surface of the sea. They should also be equipped with an on-load release capability to release the lifeboat with a load on the hooks.

The launching sequences can be as follows:

1. As soon as the alarm is triggered, the diving superintendent instructs the diving supervisor and the LSS to prepare to abandon the vessel. Also, the rescue vessel is instructed to move to the proximity of the diving support vessel or facility. The LSS/LST asks the divers in the chamber(s) to prepare.

2. The divers in saturation prepare for immediate transfer to the SPHL. They prepare clothes for those in the bell.
3. The on-shift supervisor recovers the bell if it is in the water.
4. The off shift nominated personnel for the launching of the SPHL goes to the launching station. Those who are not attributed to a task go to the muster point.
5. At the launching station, the diving supervisor in charge of the launching station, or his replacement checks the list of people and reports to the bridge by radio.
6. The LSS/LST on-shift in the saturation control blows the shallower chambers to the deeper storage level and ensures that the depth of the SPHL is at this level. If the system is fitted with two SPHL and that the gap between the storage depths of the teams in saturation is too large to allow for compression at the deepest depth, the shallowest team is guided to one SPHL and the deepest one to the other SPHL. Rich mixes may be used for this purpose.
7. The divers in the system transfer to their attributed SPHL and carry out the internal check list.
8. When the bell is recovered and clamped, the divers transfer directly to their SPHL. The last diver out of the diving bell, closes the internal bell door equalization valve and holds the door to obtain a seal.
9. The on-shift diving supervisor ensures he gets a seal on the door 1.5 - 3 m (5 -10 feet).
10. Then, the last diver who leaves the bell closes the door of the trunk and the equalization valves, and goes to the SPHL. The on-shift diving supervisor closes the valves of the dive control, and ensures that the transfer of the divers is ongoing. He informs the diving superintendent that the bell is secured and the divers are transferring to the SPHL. According to the situation he can be assigned to the launching station or to the saturation control room to help the LSS/LST if needed.
11. The last diver who leaves the transfer lock closes the door and the equalization valves of the trunk and goes to the SPHL.
12. The SPHL crew (LST, coxswain, sailor/technician, + LSS or diving supervisor) boards in the cockpit, switch electrics and communications on, and run through check-lists.
13. The nominated technician secures the valves of the external panel according to the checklist. Then, he disconnects all the gas whips from the diving system to the SPHL, and secures the connectors.
14. The divers in the SPHL install the soda-lime canisters, and confirm that all valves are set according to internal launch check list.
15. When the last diver arrives in the HRC, he closes and secures the bottom door for a seal.
16. When the chamber operator of the SPHL and the divers are ready, the LSS/LST in the saturation control vents the trunk about 1.5 m (5 feet), and confirms he has a good seal with the divers inside the SPHL. The divers in the SPHL prepare for launching and take seasick tablets.
17. When the seal is confirmed, the LSS/LST in the saturation control vents the trunk to the surface.
18. The LSS/LST in the saturation control room confirms to the supervisor in charge of the launching station that the trunk is vented (0-by gauge).
19. The nominated supervisor in charge of the launching station confirms with the crew in the SPHL that the divers and themselves are ready for launching. Then he reports it to the bridge and standby for confirmation from the vessel master to launch or abort.
20. The vessel master informs the radio room of the oilfield and the rescue vessel that the SPHL is ready for launching. The radio room should acknowledge, and the rescue vessel should confirm that they are ready to assist the SPHL.
21. Upon confirmation from the vessel master to launch the SPHL, the supervisor in charge of the launching station confirms with the nominated clamp operator that the clamp's depth gauge indicates zero and then orders to open the clamp. The operator pulls out the safety interlock mechanism of the clamp and operates the clamp screw mechanism. When the clamp is fully opened, he confirms it to the supervisor in charge of the launching station.
20. When the clamp is confirmed opened, the supervisor in charge of the launching station orders to remove the sea fastenings rigging of the SPHL. Meantime, the davits are prepared to overboard the SPHL.
21. When the clamp is opened, the LSS/LST in the saturation control room secure the panels and inform the diving superintendent that the saturation control is secured and that the personnel leaves the saturation control room. He then transfers to the launching station.
22. Before launching the SPHL, the supervisor in charge of the launching station ensures that the LSS or one of the supervisors available is with the LST, the coxswain, and the sailor/technician. If there is no supervisor and LSS available, he boards the SPHL.
23. The SPHL is then deployed by the davits using the hydraulic system driven by the Hydraulic Power Unit (HPU) or the back-up stored energy of the hydraulic accumulators.
    - The operator ensures that the brake accumulator is loaded
    - Then he brings the davit lower block vertical over the hooks (the SPHL is still on its cradles).
    - He lifts the boat to the limit, so the SPHL is cleared from its cradles and can be moved overboard.
    - Then the davits are pivoted to be above the water.
    - When it is above the water, the lifeboat is lowered using the hoist.
    - The Lifeboat engine is started before reaching the water *(however, note that this engine is water-cooled and must not be started a too long time before reaching the water)*.



