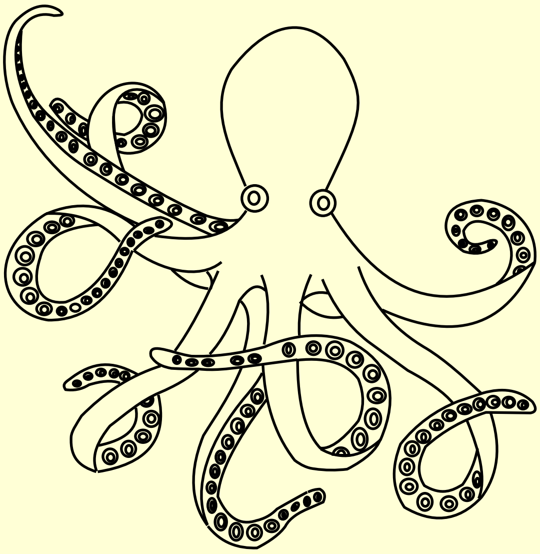

Diving & ROV specialists

Description of a saturation diving system

24 August 2021

Diving & ROV specialists is a branch of CCO ltd

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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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1) Purpose

1.1 - Function of a saturation system

When the divers have been saturated to their life level, the return to the surface cannot be done immediately as a sudden exposure to atmospheric pressure will result in an explosive decompression and immediate death (see "Byford Dolphin" accident).
For this reason, it is of utmost importance to keep them at depth and in a safe place where suitable living conditions can be controlled. It is the function of the saturation diving system that is designed to:

- Protect the divers from uncontrolled variations of pressure during the various phases of the diving operations.
- Provide suitable breathing gas to the divers and protect them from pollutants and against pathogens.
- Accommodate the diver at a suitable temperature and hygrometry.
- Allow the divers to rest, eat, wash, perform their natural needs, and provide them clean clothes and bedding.
- Provide a safe means of transfer from the hyperbaric living facility to the underwater work site.
- Provide first aid equipment and means of evaluation of the condition of a casualty inside the system.
- Provide a safe means of escape in the case of an abandon ship.

1.2 - Importance of having knowledge of the design of a saturation system

It is evident that when people are living in a hostile surrounding as it is the case of divers stored at depth, their survival depends on the quality of the elements that compose the system that maintain them alive, and of the comprehension of their interaction. Such an understanding makes them able to react rapidly and efficiently if something goes wrong. So, we can say that the diving safety procedures are based on the control of the saturation system and the backup solutions provided. That is similar to other activities such as space and aviation industries where the life of operators and passengers depend on the perfect control of machines.
Past incidents have demonstrated that lack of knowledge of the design of the systems in use leads to their inappropriate exploitation and improper safety procedures.

In addition to its design and the quality of the materials that have been used to build it, the reliability of the saturation system is linked to the way it is maintained. So a maintenance plan must be established and documented.
This plan will not be possible in the absence of knowledge regarding the design of the system, and if the technicians and managers in charge of it are insufficiently formed. So, we can say that the selection of these persons is a crucial point for a successful maintenance plan.
Also, it is essential to select competent service providers as, excepted with multinational structures, a company rarely has all the technical competencies to maintain such a system in full.

1.3 - Systems described in this book and reasons for this choice

Several strategies are possible to describe a saturation system. The one that appeared the most evident for this manual has been to find practical examples of existing systems.
For this reason, the two systems that are parts of the Ultra Deep Solutions vessels "Lichtenstein" and "Picasso" have been selected and used as supports for the descriptions provided in this document.
These vessels are sister ships, and their saturations systems, that have been designed and built by LEXMAR, a company of JFD group, are similar and of the latest generation. As a result, they are equipped with some of the most advanced technologies currently available on the market. Both ensembles have been classified by Det Norske Veritas - Germanischer Lloyd (DNV), a recognized certification body, and are now successfully used in various diving operations.

The advantage of referring to existing systems is that there are fewer risks of errors or missing some elements than starting a description from scratch. Also, it is possible to provide more precise information.
The description of an existing system implies the description of its components. It is the main reason the equipment providers indicated in this book are selected. However, note that all of them are among the most reputed manufacturers in their domains of competencies and can be considered as references. It is also the reason these two systems have been selected.

Of course, this document is designed to be an example of the information that should be in a saturation diving handbook, and I was free to choose systems I have considered the most relevant for this purpose.
It is evident that those who need to write a company manual must refer to the systems their company uses.

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2) Saturation systems in service and their general design

2.1 - Organizations publishing standards or guidelines that influence the conception of saturation diving systems.

As every industrial equipment, a saturation diving system must be designed and built according to recognized international and national standards.
Such standards are emitted by organizations whose aim can be the protection of people, the defense of the interests of one or several countries, or the development of trade activities. In parallel, professional associations issue guidelines for their members that can be adopted by national or international competent bodies. Thus, there are multiple reasons for the publication of standards, that can be based on logical scientific facts or not.
Note that most countries have a governmental organization whose purpose is to select or create standards. However, most standards applied in the diving industry are issued by international organizations or national bodies that are internationally recognized. As these organizations are taken as references throughout the description of the elements that compose a saturation system, it is essential to be familiar with the most famous.

2.1.1 - Organizations publishing standards

2.1.1.1 - European Standards – European committee for standardization

European Committee for standardization (CEN) is an organization based at Brussels (Belgium) that groups the national industrial standards of the members of the European Union plus some external members such as members of the European Free Trade Association (EFTA).
European Standards (EN) are a vital component of the European market, and for this reason, they cover nearly the totality of industrial activities. They are designed and created by all interested parties through a consensual process.
The European Committee for Standardization governance is composed of the general assembly, the presidential committee and its advisory bodies, and the administrative board. Other bodies such as technical boards, committees, and working groups support the achievement of the scope of the organization.
These standards are commonly used for the fabrication of devices such as chambers, helmets, regulators, gas cylinders, etc. Tools built according to these standards are marked with the initials "CE".
Note that these standards are distributed through the normalization bodies of the members. For this reason, the mention "EN" is usually preceded by the name of the normalization body of the country it is sold in. As an example, EN 1802 "Periodic inspection and testing of seamless aluminum alloy gas cylinders" is BS EN 1802 in the United Kingdom and NF EN 1802 in France. As a result, many authors of documents continue to refer to their national organization instead of the real emitter of these standards.

2.1.1.2 - ISO (International Organization for Standardization)

ISO (International Organization for Standardization) is an independent, non-governmental organization based in Geneva (Switzerland), the members of which are the standards organizations of the 168 member countries.
The organization provide standards that cover nearly the totality of industrial activities. It also provide certifications regarding quality management systems.
The organization proposes three types of membership:

- Full members (or member bodies) influence ISO standards development and strategy by participating and voting in ISO technical and policy meetings. Full members sell and adopt ISO International Standards nationally.
- Correspondent members observe the development of ISO standards and strategy by attending ISO technical and policy meetings as observers. Correspondent members can sell and adopt ISO International Standards nationally.
- Subscriber members keep up to date on ISO's work but cannot participate in it. They do not sell or adopt ISO International Standards nationally.

The "council" is the governance body of the organization that reports to the "general assembly". It meets three times a year and is composed of twenty members. Council standing committees address matters related to finance, strategy and policy, nominations for governance positions, and oversight of the organization's governance practices. Membership to the council is open to all member bodies and rotates to make sure it is representative of the member community.
ISO standards are commonly used by manufacturers involved in the diving industry.

2.1.1.3 - ANSI (American National Standards Institute)

The American National Standards Institute (ANSI) is a private non-profit organization, based in Washington DC (USA) that oversees the development of standards for products, services, processes, systems, and personnel in the United States.
ANSI does not write standards but accredits developers who are in charge of establishing consensus among qualified groups. Its guiding principles " consensus, due process, and openness " are followed by the 220 distinct

entities currently accredited to develop and maintain the American National Standards (ANS).
The Institute's membership is composed of businesses and industrial organizations, standards-setting and conformity assessment bodies, trade associations, labour unions, professional societies, consumer groups, academia, and governmental organizations.
ANSI also promotes the use of United States standards internationally, and advocates United States policy and technical positions in standards organizations. It is the case with National Pipe Threads (NPT) standards that are promoted through this organization. Also, ANSI encourages the adoption of international standards as national standards where appropriate.
Note that a lot of standards promoted by this organization are used in the diving industry.

2.1.1.4 - ASME (American Society of Mechanical Engineers)

ASME (American Society of Mechanical Engineers) is a professional association, which headquarters are in New York. It promotes art, science, and practice of multidisciplinary engineering and allied sciences around the world via education, training, codes and standards, research, conferences and publications, government relations, and other forms of outreach.
This organization emit standards covering a lot of industrial activities such as pipelines, pressure vessels, and power plant systems. It is the reason these standards, that are developed by committees using a consensus process, are commonly used for the design of diving systems.
A lot of ASME standards are adopted by governmental agencies, and for this reason, the organization has three international offices in Beijing (China), Brussels (Belgium), and New Delhi (India).

2.1.1.5 - ASTM international

ASTM International, formerly known as the “American Society for Testing and Materials”, is a nonprofit organization based in West Conshohocken (United States) that develops and publishes voluntary consensus technical standards covering procedures for testing and classification of materials. These standards are developed within committees, and new committees are formed as needed upon request of interested members. Participation to committees is initiated at the member's request instead of by an appointment or invitation. Membership in the organization is open to anyone with an interest in its activities. Members are classified as “users”, “producers”, “consumers”, and "general interest". Also, to comply with American antitrust laws, “producers” must constitute less than 50% of every committee or subcommittee, and their votes are limited to one per producer company. Note that the organization report 30,000 members and says that its standards have been adopted in at least 140 countries.
ASTM is also appointed for the United States Technical Advisory Group.

2.1.1.6 - ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers)

ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) is an American professional association seeking to advance heating, ventilation, air conditioning and refrigeration systems design and construction. This organization has already published more than four thousand standards for the design and maintenance of indoor environments. Three types of standards are available: method of measurement or test, standard design, and standard practice. These standards are often used in the conception of the heating and refrigeration systems of the chambers,

2.1.2 - Organizations publishing guidelines and conventions

2.1.2.1 - IMO (International Maritime organization)

IMO (International Maritime Organization) is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships.

IMO publishes maritime and diving resolutions and codes that are used to establishes standards and design diving systems. As an example, the resolution A.692, provides “guidelines and specifications for hyperbaric evacuations systems”. Note that the guidelines from this organization are the minimum to be in place everywhere in the world.

IMO also publishes international conventions such as MARPOL (International Convention for the Prevention of Pollution from Ships) and SOLAS (International Convention for the Safety of Life at Sea) that must be taken into account by the diving system manufacturers when designing the evacuation of used waters from the living chambers, or the firefighting system and the hyperbaric rescue units for abandoning the installation.

2.1.2.2 - NORSOK (Norsk Sokkels Konkuranseposisjon - Norway)

NORSOK is an organization created by the Norwegian petroleum industry that is involved in the offshore activities in Norway and emits specifications and recommendations. These specifications that are based on European (EN) and ISO standards are developed to ensure adequate safety, value-adding, and cost-effectiveness for the Norwegian petroleum industry developments and operations. They are intended to replace oil company specifications and serve as references in the regulations published by the authorities. So, they are to be applied in Norwegian waters.
NORSOK standards are among the most stringent, and are often taken as references by companies and safety

organizations for this reason.
Among the documents published by this organization, NORSOK standards U100 and U101 are commonly used by the manufacturers for the conception of their system to be sure that they can be operated everywhere in the world.

2.1.2.3 - IMCA (International Marine Contractor association)

This association groups marine, diving, survey, & ROV contractors involved in offshore projects (outside the "territorial waters") or using techniques implemented offshore for the petroleum industry.

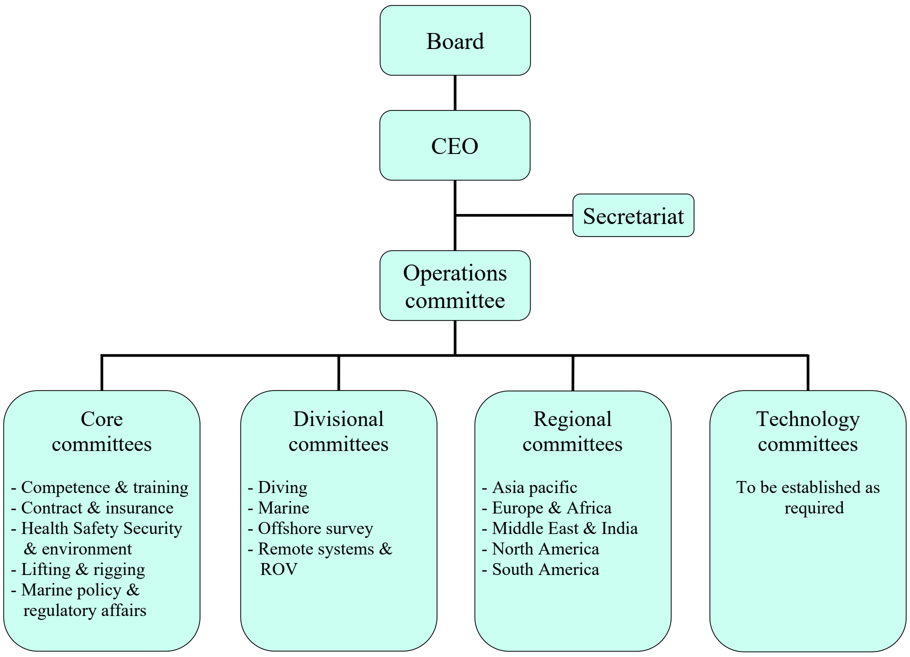
IMCA was formed in 1995 through the merger of the former Association of Offshore Diving Contractors (AODC, established in 1972) and the Dynamically Positioned Vessel Owners Association (DPVOA, formed in 1989).

This organization has published numerous safety guidelines that are taken as references by a lot of governmental standardization bodies and safety organizations. In parallel to guidelines, the association has initiated formation and certification processes for divers, technicians, supervisors, ROV pilots, and other functions that are recognized internationally. So, we can say that the influence of IMCA in the diving industry is enormous.

IMCA is divided into four divisions:

- Diving
- Marine
- Offshore survey
- Remote systems & ROV

The governance and corporate structure is composed of "the Board", "Operations Committee" and numerous "technical committees" and "workgroups". Also, a secretariat manages the day-to-day business of the association. This governance structure can be summarized as follows:



The guidelines provided by this association discuss many aspects of the offshore industry such as Competence & Training; Contracts & Insurance; Lifting & Rigging; Marine Policy & Regulatory Affairs; Health, Safety, Security & Environment (HSSE); Diving (including those from AODC); Marine (including those from DPVOA); Offshore Survey; Remote Systems & ROV.
The published guidelines and reports can be found on the website of the association, along with safety alerts and other useful information. Among these documents, the "Diving Equipment Systems Inspection Guidance Notes" remain some of the most accurate guidance for the organization of audits and the maintenance of equipment.

2.1.2.4 - DMAC (Diving Medical Advisory Committee)

This independent body seeks to provide advice about medical and certain safety aspects of commercial diving. The committee comprises doctors involved in the practice of diving medicine in Northern Europe *(currently France, The Netherlands, Norway and the United Kingdom)*, representatives of relevant health authorities *(the UK Health & Safety Executive and Norwegian Directorate of Public Health)*, medical representatives from relevant navies *(UK & The Netherlands)* and a diving safety officer nominated by IMCA *(the International Marine Contractors Association)*. Members of the committee receive no payment for their time or contributions to committee proceedings; the work of the committee is entirely voluntary.

DMAC does not emit standards regarding the construction of diving systems. However its advice and guidelines lead to the creations of standards by the legal authorities and the modification of some equipment. For this reason, this organization is always taken into consideration by equipment manufacturers.

2.1.2.5 - ADCI (Association of Diving Contractors International)

ADCI (Association of Diving Contractors International) was originally a small group of American diving companies that created a nonprofit organization dedicated to commercial diving to establish safe practices throughout the world. Some of these guidelines have been adopted as standards by competent national bodies and other safety organizations and are today taken into account for the construction of diving systems.
This association, which is based in Houston (USA), represents today more than 600 members conducting safe underwater operations throughout the world.
Similarly to IMCA, this association has its formation and certification processes for divers, technicians, supervisors, ROV pilots, and other functions.
The organization also share guidelines and point of views with other competent groups such as IMCA, NOAA (National Oceanic and Atmospheric Administrations), DMAC and others.

2.1.2.6 - IOGP (International Association of Oil and gas producers)

International Association of Oil and gas producers (IOGP) is an organization that defends the interest of some multinational petroleum companies such as Shell, Exxon, BP, Total, and others. This organization acts as a group of pressure to impose the point of view of its members to the contractors working for them and try to influence national and international safety organizations to establish its members in a dominant position.

2.1.2.7 - National safety organizations and ministries of labour.

These national organizations and authorities are in charge of the protection of the citizens of their country. They may impose standards for the diving operations in the waters under their jurisdiction. As a result, some of the rules they publish may impact the design of the diving systems, and the way they are certified.
As examples of these numerous organizations note the UK Health and Safety Executive, the French Ministry of Labour, NOAA (National Oceanic and Atmospheric Administration - USA), etc.

2.2 - 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:

2.2.1 - 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.

2.2.2 - 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:

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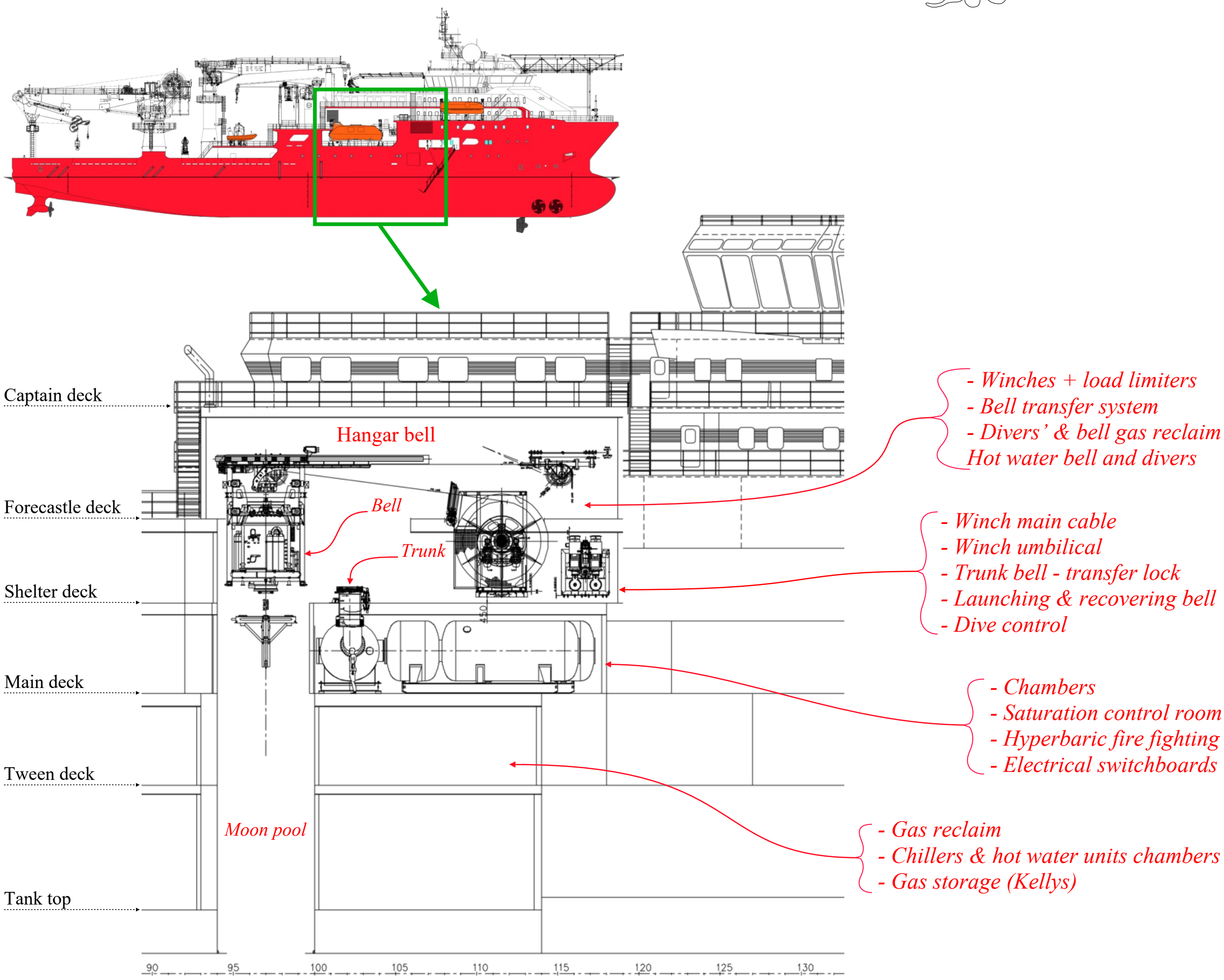
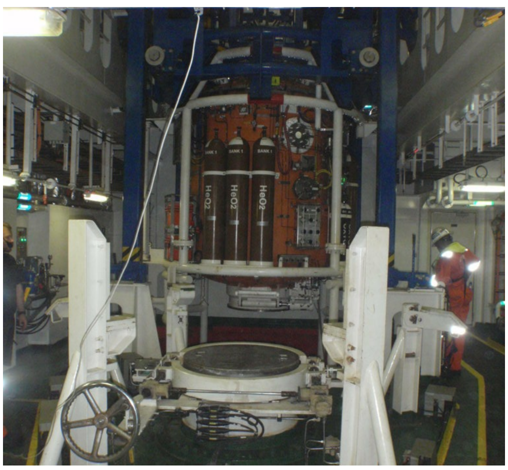
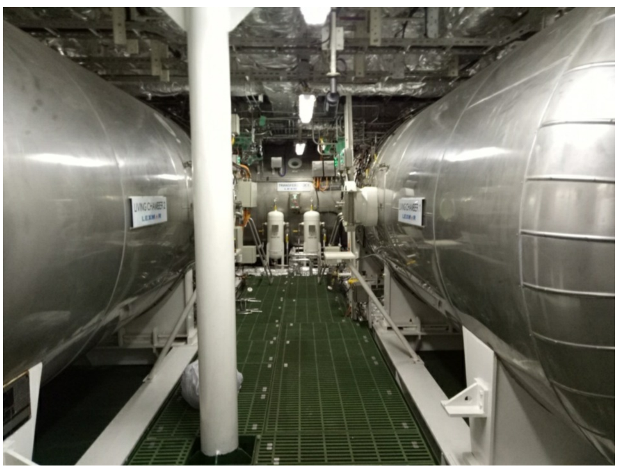


In addition to the deck that remains available for cargo and tools, built-in systems have the following advantages:

- 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.

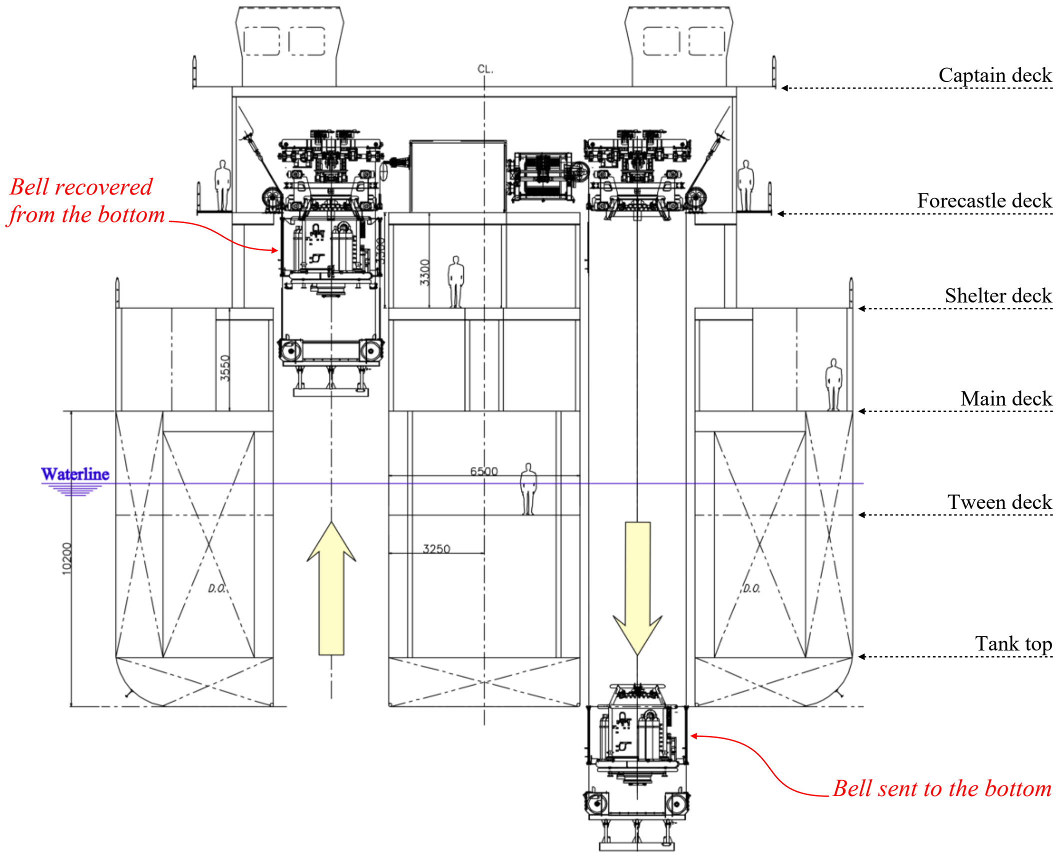


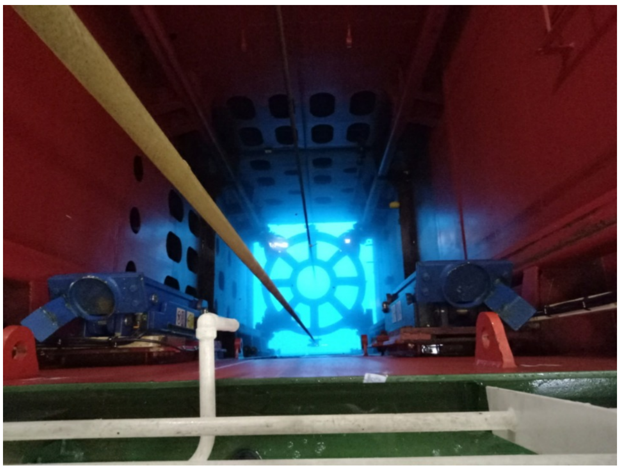
Bell in its launching hangar



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.



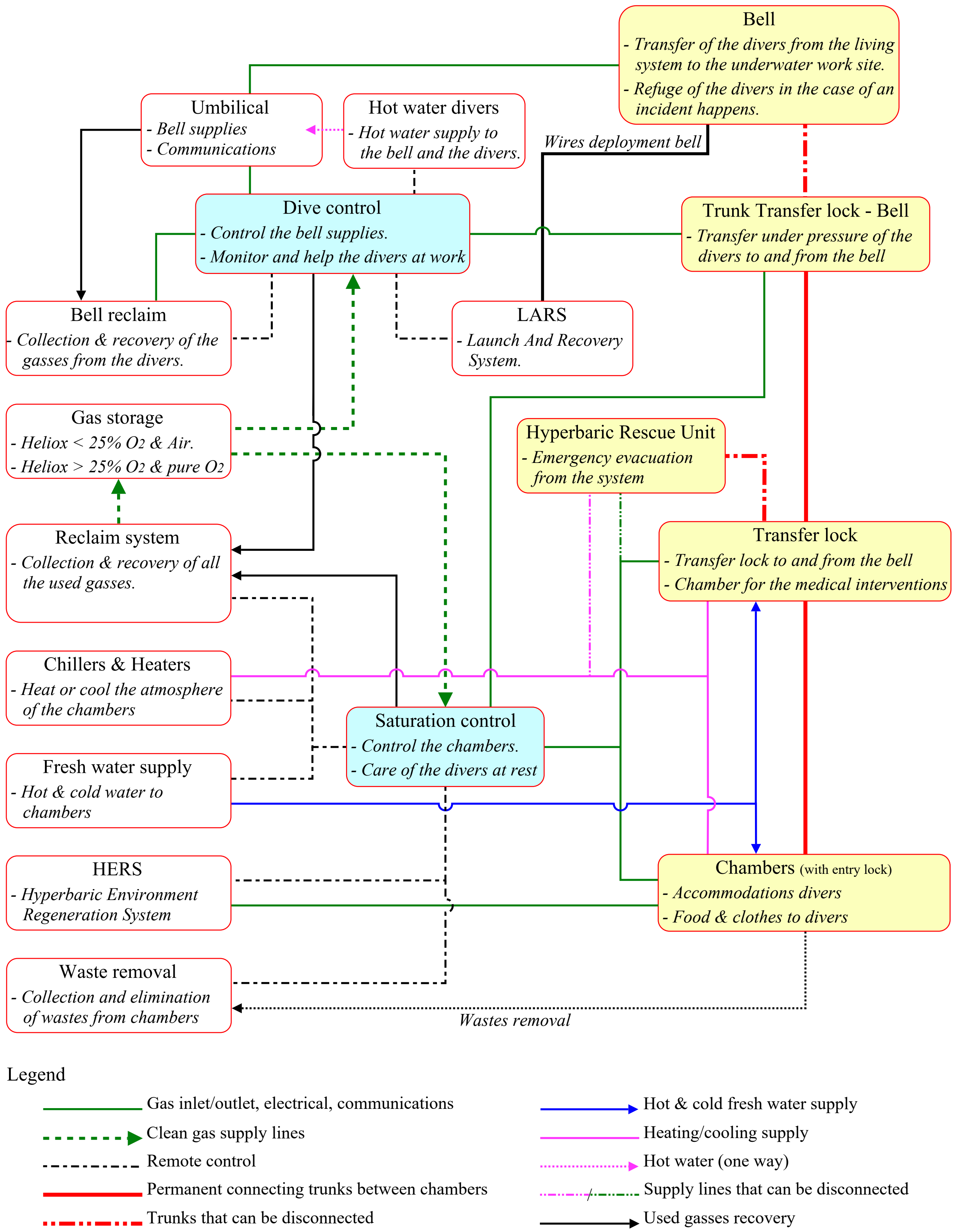

Moon pool (bell at work)

Bell above its moon pool

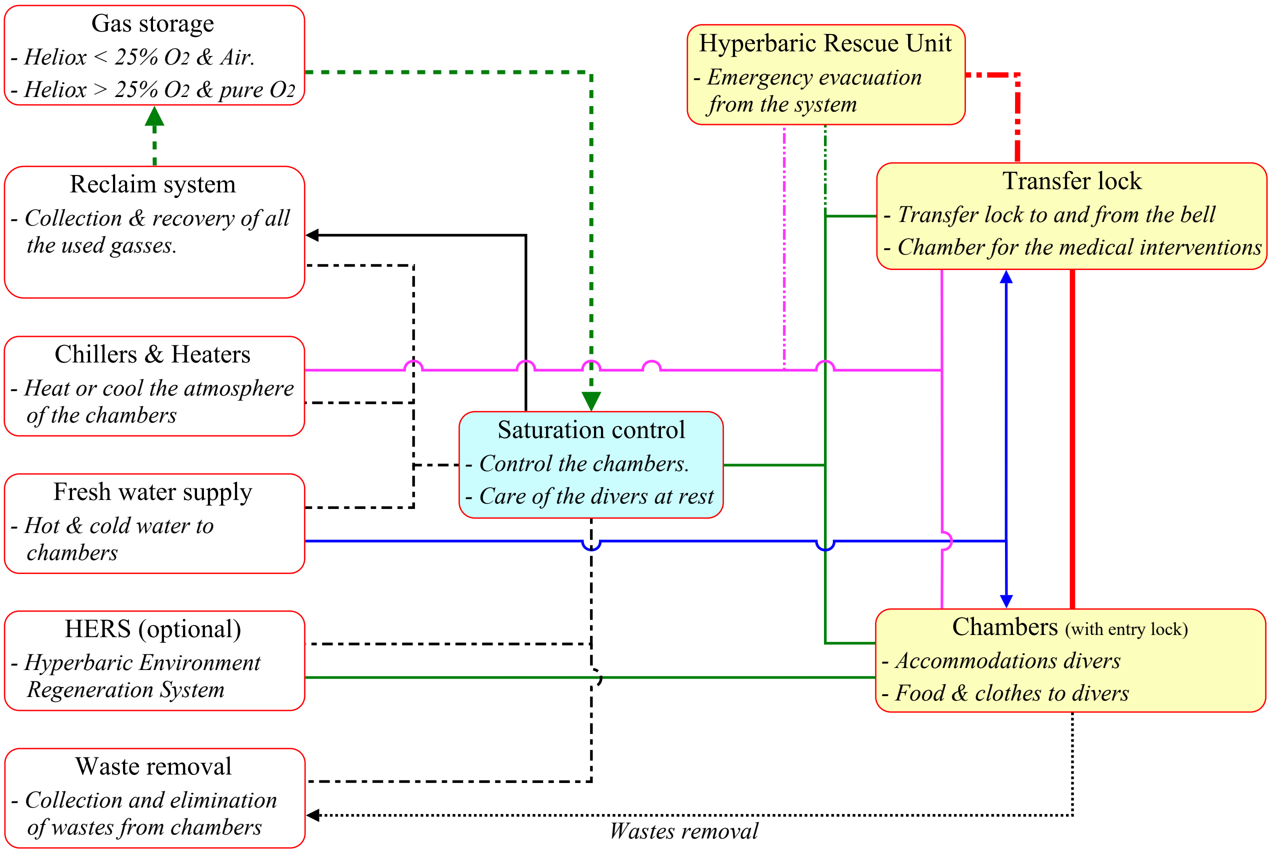
2.3 - Main elements of a saturation system

2.3.1 - Overview

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.