- According to IMO, lifting hooks should be automatically released once the lifeboat is waterborne. It is recommended that the operator does not stop the wire's deployment immediately to provide some slack to facilitate the unhooking of the lifting wires. Note that the boat can also be released manually.

- Also, the lifting wires can be released when the vessel has not yet reached the water.

24. When the SPHL if freed from the lifting slings, its crew moves it toward the rescue boat that should be inside the 500 m limit of the field. The crew informs the radio room of the oilfield, the bridge of the DSV, and the rescue vessel.

25. If necessary (not sufficient people to start the deco), off-shift crews, diving supervisor, LSS, LST, and 2 technicians transfer to the rescue vessel. The remaining personnel goes to the muster point to evacuate the vessel.
29. Once the SPHL is at proximity of the rescue vessel, it can be recovered onboard the rescue vessel (preferred option), or towed, or sailing by its means aside the rescue vessel. Before sailing to the destination, the master of the rescue vessel and the coxswain of the SPHL confirm the following with the radio room of the client (OIM) and the bridge of the diving support vessel:
    - The names of the divers inside the SPHL.
    - The names of support personnel in the SPHL.
    - Whether the SPHL is transferred onboard the rescue vessel, towed, or sailing.
    - The storage depth in the chamber of the SPHL.
    - The names of support personnel transferred to the Rescue Vessel.
    - The time of departure to the designated haven.
    - The estimated time of arrival at the haven.

    This information is transmitted to the Emergency Response Team, who organizes to assist the rescue vessel and prepares for having the decompression performed the soonest.

4.5.5 - Transfer to the haven

4.5.5.1 - In the chamber

Hyperbaric Rescue Units have been designed to keep the divers within normal gas parameters and not exposing them to extreme values. For this reason, gas values in the chamber should be those indicated in NORMAM 15 procedure:

- Normal oxygen parameters are between 380 and 400 mbar.
  It is considered beneficial to increase the oxygen partial pressure in the HRU above "normal" values before launching it (gas from the saturation system), considering that the respiration of the divers will deplete the excess of oxygen during the transfer at sea, but that this excess of oxygen makes them more comfortable during the launching phase and is an additional O_2 reserve of the onboard gas.
- Carbon dioxide partial pressure should be below 5 mbar. However, we can remember that it can be raised to 10 mbar in an emergency.
  Canister change of soda lime is to be scheduled. As a reminder:
  - The average consumption of a diver is 6 kg per day (6 kg soda-lime/diver/day)
  - The weight of soda-lime is 0.75 kg/litre
  - The average consumption of a diver in litres is 8 litres per day (8 litres soda-lime/diver/day)
  - The production of CO2 of a diver is estimated to 0.5 litres per minute, and thus 30 litres per hour
  - 1 kg of soda lime absorbs 120 litres of CO2
  - 1 litre of soda lime absorbs 90 litres of CO2

  The frequency of change depends of the volume of the canister.
  As an example, a canister of 9.5 litres contains 7.2 kg of soda lime (9.5 litres x 0.75 kg per litre).
  Applying the formula "*(number of divers x average consumption in kg)/ weigh of soda lime in the canister*", we obtain 10 daily changes for 12 divers, 15 daily changes for 18 divers, and 20 daily changes for 24 divers.
- Humidity should be kept between 30 and 70% if possible. Extreme values can be 30% for the lowest one and 80% for the most elevated one.
- Temperatures should be those promoted in point 3.2.3.2.2 if possible:

Depth (msw)	Temperature range (C°)
0- 50	22 - 27
50 - 100	25 - 29
100 - 150	27 - 30
150 - 200	28 - 31

Depth (msw)	Temperature range (C°)
200 - 250	29 - 31
250 - 300	30 - 32
300 - 350	31 - 33

  Note that temperatures cannot be controlled in Hyperbaric Rescue Chambers as long they are not connected to the Life Support Package.