Also, the Hyperbaric Reception Facility (HRF), which 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 on the next page.


Gas storage
- Heliox < 25% O2 & Air.
- Heliox > 25% O2 & pure O2
Reclaim system
- Collection & recovery of all the used gasses.
Chillers & Heaters
- Heat or cool the atmosphere of the chambers
Fresh water supply
- Hot & cold water to chambers
HERS (optional)
- Hyperbaric Environment Regeneration System
Waste removal
- Collection and elimination of wastes from chambers
Saturation control
- Control the chambers.
- Care of the divers at rest
Hyperbaric Rescue Unit
- Emergency evacuation from the system
Transfer lock
- Transfer lock to and from the bell
- Chamber for the medical interventions
Chambers (with entry lock)
- Accommodations divers
- Food & clothes to divers
Wastes removal

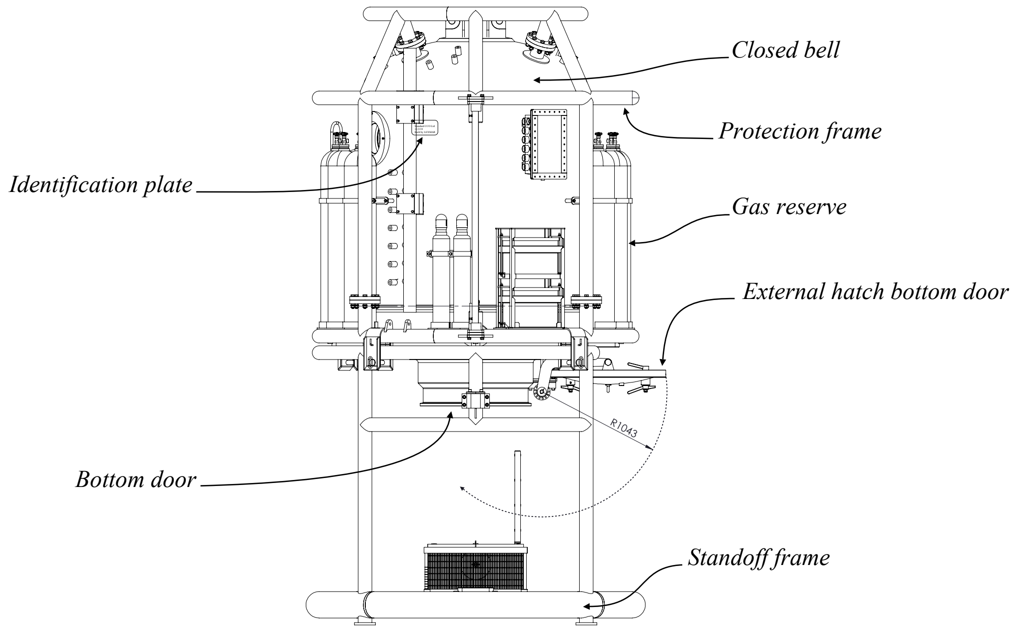
2.3.2 - Diving bells

If the saturated divers are exposed to the atmospheric pressure explosive decompression occurs and they are immediately killed. For this reason, a sealed diving bell is necessary to transfer them from the system where they are kept at the pressure planned at depth to the underwater work site. When the bell arrives at the selected depth, the bottom door is opened, and the dive can start. The bell is also the refuge of the divers in case an incident happens.
Note that doors are fitted with two hatches: The internal hatch protects the divers from decompression accident (which could be explosive decompression) when the external pressure is inferior to the internal pressure in the bell, and the outer door that protects the divers from over pressurization if the bell drops below the planned storage depth.

Bells are pressure vessels that must be built according to recognized international standards. These norms and the certification body must be indicated on the identification plate that summarizes the characteristics of the bell and its manufacturer and must be clearly visible on the outside of the shell.
As a result of technical choices of the manufacturers and their clients, a lot of models of bells are in service in the industry. However, despite some changes in configuration, the functions provided remain the same.
Bells are generally designed and built for two, three or four divers. IMCA says that depending on their configuration, they should have the following minimum volume:

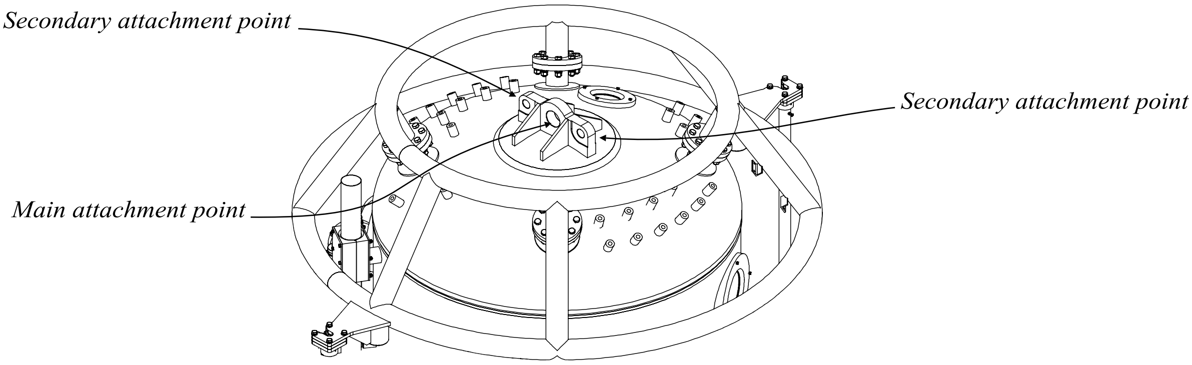
- 2 divers bell – 3.0 m 3 (105 cu ft)
- 3 divers bell – 4.5 m 3 (160 cu ft)
- 4 divers bell – 6.0 m 3 (210 cu ft)

Note that NORSOK standard U-100 says:
Diving bells intended for two divers shall have an inside volume of at least 4,5 m³. Diving bells intended for more than two divers shall have an extra inner volume of 1,5 m³ per diver in excess of two. The specified volume should be usable, i.e. apportioned around what is normally within the height required for a diver to stand up



2.3.2.1 - Deployment cable attachment point

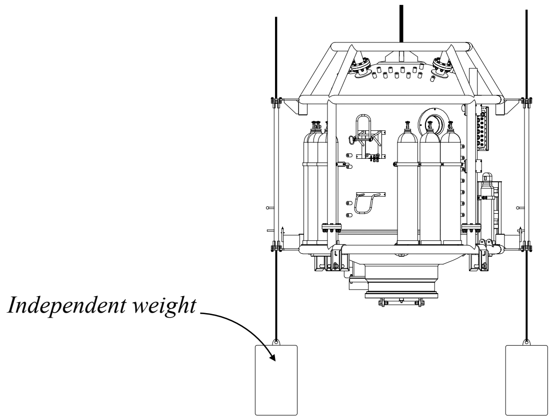
The bell is deployed to the bottom using the main wire that is coiled in a winch that is part of the Launch and Recovery System (LARS). This cable is connected to the top of the bell.
IMCA D 024 says in section 4 that the main lift attachment point to the bell should be by means of a properly designed pad eye or similar.
Also, there should be a secondary attachment point on the diving bell if the main one is damaged. This secondary point should also be a properly designed pad eye or similar *(it may be a second hole in the same pad eye)*. A soft sling should be installed on a secondary lifting point, ready to be deployed by a diver or a ROV.

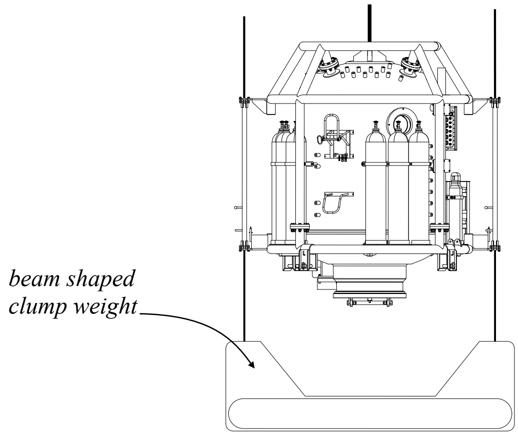


2.3.2.2 - Anti gyration systems

To avoid the bell gyration around its main cable, two parallel cables are installed at each side of the bell. Two configurations are possible:

- Two weights that are deployed by two separated winches. This solution that was used with some systems in the past is not found with the last generation systems.
- A beam shaped clump weight which is deployed by a single cable passing through it. The deployment cable that is adjusted by a single winch pass through the clump weight by the means of pulleys and is connected to the other side of the deployment frame. This clump weight is generally adjusted to create a platform under the bell that allows the divers to enter and leave it easily. Also, some clump weights are fitted with closed boxes where the divers can store tools.

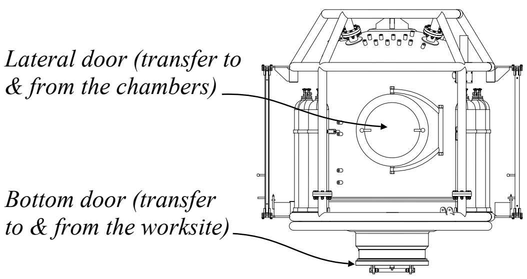


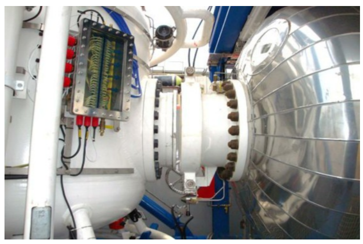


2.3.2.3 - Transfer to and from the living chambers

The transfer from the living chambers to the bell can be performed through a lateral door or the bottom door:

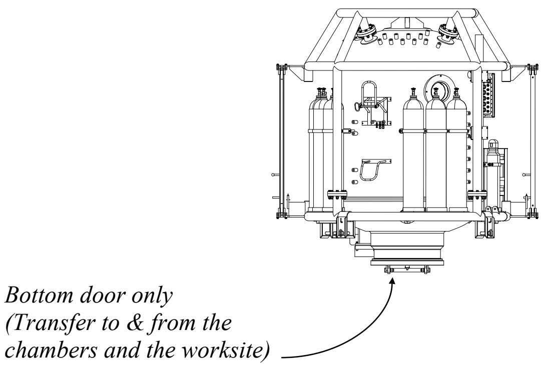
- Bells with lateral doors were common with systems made by COMEX and it is still the case with some last generation systems. As an example, the system displayed in point 2.2.1. The advantage of this system is that the transfer lock and the chambers are at the same level of the bell which reduces the risks of falling during the transfer to and from the bell and that the transfer trunks are generally short.
  Also, the bells of some systems which are connected to the chambers by the bottom door have a lateral door which allows entering into them without disconnecting them from the system. However, this configuration seems no more used with the latest products proposed by the manufacturers.





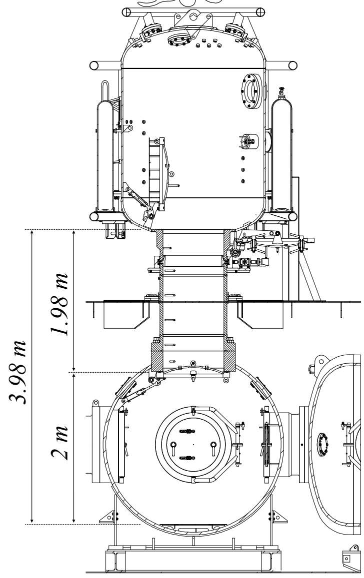
Bell connected laterally

- Bells with only a bottom door are often adopted with the last generation systems. This configuration has the advantage to simplify the design of the bell and avoids the problems of water intrusion between the internal and external hatches of lateral doors that may happen if the external hatch is not correctly sealed. Also, some engineers say that the connection to the system is easier with a bell that is hung and lowered to the connecting flange than with a bell that is approached laterally. However, the transfer of the divers to and from the bell is more dangerous as a fall from more than 2 m height is possible *(see in next page)*.



Connecting the bottom hatch

Internal view of the bottom trunk of the bell



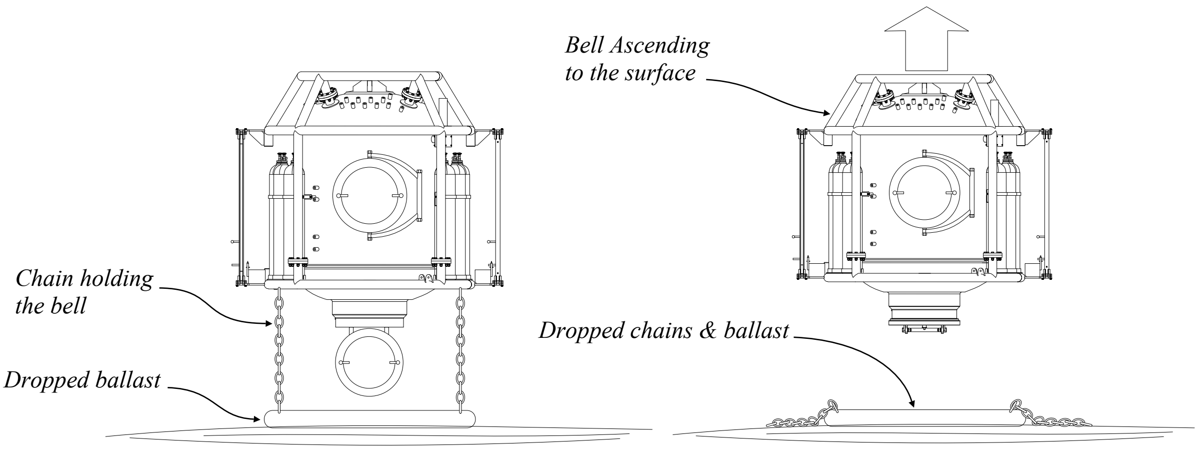
Note that due to the configuration of some systems, there is a risk that a diver falls from a height that can be up to 4 metres.
For this reason, precautions should be implemented to avoid such an incident during the transfers and the checklist of the bell.

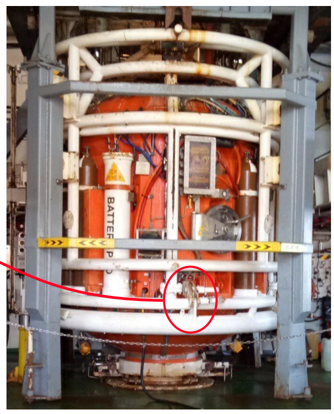
The bottom internal diameter of the hatch in the previous page is 90 cm which is sufficient to enter and leave the bell with a bailout. Note that NORSOK U 100 says: "*The bottom trunk for entry into and exit from the diving bell shall have an inner diameter of minimum 80 cm*".
IMCA does not give precise dimensions of the hatches and only says that the diver must be able to exit and re-enter the bell and that there should be the possibility to open the doors from either side. It is also said that the doors must be in perfect condition and their seals protected by a slight film of silicone grease.

2.3.2.4 - Bell ballast release option

Bell ballast release systems and buoyant ascent in offshore diving operations are explained in AODC 061 and discussed in the document "Bell diving operations". Two options are currently available:

- Bell equipped with a ballast release system.
  This option that was common with old systems is still used with last generation systems. Its function is that if the bell has fallen to the bottom, it allows dropping the ballast that is still attached to the bell by chains to the bottom. As a result, the buoyancy of the bell becomes positive allowing it to take off from the seabed to which it is maintained by the chains attached to the ballast, which allows the divers to leave and enter in it.
  Also, the system allows a complete release of the ballast to let the bell ascend to the surface as a result of its positive buoyancy.





Ballast release system

IMCA says that such a system must meet the following criteria:

- It must be designed to be operated from inside of the bell and the release mechanism must be protected against accidental release. For this reason, two independent actions must be necessary to release the weights.
- Also, the weights must be secured so as not to be shed accidentally. For this reason, if the system utilizes only one weight then there must be no single component whose failure could cause the weight to become detached. This requirement does not apply if there are two or more weights operating independently.
- In addition, IMCA says that if the release mechanism is operated by means of pressurisation (gas or hydraulic), then isolations need to be in place such that they cannot be activated accidentally by external water pressure or internal gas pressure.

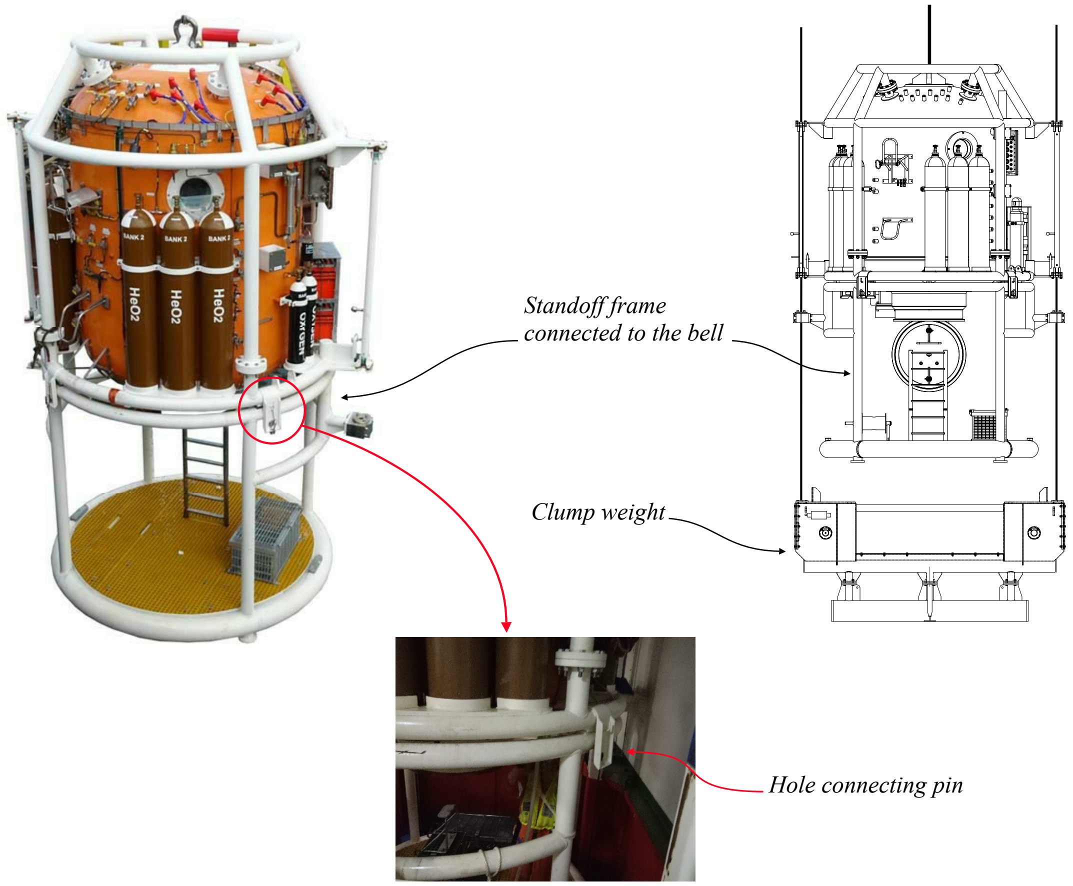
- Bell without ballast release system.
  Some companies consider dangerous the use of bells that can float as the ascent to the surface is uncontrolled and the bell may hit a structure or a vessel during its ascent. For this reason, they prefer recovering it using a crane and another bell and remove this option to avoid the divers having the temptation using this system.
  IMCA says that this decision must be clearly recorded in the appropriate documents and made known to all on the work site. Also, the ballast weights must be secured not to accidentally come off. In addition, the alternative recovery method must be identified
  Note that the equipment used to permanently secure bell ballast weights and neutralize the components forming part of the buoyant ascent system not intended to be used must be inspected every 6 months.
  IMCA D 024 also says in section 5 that the diver must be able to exit and re-enter the bell if it is resting on the bottom using a standoff frame or a ballast release system. It means that if the ballast release system is fully neutralized, a standoff frame must be physically fitted to the bell.

2.3.2.5 - Bells with standoff frames

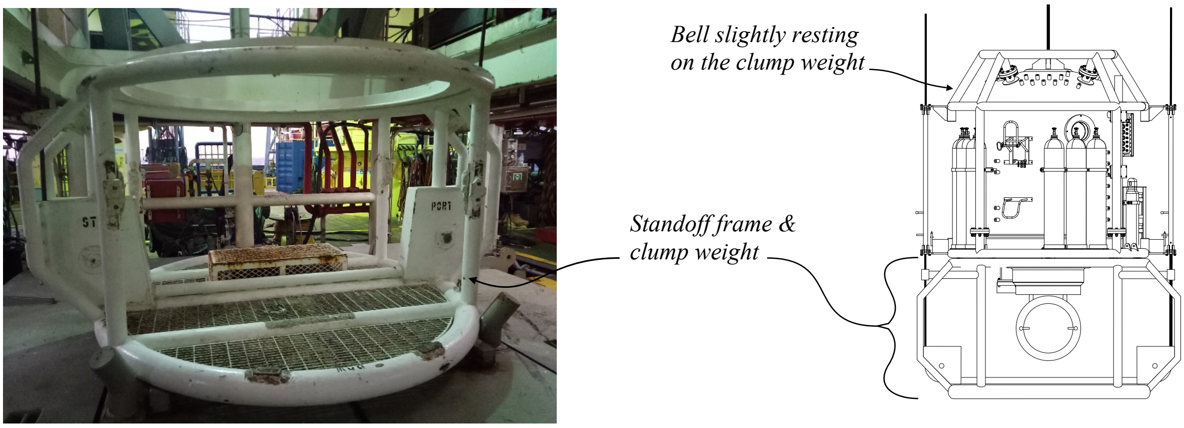
Standoff frames can be found with some models of bells.
The function of the standoff frame is to allow the divers to easily enter and leave the bell and provide them a place under the bell where they can standby in the case of an alert or if a small change of working area has to be performed without recovering the bell. Also, it is designed to protect the bottom door of the bell.
As explained in the previous point, IMCA says that standoff frames are mandatory with bells that have no ballast release system to allow the divers to leave and return to the bell if it has dropped to the seabed.

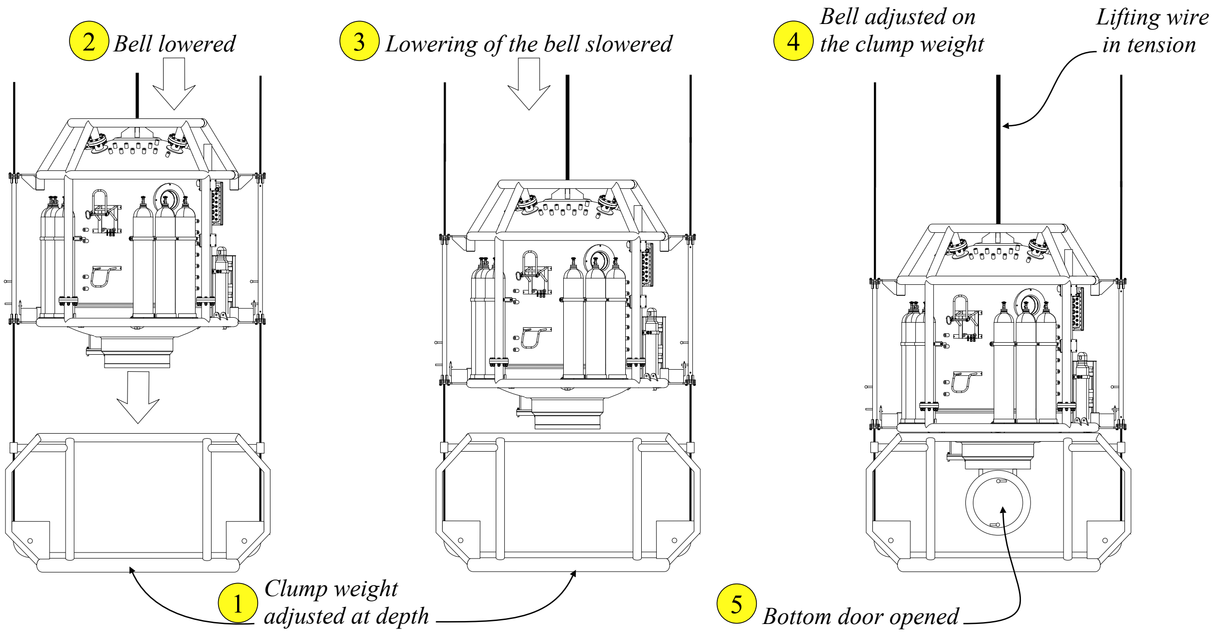
Two types of standoff frames can be found currently:

- A standoff frame that is connected to the bell which does not act as a clump weight. So the clump weight is deployed and adjusted below it.



- A standoff frame that is also used as a clump weight on which the bell slightly rests when arrived at depth. Note that because this model of standoff frame is not physically fitted to the bell, it can be used only with bells that are equipped with a ballast release system.





2.3.2.6 - External equipment

Equipment and gas reserves are installed all around the bell to provide a minimum autonomy in the case that the bell is lost on the bottom:

- IMCA D 024 says that There must be an emergency supply of breathing gas carried on board sufficient to support each working diver plus the bellman outside the bell for a minimum of 30 minutes at a breathing rate of 40 litres/minute at the maximum depth of the diving operation.
  Also, sufficient oxygen must be available for metabolic consumption by the maximum number of divers at 0.5 litres per minute per diver for at least 24 hours at the end of a bell run.
  As an example, the bells of UDS Lichtenstein are fitted with the following gas reserves that can be filled using a panel installed on the side of each bell:

- Two oxygen banks 2 x 10 litres x 200 bar.
- Three heliox banks 3 X 67 litres x 300 bar filled with bottom mix.

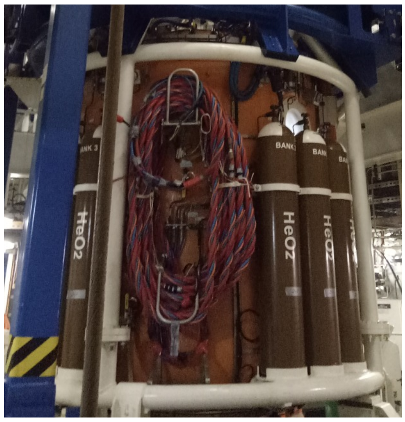
As with any gas stored on the worksite, the cylinders must be colour-coded and marked with the name and chemical symbol of their contents. The stamp of the last test date should be on the shoulder of each cylinder and painted over with a small patch of distinctive colored paint to help for its localization. If this is inaccessible then the cylinder serial number should be visible or else stenciled in a visible location.
Note that the valves of the cylinders and the bell must not be corroded and easy to close or open. In addition, the onboard gas *(oxygen and heliox)* must be regulated not to be above 30 bar over the ambient pressure in the bell.

IMCA D 024 also says that valves carrying oxygen (or mixes containing more than 25% oxygen) 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, 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 25% oxygen.


Bell charging panel heliox

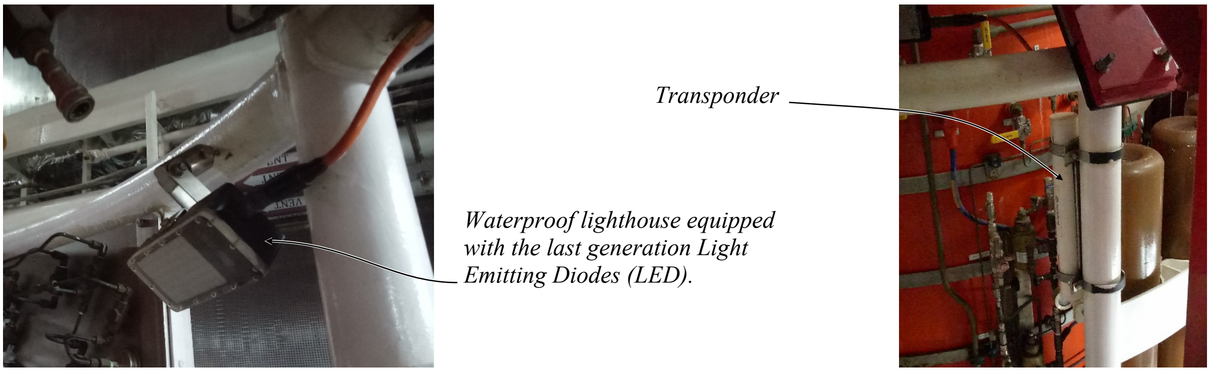


Onboard gas colour coded

The bell must be designed to be visible so that the diver can see it during the operations. Also, it must be discoverable if it is lost. For this reason, the following equipment should be installed.

- Lights should be arranged such as the bell is visible from any direction (360º), and that the failure of one does not affect the others. They should be supplied by the electricity coming from the surface and, in the case of an emergency, from the onboard batteries that are installed at the external of the bell.
- The onboard batteries that are designed to supply the lights and other functions in the bell should be isolated and protected against short circuits and polarity reversal (a shunt diode should be installed). The housing of the batteries should be designed for the pressure the bell is rated for, and fitted with appropriate mechanisms such as relief and equalization valves. Batteries and their housing should be inspected at least every six months.
- A strobe light that is designed to work independently for at least 24 hours must be installed at the top of the bell.
- A transponder is fitted to the bell to allow for it's detection electronically. Its specifications must be in line with those described in AODC 019 and can be summarized as follows:
  - A pressure housing capable of operating to at least the depth the bell is designed for.
  - Common emergency reply frequency 37.5 KHZ
  - Individual interrogation frequencies:
    Channel A 38.5 KHZ ± 50 HZ
    Channel B 39.5 KHZ ± 50 HZ
  - Receive sensitivity + 15 DB RE 1 Microbar
  - Minimum interrogation pulse width 4 MS
  - Turnaround delay 125.7 ± 0.2 MS
  - Reply pulse width 4 MS ± 0.5 MS

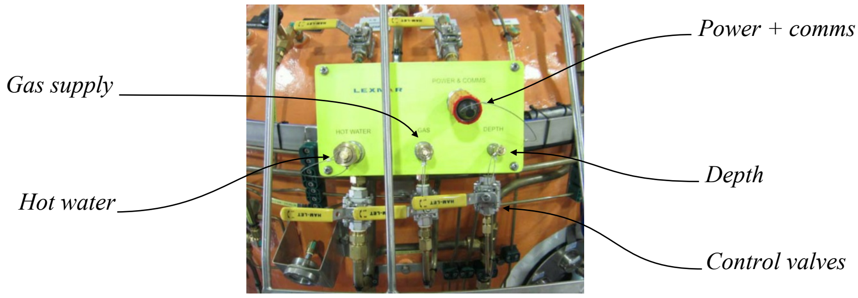
- Reply frequency 37.5 KHZ ± 50 HZ
- Maximum interrogation rate:
  More than 20% of battery life remaining once per second.
- Less than 20% of battery life remaining once per 2 seconds.
- Minimum transponder output power 85 DB RE 1 Microbar at 1 metre
- Minimum transducer polar diagram -6 DB at ± 135°
  solid angle centred on xponder
  vertical axis
- Minimum listening life in water 10 weeks
- Minimum battery life replying at 85 DB 5 days
- A means of testing and interrogating this transponder must be available on the surface at the dive site.



The bell must be designed to be supplied in an emergency if the main umbilical has been severed. For this reason, emergency connectors are provided in a very accessible part of the bell that should be highlighted with a bright colour to connect a 2nd umbilical.

- IMO says that at least the two following connectors should be in place:
  - ¾" NPT (female) for hot water.
  - ½" NPT (female) for breathing gas

  However, a depth gauge, and power supply and comms connections are desirable and are in place on most bells.