In addition to gas parameters, a close management of toilets and medical lock usage should be observed in SPHL as long they are not connected to the Life Support Package to avoid gas dumping. For this reason, manufacturers such as IHC Hytech and other, recommend limitations according to the type of SPHL.

- For toilet use:
  Gas loss = *flushes per day x pressure x 3 days x dead volume of the system*.
  Toilets are to be flushed only if they are full of waste at the following recommended frequencies:
  - SPHL 12 seats = 2 flushes per day
  - SPHL 18 seats = 3 flushes per day
  - SPHL 24 seats = 4 flushes per day
- For medical lock use:
  Gas loss = *3 days x medical lock volume empty x pressure x number of operations*.
  The operations of the medical lock are calculated to six per day.
  Sufficient quantities of water, food (combat rations), and soda lime canisters should be provided in the chamber to avoid using the lock too often.
- Note that manufacturers evaluate the gas losses due to leaks to 1% per day.
  Gas loss = *3 days x 1% x vessel volume x pressure*.

Divers should observe strict discipline and follow the guidelines below:

- They should watch each other to prevent any health problems.
- Divers who were in the bell should dry themselves (towels) and dress in the clothes provided by their colleagues.
- If the sea conditions are bad, they remain seated with their safety belts and helmets in place. Anti-embolic stockings recommended in IMCA D 052 should be worn. The divers should also be encouraged to move their legs and arms as possible to favour blood circulation (extensions, flexion, and relaxation of the muscles). IMCA also recommends performing deep breathing periodically (30 seconds every 15 minutes).
- When the sea condition is more favourable, they can walk one by one in the middle of the chamber.

- Fluid intake should be organized at 100-150 ml per hour for each diver.
- Anti seasick tablets should be renewed. Hyoscine, also known as scopolamine, is the medication recommended in IMCA D 052 to treat motion sickness. It can be administered by tablets or patches, which will start after 20 minutes and last 8 hours. Note that other treatments exist that can be selected by the diving medical specialist.
- The LST normally adjusts the thermal balance of SPHL on the panel. It is not the HRC case that has only passive protection and can become either very hot or very cold. In case of too cold conditions, survival bags that should be provided can be used (Note that they allow arms to be outside). Hot conditions are more difficult to control without refrigeration means.
- IMCA says that sealable gel bags for toilet effluences, urinary sheaths, and vomit bags should be locked out of the chamber. However, medical locks operations are limited in an SPHL sailing without external assistance and impossible in an HRC floating at the sea's surface. For this reason, these bags should be stored in additional strong sealed bags and transferred outside when possible.
- Injured divers should be secured in the HRU and be watched at all time. The diver medics should be seated at his direct proximity, with the medical kit ready, so they can intervene whatever are the sea conditions.
- Any problem should be reported to the Life Support Technician on panel

4.5.5.2 - In the cockpit of the SPHL

As already discussed, the preferred procedure is to transfer the Hyperbaric Rescue Units to the deck of the rescue vessel as soon as possible. Moreover, the most promoted procedure is to install the Hyperbaric Reception Facility on the rescue vessel for the reasons explained previously. However as long the Self Propelled Hyperbaric Lifeboat is sailing, the supporting team is responsible for the navigation and the well being of the divers.

- Regular communications should be organized between the divers and the support crew. The surface crew should do his best to keep them in good spirits and inform them of what is happening.
- During the sail to the haven, the team should maintain communication with the Emergency Response Team, the rescue vessel, and other vessels cruising in the vicinity. These communications allow managing any program change that may happen.
- The team should remain alert to ensure the safety of the SPHL, its crew, and the divers inside the chamber. If the plan is to sail to the shore using the SPHL, the crew should organize to be at the proximity of the rescue vessel and vice versa. In case of a problem, the team should be prepared to receive assistance from the rescue vessel or another vessel.
- In point 4.5.1.5 it is recommended to limit the sailing time of the HRU to 12 hours. However, unplanned events may happen that can result in a longer navigation time to reach the haven or the point of meeting with the rescue vessel. For this reason, the supporting team must be able to organize rotational sleeping periods making sure that navigation, chamber parameters, and communications are all under control.

4.5.5.3 - Transfer to the rescue vessel.