- NORSOK recommends more connectors than IMO and says that they should be designed to be operated by divers and ROV. They are described as follows:

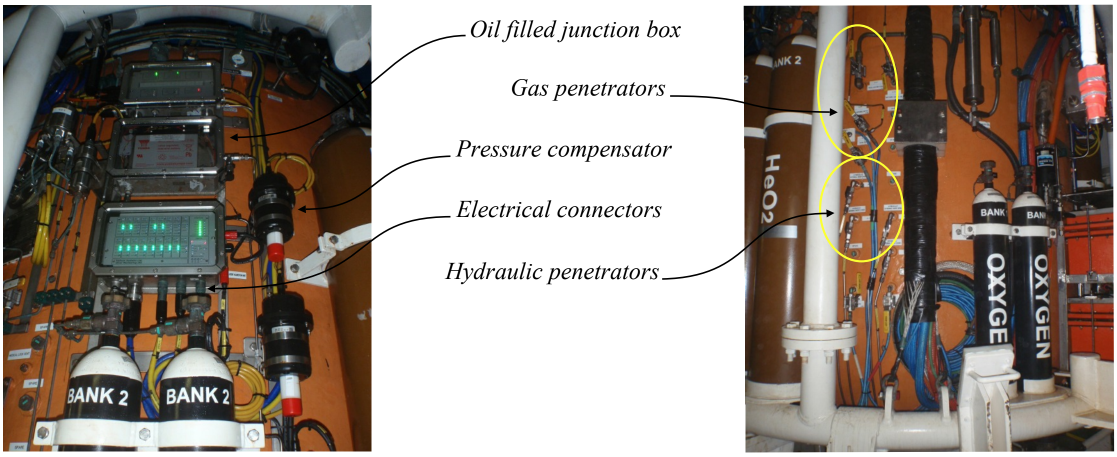
Item	Diver operable	Diver and ROV operable
Breathing gas	1/2" NPT Female	1/2" Male Snaptite SVHN-8
Hot water/heating	3/4" NPT Female	3/4" Male Snaptite SVHN-12
Depth	1/4" NPT Female	1/4" Male Snaptite SVHN-4
Communication	8-contact-4-pins-EO connector (Contacts 1 and 2 used, others n.c.)	8-contact-4-pins-EO connector (Contacts 1 and 2 used, others n.c.)
Emergency power	4-contact-4-pins-EO-connector (Pin 1: 24V, pin 2: 0V, pin 3: ground, pin 4: n.c.)	4-contact-4-pins-EO-connector (Pin 1: 24V, pin 2: 0V, pin 3: ground, pin 4: n.c.)
Gas analysis	1/4" NPT Female	1/4" Male Snaptite SVHN-4

Key:
- EO: "Electro Oceanics"- trade mark - underwater electrical connector
- n.c.: not connected
- NPT: National (standard) Pipe Tapered (threads)
- Snaptite SVHN: trade mark and type designation

As communications to the bell could be lost, a copy of the IMO/AODC/IMCA bell tapping code must be mounted on the outside of the bell in a clearly visible position *(Generally, at the top of the bell)*.

Tapping code	Situation
3.3	Communication opening procedure (inside and outside)
1	Yes or affirmative or agreed
3	No or negative or disagreed
2.2	Repeat please
2	Stop
5	Have you got a seal?
6	Stand by to be pulled up
1.2	Get ready for through water transfer (open your hatch)
2.3.2.3	You will NOT release your ballasts
4.4	Do release your ballast in 30 minutes from now
1.2.3	Do increase your pressure
3.3	Communication closing procedure (inside and outside)

Electrical, communication, and video connections should be made in junction boxes filled with oil and pressure compensated to avoid water intrusion. Also, penetrators that are designed to seal the electrical cables coming from the external of the bell to its inside should be in place and be certified as fit for purpose by a competent person *(IMCA D 018 category 3 or 4)*. They should be installed in strategic points and be appropriately marked.
Penetrators are also in place to seal the hoses coming into the bell. They must be fitted with protection valves or other devices to stop catastrophic pressure loss and be appropriately marked.



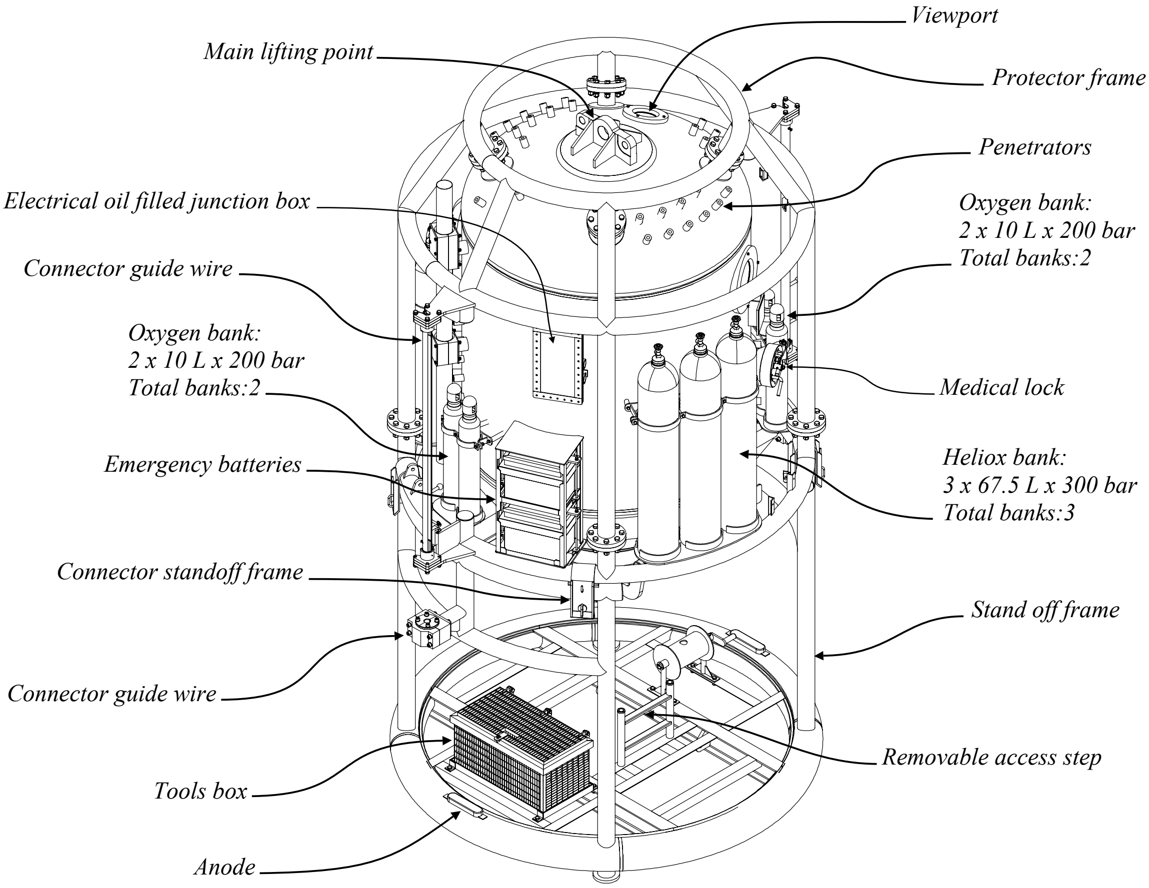
Bells are fitted with a food/medical lock and viewports:

- The medical lock must be equipped with a safety interlock that prevents the opening of the door if the lock is still under pressure. Also, the system should make it impossible to obtain a gas-tight seal on the lock if the clamp is not properly closed.
- Viewports are designed to see what happens around the bell. Those that are in the lower half should have both internal and external protective covers. Those that are in the upper half require external protective covers only. The serial number or other identifying mark for each viewport should be visible and be prominently marked on the outside of the bell adjacent to each viewport. Also, the date of installation should be indicated.
  During the inspection, the person in charge must ensure that they are free of cracks or scratches that could affect their integrity. Note that they must be changed every 10 years.

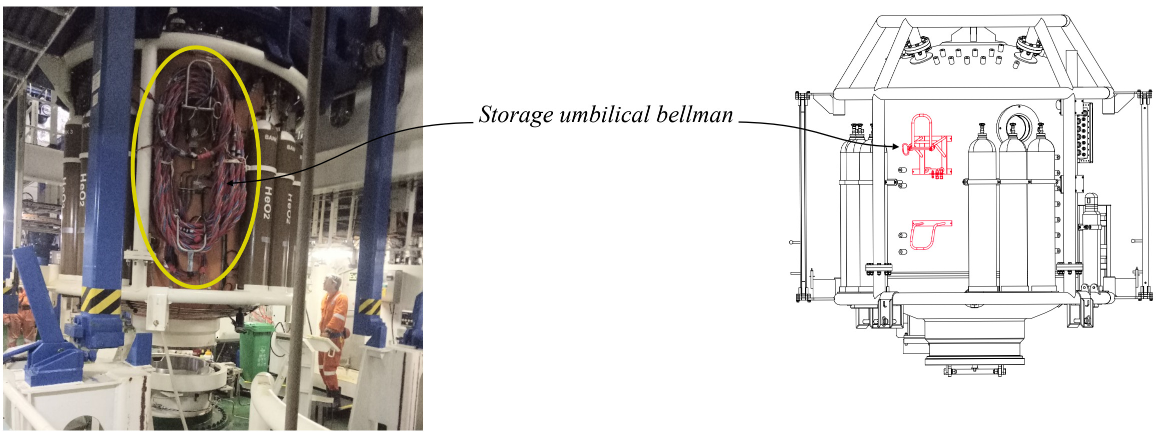
A protector frame is fitted to the bell to protect the pressure vessel and the elements described above from shocks during the launching and the recovery. Note that the pressure vessel must always be in perfect condition.

- The protective paint must be in good condition and there not be serious corrosion visible with anodes that are reasonably depleted. Note that anodes should never be painted.
- Some bells are fitted with external isolation. If it is the case, it must be clean and in good condition. During the inspection, the auditor should ensure that there is no crack or disjointing that could lead to water intrusion and then internal corrosion.

- Note that the identification plate must be clearly visible on the outside of the bell. It should indicate the name of the manufacturer, the reference number of the pressure vessel, its date of fabrication and characteristics *(dimensions, test pressure, max working pressure, etc)*, and the name of the certification body. Note that the bell cannot be used if the plate is missing or suspicious.
- As every pressure vessel, the bell must be fitted with a relief valve. Note that IMCA D 024 says that the relief valve can be replaced by an overpressure alarm.



It often happens that the umbilical of the bellman is stored on the outside of the bell. That gives the advantage to recover some space for the divers and equipment inside the bell. IMCA D 024 says that this umbilical must be secured on an adequate storage point that allows to protect it from damage during the launching and the recovery of the bell. Also, the storage system must be designed such that the bellman is able to quickly release his umbilical once he is out of the bell in an emergency.
IMCA also says that if it is planned to undertake two man bell runs using a bellman's umbilical stowed outside the bell, then the end of the umbilical must be arranged in such a way as to allow the bellman to attach his mask or helmet and test it before the working diver exits the bell.

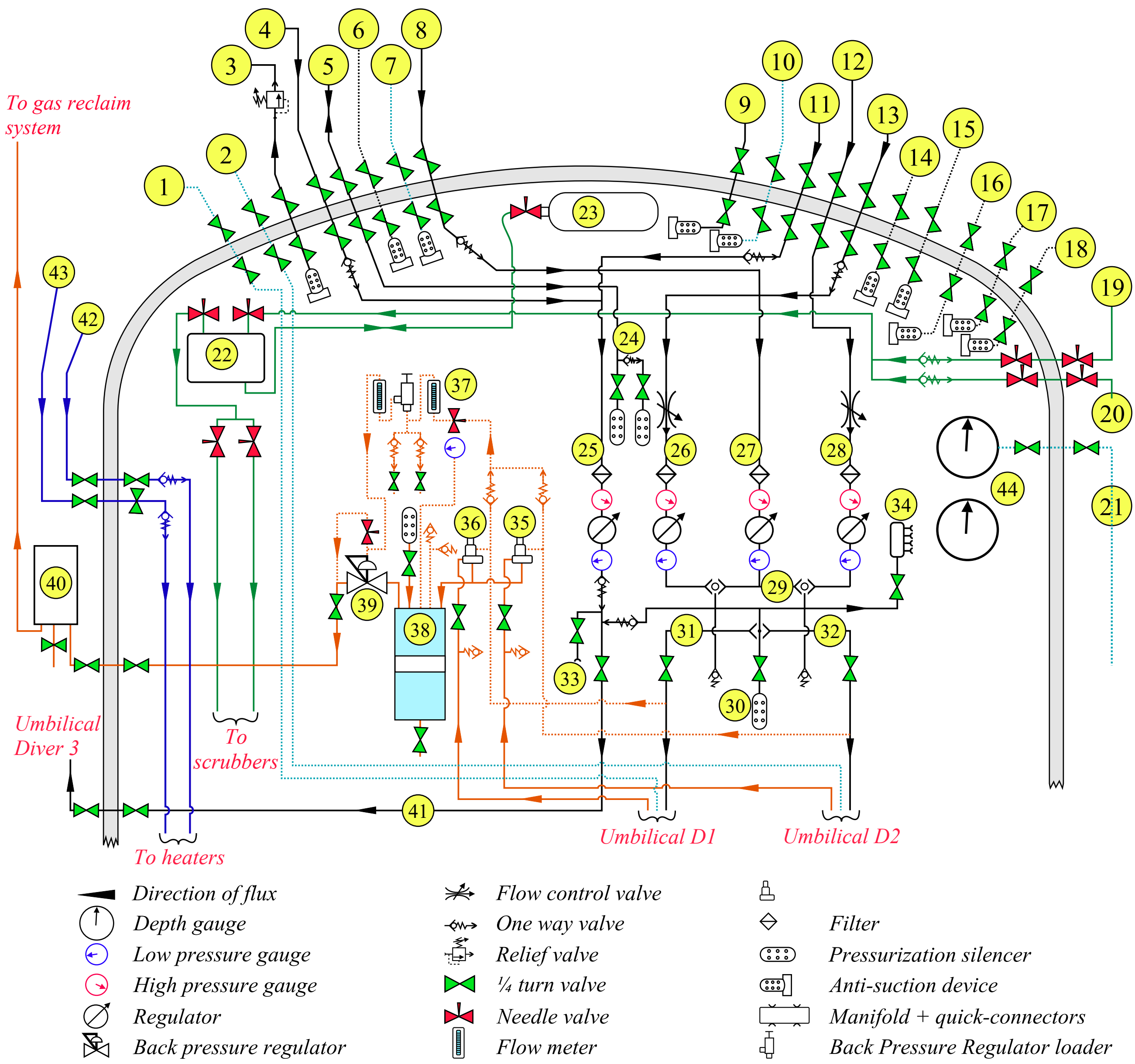


2.3.2.7 - Internal equipment

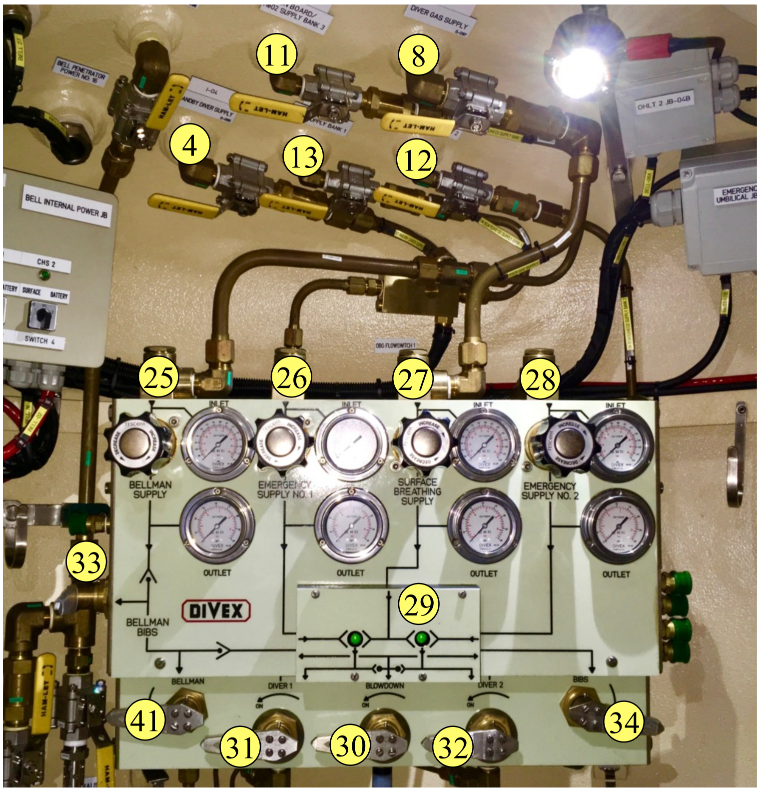
The following gas supplies and exhaust systems, but not limited to, that are also described in the documents #2 "Gas supplies and environmental control" and #4 "Bell diving operations" should be in place:

- Depth Diver 2 *(#1 in the drawing next page)*
- Depth Diver 1 *(#2 in the drawing next page)*
- Safety pressure relief valve bell *(#3 in the drawing next page)*

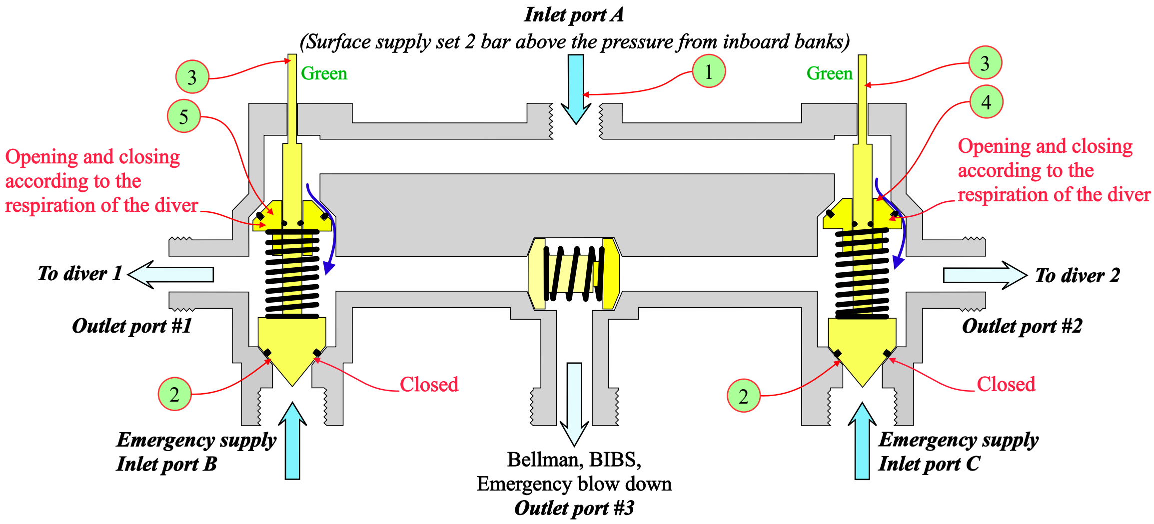
- Standby diver supply *(#4 in the drawing)*
- Bell blow down and exhaust *(#5 & #24 in the drawing)*
- Analysis from dive control *(#6 in the drawing)*
- Bell internal depth monitoring from dive control *(#7 in the drawing)*
- Divers' gas supply from surface *(# 8 & 27)*
- Emergency blow-down and exhaust *(#9 in the drawing),* designed to be connected to the replacement umbilical.
- Emergency internal depth monitoring *(#10 in the drawing)*
- Dedicated supply to diver 3 from onboard bank 3 *(#11, #25 & #41 in the drawing)*
- Emergency supply from onboard bank 2 *(#12 & #28 in the drawing)*
- Emergency supply from onboard bank 1 *(#13 & #26 in the drawing)*
- Tracking regulators banks 1, 2, & 3 *(#14, #15, & #16 in the scheme)*
- Tracking regulators O2 banks #1 *(#17 in the scheme)* & #2 *(#18 in the scheme)*
- O2 banks #1 & #2 *(#19 & &20 in the drawing)*
- External depth bell *(#21 & #44)*
- Manifold O2 add *(#22)* and Buffer tank (#23 *in the drawing*)
- Shuttle block *(#29 in the drawing below),* which is designed to protect the divers from loss of gas supply.
- Emergency blow-down bell *(#30 in the drawing)*
- Gas supply to diver 1 (#31) and gas supply to diver 2 (#32 *in the drawing*)
- Bibs bellman (#33) & bibs divers 1 & 2 (#34 *in the drawing*)
- SEACO (supply actuated exhaust cut-off) valves *(#35 & #36)* protect the diver(s) from too elevated suction.
- Tracking pneumo & back pressure regulator loader (#37) that reduce the depression of the exhaust.
- Internal & external water traps *(#38 & #40 in the drawing)*
- Main and emergency hot water supplies *(#42 & #43 in the drawing)*



IMCA D 024 says that gas supplies must be arranged so that blowing down or flushing the bell does not interfere with the gas supply of any diver outside the bell (item 6.31).
IMCA also says that there must be a primary gas supply for the bellman, which can be from on board bottles or from the surface, sufficient to allow him to exit the bell and recover an injured diver. This supply must be independent of the primary gas supply to the diver(s) in the water. The bellman must also have a secondary supply but this supply may be common with the working divers primary supply, provided it is protected if the working diver's line fails.
It is achieved by the means a gas management panel similar to the model below from DIVEX that allows opening and isolating the supply lines indicated in the scheme on the previous page according to the requirements from IMCA.



The isolation of the supply lines described above is performed by means of the shuttle valves opening or closing according to the scenarios that are described below:
- Scenario A - Normal diving conditions
    1 - The breathing gas is supplied from the surface to the inlet Port A at a pressure slightly above the gas from the emergency onboard gas banks (2 bar).
    2 - The lower part of shuttles closes ports B and C due to the differential pressure (2 bar) between the set up of the emergency onboard gas and the surface supplied gas that pushes them against their seal.
    3 - As a result, surface gas is available to all outlet ports #1, #2, and #3. Also, the emergency indicators on the panel are green.
    4 - If the divers do not breathe, the upper parts of the shuttles that slide on the tails of the lower parts are sealed against their respective housings by the pressure of the springs.
    5 - When a diver inhales, the depression created in the outlet port is sufficient to open the upper part of the shuttle. As a result, surface gas from port A enters in the outlet port until the pressure is equal to the pressure from inlet port A.



- Scenario B - Surface Supply umbilical severed

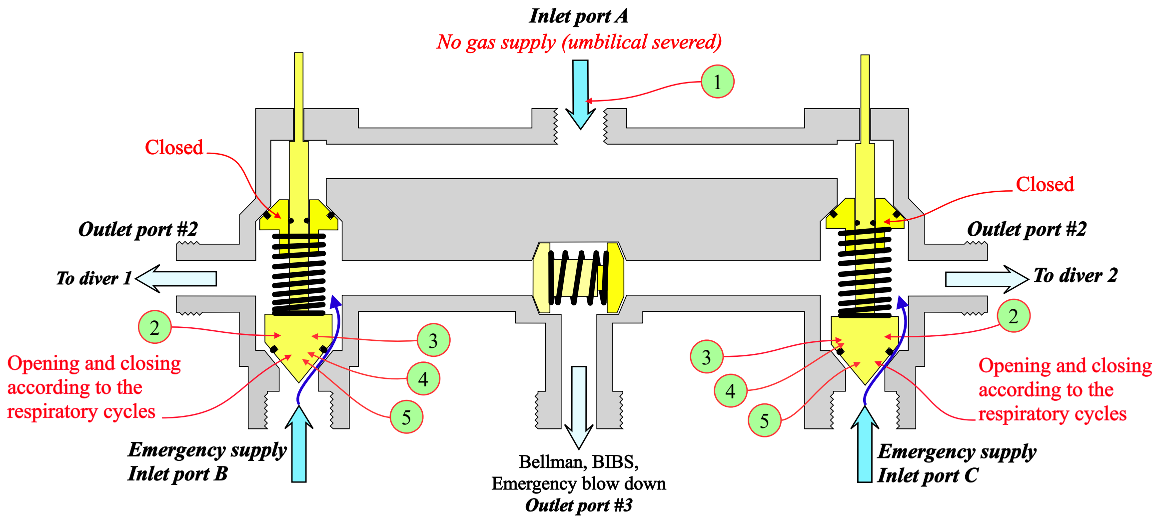
1 - As a consequence of the main umbilical ruptured, no gas is delivered to port A and the pressure in the outlet ports #1 & #2 falls below the supply pressure of inlet ports B and C from the onboard banks. As a result, the bottom part of the shuttles open and the upper parts of the shuttles that slide on the tails of the lower part of the shuttle close as they are pushed by the pressure of the gas from inlet ports B & C.

2 - The onboard supply “Inlet Port B” supplies the outlet Ports #1 and #3 and the onboard supply “Inlet Port C” supplies outlet Ports #2 and #3. The indicator rods rise, and the emergency indicators are red.

3 - When the pressure has been reestablished and if the divers do not breathe, the springs maintain the lower parts of the shuttles against the opening of inlet ports B & C.

4 - As a diver inhales, the reduction in pressure created in the outlet port causes a differential of pressure sufficient to open the lower part of the shuttle.

5 - As the diver exhales the pressure in the outlet port plus the force of the spring are above the one from the emergency supply and the lower part of the shuttle closes again. The opening and closing of the shuttle valves continue according to the respiratory cycles. Note that both emergency indicators on the panel are red.



- Scenario C - Diver 1 umbilical severed

1- In the case of an umbilical being ruptured during the dive, as an example diver 1 umbilical, the continuous free flow in outlet port 1 results in the pressure in Port A falling below the preset differential (2 bar) and the surface supply is unable to maintain a correct flow to supply the divers.

2 - As a result, the auxiliary shuttle closes the side affected (outer port #1) to protect the other half of the block.

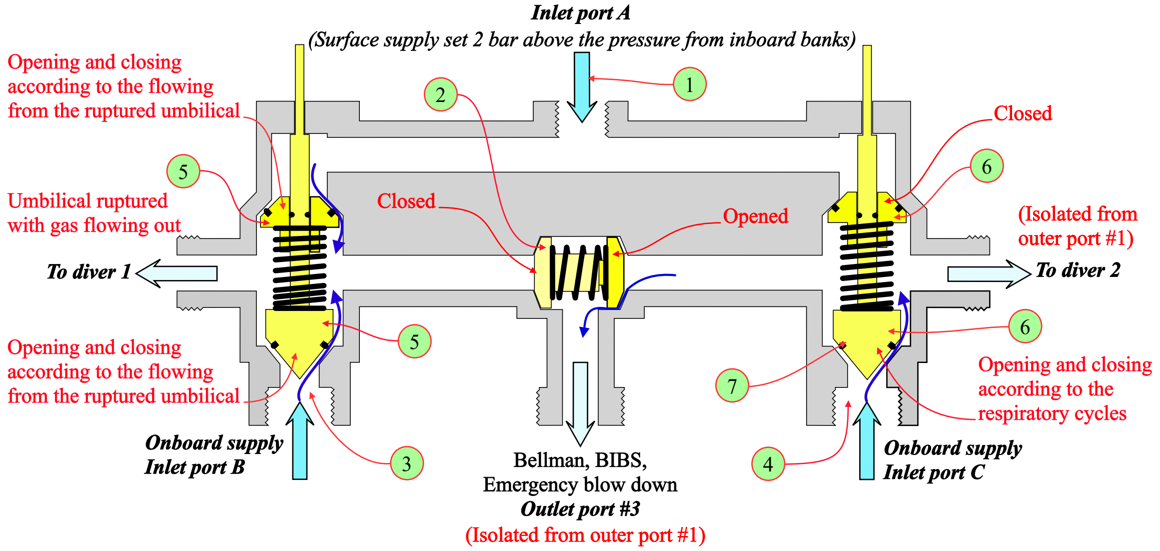
3 - The onboard supply No.1, Port B supplies outlet Port #1.

4 - The onboard supply No.2, Port C supplies outlet Ports #2 and #3 that are isolated from port B by the auxiliary shuttle.

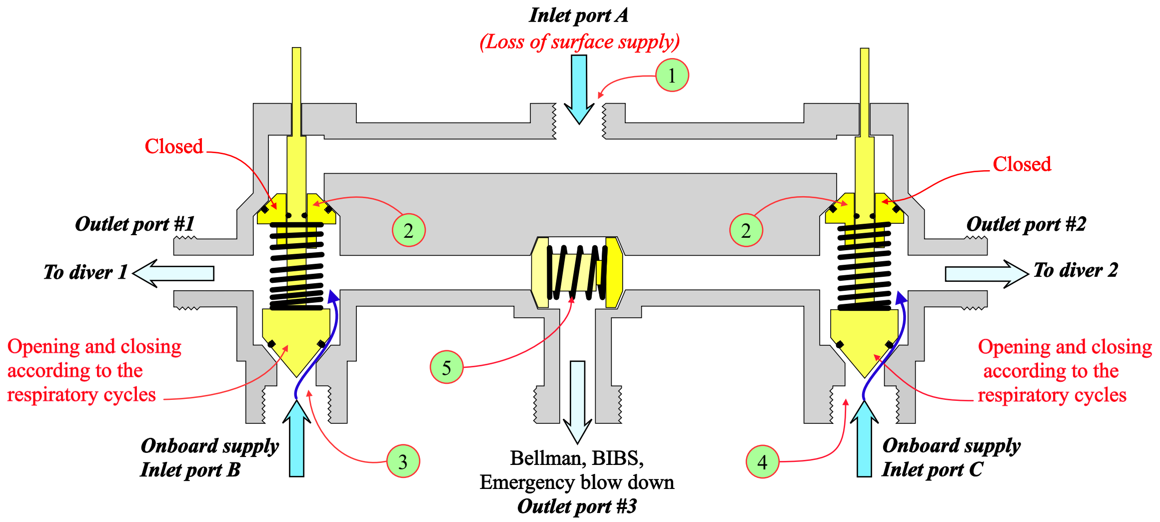
5 - Due to the ruptured umbilical, the continuous free flow in Outlet Port #1 causes both the upper and the lower halves of the shuttle to provide gas. Note that Diver 1 indicator on panel remains red until the emergency supply 1 bank has been depleted and the shuttle spring resets the lower half of the shuttle. At this point, diver 1 indicator will revert to green. the indicator rods lift to give a red indication.

6 - In the outer port #2, the lower half of the shuttle opens to compensate the loss of pressure and the upper half closes as the result of the pressure of the gas from inlet port C and the force of the spring.

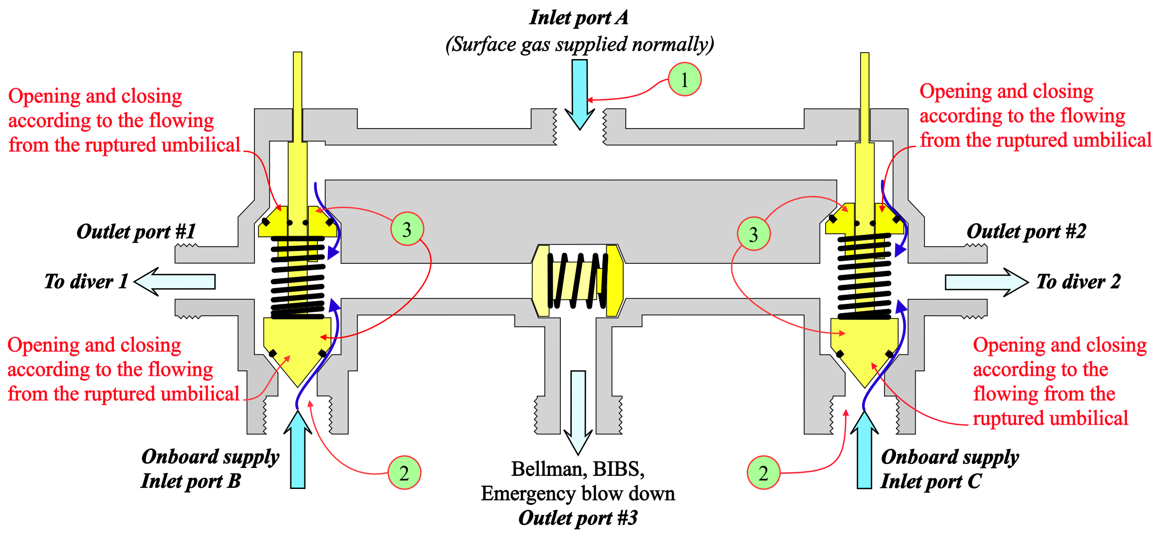
7 - The lower half of the shuttle diver 2 opens and closes to replace the inhaled gas in Outlet Port #2 according to the respiratory cycles. Diver 2 panel indicator remains red.



- Scenario D - Loss of surface supply
    1 - In the case of a loss of surface supply the pressure differential of 2 bar, initially set up between the surface and the onboard supplies, diminishes and eventually equalises with or becomes lower than the onboard supply pressure.
    2 - As a result, the upper parts of the shuttles close and the lower parts open. At this point the indicator rods lift to give a red indication.
    3 - The onboard supply No. 1, Port B, supplies the outlet ports #1 and #3. When diver #1 inhales, he creates a depression that opens the lower shuttle, allowing the gas from the onboard banks to flow in the outlet port #1. When diver #1 exhales, he creates an overpressure which, with the help of the spring, closes the lower shuttle. The process is renewed at each respiration cycle. Due to the differential pressure, the upper part of the shuttle remains closed.
    4 - The onboard supply No. 2, Port C, supplies the outlet ports #2 and #3. The lower shuttle is opened and closed according to the respiration cycles described above.
    5 - Under static conditions the spring loaded auxiliary shuttle valve seals against each half of the block. They open and close when the port #3 is solicited to supply Diver #3, Bibs, or the emergency blow down.
    6 - When the surface supply is restored and the 2 bar differential pressure reinstated, the lower shuttles close and the upper shuttles return to their original status. Note that the indicator returns to the green status.

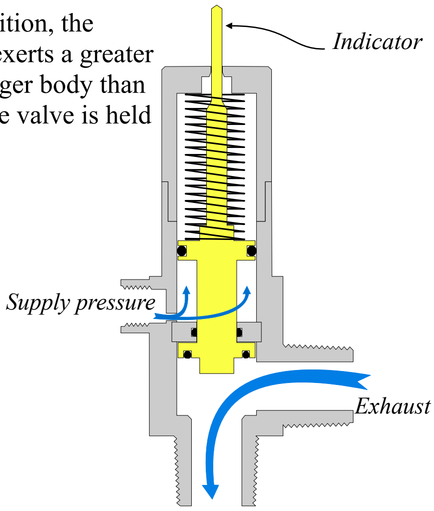


- Scenario E - Divers 1 and 2 umbilicals are severed
    1 - In the case that divers 1 and 2 umbilicals are ruptured during the dive, the surface supply is unable to maintain the flow and the pressure in Port A falls below the preset differential pressure (2 bar).
    2 - As a result, the on board emergency banks 1 and 2 will be brought on line to both Ports B and C.
    3 - Due to the ruptured umbilicals causing excessive free flow in the outlet ports #1 & #2 both the upper and lower halves of Diver’s 1 and 2 shuttle provide gas until the contents of the surface and onboard banks are depleted or the inlet valves are closed. Note that both indicators will remain at red until the two on board banks are depleted or the valves closed, at which point they will revert to green.
    4 - The bellman is supplied from emergency bank #3 *(supply line #25 in the photo)* and remains unaffected by the loss of gas to divers 1 and 2.

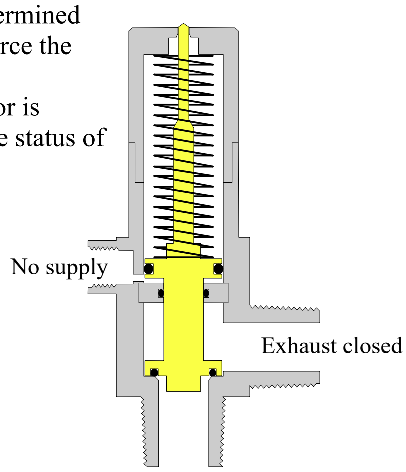


Modern bells are connected to gas reclaim systems that recover the gas mixture breathed by divers, re-process it, and deliver it into the supply system. The breathed gas is removed from the helmet, pass via the bell *(see #35, to #40 in the general scheme)* from which it is sent to the reprocessing unit at the surface where the carbon dioxide, moisture, and particulate or biological contaminant, are removed and oxygen is added. It is then compressed and stored for further use. The gas is recovered to the surface by the suction resulting from the differential pressure between the surface and the depth the bell is stored. However, a too lofty aspiration may injure or kill the divers. For this reason, a back pressure regulator *(#36 in the general scheme)* is used to reduce the differential pressure to only 1 or 2 bar. Also, SAECO (supply actuated exhaust cut-off) valves *(#35 & #36 in the general scheme)* are in place to isolate the divers from the exhaust line in the case that the surface supply drops below the predetermined value. The principle of the SAECO valves is as follows:

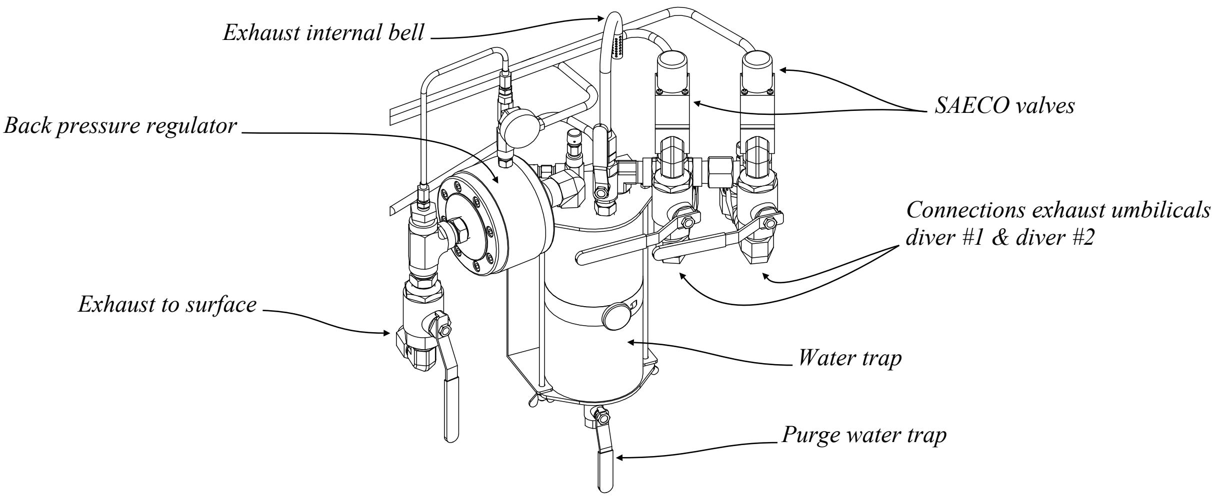
In a normal condition, the supply pressure exerts a greater force on the plunger body than the springs, so the valve is held open.



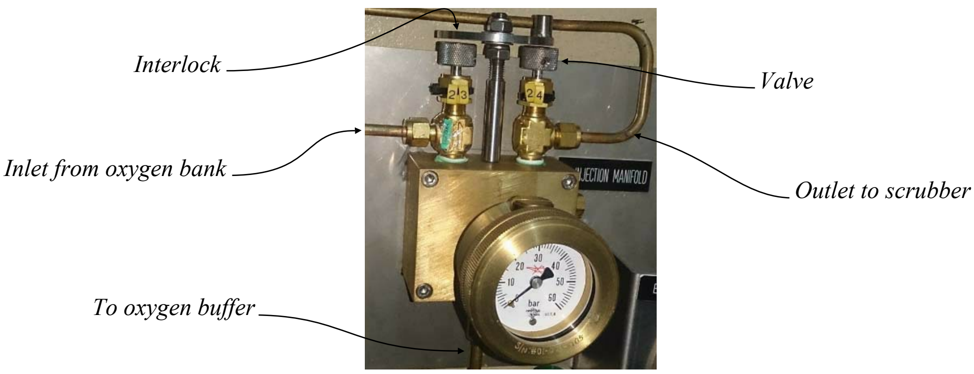
If the diver gas supply pressure falls below a predetermined value, the springs force the piston to close.
Note that an indicator is provided to show the status of the valve.



Water traps are installed to remove the excess moisture from the gas sent to the reclaim system *(see #38 in the general scheme)* They are made of robust transparent materials such as polycarbonates or similar. IMCA says that that the water trap inside the bell must be readily accessible to the bellman. Also, NORSOK U100 also says that they must be designed for simplicity of cleaning, disinfecting and drying, to prevent microbiological contamination.

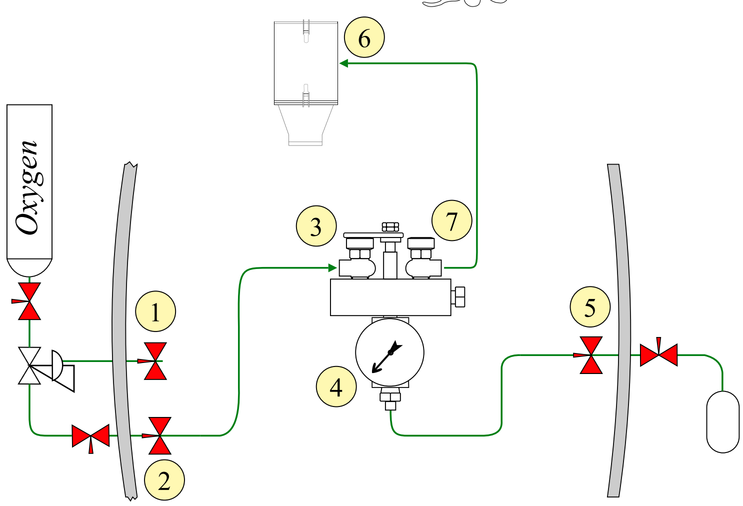


The metabolic consumption of oxygen of one diver during 1 hour is thirty litres. This oxygen must be renewed during the bell run and in the case that the bell is lost. This is the function of the oxygen add system.
IMCA says that the oxygen supplied to the inside of the bell must be reduced to low pressure (normally < 40 bar). Also, there must be a system which limits either the rate of flow or the volume which can enter in the bell to minimize the risk of O_2 building up. This is done through the oxygen add manifold and the buffer *(#22 & #23 in the scheme)* which is explained below.
The O_2 add manifold controls the O_2 injection in the bell (or the HRC) by means of a buffer tank. The interlock between the two valves prevent the O_2 storage gas bottle to be in direct communication with the hyperbaric vessel when the buffer tank is pressurised. The buffer tank is generally designed to contain 30 to 35 litres of oxygen.



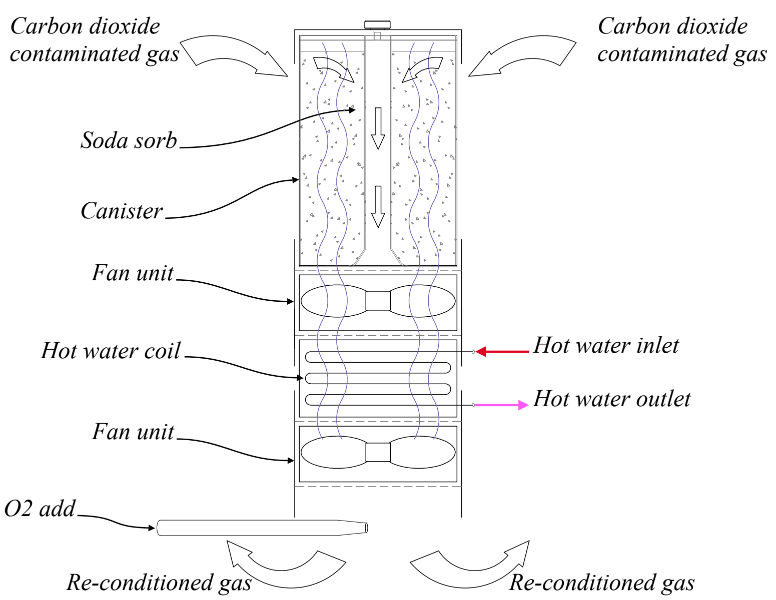
The principle of use is as follows:

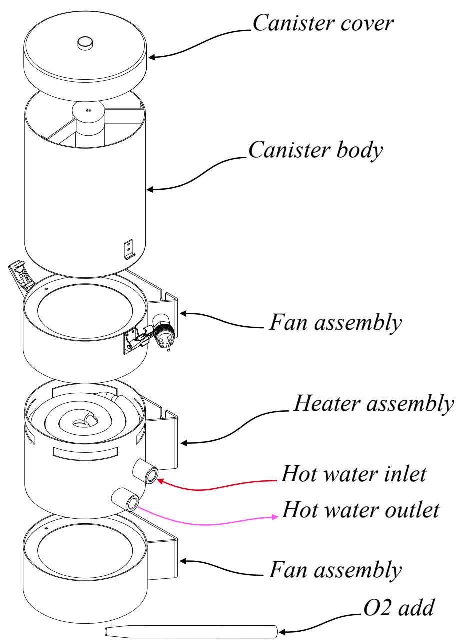
1. *Open the pilot valve of the O2 regulator (#1).*
2. *Open O2 supply valve (#2).*
3. *Move the interlock plate and open the manifold valve No 1 (#3).*
4. *Adjust the pressure to 5 bar above the ambient pressure (#4).*
5. *Open the valve of the buffer cylinder, and fill the cylinder (#5). Close the valve No 1.*
6. *Scrubber on (#6)*
7. *Move the interlock plate above valve No 1 and open the manifold valve No 2 (#7). At this moment the dose of O2 is introduced in the bell.*
8. *Close O2 supply valve (#2), Pilot valve (#1), Buffer valve (#5).*



As already said, valves carrying oxygen (or mixes with more than 25% oxygen) at a pressure higher than 15 bar must not be quarter turn *(See #1 in the picture on the next page)*. Note that the American Society for Testing and Materials (ASTM) recommends needle valves with a non-rotating stem. IMCA says: *"Due to the depths involved in saturation diving, the pressure of such gases will often require to be above 15 bar. All valves and pipework must be cleaned for oxygen service when used for gas mixes containing more than 25% oxygen. This may be demonstrated by means of a suitable procedure to ensure cleanliness which is applied when any components are new, first installed, or moved."*

CO_2 may quickly build up if it is not regularly removed. IMCA D 024 says: *There must be a powered scrubber unit to provide primary CO_2 removal from the atmosphere.*
The scrubbers in use in bells are composed of a cartridge of soda sorb into which a blower pushes the bell atmosphere. Note that the hot water coil is sometimes fitted to the bottom of the scrubber *(see below)*. However, it often happens that the hot water coil is in a separated device. Besides, the blower is used to mix the O2 added through the O2 add system to the chamber atmosphere. The scrubbers are designed to be energized by the onboard batteries of the bell.

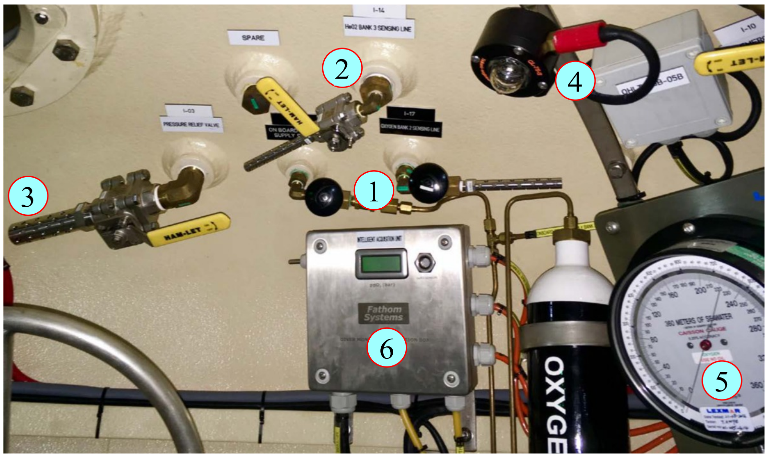




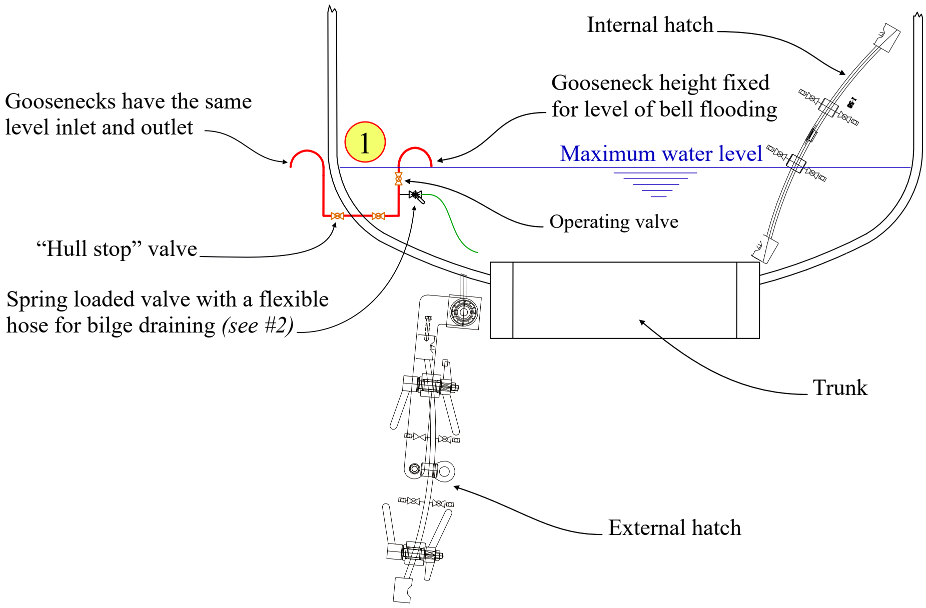
Note that the following elements should be taken into account:

- IMCA D 024 says: *The bell diving supervisor should have control of the bell blow-down at all times*
- As with the external of the bell, Hollow penetrators must be fitted with protection valves or other devices to stop catastrophic pressure loss. They must be clearly marked to show their function *(see #2 in the photo on the next page)*. Also, IMCA D 024 says that any open-ended exhaust pipework must be fitted with guards for finger protection *(see #3 on the next page)*. Any gas inlet pipework should be fitted with some form of a diffuser.
- Valves must be free of corrosion and should move freely through their full range of operation.
- Lighting must be provided to allow reading gauges or documents, operating the gas control panel and any other instruments, and dressing and undressing the divers *(see in the photo above and #4 on the next page)*. These lights are often composed of 24 volts bulbs powered by the main electrical supply from the surface. Also, battery-powered backup lighting must be provided. Note that there must be sufficient energy in the onboard batteries to supply the backup lighting system for at least 24 hours. A lot of modern bells are designed with lights that are automatically switched to the onboard batteries in the case of loss of electrical supply from the surface. These systems must be tested during the checklist.

- Depth gauges must be provided to let the divers know both the internal and external depth of the bell *(see #5 in the picture below and #21 & #44 in the general scheme)*. Also, there must be gauges or an alternative system to monitor the pressure of the onboard gas cylinders from both inside and outside the bell. The frequency of calibration of the gauges must not be less than six months.
- O_2 and CO_2 analysers must be available in the bell so the divers can monitor the atmosphere independent of the surface *(see #6 in the picture below)*. Also, hydrocarbon and H_2S analysers are mandatory and must be in place.



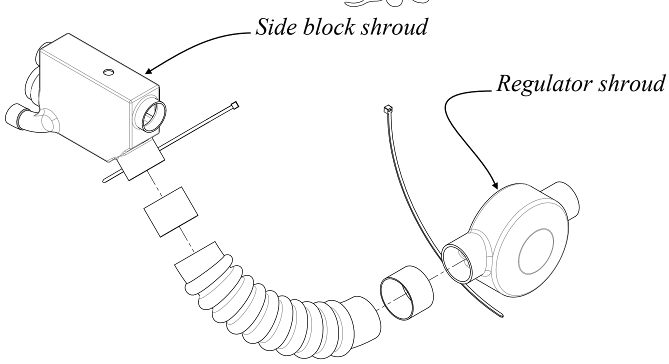
Bottom flooding system:
The lifting of a helpless body fully inside the bell from a point below floor level requires strenuous physical effort. Raising the level of the water inside the bell can help in this matter as a higher water level will help the bellman or the divers to climb back inside. Nevertheless, care must be taken not to fully flood the bell.
For this reason, a partial flooding system is designed to avoid the bell being totally flooded if the valve is left open while the bellman is leaving the bell to rescue the diver *(see #1 in the pictures below)*.
IMCA D 024 says point 6.12: *"There should be a valve fitted to allow partial flooding of the bell by the bellman. This should be in an easily accessible position and clearly visible. This valve should be in addition to the internal hull stop valve. This valve should be protected from accidental opening".*
Important: The operating valve must be reachable from the trunking. Note that, with some bells, if the bellman does forget to raise the level before leaving the bell, he may have great difficulty in getting back inside.



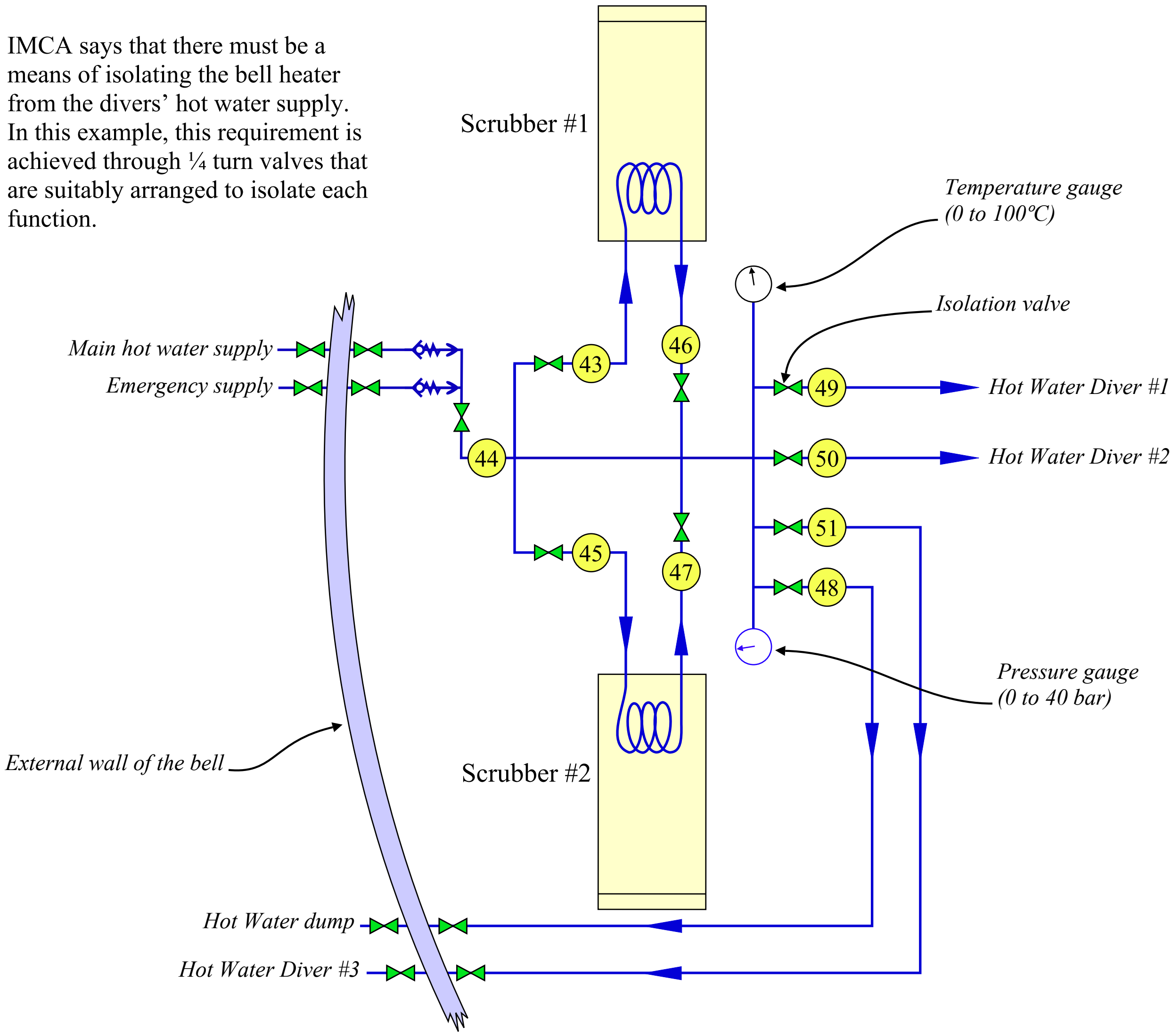
Heating system:
As the water is very cold at depth, the bell must be fitted with a means for warming the divers in the water and inside the bell. Conventional systems in use are based on hot water flowing from the surface through a heater in the bell and the suits of the divers. The heater in the bell is generally integrated into the scrubber. That gives the advantage that the exchanges with the chamber atmosphere are speed up by the fan of the scrubber. IMCA says that this requirement only applies to areas of the world where the ambient water temperature at the diving depth requires the diver to be heated. However, even though the water is hot at shallow depths in tropical and equatorial seas, it generally becomes too cold for long interventions at depths deeper than 40 metres. For this reason, hot water supply to the bell should be ready for use anytime and everywhere in the world. IMCA also says that there should be:

- A means of monitoring the hot water supply temperature inside the bell.
- A means of isolating the bell heater from the divers' hot water supply.
- Note that new bells are equipped with sensors allowing to monitor the temperature of the bell and the divers.

- A means of heating the divers inspired gas if diving at depths below 150 msw:
  The system consists of a rubber shroud inside which hot water flows. This shroud completely encases the side block, bent tube, and the regulator of the helmet to isolate the hot water flow from the surrounding cold water and so provide efficient gas heating. It is connected to the hot water supply of the diver by a splitter block assembly.

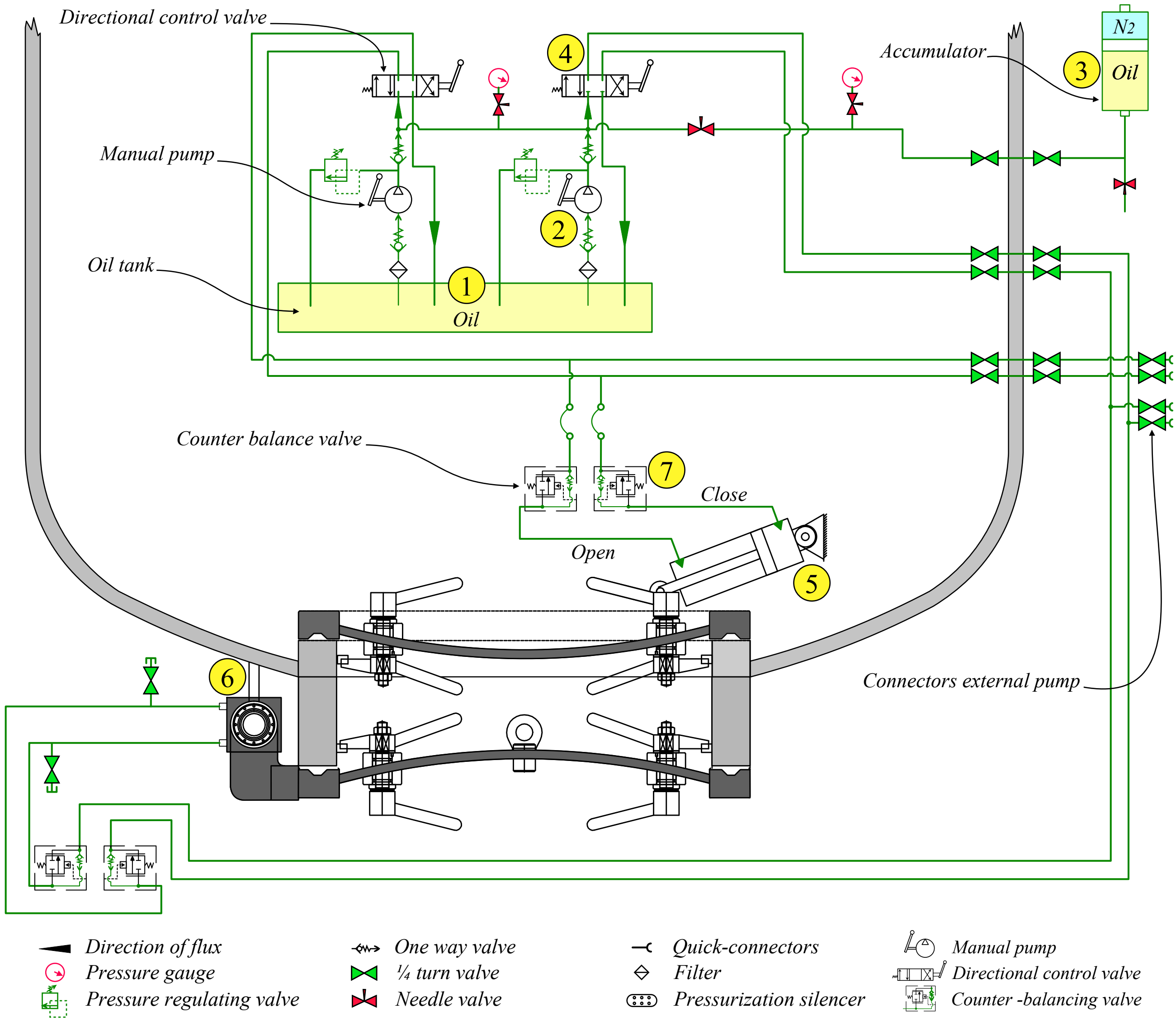


IMCA says that there must be a means of isolating the bell heater from the divers' hot water supply. In this example, this requirement is achieved through ¼ turn valves that are suitably arranged to isolate each function.

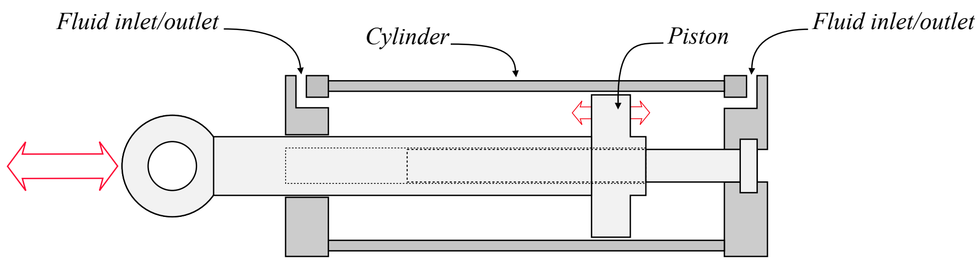


Bottom doors opening and closure *(source: LEXMAR & UDS)*:
As the bottom doors are weighty, moving them manually requires extreme efforts. For this reason, they are opened and closed by hydraulic actuators that are operated from the inside of the bell using manual hydraulic pumps. They can also be operated from externally. In addition to the comfort they provide, the hydraulic actuators prevent the divers from being injured and the seals and the hatches from being damaged. The system is generally designed as follows:

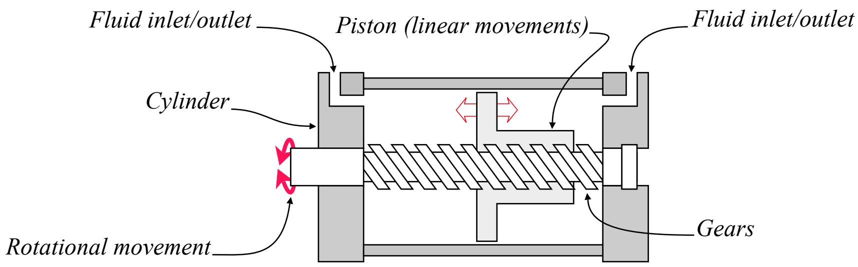
- The hydraulic oil that is stored in a hydraulic tank *(see #1 in the drawing below)* is pumped manually to the hydraulic circuit *(See #2)*. An accumulator *(see #3)* maintains the system at the ideal pressure.
- The Directional Control Valves *(see #4 in the drawing)* allows selecting whether the door is going to be closed or opened.
- The hydraulic fluid is pushed inside the actuator that opens or closes the door, depending on the direction of the flux *(see #5 & #6 in the drawing)*.
- Counterbalance valves *(see #7 in the picture)* are installed to create a back-pressure that prevents the door from free falling when the directional valve that controls the actuator is shifted to lower the load. This system protects the divers from being injured by a door closing unexpectedly and prevents the doors and their seals from being damaged as a result of shocks resulting from uncontrolled closing or opening.



- Note that two types of actuators are used:
  - Linear actuators are composed of a piston that moves out and retracts from and in a cylinder, which creates motion in a straight line such as with hydraulic jacks *(see scheme below)*. They are often used to open and close the internal bottom door of the bell *(see #5 in the drawing above)*.

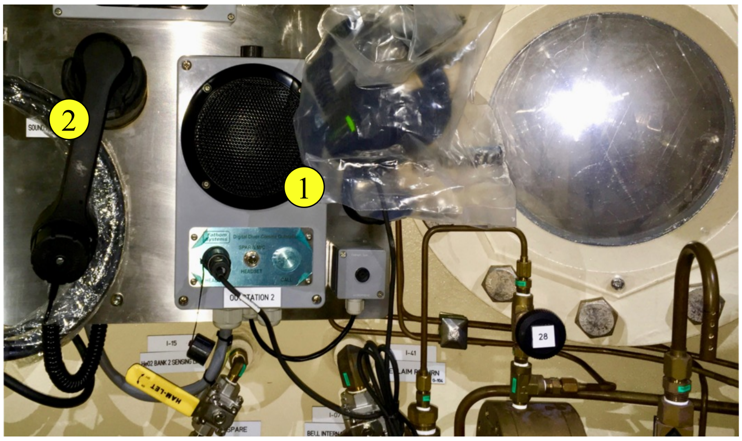


- Rotary actuators are composed of a piston moving in a cylinder that activates gears that create a rotational motion *(see the scheme below)*. They have the advantage of being compact and are often used to open and close the external bottom doors *(see #6 in the general drawing)*.



Communications to and from the diving supervisor should be provided to each diver and the bellman:
The communications of the divers are those of the helmets. The communications of the bellman are composed of an intercom, a sound powered-telephone, and a through water communication system. These devices should be water resistant and be installed in the upper parts of the bell.