Transfer of the Hyperbaric Rescue Unit to the rescue vessel and connection procedures to the Life Support Package are detailed in points 1.2.7.9 and 1.2.9 and not explained further here.
When the Hyperbaric Rescue Unit is secured on deck, the Life Support Package (LSP) is connected as soon as possible, and the parameters in the chamber are stabilized. Life Support Technicians and helpers should organize shifts to continuously monitor the chamber as long as it is not connected to the Hyperbaric Reception Facility.
If the Hyperbaric Reception Facility is installed on the rescue vessel (recommended option), the HRU is connected to it, and the divers transferred into it as soon as possible.
If the Hyperbaric Reception Facility is onshore, the rescue vessel should sail to it at the maximum possible speed. Meantime, the master of the rescue vessel should contact the emergency response team to confirm that the HRU is on deck, connected to the LSP, and that vessel is sailing to the haven. The Estimated Time of Arrival should also be indicated.

4.5.6 - Transfer the divers from the Hyperbaric Rescue Chamber to the Hyperbaric Rescue Facility

Note: The hyperbaric reception facility and the procedures for connecting the Hyperbaric Rescue Unit are described in point 1.2.10. For this reason, they are not explained further here.

4.5.6.1 - Preparation for the decontamination of the divers

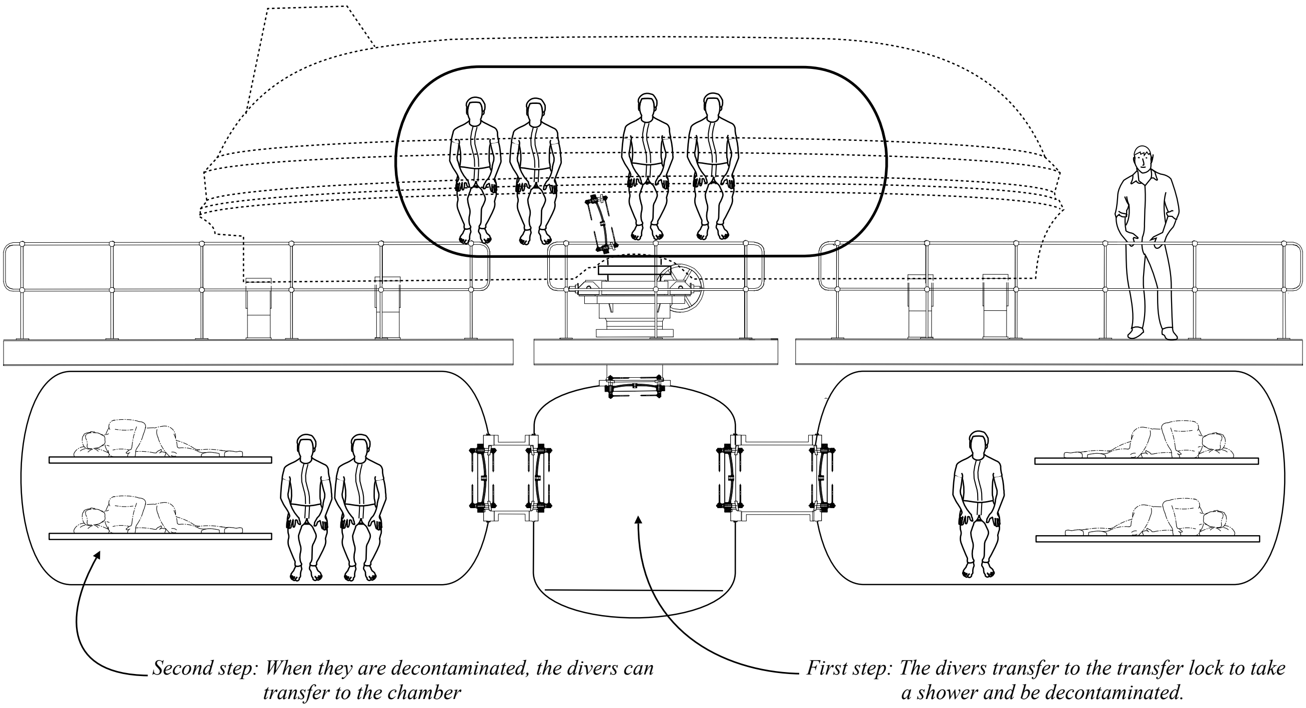
During the transfer at sea, the divers can be contaminated due to the unsanitary conditions inside the chamber during the transfer at sea. For this reason, decontamination of the divers must be organized before their transfer into the Hyperbaric Reception Facility. This decontamination should be performed inside the transfer lock.