- The intercom that is directly connected to the dive control is generally installed on the wall of the bell *(see #1 in the picture below)*. It should be equipped with a "bell button" that can be used by the bellman to attract the attention of the supervisor when a conversation is required.
- A sound-powered telephone *(see #2)* is a communication device powered by the sound pressure of the voice of the user rather than batteries or an electrical power source. When the user speaks into the mouthpiece, the sound waves of his voice cause a diaphragm to vibrate. The vibrations are transferred from the diaphragm through a drive rod to an armature centered in a wire coil that generates an electrical current. The current then is transmitted to the earpiece of the receiver, where the process is reversed. As a result, the person at the other end of the circuit hears the sounds transmitted. Note that the earpiece and the mouthpiece can be used interchangeably. As a result, the user can talk into the earpiece or hear through the mouthpiece, which allows continuing a conversation if one of these two elements fails. Ringing is accomplished by a manually activated magneto producing sufficient electrical power to operate a howler at the called station.
- Through water communications, also called Emergency bell communicator, are wireless communications that must be available to allow the supervisor to talk to the divers inside the bell when it is in the water and communications through wired systems are no more possible. The system operates by using high frequency ultrasonic sound waves that are passed through the water between the bell and the surface vessel. The set installed in the bell is powered by the onboard batteries of the bell or a dedicated battery pack *(see #3)*.



Note that NORSOK U100 says that a means for processing of speech (unscrambling) should be available when using helium mixtures and used when required. A Modified Rhyme Test (MRT) should be used to verify that the operational communications systems are in accordance with the requirements of the table below.

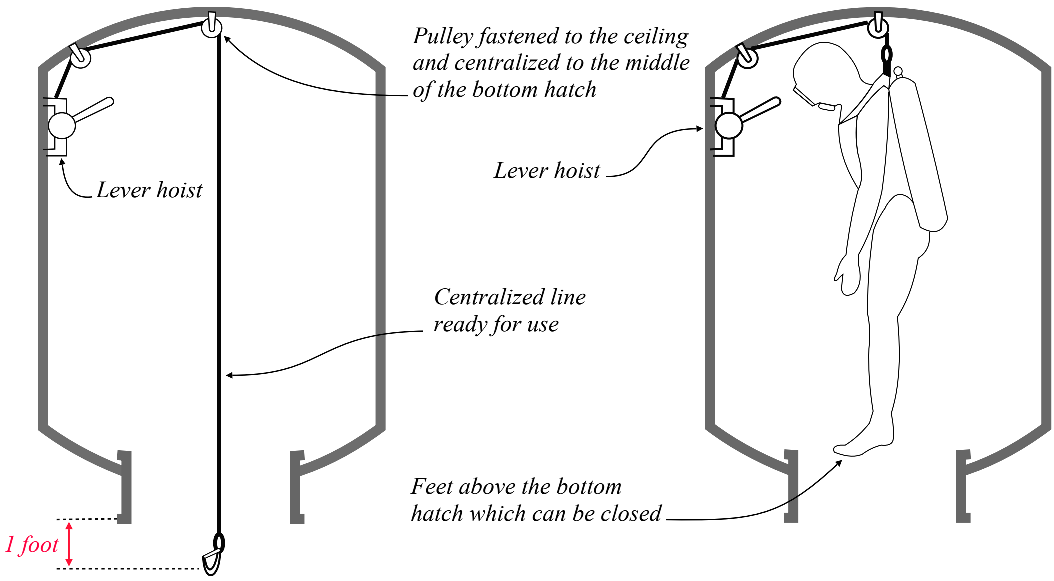
Communication requirement	***MRT score***
Exceptionally high intelligibility; separate syllables understood	0.97
Normally acceptable intelligibility; about 98 % of sentences correctly heard; single digits understood	0.91
Minimally acceptable intelligibility; limited standardized phrases understood; about 90% sentences correctly heard (not acceptable for operational equipment).	0.75

Cameras connected to a Close Circuit Television must be installed in the bell. They should be arranged in such way that the diving supervisor has a panoramic internal view of the bell and can observe the bellman and the divers during the dives and when performing the checklists.

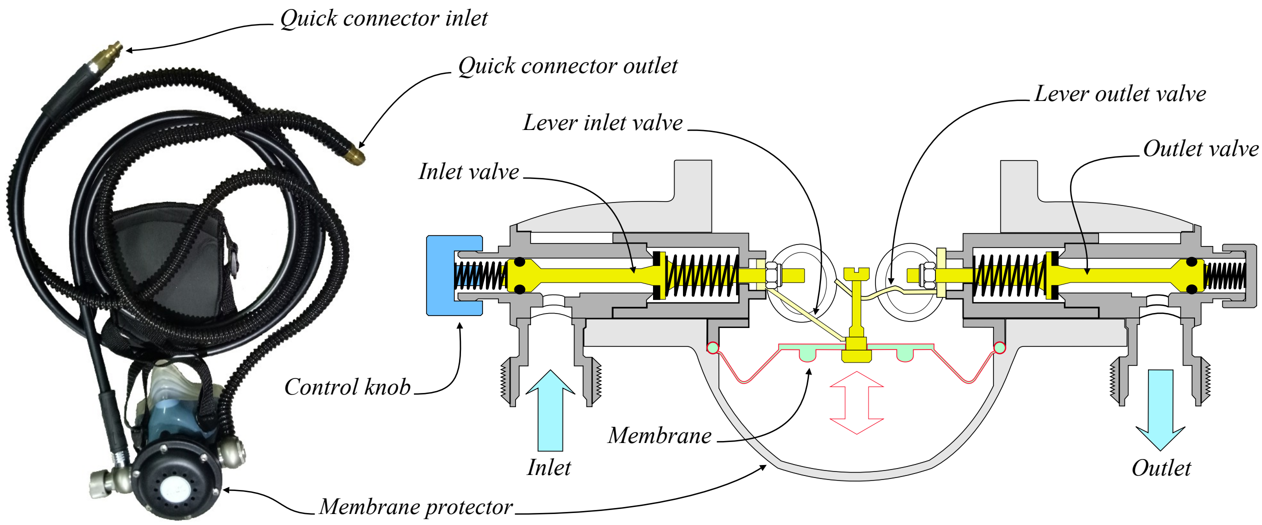
Other requirements to take into account:

- The umbilicals must be appropriately stored. It is achieved by the means of dedicated supports to which they are secured. In the bell taken as an example below, only divers' 1 & 2 umbilicals are stored inside the bell despite its internal volume of 6 m³ *(see the photo below from the CCTV).*
- IMCA D 024 says: *There must be a seat provided in the bell for the bellman. This seat should have a restraining harness or lap belt fitted which is available for use. There must also be a means of restraining each diver during ascent and descent in order to minimise the risk of injury. Note: This does not signify a separate seat for each diver.*
  The restraining of divers can be achieved by the use of handles adequately positioned. Nevertheless, a lot of bells, such as the bell from UDS Lichtenstein below, are equipped with a seat for each diver *(note that these seats are provided with lap belts instead of harnesses)*. These seats usually are retractable, so they can be folded up not to disturb the divers if necessary.

- IMCA also says: *Consideration should be given to providing a means to stop the bellman falling into the open manway either as a result of a slip or of losing consciousness.* Note that this requirement is optional
- A lifting device must be installed in the bell to recover and secure an unconscious diver into the bell. The system must be arranged to lift the casualty up as high as possible inside the bell to clear the trunking. For this reason, the topside pulley is connected to a padeye which is welded to the top of the bell and centralized above the middle of the bottom hatch. IMCA says that consideration should be given to providing a second pulley system in the case of bells where more than one diver may be locked out. Also, the attachment points for the pulleys inside the bell should be designed for the purpose and approved by a competent person.
  Note that during the bell run, the hook of the lifting device should be deployed and adjusted around 1 foot below the hatch.



Individual emergency breathing system:
IMCA D 024 says: *An oral/nasal or full face BIBS mask must be supplied for each occupant of the bell. This should be capable of providing breathing gas either from the surface or from the on board cylinders.*
Built-In Breathing System (BIBS) masks are also used in chambers to provide breathing gas in an emergency. These masks must be always ready for use. In the LEXMAR bells taken as an example, they are connected to the sides of the gas management panel using quick connectors. Note that there must be one mask for each diver plus one that is kept as a backup.
Depending on the model, the supply pressure for the mask generally ranges from 5 bar to 12 bar over the ambient bell pressure. Most masks can be adjusted to the optimum breathing resistance using a flow control knob.
The system consists of one membrane connected by two levers to an inlet valve and an outlet valve. When the diver inspires, the movement of the membrane opens the inlet valve and closes the outlet valve. When the diver expires, the movement of the diaphragm closes the inlet valve and opens the outlet valve.



Individual emergency CO_2 removal and heating systems:
IMCA says: *There should be a means provided, independent of surface supplies, to maintain the diver's body temperature and reduce CO2 for a minimum period of 24 hours in an emergency. This will normally be by means of survival bags and emergency scrubbers. Note: The heating requirement only applies to areas of the world where the ambient water temperature at the diving depth (or the depth the bell may descend to) requires the divers to be heated. The CO2 reduction requirement will apply in all circumstances.*
Lung Powered Scrubbers are used in hyperbaric environments to ensure the scrubbing of carbon dioxide contained in breathing gases in the event of a breakdown of gas supplies and ventilation.
The system consists of a mask connected by a ringed flexible hose to a cylinder that contains a cartridge of soda sorb. This cartridge that is designed to be used for 4 hours can be easily and quickly changed.
Sufficient refills must be provided to ensure at least 24 hrs breathing in case of a lost bell. They must be stored in sealed containers that fully isolate them from the atmosphere.
Lung powered scrubbers must be included in the survival kit of the bell and be regularly checked for integrity.

The survival bags should be specifically designed to be used in diving bells and may have active heating systems.
Regarding this point, NORSOK U100 says: *Shallower than 180 msw it may or may not include active heating (from e.g. electric energy). However, deeper than 180 msw it shall include active heating (from e.g. electric energy). The survival system shall ensure the occupants' ability to participate in the rescue operation.*
They should be stored in dry and fully sealed bags to protect them from the moist atmosphere found in bells.

Other emergency devices:
A copy of the AODC/IMCA emergency tapping code must be easily accessible to the bell occupants. Remember that this code must also be displayed on the outside of the bell. Also, IMCA says that a plasticized copy of the relevant emergency procedures must be available inside the bell with the list of valve positions to be adopted in an emergency. These procedures and list should duplicate those kept in dive control.

A medical kit that conforms with DMAC 15 list must be available and stored in a dedicated waterproof container that is marked with a white cross on a green background. This kit should be checked at least every 6 months

Also, the following tools that are not listed in IMCA D 024 should be available in the bell. Note that they must be adequately stored.

- Pliers and spanners that can be used to disconnect the wires and the umbilical or perform a quick repair.
- A cable cutter and a saw to cut the ruptured umbilical.
- A blank for closing a damaged porthole.

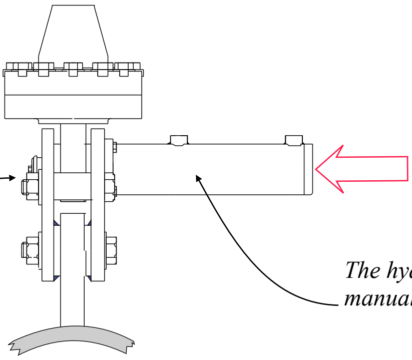
2.3.2.8 - Optional cutters or release mechanisms of the umbilical and lift wires operated from inside the bell

In the case of a lost bell that has to be recovered to the surface, the remaining parts of umbilical and wires should usually be cut or released.
Several systems exist to cut or release the umbilical and wires from inside the bell, avoiding the need to send a diver or the supporting ROV to perform this task. Nevertheless, note that these systems are only optional and that the majority of bells currently in service are not fitted with them.

IMCA says that:

- The system must be capable of operation from inside the bell, and the operating mechanism must be protected against accidental operation.
- Two independent actions are needed to operate the cutters or release mechanisms.
- If the cutters or release mechanisms are operated by means of pressurisation (gas or hydraulic), then isolations need to be in place such that it cannot be activated accidentally by external water pressure, internal gas pressure, or leakage of the hydraulic circuit.
- Visual examination and function test should be performed at least every 6 months and a full examination and function test every year

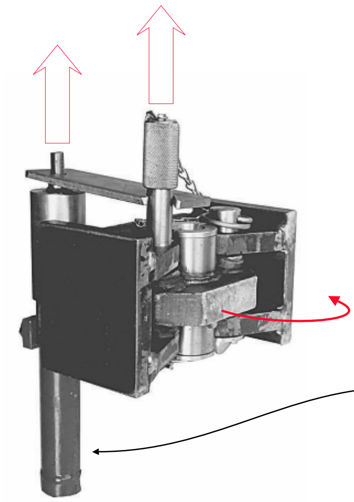
Example #1: Lifting wire release system



The socket eye is held directly by the ramrod. Removing the rod releases the socket

The hydraulic ram is actuated by a manual pump located inside the bell.

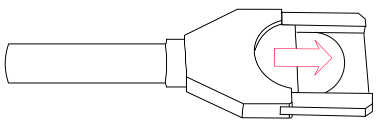
Example #2: Guide wire release system

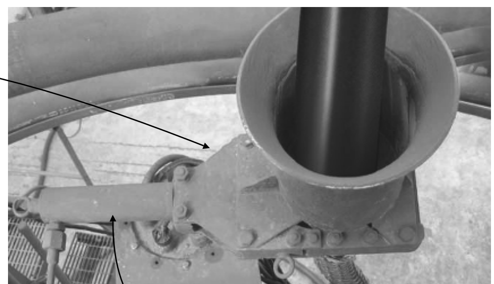


As for the lifting wire release system,the hydraulic ram is actuated by a manual pump located inside the bell.

Example #3: Umbilical cutter

The hydraulically operated device presented allows cutting an umbilical of a diameter up to 120 mm.





The system consists of a guillotine of which the blade is actuated by a hydraulic piston

Hydraulic piston

2.3.2.9 - Maintenance

During the operations, all the components of the bell must be visually checked and function tested before every dive. Also, the manufacturer provides the following guidelines regarding daily, weekly and monthly maintenance:

- Daily maintenance:
  - Visual inspection of the inside and the outside of the bell for damage.
  - Washing of the exterior of the bell if prone to oil / mud etc.
  - Battery diaphragm checks and removal of the gas in excess.
  - Tests of the Through Water Communication System.
- Weekly maintenance:
  - Close visual inspection of the sealing faces and O-rings
  - Close visual inspection of the batteries and their containers.
  - Checks of the quality and clarity of the mineral oil of the external bell enclosures. (Note that a degraded quality may indicate water intrusion).
- Monthly maintenance:
  - Visual check of viewports, pipework, electrical wiring, and hull penetrators.
  - Lighting, heating, and scrubber checks.
  - Inspection of the hull beneath the floor plates (possible accumulated water or corrosion).
  - Valve function tests.
  - Verification of the Labels of the penetrators.
  - Visual inspection of webbing straps and stitching on bags.

The six-monthly and longer frequencies inspections recommended by the manufacturer conform with those of IMCA Diving Equipment Systems Inspection Guidance Note (DESIGN) D 024. They are used for the regular audits and certification of the bell:

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*
Design and manufacturer				According to the certification body
Pressure vessel	6 months	2 ½ years	5 years	
Viewports	6 months	2 ½ years	5 years	10 years old max.
Buoyant ascent: Secure mechanism.	6 months			
Buoyant ascent: Other components	6 months			Test buoyancy: 1 year
Ballast release system	Dry function test: 1 year		1 year (Overload static test)	NDE of critical items: 1 year
Cutter/ release system	Visual: 6 months Dry function test : 1 year			
Transponder	6 months			
External cylinders	6 months	2 years	4 years	
Interlock pipework	6 months	2 years		
Overpressure relief valve	6 months	2 ½ years		
External battery pack : overpressure relief testing	6 months	2 ½ years		Renewal bursting discs: 10 years
Valves, Pipework, fittings (external)	6 months	2 years	1st installation	
Electrical	6 months			
Gauges	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*
Emergency survival packs and passive scrubbers	6 months: (Water ingress and integrity packaging)			Fully checked and repacked: 12 months
Gas monitoring (O_2 and CO_2)	6 months			
Bell contamination control	6 months			
Gas cylinder pressure gauges	6 months			
Communication (all systems)	6 months			
Approval pulley attachment point inside the bell				Permanent
Medical equipment (DMAC 15)	6 months			
Valves, Pipework, fittings (internal)	6 months	2 years	1st installation	
Electrical (internal)	6 months			
Alarm (internal)	6 months			

2.3.3 - Divers' excursion umbilicals

2.3.3.1 - Function

Divers' excursion umbilicals are life lines that link the divers to the bell and provide the following functions:

- Gas supplies and exhausts:
  - Gas supply hose
  - Divers' #1 & #2 gas reclaim exhaust. Note that this function is not available for the standby diver as his mask is not equipped with reclaim.
- Temperature & depth control
  - Hot water supply
  - Depth control through pneumo hose which can also be used as a backup gas supply in the case of an emergency.
  - Telemetry. Note that this function is optional and performed through an electronic sensor installed at the end of the umbilical and sending information such as the depth and dive profile of the diver to a computer in the dive control.
- Communications & video recording
  - Communications to the dive control
  - Helmet camera wiring
  - Helmet light wiring

The excursion umbilical is also used to recover an injured or unconscious diver into the bell. For this reason, it must be extremely robust and resist the traction exerted by the diver and the tender during a critical recovery.

2.3.3.2 - Fabrication requirement

A good umbilical must be in one piece and able to slide easily to allow a recovery of the diver in any circumstance. Umbilical assemblies in use in the diving industry are of two basic constructions; spiral-wound and parallel.

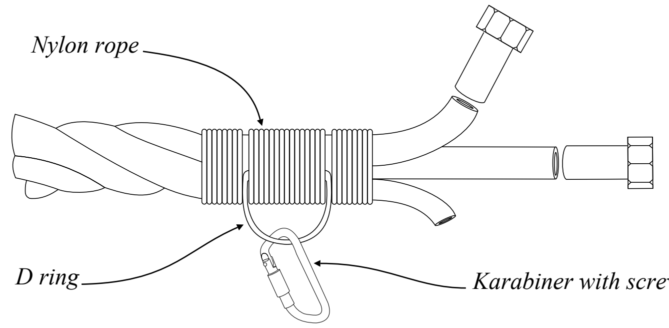
- Spiral-wound umbilicals are manufactured industrially as only machines allow producing this type of equipment with perfect twisting. Their strength comes from their spiral construction where hoses and cables are supporting each other. They resist kinking and abrasion and provide good flexibility, which allows them to slide along obstacles without being caught and damaged. As a result, they are recommended and imposed by most clients.
- Parallel (taped) assemblies are generally homemade umbilicals where hoses and cables are bought separately and taped together around a rope that is designed not to extend while under traction. These umbilicals are no more used in the majority of the saturation diving sites as most clients request manufactured spiral-wound umbilicals with a guarantee from the manufacturer.
  Also, even though some isolated clients do not impose these requirements, home umbilicals are far from the level of safety of industrial umbilicals because it often happens that the cables and hoses are not perfectly grouped, which results in an umbilical with asperities and buckles that can be caught in debris or parts of the structures and can preclude the recovery of the diver. Besides, they do not offer the degree of flexibility of spiral-wound umbilicals, and the grey tape commonly used to keep the hoses and cables together has to be replaced often. For these reasons, such umbilicals should not be used.

The previous generation of umbilical breathing hoses was made of rubber or PVC compounds. New generation hoses are made predominantly from polyurethane, which is a polymer without potentially harmful additives. Also, US Navy says that the maximum life of a rubber breathing hose should be limited to twelve years, and that synthetic umbilical assemblies do not deteriorate significantly with age, and may remain in service as long as it is deemed to be satisfactory. The size and working pressure of the hoses and cables that compose the umbilicals are commonly as follows (*Note that the telemetry cable, which is optional, is not indicated in this table)*

Item	*Common colour*	*Internal diameter*	*External diameter*	*Working pressure*	*Burst pressure*	*Weight in seawater*
Gas supply hose	*Yellow or blue*	*9.5 mm (3/8")*	*17.5 mm (0.69")*	*35 bar*	*140 bar*	*52 g/m*
		12.7 mm (1/2")	*21 mm (0.83")*	*35 bar*	*140 bar*	*128 g/m*
Pneumo hose	*Blue or yellow*	*6.5 mm (1/4")*	*11.5 mm (0.45")*	*35 bar*	*140 bar*	*16 g/m*
Hot water hose	*Black*	*12.7 mm (1/2")*	*21 mm (0.83")*	*25 bar*	*100 bar*	*105 g/m*
Reclaim hose	*Black*	*16 mm (5/8")*	*27 mm (1.6")*	*69 bar*	*276 bar*	*95 g/m*
Comms cable	*Red*	*N/A*	*10.8 mm (0.43")*	*N/A*	*N/A*	*21 g/m*
Light cable	*Not specified*	*N/A*	*8 mm (0.31")*	*N/A*	*N/A*	*20 g/m*
Video cable	*Orange*	*N/A*	*11 mm (0.43")*	*N/A*	*N/A*	*70 g/m*

Also, note the following:

- Hoses and cables that compose the umbilical must be in one piece.
- There must be four wires into the communication cable to allow the installation of duplex communications. A duplex communication system enables all parties connected to the system to talk and listen at the same time.
- Safety and manufacturer organizations say that only swaged/crimped fittings should be used with hoses. Precautions must be implemented to be sure that these fittings conform with those of the helmet and the bell.
- The communication, light, and video fittings that are installed onto the cables at the diver's end must be waterproof. US Navy says that the preferred method of construction is to have the fitting molded onto the cable as with "marsh marine" connectors. However, there are several commercial self-curing rubbers, or epoxy kits can be used for sealing these types of connectors. Also, electrical and communication fittings which body is made of copper or brass and are waterproofed by the use of O rings and mechanical sealing systems can be used. However, these fittings which are often employed on bells and ROVs are expensive.
- Hoses must be tested at 1.5 times the working pressure when new or repaired.
- IMCA recommends that the diver's end of the umbilical is fitted with a means which allows it to be securely fastened to the diver's safety harness without putting any strain on the individual whip ends. This is generally done by the use of a D ring that is seized by nylon ropes onto the umbilical. US Navy says that the D ring must be welded and be able to hold a weight of 227 kg (500 pounds). US Navy also says that when seizing the D-ring to the umbilical assembly, wraps must be tight, but care must be taken to ensure that the hoses and cables are not crushed or pinched.
  A device with a locking mechanism should be used to link the D ring of the umbilical to the D ring of the harness. A 3¾"/100 mm carabiner is often used for this purpose.



Also, the lengths of the hoses and cables after the D ring must be adjusted to allow comfortable movements to the diver. However, these lengths must not be in excess. Thus, they must be calculated in function of the position of the attachment of the umbilical on the harness.

2.3.3.3 - Installation in the bell

IMCA D 024 says that the umbilical must be marked for length at least every 10 m using a recognized system which allows easy visual identification of the length paid out. However, NORSOK and a lot of organizations say that the umbilicals must be marked for length at least every 5 metres using a system similar to the one displayed below which is the system recommended in this manual:

Umbilical length	*Black tape*	*Red tape*
5 m		*1 turn*
10 m	*1 turn*	
15 m	*1 turn +*	*1 turn*
20 m	*2 turns*	
25 m	*2 turns +*	*1 turn*
30 m	*3 turns*	
35 m	*3 turns +*	*1 turn*
40 m	*4 turns*	
45 m	*4 turns +*	*1 turn*
50 m	*1 broad turn*	
55 m		*1 turn*
60 m	*1 turn*	

NORSOK U 100 says that when determining the maximum umbilical length, the following safety factors should be taken into consideration:

- The distance from the diver to the nearest hazard point *(thrusters, seawater intake, etc.)* should be a minimum of 5 metres;
- duration of bail-out equipment;
- breathing resistance;
- thermal conditions;
- umbilical storage, deployment, handling and recovery;
- wet tendering;
- ROV survey with mapping of debris/ obstructions;
- positioning and stability of the work-site

Also IMCA & NORSOK say that the bellman's umbilical should be 2 metres (6½ feet) longer than the working diver(s) umbilical.
As a result, the maximum allowable distances of the divers must be clearly identified for each diving operation and the umbilicals restricted in the bell to these maximum lengths. The means of restriction must be sufficiently solid not to be removed unexpectedly, and smooth enough not to damage the umbilical. Dedicated ropes securing the umbilicals to their supports are commonly used for this purpose. Also, the fittings of the umbilicals in the bell must be protected from direct tractions. For this reason, the fastening of the umbilical must be designed in the same manner as for the diver's end.

Note that NORSOK standard U100 says: *"The length of the diver's umbilical shall be limited to the length considered necessary at any given time, and shall not exceed 45 m from point of tending in the bell/wet bell/basket."*

2.3.3.4 - Backup excursion umbilical and their storage

Note that backup excursion umbilicals are not mandatory with IMCA or NORSOK. However, they should be available on site in case one of those in service has to be repaired.
It must be understood that repairing a damaged umbilical may take time and require specific equipment. As a result, the diving operations may be delayed which is not conceivable in the scope of expensive operations such as saturation diving. For this reason, replacement excursion umbilicals are often required by the clients. They should be ready for immediate use and stored in such condition that they will not be damaged by the surrounding activities and the external weather conditions.
Also, regarding the umbilical of the surface standby diver, IMCA says that an adequate stowage allowing it to be coiled up away from risks of damage and such that a minimum bend radius of components is not compromised should be provided. These recommendations should be applied to stored umbilicals.

2.3.3.5 - Maintenance

Umbilicals must be checked and function tested before every dive. Also, IMCA D 024 says the following:

- The continuity and resistance of all cables must be checked every six months. Also, the other electrical components of the umbilical should be examined and function tested at the same time.
- Hose components should be carefully monitored, and function tested every six months. Also, they must be tested to their maximum working pressure every two years. Besides, they must be hydro tested to 1.5 times their maximum working pressure when they are new or as recommended by the manufacturer or the certification body.

Hyperlink Tables of contents

2.3.4 - Diving suits

Diving suits are of primary importance to protect the diver from wounds, marine growths, venomous animals, and of course, isolate him from the effect of cold waters that are often encountered at depth. Note that water has a thermal conductivity of 0.606 Watt per metre Kelvin (W/mK) at 25 ºC when air is only 0.0262 W/mK.
Two means of protection are proposed by the manufacturers: Passive and active protection.

- Passive protection suits are based on materials, such as foamed neoprene, that isolate the diver from the surrounding medium. Thus, they slow down the loss of heat during a limited time that depends on the temperature of the water, the convection due to the underwater current, and the pressure at depth, which crushes the isolation materials. As a result, depending on the surrounding conditions, the divers may become hypothermic if these suits are used for too long exposures.
- Active protections suits are designed to supply heat that is monitored to provide a comfortable temperature allowing the diver to work a long time. Modern systems are all based on suits heated by hot water. However, electrically-heated diving suits have been studied and tested in the past.

As diving operations in saturation imply long dive times, active protections suits are the most appropriate..

2.3.4.1 - Neoprene hot water suits

These suits that are made of pre-compressed 4 mm neoprene or thicker standard neoprene are reinforced by an anti-abrasion lining and are designed with a zip to allow easy dressing. Besides, rubber protections are glued to the knee and elbow areas, which are the most exposed to shocks and wear.
They are the continuation, and in fact, the termination of the hot water circuit installed in the bell: Thus, the hot water is delivered from the surface to the bell, and then to the divers through the water hose of the umbilical. This hose is connected to a manifold situated on the right-hand side at a hip level using a quick connector that must be designed to be secured. This manifold, that must allow for easy adjusting of the flow of water, must be designed with a water dump option to divert the water flow outside the suit if necessary.
The hot water is distributed by small flexible tubes carrying it from the manifold to the wrists and ankles, in addition to those in place to heat the bulb and the spinal cord. This hot water distribution system should capable of supplying a flow of up to 30 litres per minute. Note that the flow and the temperature of the hot water are monitored and adjusted by the diving supervisor according to the indications of the diver. The manifold of the suit is only used to refine the adjustments made at the surface or shut off the water supply if it becomes scalding.
The suit is closed by appropriate boots and gloves that are selected according to the operation to perform. These items are generally fitted with long sleeves to slow down the flow moving out of the suit by these openings.
In the case that the hot water supply is lost the neoprene allows sufficient passive protection to return to the bell safely.
Note that when performing the pre-dive checks, the following points should be closely monitored:

- There must not be tears or excessive wear of the neoprene cloth, and the teeth of the zip must be in perfect condition with the slider moving smoothly.
- The manifold must be easy to open and close, and the small tubes must be all in place and connected.
- The quick connection of the hot water hose of the umbilical must be able to be secured and not to be disconnected unexpectedly; The male coupler must not have any visible shock, and the ring of the female coupler should move and lock easily with all the locking balls in place.

2.3.4.2 - Hot water suits made of linen cloth or similar

The neoprene hot water suits described above are often too hot in shallow tropical waters and outfits that are made of heavy linen cloth are usually preferred. They can be suits that are specifically manufactured for this purpose or modified and reinforced robust coveralls. They are supplied with hot water with the same components as a neoprene hot water suit. However, they do not offer any extra buoyancy and passive thermal protection, which limits their usage to depths less than 100 m.
Rubber gloves and reinforced boots generally close them. However, neoprene socks are worn when fins are used. As with neoprene suits and standard working coveralls, a sturdy zip allows easy dressing.
Suits made of linen are sufficiently robust to protect against corals, shells and small shocks. However, they should not be used if there is the risk of cold underwater currents. Thus, when the conditions at the location are doubtful, a neoprene hot water suit should be preferred.
Also, linen clothes are often aggressive to wet skin, and it is recommended to use soft under-suits to protect it. It is also recommended that these under suits are designed to follow the shapes of the body as the openings of the linen suits are often imperfectly sealed and wide enough to allow small venomous animals such as jellyfish and others to enter into them. As these suits do not offer any thermal protection, wet suits made of foamed neoprene 3 mm or thicker are often used.
The points to closely monitor during pre-dive checks are those already described for the neoprene hot water suits.

2.3.4.3 - Hot water undersuits

They are liners which stops suit chafe and direct contact of the hot water to the skin.
As with wetsuits used for swimming, they are made of foamed neoprene 3 mm thickness that is protected from wear and other damages by an external sheet of lycra or a similar textile. They are generally one-piece suits. Nevertheless, suits composed of two pieces can be used.
Due to their elasticity, such suits follow perfectly the shapes of the body and the flow of water entering into them is reduced to a very minimum that is then trapped underneath the neoprene layer. Thus, the body is isolated from direct contact with the hot water. Also, they offer additional isolation if the hot water supply fails.
The performances of a wetsuit depends on the number and the size of the bubbles that are in the neoprene foam. The high-density neoprenes are more compressed and have more small bubbles. As a result, they are less subject to crushing and buoyancy change than low-density neoprene. Thus, they are offering better thermal protection and are often used to manufacture diving suits such as neoprene hot water suits. However, their inconvenience is that they are not as soft as low-density neoprenes that, despite more reduced isolation, are preferred for undersuits that must allow maximum movements.
It must be noted that these undersuits are designed to be worn underneath hot water suits that are made of 4 mm high-density neoprene or thick non-compressed neoprene. However, when hot water suits made of linen cloth are used their thickness, and isolating materials can be selected to compensate for the absence of isolation offered by these suits.

2.3.5 - Diving harness

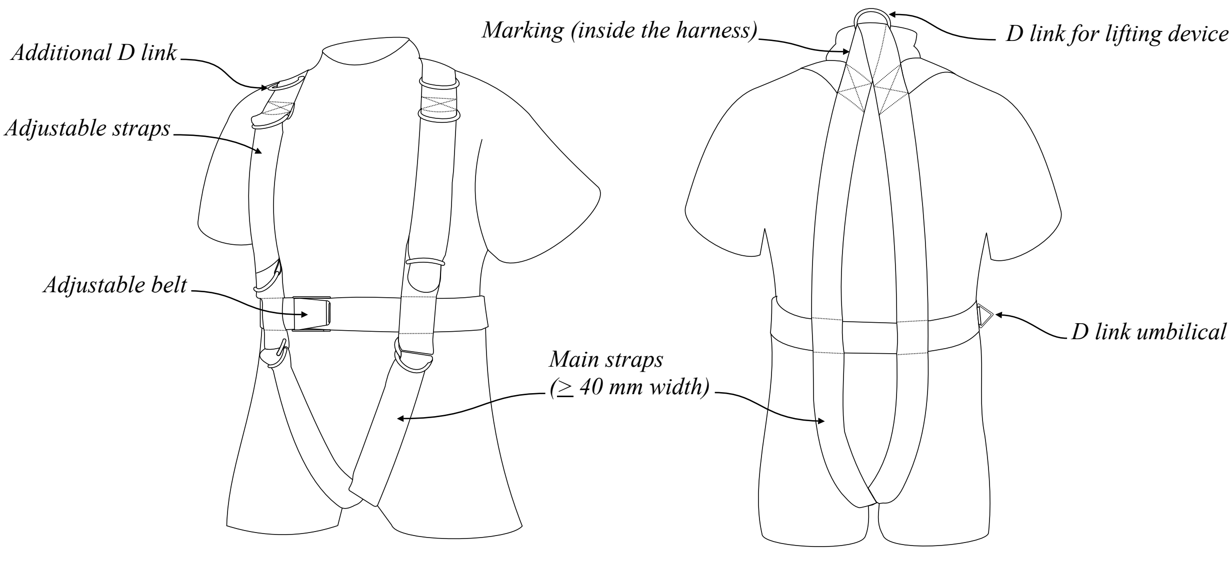
2.3.5.1 - Description

Each diver (including the standby) should be provided with a safety harness. This harness should be manufactured to an appropriate and recognized standard and be fit for the purpose it is to be used.
Note that the standards published according to which these items are manufactured such as EN 361, ISO 10333-1, ANSI Z359.11, are those for the design of "full body harnesses" which are personal protective equipment against falls from a height. However even though their conception and process of manufacturing are very similar, there are differences between harnesses that are designed to stop a fall and the diving harnesses which aim is the recovery of an injured diver from the water and the securing of his umbilical.
For this reason, diving harnesses should never be used for working at height, and a harness which purpose is to stop a fall should not be used underwater as it is not designed for that.
Among the common elements found on each type of harness we can note the following:

- Webbing and sewing threads should be made from virgin filament or multi-filament synthetic fibres suitable for their intended use. According to EN 361, the breaking tenacity (Tensile Strength) should be at least 0,6 N/tex (one N/Tex is the same as one GPa per gram per cm^3).
- The threads used for sewing must be physically compatible with the webbing, and the quality must be compatible with that of the webbing. They must be of a contrasting shade or colour to facilitate visual inspections.
- A harness must comprise straps or similar elements which are placed near the pelvic area and on the shoulders. It must fit the wearer and means of adjustment should be provided.
- The harness should be designed in such a way that straps cannot migrate from their position and be loosen by themselves. Also, the width of the straps that support the body must be at least 40 mm and the other straps at least 20 mm. Note that the straps which support the torso or exert pressure on it must be the primary straps.
- The securing buckles must be designed in such a way that they can only be assembled in a correct manner. If they are capable of being assembled in more than one way, each method of assembly must conform to the strength and performance requirements.
- Metallic fittings must be treated against corrosion. As a result, evidence of corrosion of the metal is not acceptable. However, the presence of tarnishing and white scaling is acceptable.
- Marking on the harness must be in the language of the country of destination or in a common language. The marking must include the following:
    - A pictogram to indicate that users must read the information supplied by the manufacturer.
    - The model/type identification mark of the harness, the standard the harness conforms to, the name of the manufacturer, the reference number, and the date of manufacture.
    - The 1st date of service should be written on it in such a way that it is clearly visible and cannot be erased.

Regarding the particularities of diving harnesses note the following:

- The D link dedicated to connecting the lifting gear is a the top of the harness to be easily accessible despite the bailout and not in between the shoulders as with the stop fall harnesses. This D link must be sufficiently wide and robust enough to connect a sling or a small hook and recover an injured diver to the bell when necessary. As a result, it must be capable of withstanding the weight of the diver and a dynamic shock that may result from bad handling. Note that the tests performed for "full body harnesses" by manufacturers consist of a falling dummy of 100 kg on a vertical distance of 4 m.
- There must be an attachment for the umbilical of the diver that is commonly situated at a hip level for the saturation divers. However, connectors at chest level are often used for surface orientated diving. Remember that US navy says that this D link must be welded and be able to hold a weight of 227 kg (500 pounds).
- A backpack may or may not be fitted to the harness.



They are numerous models of harnesses. However, they can be classified into two main categories:

- Standard recovery harnesses are similar to the one drawn on the previous page and the blue one below. They may be fitted with a backpack. However, they are often worn underneath stabilizing jackets or backpacks that are not provided with a recovery attachment point designed to recover an injured diver.
- Vest harnesses are composed of straps similar to those used for standard harnesses that are sewed to a robust vest. These harnesses are generally designed to be fitted with a backpack. Also, numerous pockets where the diver can distribute additional weights (to control his buoyancy) and tools, are available. They are comfortable to wear, are very robust, and allow quick dressing.

Vest harness

Standard harness

Also, a lot of models that can be considered as hybrids between these two categories exist. In addition, note that recovery harness may be part of equipment such as rebreathers and Buoyancy Control Devices (BCD).

2.3.5.2 - Pre-dive check and preventive withdrawn

Harnesses must be controlled before each dive. This control consists of the inspection of the elements described above. As an example:

- There must not be any excessive wear of the straps, and the sewing threads must be in perfect condition.
- The D links must be without deformation and not be corroded
- The securing buckles must not be corroded, and the straps must not slide when they are secured
- The backpack, if fitted with, must be correctly secured so the bailout cannot be lost.

It is essential to be aware that diving harnesses have a limited life time. As a reference, IMCA D 024 says:

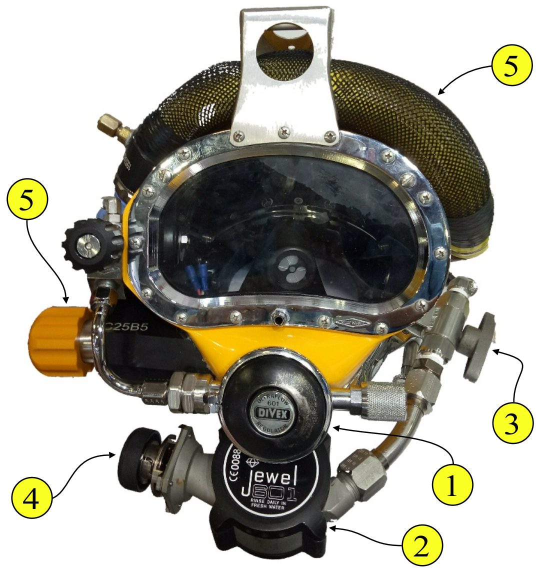
- Harnesses should be discarded 5 years from the time first put into service, or sooner if recommended by the manufacturer or deemed appropriate by the divers or the technician in charge of the maintenance of the diving system due to conditions of use.
- Harnesses should be discarded 10 years from the date of manufacture or sooner if recommended by the manufacturer or deemed appropriate by the divers or the technician in charge of the maintenance of the diving system due to conditions of use. Note that they must be discarded even though they are in service for less than 5 years.

As a result of what is said above, it is prudent to control the dates of service and the condition of these items before starting the project

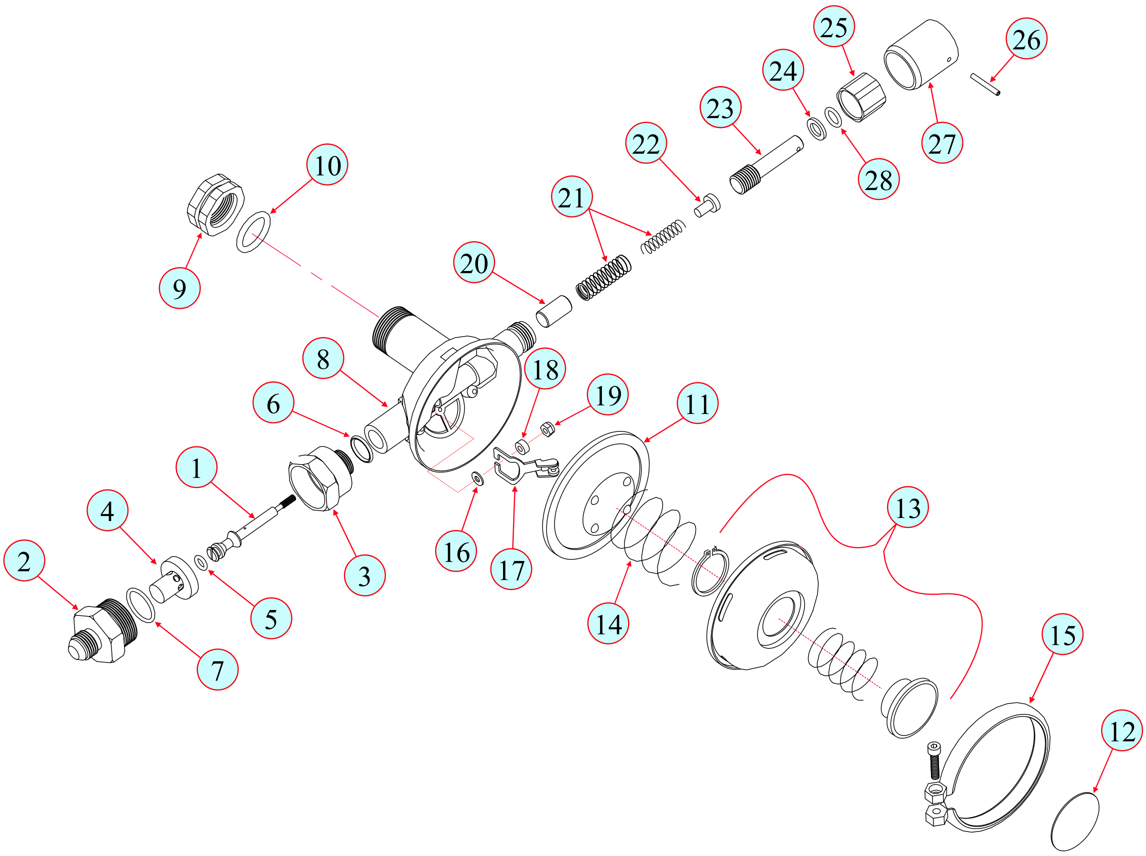
2.3.6 - Helmets and Standby diver mask

2.3.6.1 - Working divers helmets

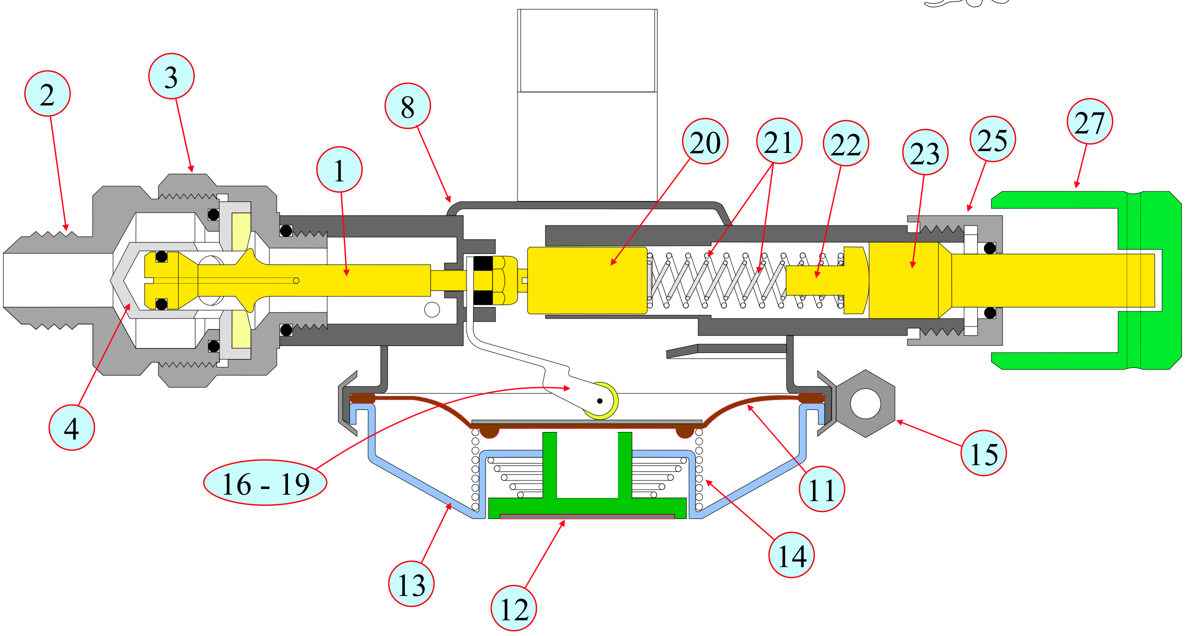
As already said, new bells are fitted with a gas reclaim system. For this reason, helmets used by the working divers must be equipped for this purpose. Also, these helmets must be designed to protect the head of the divers from shocks and dropping objects and they should be fitted with a means to stop them becoming detached from their clamp while in use.
The Divex "Ultrajewel 601" is the model fitted with a gas reclaim valve that is the most used in the industry.
It is composed of the fibreglass shell of the Kirby Morgan 17 C to which the Divex "Ultra-flow 601" balanced demand regulator *(see #1)* and the "Divex Jewel 601" two stages reclaim valve *(see #2)* have been installed.
When used with an efficient heliox reclaim system, this helmet allows a reduction of 90% of gas consumption or better.
The closed-circuit reclaim system is activated by the opening of the 1/4 turn exhaust valve situated on the left-hand side of the helmet *(see #3)* and the closing the "open circuit valve" *(See #4)* that is installed on the right-hand side of the Divex Jewel 601 two stages reclaim valve *(See #2)*. In the case of a problem with the reclaim circuit, the helmet can be operated in open-circuit mode. In this case, the "open circuit valve" is opened and the exhaust ¼ turn valve is closed to isolate the hose that returns the exhaled gas to the reclaim system.
Note that the model in the picture is also designed for the use of a Compact Bailout Rebreathing Apparatus (see #5).



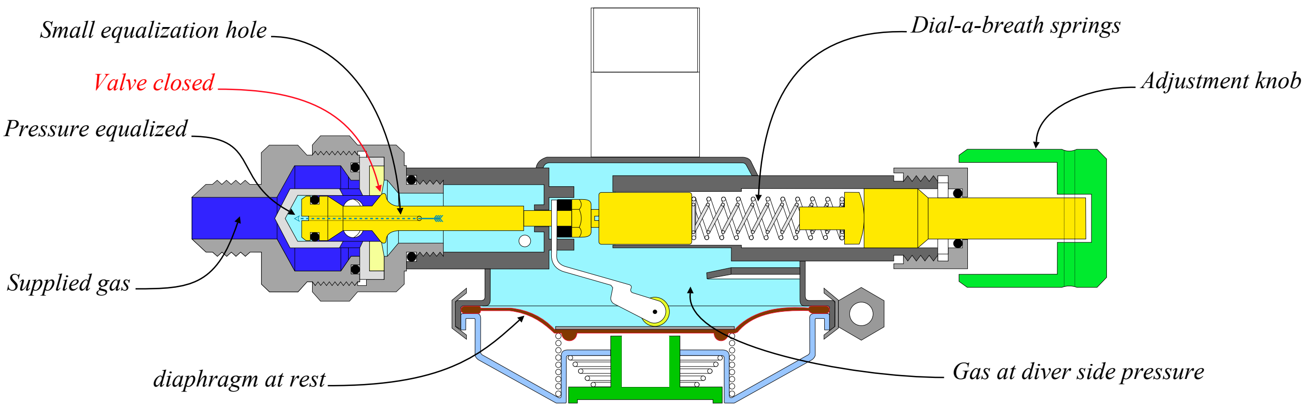
The "Ultraflow 601" is a balanced demand regulator designed to depths up to 500 m. The components of the inlet valve consist of a 316 stainless steel housing a brass seat retainer with a valve seat material and the brass inlet valve which connects to the lever.



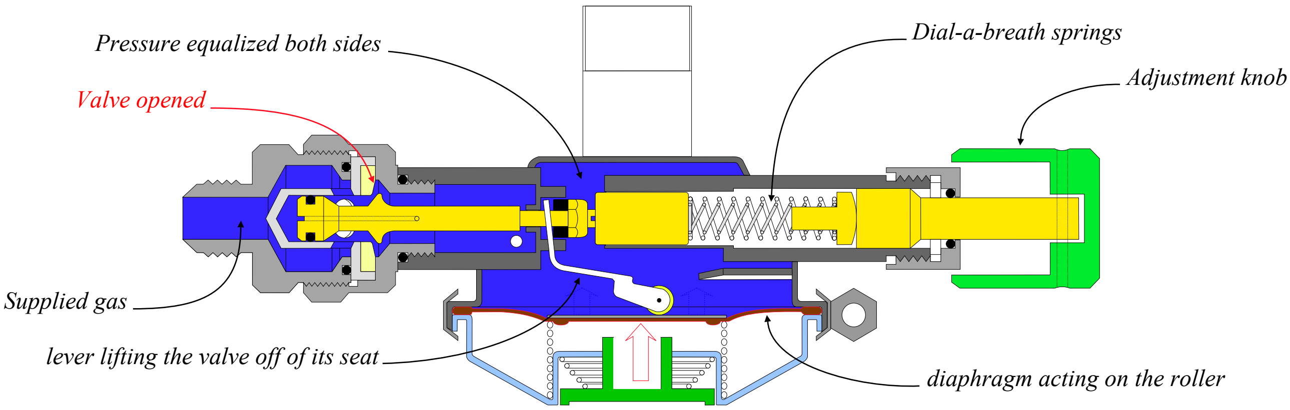
1 - Valve stem	*7 - O-ring*	*13 - Cover assembly*	*19 - Nut*	*25 - Packing nut*
2 - Inlet cap	*8 - Ultraflow body*	*14 - spring diaphragm*	*20 - Piston*	*26 - Retaining pin*
3 - adapter	*9 - Nut*	*15 - Clamp*	*21 - Spring set*	*27 - Adjustment knob*
4 - Valve seat retainer	*10 - O-ring*	*16 - washer*	*22 - Spacer*	*28 - O-ring*
5 - O-ring	*11 - Diaphragm*	*17 - Roller lever*	*23 - Shaft*	
6 - O-ring	*12 - Decal*	*18 - Spacer*	*24 - Washer*	



In the closed position, the supply pressure acts on both the valve and an ‘O’ ring on the balance piston part of the stem (see below). The balance piston is inside the seat retainer and the pressure on the other side of the piston is equalized to the body of the regulator via a small hole in the stem connected to a point sensing the pressure in the regulator body (see below). Note that this equalization that allows easiest breathing does not exist with a standard regulator.
The balance piston is slightly smaller in diameter than the inlet valve and this tends to keep the valve firmly closed using the supply pressure itself.



As the diver inhales, this reduces the pressure in the regulator body, which reduces the closing balance force enabling the diaphragm acting on the roller lever to lift the valve off of its seat easily.



At the end of the inhalation, the “dial-a-breath” springs reseal the valve and restore the rest configuration with the supply valve closed.

Note that Divex says that the adjustment of the springs is crucial to easy breathing.
If it is over-tightened, a large force will be required to lift the inlet valve, requiring a considerable effort on the part of the diver during inhalation.
Similarly, if there are large gas supply pressure changes, the pre-load set by the knob must be altered.
Thus, changes in gas supply pressure produced by either a change in the actual gas supply pressure or a change in the divers' depth, will require “dial-a-breath” adjustment. As the regulator inlet valve assembly is balanced, the “dial-a-breath” movement is minimal for small pressure changes compared to a standard regulator.

The “Jewel 601” exhaust regulator that is situated just below the “Ultraflow 601” demand regulator, in the place of the classical exhaust whiskers of an air helmet, is also manufactured from 316 stainless steel.
It has two stages to make it insensitive to variations in return line suction. The second stage also acts as a safety shut off valve in the event of a first stage failure. Note that the “open circuit valve” which has been already described in this presentation is also preventing excess pressure in the helmet. This is achieved by means of the spring (see #13) that exerts a force onto the insert which holds the mushroom valve (see #11) closed until the pressure in the valve exceeds the pressure of 18-23 cm of sea water above diver ambient. When in the open circuit mode, the spring is unloaded, and the mushroom valve can open freely. The “open circuit valve” must be pushed and turned clockwise to operate the helmet in closed circuit. As a result, turning this valve anticlockwise allows using the helmet in open circuit mode.

1 - Body

2 - 1st stage valve seat

3 - Filter screen

4 - 1st stage diaphragm

5 - Topside over

6 - Spring 2nd stage

7 - 2nd stage diaphragm

8 - Bottom side cover

9 - O/C Mushroom support

10 - O/C Spacer

11 - O/C Mushroom

12 - O/C Open/close insert

13 - O/C Spring

14 - O/C Body

15 - O/C Spring up rated

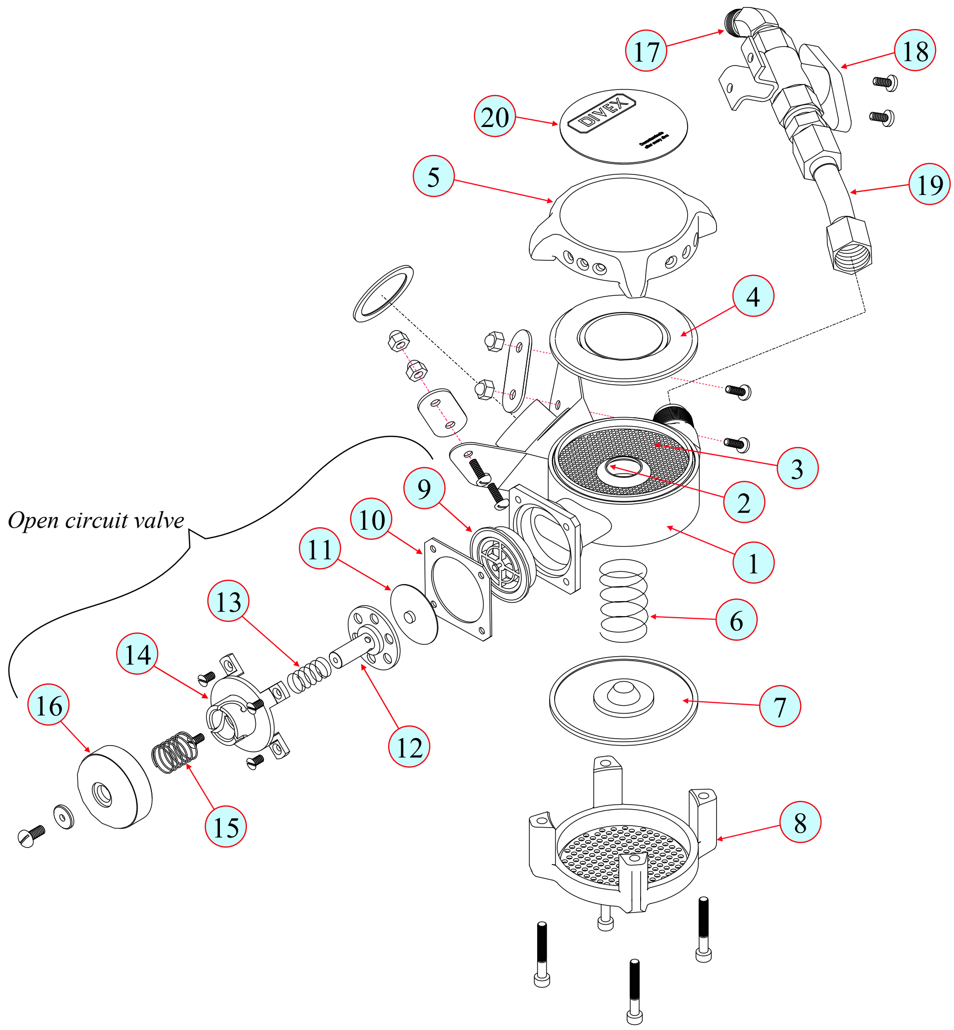
16 - Cover

17 - Elbow tube

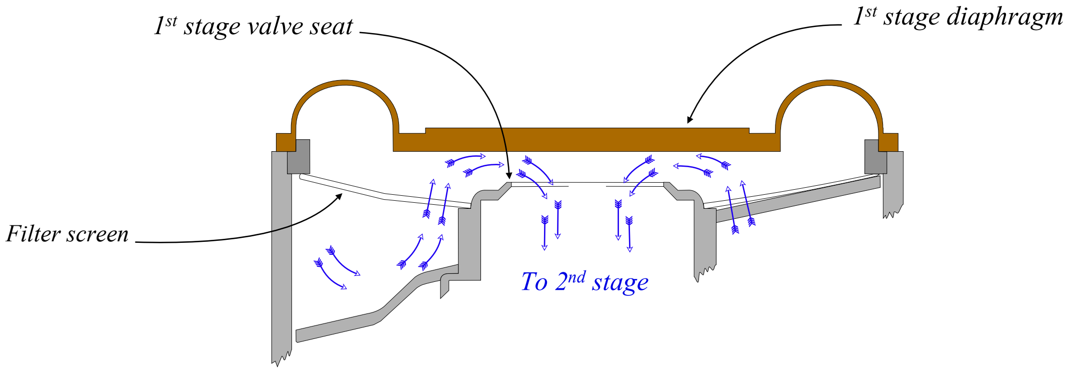
18 - Shutoff valve

19 - tube

20 - Brand & model sticker

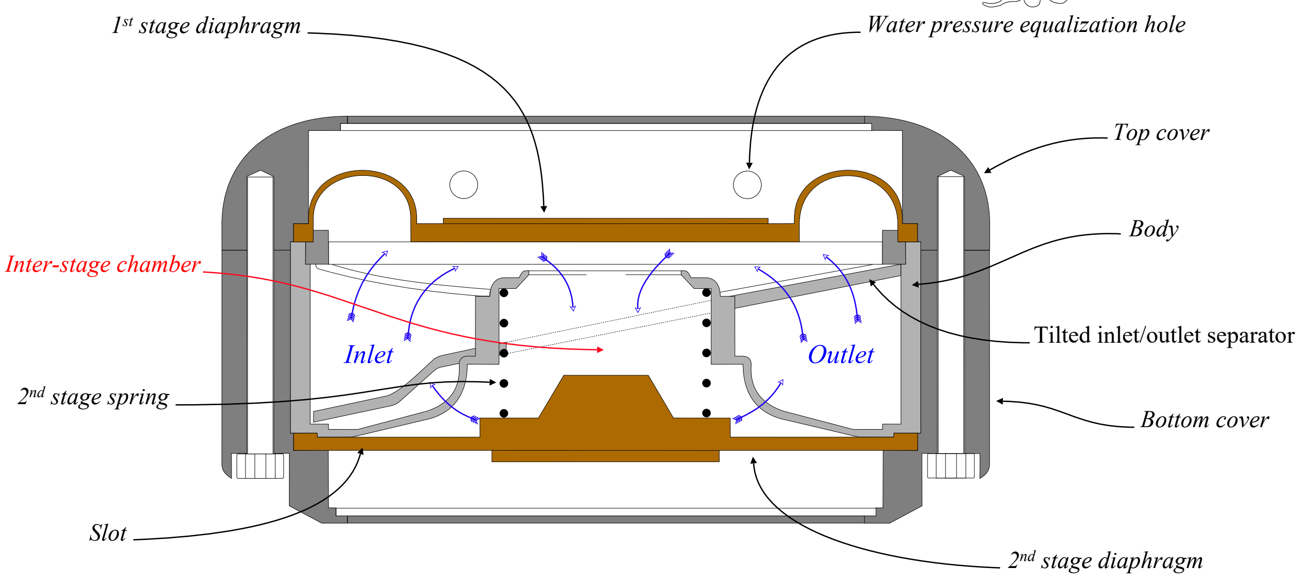


The first stage diaphragm controls the opening pressure of the regulator.
It is situated as close as possible to the “Ultraflow 601” diaphragm to minimize the hydrostatic imbalance when the diver changes orientation.
When the diver exhales, the helmet pressure increases slightly, and this lifts the first stage diaphragm off its seat and allows the exhaled gas flowing into the second stage of the regulator. The large diameter (19 mm) of the valve seat favorize very high flows into the second stage.

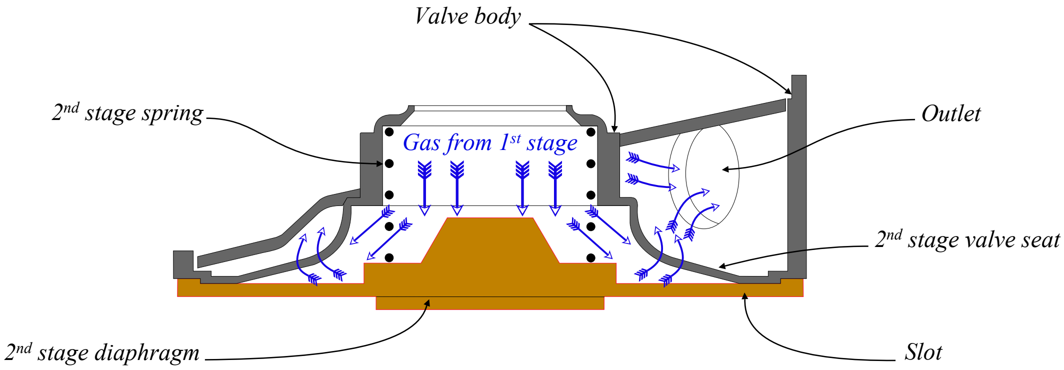


When the diver stops exhaling, the helmet pressure drops slightly below ambient water pressure and the diaphragm is drawn back onto its seat.

The gas flowing into the inter-stage chamber increases the pressure in it.



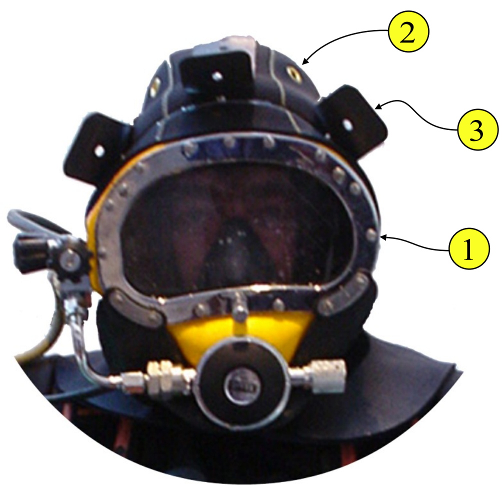
This increase in pressure, together with the second stage spring, lift the second stage diaphragm off twelve tapered radial slots and allows the exhaled gas flowing into the return line.
The second stage spring regulates the inter-stage pressure to between 30 and 60 cm of seawater below the ambient pressure.



This low suction means that there is only a small force holding the first stage diaphragm on its seat and provides no hazard to the diver in the unlikely event that the first stage fails to open and the Ultraflow demand regulator fails to shut.
The slots in the second stage are tapered so that only a small force is required to lift the diaphragm from their tips when there is a high suction in the return line.
As the flow increases and the suction in the return line reduces, the diaphragm lifts further to expose more of the slots. This allows the Jewel regulator to operate satisfactorily at suctions varying from 0.5 to 5 BAR below the diver's ambient pressure.

2.3.6.2 - Standby diver's mask

Because they are compact and can be quickly and easily set up without outside help, a face mask is commonly supplied to the tender who is also the standby diver and must always be ready to intervene.
These masks are composed of a rigid frame made of composite fibers or injected plastic with a viewport and a regulator that are similar to those used with rigid helmets *(see #1)*.
A shaped metal band secures a hood and face seal *(see #2)* fabricated from foam neoprene and open cell foam to this frame. The open cell foam forms a cushion that pushes the sealing surface of the foam neoprene against the diver's face. Pockets are fitted inside the hood to accommodate the earphones. A rubber spider is used to secure the mask to the face of the diver *(see #3)*.
Note that these masks are not equipped with a reclaim system as they are operated only in the case of an emergency. However, their regulator must be capable of supplying sufficient quantities of gas to allow the rescue of the working divers at their maximum operating depth.



An example of a mask designed for deep diving that is commonly operated in diving bells is the Divex "Ultraflow 501-18 B". This model uses the same elements like the well known Kirby Morgan KMB 18 B. However, the regulator "SuperFlow 350" from Kirby Morgan is replaced by the "Ultraflow 501" regulator, which is a balanced demand regulator similar to the "Ultraflow 601" previously described. Similarly to the "Ultraflow 601", this regulator is designed to depths up to 500 m.