- Clean cotton clothes and shoes should be prepared for each diver with a ear drop set.
- Linen laundry bags should be prepared to collect the contaminated clothes of the divers through the medical lock or later on if the medical lock is not sufficiently wide for this purpose.
- The shower should be ready with disinfectant soaps and disinfected towels (1 towel /diver).

4.5.6.2 - Transfer and decontaminate the divers

The transfer can start once the Hyperbaric Rescue Unit is connected and the trunk is confirmed safe for personnel transfer:

- Once the internal Hyperbaric Rescue Unit (HRU) door is opened, the 1st diver transfers to the Transfer Lock (TL) on instruction from the LSS/LST. The HRU and TL doors are closed when the 1st diver has finished transferring.
- When the 1st diver is in the Transfer Lock (TL), he removes his clothes and puts them into the linen bag, and if the medical lock is sufficiently wide to do it, he transfers the bag outside the transfer lock. The diver takes a shower and dresses in the new clothes.
- When the diver is decontaminated, he transfers to the chamber through the dedicated trunk (classical transfer procedure). He closes both doors of the transfer lock and the chamber. The trunk is then isolated.
- The dirty water is removed from the TL using the sump drain.
- The next diver is then transferred to the transfer lock and decontaminated.
- Before transferring to the transfer lock, the last diver performs the checks of the Hyperbaric Rescue Unit (HRU). Once the diver has completed the checks, he transfers to the TL and closes both the HRU and TL doors. When he has finished decontaminating, he can transfer to the chamber.
- The Transfer lock is then isolated from the chambers.



4.5.6.3 - Transfer and decontaminate casualties

One or more casualties may be among the divers to transfer into the HRF.

Depending on the extent of the casualty injuries, one or two diver medics are transferred 1st from the HRU to the transfer lock. The casualty is then transferred, and the diver medics wash themself with the casualty who is then transferred to the dedicated chamber.

It may happen that the diver medics inside the HRU are not in a condition to take care of the casualty. In this case, two diver medics who are free of penalty are transferred in the HRF prior to connecting the HRU and will receive the casualty in the transfer lock and take care of him.

4.5.6.4 - Decontaminate the Hyperbaric Rescue Unit and the Transfer Lock

The transfer lock and the HRU must be recovered to the surface to be fully decontaminated:

- Dirty cloths and towels are collected, washed, and disinfected.
- Wall and bilges must be washed with hot water and soap and rinsed with fresh water.
- Shower heads, valve handles, toilet seat should be disinfected (Alcohol, “Tego”, “Trigene” or similar)
- Normally, the BIBs masks should not be contaminated except if they have been used. They should be removed for the cleaning period and disinfected if used.
- Then, the HRU and the TL are ventilated and dried.
- The Transfer lock is then returned ready for use and pressurized to the storage level.
- The HRU is closed to protect it from contamination. It can be removed from the Hyperbaric Reception Facility if the facility is equipped with a sufficient number of chambers where the divers can refuge if there is a problem in one of them. If it is not the case (as an example, only one chamber), the HRU should be reconnected.

4.5.6.5 - Stabilization period before starting the decompression

After the abandonment of the ship and a period spent in the Hyperbaric Rescue Unit that can have been long and uncomfortable, in addition to the fact that they worry about their friends who were outside the dive system, it may be probable that a lot of divers will wish to be decompressed as soon as possible.
However, in point 3.6.1.3, it is recommended to stabilize the divers 8 hours prior to start the decompression.
It must be noted that this duration is recommended for decompressions in normal conditions, which is not the case after a ship's abandonment.
For this reason, an extension of the stabilization period should be considered. Nevertheless, its duration should be estimated, taking into account the divers' physical and psychological condition and according to the diving medical specialist's guidelines.

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5.2 - Addresses

- CCO Ltd -
52/2 moo 3 tambon Tarpo 65000 Phitsanulok - Thailand http://www.ccoltd.co.th/

- **DIVETECH** -
1543 Chemin des Vignasses 06410 Biot, FRANCE

- Association of Diving Contractors International (ADCI) -
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- IMO - International Maritime Organization -
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