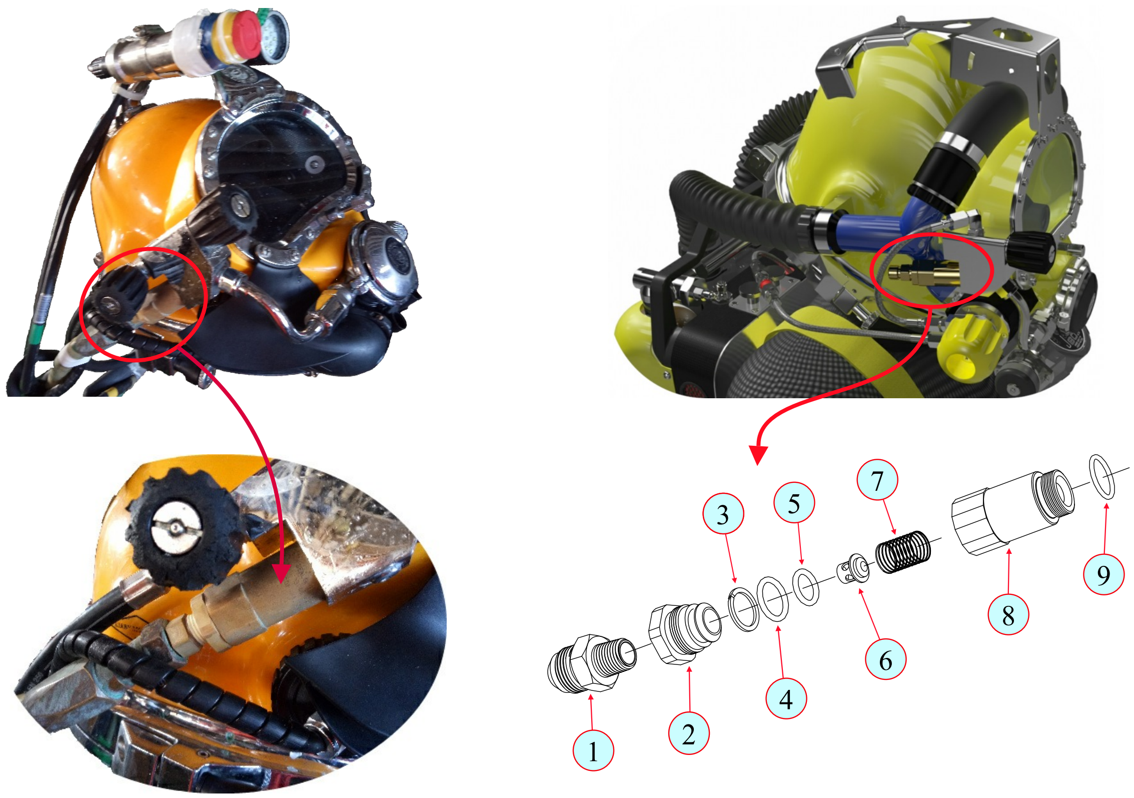
2.3.6.3 - Recommended supply pressure for mixed gas diving applications

The helmet manufacturer should provide tables and recommendation regarding the adjustment of the supply pressure. As an example, Divex recommends to provide the following minimum supply pressures in the diving bell to set up the Ultraflow regulators. Also, note that it is highly recommended not exceeding 20 bar.

Bell depth in MSW	*Diver supply pressure*		*Bell depth in MSW*	*Diver supply pressure*
30 - 150	10 bar		316 - 350	16 bar
151 - 180	11 bar		351 - 400	17 bar
181 - 215	12 bar		401 - 430	18 bar
216 - 250	13 bar		431 - 460	19 bar
251 - 280	14 bar		461 - 480	20 bar
281 - 315	15 bar		481 - 500	20 bar

2.3.6.4 - Non-return valves fitted to the supply gas hose

A supply hose severed or suddenly depressurized may expose the diver to a depression that can be fatal. For this reason, a non-return valve must be fitted between the side block and the gas supply hose of the umbilical. Note that this valve must be function tested before each dive.
Note that as previously described, the “Ultrajewel 601” and the SEACO valves in the bell are designed to isolate exhaust hose that returns the exhaled gas to the reclaim system in the case of a malfunction or a rupture.



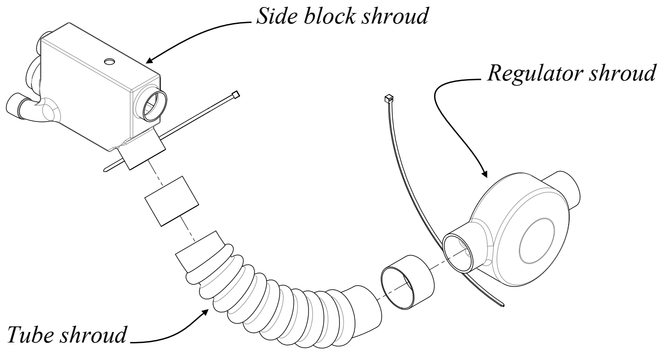
1 - Connector umbilical
2 - Seat
3 - Wiper
4 - O ring
5 - O ring
6 - Poppet valve
7 - Spring
8 - Valve body
9 - O ring

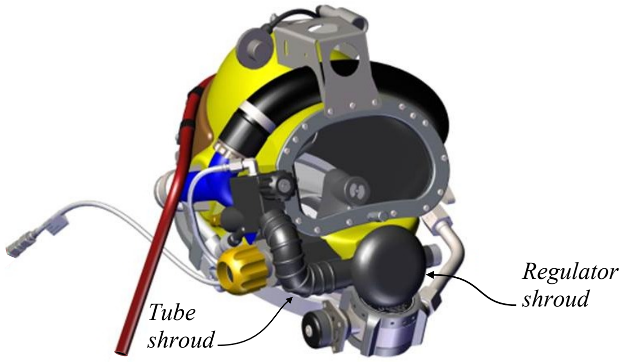
Non- return valves are composed of a poppet valve (see #6), which is pressed to its seat (see #2) by a spring (see #7). This valve is lifted from its seating by the axial force resulting from the pressure of the breathing gas supplied through the umbilical. As a result, when the umbilical is under pressure, the poppet valve is maintained open. If the gas supply is lost, the valve is pushed against its seat by the spring and the gas circuit is closed.

2.3.6.5 - Systems for cold waters

Note that this point has been partially discussed in “Bell internal equipment.”
Depending on the area, the water temperature at depth quickly falls below four degrees and may become close to zero degrees. Note that salt water freezes a -2 C°. Regulators are affected by low temperatures, which may result in an affected flowing of gas or a frozen mechanism that stop working. To solve this problem, the manufacturers propose a heating system for the regulator. Professional organizations also recommend this procedure. As an example, IMCA says that a

means of heating the divers inspired gas is necessary if diving at depths below 150 msw. However, depending on the latitude where the dive is carried on, the regulator may have to be heated at a depth close to the surface.
The system consists of a rubber shroud inside which hot water flows. This shroud completely encases the side block, bent tube, and the regulator of the helmet to isolate the hot water flow from the surrounding cold water and so provide efficient gas heating. It is connected to the hot water supply of the diver by a splitter block assembly.





2.3.6.6 - National & international approval and marking

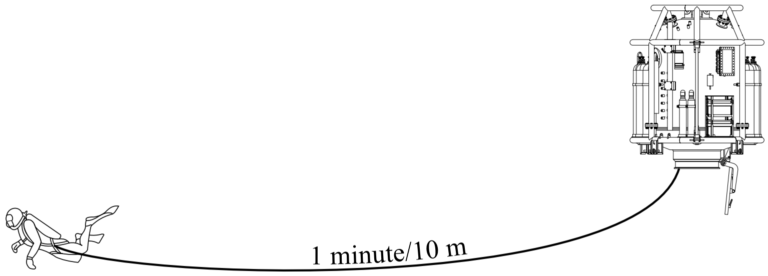
Every device used in a diving system must be certified according to recognized standards.
As an example, the helmets describe in this presentation are certified as PPE devices according to the European Directive 89/686/EEC, which give guidelines and procedures for the certification process of this type of equipment. Note that for this directive, PPE means any device or appliance designed to be worn or held by an individual for protection against one or more health and safety hazards. When the process of certification is successful, a “CE marking” that must be indicated on each device produced is given. As an example, the marking of the Divex Ultrajewel 601 is CE 0088.
Note that the certificate of approval that summarize the process applied and the competent bodies involved must be available and its reference number should be indicated in the brochures supplied with the device.
In addition, Each helmet (or mask) should be indelibly marked with a unique serial number.
All these elements allow establishing whether the helmet conforms to the international and national legislation and also trace its process of certification and fabrication.

2.3.7 - Bailout systems

2.3.7.1 - Purpose

IMCA says that every diver (other than the bellman) must be provided with a reserve supply of breathing gas carried in a bailout system.
NORSOK U100 says that this bailout system should be designed to ensure an easy entrance into the bell and be ergonomically adapted to the primary system. Also, it must be possible to activate it with no more than two operations.

Regarding the bailout endurance, IMCA D 022 says that a calculation should be available showing that the capacity of the cylinder(s) at the depth of diving will allow breathing gas for 1 minute for every 10 metres of umbilical deployed from the diving bell.



Note that NORMAM- 15 limits the umbilical length to 33 metres and the bailout duration to at least 15 minutes during exceptional saturation.
Also, NORSOK standard U 100, which limits the umbilical length to 45 m, says in point 7.8.3 that the bail-out system should provide the diver with gas for 10 min based on an average consumption of 62,5 1/min (at the surface). This consumption value, that should be considered as a minimum, is confirmed by the UK HSE study *"The provision of breathing gas to divers in emergency situations"* which recommends a rate between 50 & 75 litres.

The bailout systems used for saturation operations can be scuba diving cylinders or rebreather apparatus. They should be selected depending on the depth and the distance from the bell to fulfill the requirements indicated above,
Diving cylinders are commonly used as bailout systems for "surface orientated" diving operations. They are often used for shallow saturations.
Rebreather apparatus are used by militaries and experienced recreational divers for diving operations that cannot be organized with standard scuba sets. Note that the systems they used are not adapted to the requirements of commercial diving. Nevertheless, two models of rebreather apparatus have been designed for this purpose by Divex (JFD group): The "Secondary Life Support Mk 4" (SLS Mk4), which is now discontinued and the "Compact Bailout Rebreathing Apparatus" (COBRA) which replaces the SLS Mk4. They are described in the next points with the diving cylinders.

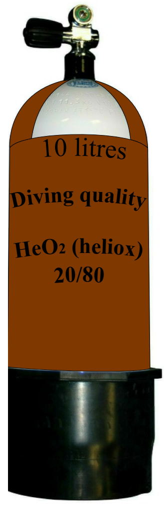
2.3.7.2 - Scuba diving cylinders and 1st stage regulator

The fabrication and the maintenance of scuba diving cylinders are explained in the diving study #2 "Organize the maintenance of diving cylinders". For this reason, these technical aspects are not explained here as they can be found in this study of 98 pages.
Diving from a closed bell imposes the use of cylinders that are not too voluminous to be able to pass through the bottom door. As a result, the bottles used should offer a maximum of gas in a container that has a reduced volume. For this reason, and depending on the size of the bottom door, twin sets composed of bottles of 7, 10 or 12 litres of floodable volume that can be topped up at a pressure up to 300 bar are preferred to mono cylinders of 15, 18 or 20 litres that have a wider diameter, or cylinders limited to 200 or 232 bar.
Note that aluminium cylinders found on the market are generally limited to 200 bar. As a result, composite and steel cylinders which can withstand 300 bar are preferable. The advantage of composite cylinders is their reduced weight and their capacity to withstand extremely high pressures. It is the reason they are used in the space industry. However, the models sold for diving are limited to 300 bar maximum. Their major inconvenience is their limited lifetime and that they are more sensitive to shocks than steel cylinders that can be considered more robust and are cheaper. For these reasons, most contractors often prefer using steel cylinders.

Approximate dimensions and weights of steel cylinders commonly used to compose twin sets

Volume cylinder	*Ø in mm*	*Length in mm*	*Weight in Kg*
7 litres	*140*	*625*	*9.8*
8 litres	*140*	*700*	*10.5*
10 litres	*178*	*600*	*15.1*
12 litres	*178*	*625*	*18.2*

Identification and marking of the cylinders:
Diving cylinders must be colour-coded according to the recommendations of IMCA D 043 that are based on the European standard EN 1089-3. This colour coding is also indicated point 269 of the "code of safety for diving systems 1995" published by the International Maritime Organization (IMO). It is achieved through the use of colour paints.
Also, the information regarding the gas used, the construction and the condition of the cylinder must be always visible.
For these reasons, IMCA says that cylinders used with heliox should be organized as follows:



- The shoulder must be colour coded with white and brown quarters or bands and the body must be brown.
- The words "HeO2" + " heliox" and "diving quality" must be written with the gas percentage by volume, quoting percentage of oxygen first. Also, the floodable volume should be indicated.
- The cylinder serial number should be visible or else stenciled in a visible location on each cylinder. Also, the last test date stamp should be painted over with a small patch distinctive colored paint to aid location. These identification marks must not be hidden by accumulated layers of paint.

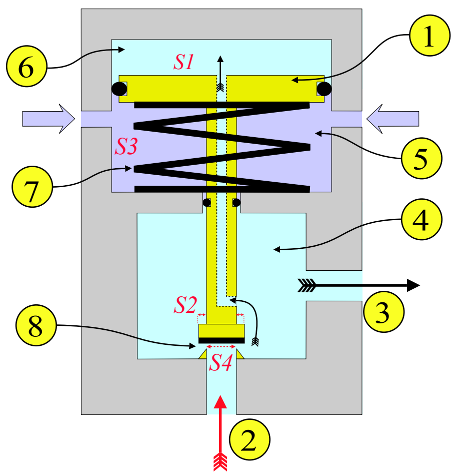
The high-pressure heliox contained in the cylinder must be regulated to a pressure and a flow that are compatible with those of the 2nd stage regulator of the helmet. This is achieved by the 1st stage of a scuba diving regulator that is installed on the bottle and connected to the 2nd stage of the helmet with a dedicated whip. Note that the mechanism used can be based on a piston or a diaphragm. However, it must be suitable for diving in cold water. Also, a balanced type mechanism is highly preferable. The differences between the several mechanisms can be explained as follows:

- A non-balanced first stage piston regulator uses a piston that moves up and down to open or close an injector from which the high-pressure heliox stored in the cylinder flows into a depression chamber. When the planned low-pressure is reached the piston closes the high-pressure injector and the gas is distributed to the 2nd stage regulator. It opens again when the pressure in this chamber drops. Note that this piston is composed of a thick plate that is continued by a hollow shaft through which the gas flows from the depression chamber to the top chamber where the pressure pushes the piston to the bottom. With this system, the opening of the valve partially depends on the high pressure. As a result, if the high-pressure decreases, the pressure opening the valve diminishes as well and breathing becomes more and more difficult as the pressure in the cylinder decreases.

Forces operating the system:

Closing	*- Low pressure x Surface piston (S 1)* *- Low pressure x Surface valve around the tail (S 2)*
Opening	*- Hydrostatic pressure at depth x surface piston (S 3)* *- Spring in wet chamber* *- High pressure x surface valve (S 4)*

1 - Piston
2 - High Pressure inlet
3 - Low Pressure outlet
4 - Depression chamber HP - LP
5 - Hydrostatic pressure chamber
6 - Top-side LP chamber
7 - Spring
8 - Valve + seat

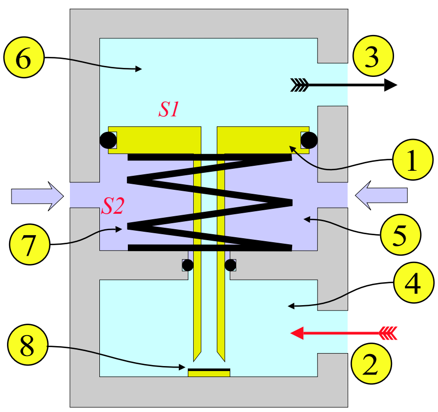


- A balanced piston regulator uses the same basic mechanism as above. However, the forces are organized in such a manner that there is no intervention of the high pressure in the opening of the regulator. As a result, the opening and closure depend only on the low pressure and the effort to inspire is always the same.

Forces operating the system:

Closing	*- Low pressure x Surface piston (S 1)*
Opening	*- Hydrostatic pressure at depth x surface piston (S 2)* *- Spring in wet chamber*

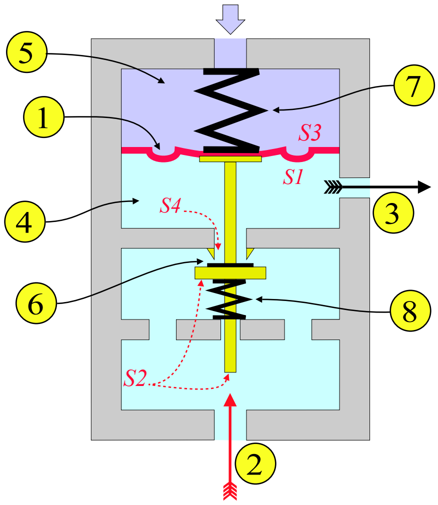
1 - Piston
2 - High Pressure inlet
3 - Low Pressure outlet
4 - Depression chamber HP - LP
5 - Hydrostatic pressure chamber
6 - Top-side LP chamber
7 - Spring
8 - Valve + seat



- Non-balanced diaphragm first stages use a thick rubber or composite membrane to which the force from the hydrostatic pressure is added to the strength of the spring situated in the wet chamber to open the valve between the high-pressure and low-pressure chambers. The valve is closed by the combined action of a return spring and the high-pressure that pushes on the bottom surface of the valve. With this design, the high-pressure acts on the closure of the valve. As a result, when the pressure from the bottle decreases, more gas can pass into the depression chamber. Thus the opening of the valve becomes more comfortable, and the regulator delivers more gas. Also, note that this design is slightly more complicated as with piston systems, as there are more parts involved.

Forces operating the system:

Closing	*- Low-pressure x surface membrane (S 1)* *- Return spring* *- Surface bottom valve (S 2) x high-pressure*
Opening	*- Hydrostatic pressure at depth x surface diaphragm (S 3)* *- Spring in wet chamber* *- Surface bottom of the valve (S 4) x low-pressure*

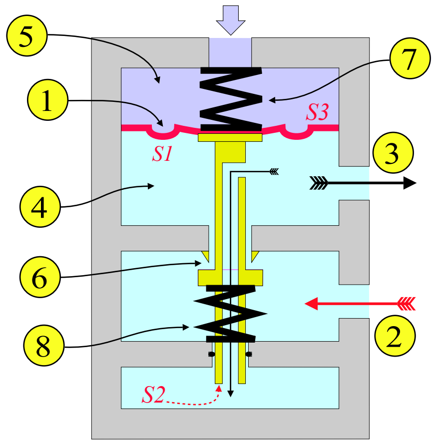


1 - Membrane
2 - High Pressure inlet
3 - Low Pressure outlet
4 - Depression chamber HP - LP
5 - Hydrostatic pressure chamber
6 - Tail + valve assembly
7 - Spring in wet chamber
8 - Return spring

- Balanced diaphragm regulators are designed with the same basic principle to work as described above. However, the forces are organized in such a manner that there is no intervention of the high pressure in the closing of the regulator. As a result, the opening and closure depend only on the low pressure and the efforts of the diver to inspire are always the same. Note that in this case the tail of the valve is hollow.

Forces operating the system:

Closing	*- Low-pressure x surface membrane (S 1)* *- Return spring* *- Surface S 2 in the equilibration chamber*
Opening	*- Hydrostatic pressure at depth x surface diaphragm (S 3)* *- Spring in wet chamber*



1 - Membrane
2 - High Pressure inlet
3 - Low Pressure outlet
4 - Depression chamber HP - LP
5 - Hydrostatic pressure chamber
6 - Tail + valve assembly
7 - Spring in wet chamber
8 - Return spring

- Regarding the advantages and disadvantages of the mechanical systems described, piston regulators are reputed robust and simple. However, they are often considered less efficient than those designed with a diaphragm in cold waters as they may become more rapidly frozen, which may result in an uncontrolled free-flowing. For this reason, diaphragm systems are often preferred for these conditions. As an example, experimentations in icy conditions conducted by the US Navy in 2008 were performed with only balanced diaphragm design regulators. Note that US Navy recommends using cold water kits consisting of silicone oil and an environmental diaphragm in water temperatures below 38 ºF (3.3 ºC).

Another point to consider when selecting the 1st stage regulator is its ability to work with heliox as some models that are originally designed for air may leak if used with heliox. Also, note that only threaded type bottle connections (commonly called DIN connections by divers) can withstand a pressure of 300 bar. For more information regarding this point, refer to the study CCO Ltd "Organize the maintenance of diving cylinders".

As a conclusion, scuba diving cylinders are reliable systems of bailouts. However, they limit the operations to shallow depths only. As an example, a set 2 x 7 litres / 300 bar allows less than 6 minutes breathing time at 100 m. Also, the gas they provide is at the temperature of the surrounding that may be cold. Because hypothermia is six times faster with heliox than air, that leaves a limited time for the diver to return to the bell before being affected in such conditions.
Note that the procedure to calculate the diving duration offered by bottles is as follows:

1) Find the pressure available = Pressure bottle - absolute pressure bottom - working pressure regulator
2) Find the volume of gas available = Floodable volume x Available pressure
3) Find the breath duration offered by the cylinders = Available volume / (62.5 x absolute pressure)

2.3.7.3 - DIVEX Secondary Life Support Mk 4" (SLS Mk4) system

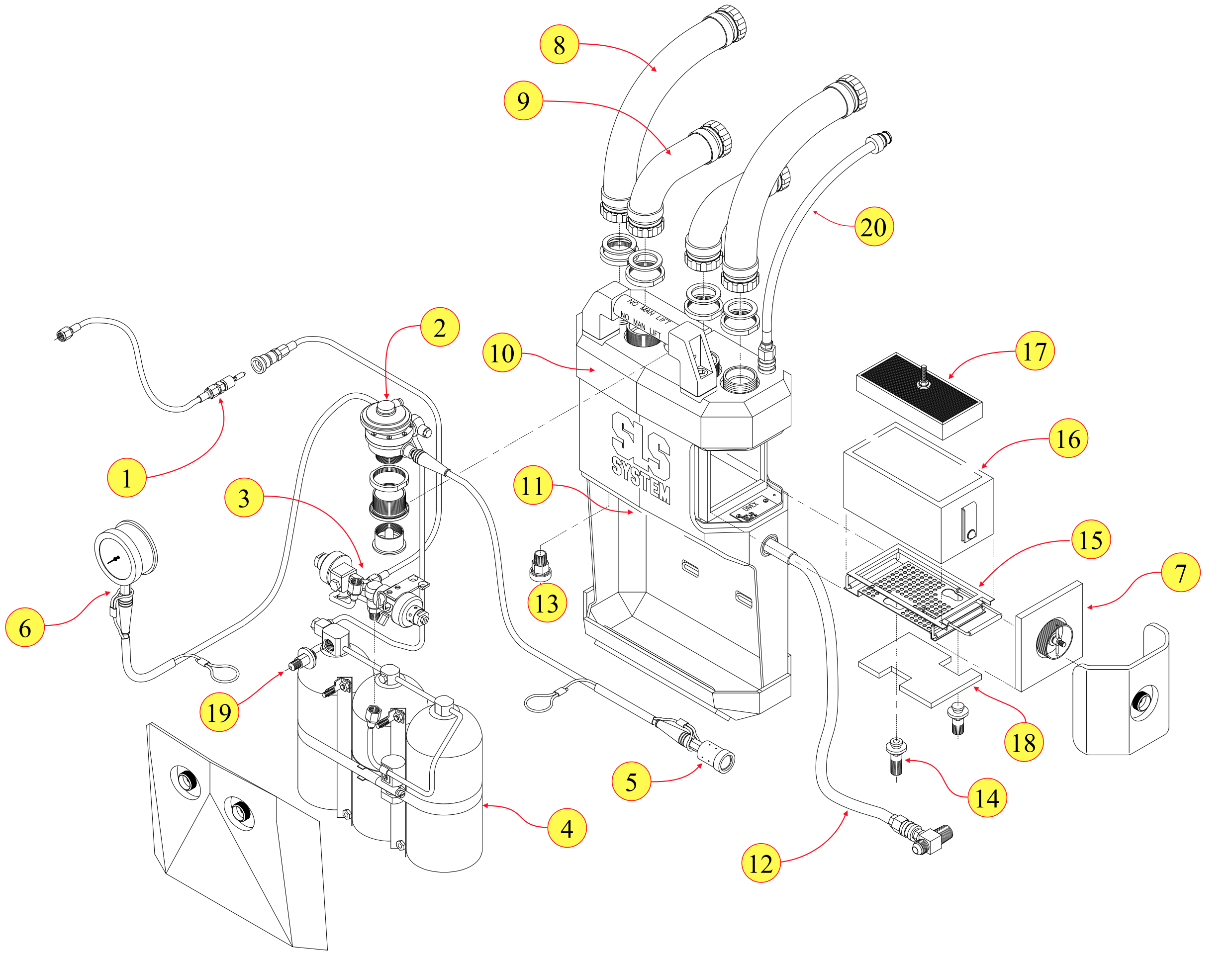
The Secondary Life Support (SLS) is a semi-closed circuit breathing apparatus designed during the eighties and nineties which allows sufficient time to return to the bell at depths deeper than 350 msw in the case that the diver's breathing and hot water supplies are severed. Note that this model is discontinued. As a result, it will be removed from service gradually. However, it will be in use as long as spare parts will be available, which is the reason it cannot be ignored. Also, the description of this rebreather of the previous generation highlights the advantages of the new COBRA system.

The system is composed of a backpack that is connected to a specific helmet.
The operational principle of the system is basically that of a conventional semi-closed circuit breathing apparatus, in which the exhaled gas is captured in counterlungs and is then re-breathed by the diver, after removal of the carbon dioxide (CO_2), and the replacement of the oxygen consumed.
The "backpack" consists of:

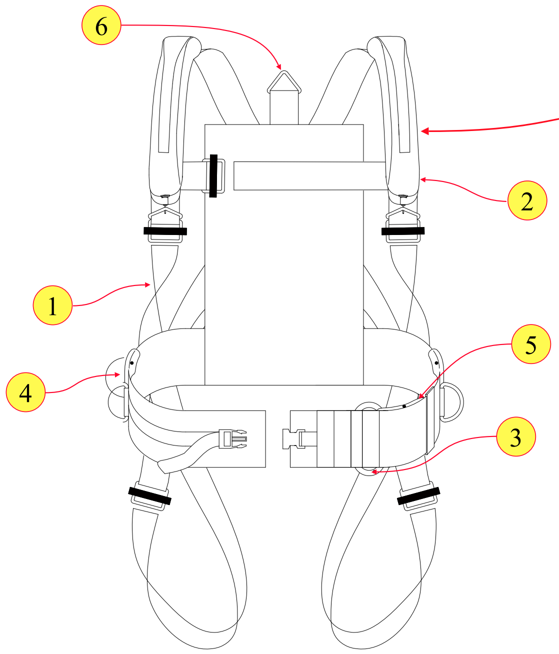
1 - The main housing containing a gas injection system, a CO_2 scrubber canister and a thermal regenerator. Also, the SLS Backpack harness has the counterlungs fitted to its shoulder straps.

2 - The gas injection system is composed of three (3) heliox cylinders with a charging point, burst disc, two stage regulator, injection orifice, single stage regulator, demand regulator and a overpressure indicator. Note that the percentage of oxygen of the breathing gas stored in these cylinders depends on the diving depth planned.

3 - The CO_2 scrubber canister provides a chemical absorbent bed for the removal of the carbon dioxide. A thermal regenerator temporarily stores the heat within the breathing gas in order to avoid losing it to the water as the breathing gas passes into the flexible bags (the counterlungs).



1 - Gas supply from helmet	*6 - Pressure gauge*	*11 - Gas system housing*	*16 - Sodalime canister*
2 - Demand valve	*7 - Lid screw assembly*	*12 - Hot water inlet hose*	*17 - Thermal regenerator*
3 - HP & LP regulators	*8 - Inhale / exhale hose*	*13 - Hot water relief valve*	*18 - moisture absorbent pad*
4 - Gas storage bottle	*9 - Counterlung hose*	*14 - Gas supply penetrator*	*19 - Charging point*
5 - Overpressure indicator	*10 - Hot water housing*	*15 - Canister loading system*	*20 - Hot water to helmet shroud*



1 - Harness

2 - Counterlung in its enclosure (see the photos above)

3 - Actuation sleeve & cable assembly

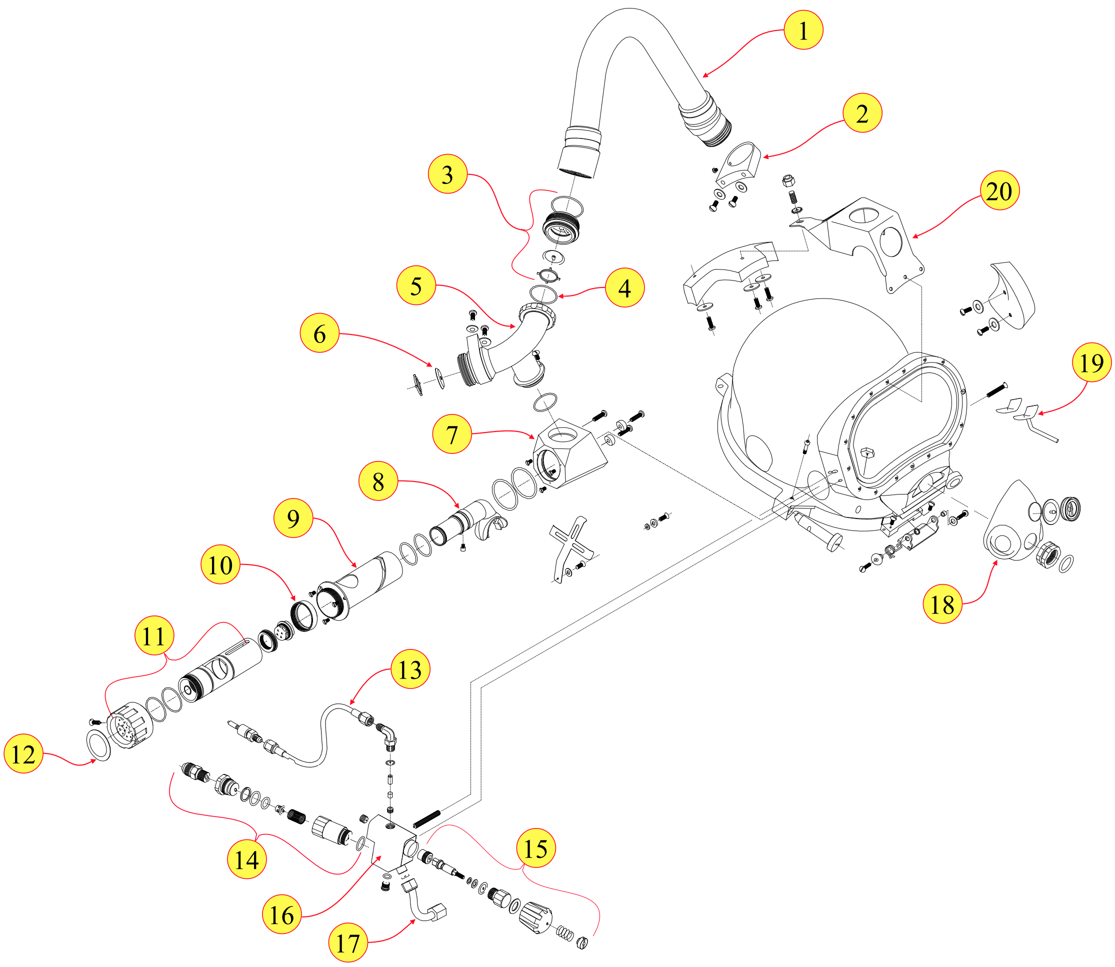
4 - Weight pocket

5 - Handle retaining band

6 - Rescue lifting point

7 - Cable wiper sleeve

The helmet is based on the Divex "Ultrajewel 601" to which the inlet and exhaust hoses from the backpack assembly are connected. The interface assembly contains a mouthpiece that is stowed retracted out of the divers way during the normal operations. In this case, the diver breathes normally in the oral-nasal mask. When activating the bailout system this mouthpiece is rotated into the helmet oral-nasal mask, and the diver bites it to breathe with his mouth as with a scuba regulator or a snorkel.



1 - Helmet hose assembly

2 - Support hose assembly

3 - Exhale flap valve assembly

4 - O ring

5 - Y piece assembly

6 - Flap valve + circlip

7 - Main body

8 - Mouth piece

9 - Outer sleeve

10 - Retaining ring

11 - Sleeve centre

12 - Mushroom

13 - SLS gas supply hose

14 - Non return valve

15 - Free flow valve

16 - Side block

17 - bend tube to regulator

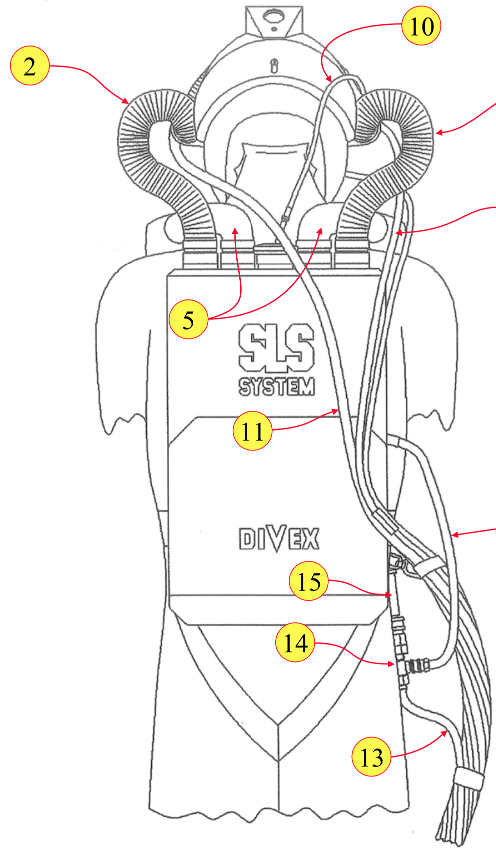
18 - Oral nasal mask assembly

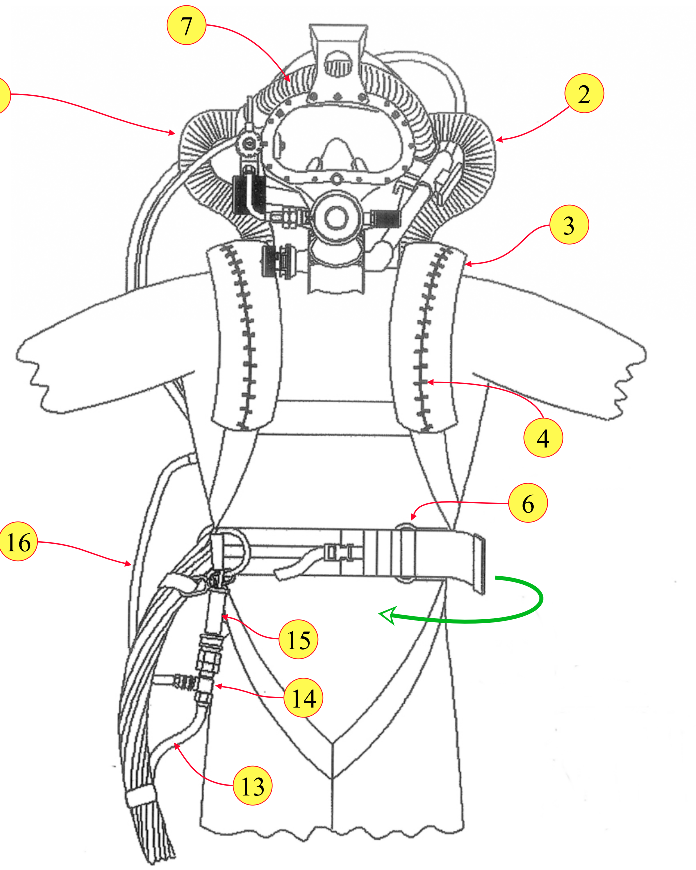
19 - Nose block device

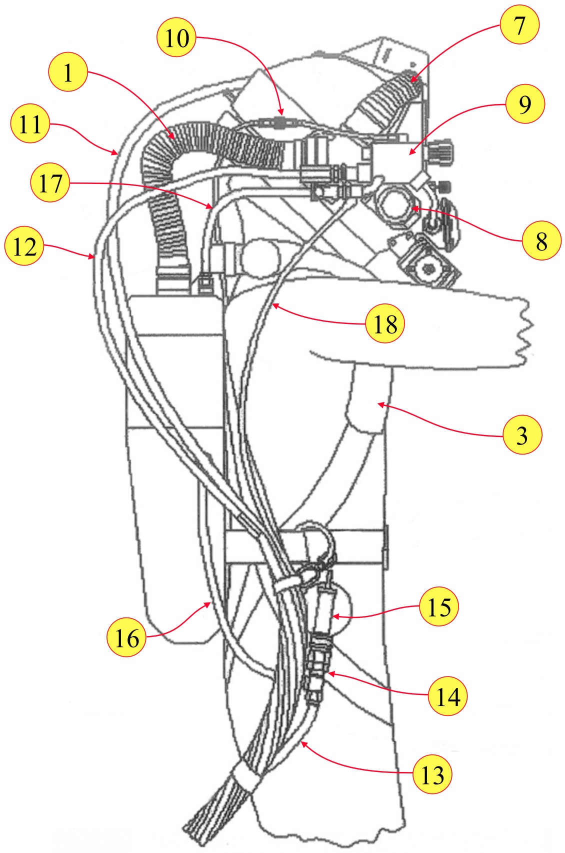
20 - Handle

Note that the following supplies from the bell are necessary to allow the system to be ready for use:

- A gas supply hose is connected to the side block of the helmet *(see #10 below)* from which heliox is supplied to a single stage regulator in the backpack. The function of this regulator is to maintain a slight positive pressure inside the SLS system while it is in its standby mode to protect it from water flooding.
- Also, the hot water flowing from the surface to the diver's suit is diverted to the hot water housing of the backpack through a splitter block *(see #14 below)*. The function of this connection is to fill the hot water housing of the backpack and warm the soda lime enough to enable the required chemical reaction that is necessary to absorb the CO2 when the system is activated. The hot water continues to flow from the hot water housing to the shroud of the regulator through a hose connected to it *(see #17 below)*.







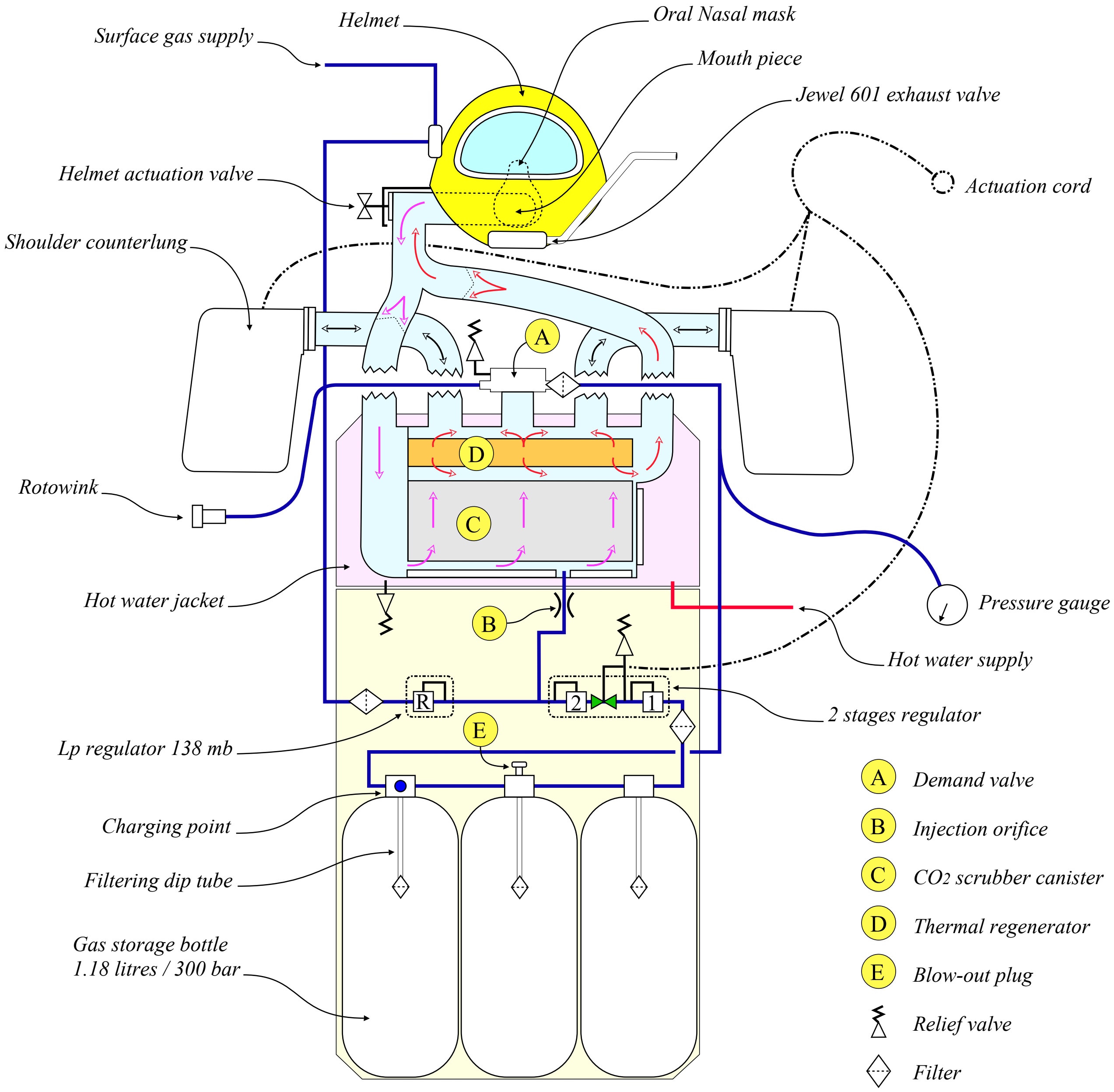
1 - Exhale hose | *10 - SLS supply (quick connect)*
2 - Inhale hose | *11 - Reclaim hose*
3 - Counterlung | *12 - Gas supply*
4 - Lacing counterlung | *13 - Hot water supply*
5 - Hoses counterlungs | *14 - Splitter block*
6 - Handle actuation system | *15 - Hot water supply suit*
7 - Helmet hose | *16 - Hot water supply SLS*
8 - Mouthpiece handle | *17 - Hot water supply shroud*
9 - Shroud side block | *18 - Communications*

The activation of the system requires two actions:

1. The interface valve on the right hand side of the helmet *(#8 in the drawing previous page)* has to be rotated through 180º, to push the mouthpiece into the oral-nasal mask where the diver can bite onto it to breath.
2. The actuation handle situated near the buckle of the belt of the harness (see # 6) has to be pulled as for a parachute to deploy the counterlungs, that are packed in their enclosures that protect them from damage, and pull a spool valve which switches on the gas bleed for make-up gas. This handle is protected by a flap.

When the system is activated:

1. The exhaled gas passes via the diver's mouthpiece through the helmet interface assembly and is directed by the check valves through an insulated hose to the backpack. It then passes through the CO_2 scrubber canister and up through the thermal regenerator into the counterlungs. The thermal regenerator removes and stores the heat from the warm gas.
2. Because the counterlungs are tightly packed, there is very little gas available for the diver to inhale after activation. For this reason, a demand valve *(see "A" below)* situated on top of the backpack supplies the gas for the first breath. Then, when the counterlungs are filled, the system functions in its semi-closed circuit mode. As the diver inhales, the new cold gas passes back through the thermal regenerator and picks up the stored heat. The gas then passes up through a second insulated hose assembly and back into the diver's mouthpiece via the helmet interface assembly.
3. The oxygen make-up is provided by means of a constant bleed of oxygen-rich gas from the three cylinders located at the base of the Backpack. This gas bleed mixes with the exhaled gas at the inlet to the CO_2 scrubber to maintain a safe oxygen partial pressure at all times. This rich gas is supplied from the gas cylinders through a two-stage regulator to the injection orifice which regulates the flow rate.
4. As already indicated, the water ingress into the SLS system in standby mode is prevented by pressurising the breathing circuit using a single stage regulator that is set up at 138 mb above ambient pressure and is connected to the side block of the helmet. An indicator of Rotowink type which changes from green to red if a significant loss of pressure occurs is fitted to the system to alert the diver in the case of loss of pressure.



Note that the Secondary Life Support (SLS) uses only mechanical systems and that there is no electronic module for the control of the partial pressure of the gas and the dosage of the oxygen in the breathing circuit as it is the case with a lot of new generation rebreathers where the diluent gas and pure oxygen are stored in separate cylinders from which they are dosed according to the needs.
Thus, as already indicated in the previous description of the system, an "appropriate mix" that must be calculated for the planned diving depth using the table displayed below is stored in the three 1.18 litres / 300 bar gas bottles, from which it is dosed into the breathing circuit through a two-stage regulator and an injector. For this reason, Divex says that it is of ultimate importance to fully empty the bottles before charging the new planned mix to avoid creating an unsuitable gas.

Diver excursion depth	***Minimum oxygen percentage***	***Maximum oxygen percentage***	***Diver excursion depth***	***Minimum oxygen percentage***	***Maximum oxygen percentage***
10	*39*	*99*	*190*	*8.2*	*11.4*
20	*28.5*	*69*	*200*	*8*	*11*
30	*23.5*	*52*	*210*	*7.8*	*10.4*
40	*20*	*42*	*220*	*7.6*	*10*
50	*17.8*	*35.5*	*230*	*7.3*	*9.7*
60	*15.7*	*31*	*240*	*7.1*	*9.3*
70	*14.4*	*27*	*250*	*6.9*	*8.9*
80	*13.4*	*24*	*260*	*6.8*	*8.7*
90	*12.4*	*21.9*	*270*	*6.65*	*8.4*
100	*11.6*	*20*	*280*	*6.5*	*8.15*
110	*11*	*18.4*	*290*	*6.4*	*8*
120	*10.5*	*17*	*300*	*6.2*	*7.7*
130	*10.2*	*15.9*	*310*	*6.1*	*7.5*
140	*9.8*	*15*	*320*	*6*	*7.3*
150	*9.5*	*14*	*330*	*5.8*	*7.1*
160	*9.1*	*13.2*	*340*	*5.75*	*6.9*
170	*8.8*	*12.5*	*350*	*5.6*	*6.8*
180	*8.4*	*11.9*	*360*	*5.55*	*6.6*

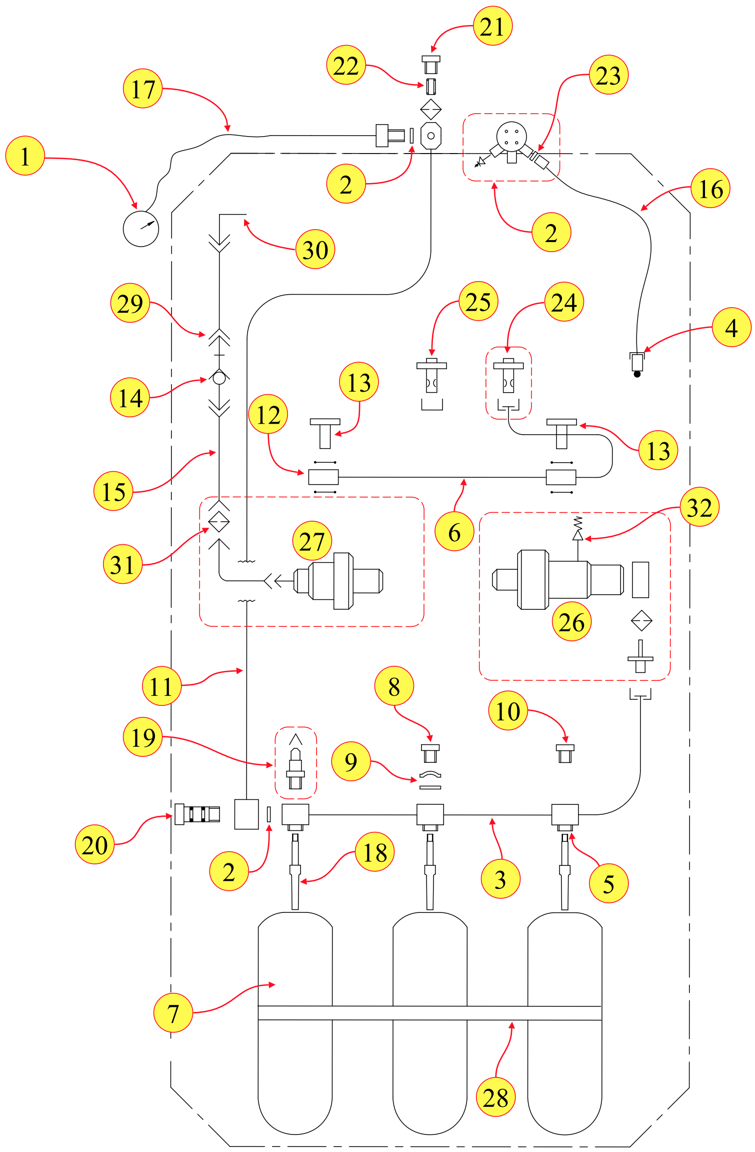
Example of a mix selection using this table:
Divers are stored at a depth of 190 m and an excursion is planned between 195 - 205 msw. The bell is planned to be stored at 190 msw:

- At 190 msw a heliox mix containing between 8.2 and 11.4% oxygen should be used.
- Find a mix that allows excursions within the planned depth range and includes a safety factor to allow excursions outside the basic depth range:
    - Note that the middle value between 11.4% & 8.2 % is 9.8%. Thus, a richer mix should favor upward excursions and a poorer mix downward excursions.
    - If a mix 9.7% is available onboard the vessel, we can see that this mix allows a maximum downward excursion to 230 msw and a maximum upward excursion above 150 msw (in fact it can be used up to 143 msw). As these depths are beyond the planned working depth range, the mix selected is suitable.

Diver excursion depth	***Minimum oxygen percentage***	***Maximum oxygen percentage***	***Diver excursion depth***	***Minimum oxygen percentage***	***Maximum oxygen percentage***
140 (143 m)	*9.8*	*15*	*190*	*8.2* ←	*9.7%* → *11.4*
150	*9.5*	*14*	*200*	*8*	*11*
160	*9.1*	*13.2*	*210*	*7.8*	*10.4*
170	*8.8*	*12.5*	*220*	*7.6*	*10*
180	*8.4*	*11.9*	*230*	*7.3*	*9.7*

Hyperlink Tables of contents

Note that these gas cylinders *(see #7 in the scheme below)* are equipped with dip tubes *(see #18)* that protect the pipework from corrosion and thus avoids blocking the gas flow. Also, burst disks *(see #9)* are fitted to protect the system from over-pressurization. These cylinders are linked together though a manifold *(see #3)* and a retainer assembly *(see # 28)* they are filled through a charging point which is installed in the left-hand cylinder fitting *(see #19)*. It has a built-in check valve to allow easy filling and a sintered filter element to protect the check valve seat from damage during charging.



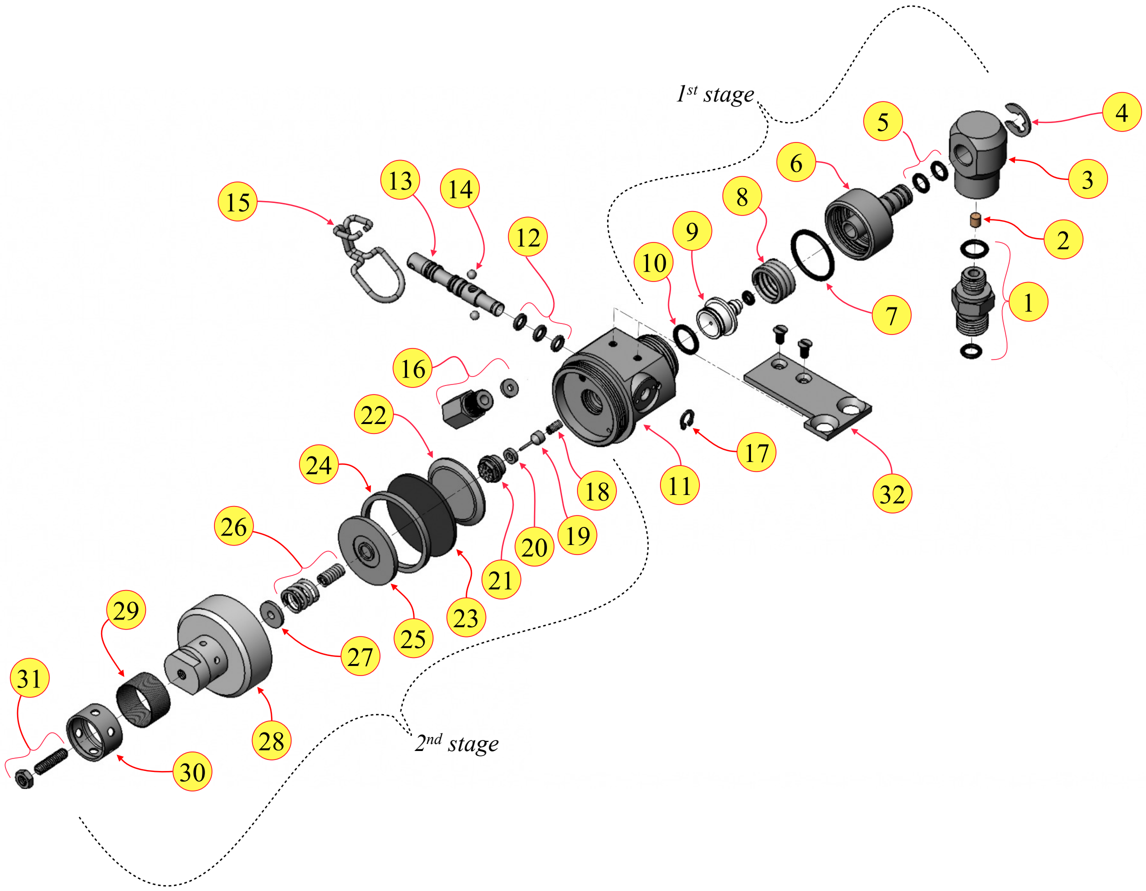
1 - Content gauge (+ O ring)	*9 - Bursting disk + seat*	*17 - Whip gauge*	*25 penetrator blank*
2 - Demand regulator	*10 - Plug + O ring*	*18 - Filtering dip tube*	*26 - Two stage regulator*
3 - Bottle manifold	*11 - Regulator pipework*	*19 - Charging fitting + cap*	*27 - Single stage regulator*
4 - Rotowink	*12 - Sintered element*	*20 - Manifold banjo bolt*	*28 - Bottle retainer assembly*
5 - O ring	*13 - Regulator connection bolt*	*21 - Blanking plug + O ring*	*29 - Connector relief valve*
6 - Regulator pipework	*14 - Non return valve*	*22 - Spring*	*30 - Connection to helmet*
7 - Gas cylinder	*15 - Whip regulator*	*23 - Valve seat regulator*	*31 - Filter*
8 - Blanking plug	*16 - Whip Rotowink*	*24 - Penetrator*	*32 - Relief valve*

The gas from the storage cylinders flows to the two stages regulator *(see # 32 above)* through the manifold *(see #3)*. The regulator is protected from the impurities that may have passed into the pipework by a sintered bronze filter. It is connected to the piping by a banjo fitting *(see #3 in the drawing next page)*.

- The first stage piston provides regulation of the inter-stage gas pressure to approximately 15 bar. This piston is initially raised from its seat by the spring *(see #8 next page)*. Gas flows past the seat and then along the hole in centre of the piston into the chamber to the left of the piston. The pressure in this chamber rises until it is sufficient to overcome the force exerted by the spring. The piston then moves across to seal the regulator port.
- The spool valve *(see #13 on the drawing next page)* is fitted to the inter-stage. The function of this device is that When the SLS System is in its stand-by mode, the spool isolates the first stage from the second stage of the

regulator. It is moved from the closed to the open position when the actuation cable *(connected to the handle)* is pulled. A bullet on the end of the cable contacts the two ball bearings *(see #14)* in the centre of the spool, drawing the valve to the open position. The ball bearings then drop out of the way allowing the bullet to pass through and away up the cable sheath.

- The second stage of the regulator is a diaphragm type. The pin *(see #19 below)* is held off the seat by the diaphragm *(see #23)*, and the support plate (see #22) under the action of the spring (*see #18*). As the pressure in the space to the right of the diaphragm increases, the diaphragm and hence the pin moves to the left, sealing off the seat fully at the pre-set outlet pressure. The outlet pressure is adjusted by varying the tension of the spring by slackening the locknut *(see #31)* and adjusting its screw *(see #31)* until the desired outlet pressure of 1 bar above ambient is achieved.

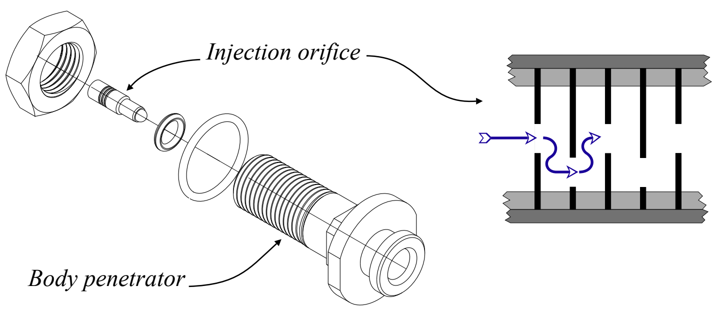


1 - Connector + O rings	*9 - Piston + Seat*	*17 - Cir-clip*	*25 - Support plate (springs)*
2 - Bronze filter	*10 - O ring*	*18 - Compression spring*	*26 - Springs*
3 - Inlet banjo fitting	*11 - Body*	*19 - Valve pin*	*27 - Adjustment plate (springs)*
4 - Cir-clip	*12 - O rings*	*20 - Valve seat*	*28 - End cap*
5 - O rings	*13 - Valve shuttle*	*21 - Valve seat retainer*	*29 - Regulator mesh*
6 - End cap	*14 - Ball bearing*	*22 - Plate diaphragm support*	*30 - Cap sleeve*
7 - O ring	*15 - Load ring*	*23 - Diaphragm*	*31 - Screw + nut*
8 - Compression spring	*16 - Relief valve + gasket*	*24 - Slip ring*	*32 - Mounting plate*

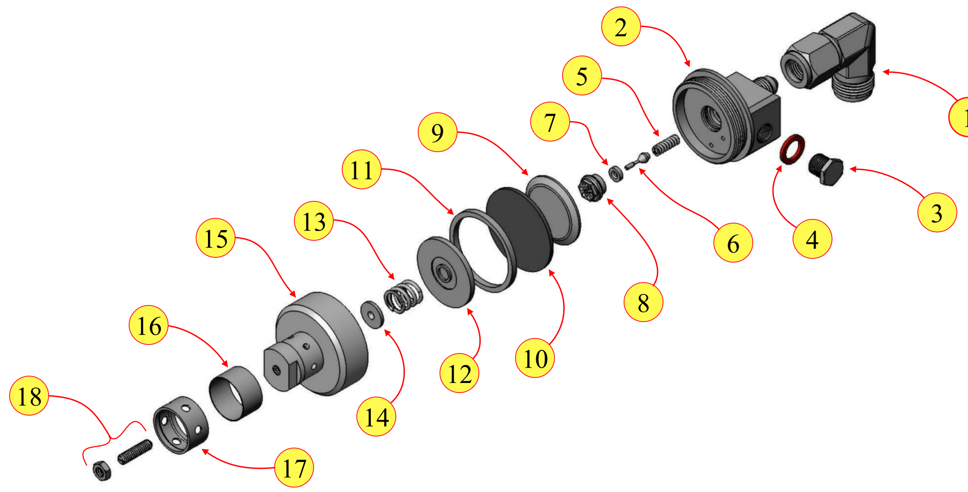
The gas is then supplied to the injection orifice located within the penetrator *(see # 24 in the general drawing in the previous page)* from which it then passes into the breathing circuit at the bottom of the CO_2 scrubber housing.

The injection orifice contains a group of orifices in series with the flow path making many 90º changes in flow direction. The combined effect is to allow the system to contain much larger holes than there would be for a single orifice with the same resistance. This arrangement is designed to reduce blockage.

Note that one penetrator is blank *(see # 25 in the general drawing in the previous page)* and is used as a locating pin for the scrubber lift mechanism.

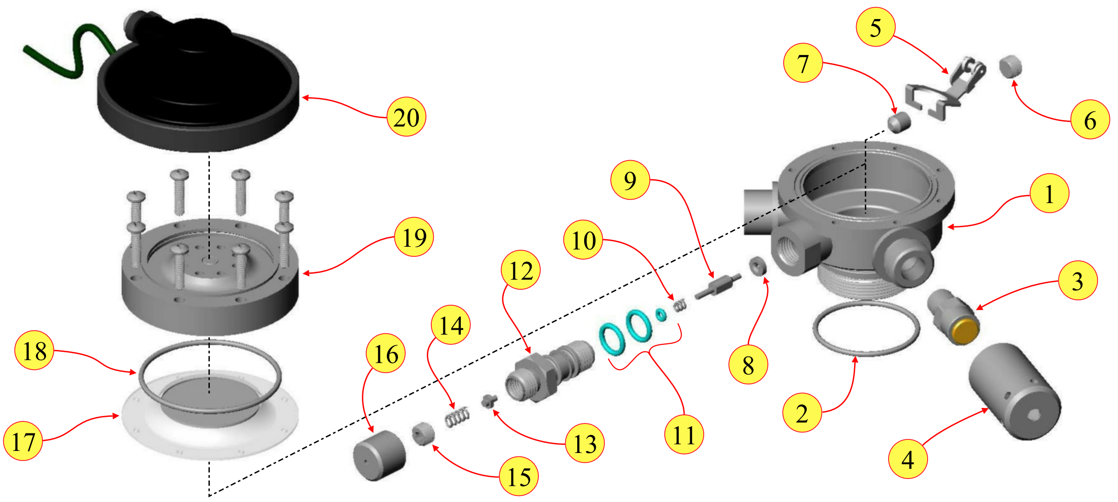


As already indicated in the previous descriptions, the single stage regulator (*see #27 in the general drawing two pages before*) which is supplied with gas from the helmet site block to which it is connected maintains a pressure of 1.38 mb over ambient pressure inside the system at all operating depths while it is in its standby mode to prevent water ingress. Also, it is designed to cope with the diver's upward and downward excursions at a rate of 22 msw / minute maximum.
This regulator is of a diaphragm type which is similar to the second stage of the two-stage regulator.
The valve pin *(see #6 below)* is held off the valve seat *(see #7)* by the diaphragm *(see #10)* and the support plate *(see #12)*, under the action of the spring *(see #13)*. As the pressure in the space to the right of the diaphragm increases the diaphragm and hence the valve pin moves to the left sealing off the valve seat fully at the set outlet pressure.
The outlet pressure is adjusted by varying the spring *(see #5)* tension by slackening the locknut and adjusting its screw *(see #18)* until the desired pressure of 1.38 mb is reached.



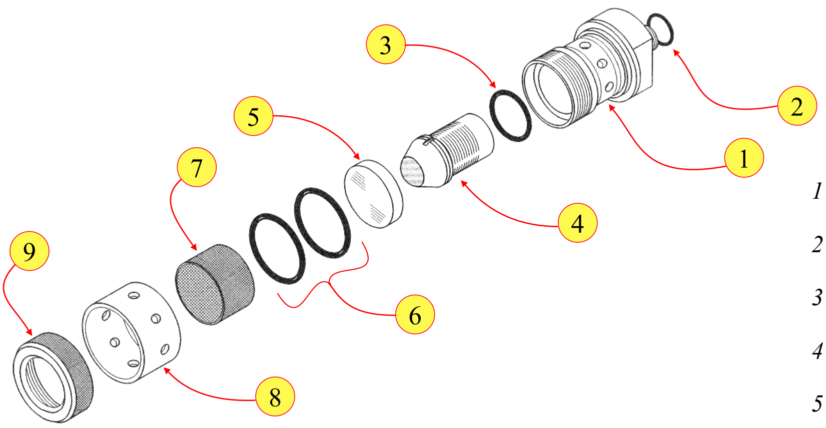
1 - Elbow swivel	*6 - Valve pin*	*11 - Slip ring*	*16 - Slip ring*
2 - Body	*7 - Valve seat*	*12 - Support plate (spring)*	*17 - Cap sleeve*
3 - Plug	*8 - Retainer valve seat*	*13 - Spring membrane*	*18 - Screw + nut*
4 - O ring	*9 - Plate diaphragm support*	*14 - Adjustment plate (spring)*	
5 - Spring	*10 - Diaphragm*	*15 - End cap*	

The demand regulator *(see #2 in the general drawing)* that supplies gas to the system for the 1st breath, and compensates the system in gas volume during any descent while the system is activated, is designed to flow gas only when it is subjected to a depression of 25,5 to 26.5 millibar to prevent the system from passing gas when it is not required.
This regulator is similar to a conventional demand regulator but differs in that it is designed to function with gas supply pressures ranging up to 300 bar so that it does not require first stage pressure regulation.

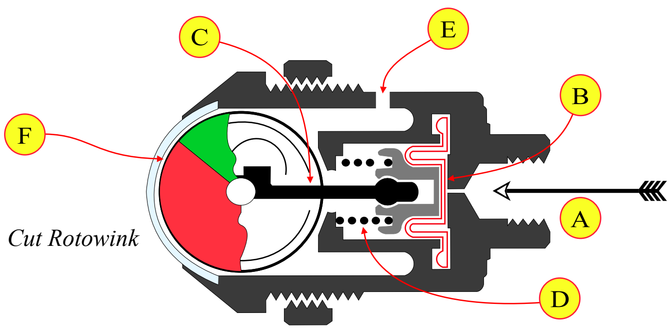


1 - Body	*6 - Set-screw*	*11 - O rings*	*16 - Cap*
2 - O ring	*7 - Demand valve shuttle*	*12 - Seat retainer*	*17 - Diaphragm*
3 - Relief valve	*8 - Valve seat*	*13 - Spring pad*	*18 - O ring*
4 - Vent cap relief valve	*9 - Valve pin*	*14 - Spring*	*19 - Lid sub-assembly*
5 - Lever	*10 - Spring*	*15 - Valve adjustment screw*	*20 - Protection cover assembly*

The high-pressure gas from the cylinders enters the demand regulator through a banjo fitting. We can observe that the gas supply pressure acts on the pin *(see #9 in the drawing on the previous page)* at the O-ring *(see #11)* and, over the same area, at the valve seat *(see #8)*. As a result, we can say that the valve pin *(see #9)* is pressure balanced. That means that the regulator supplies gas at the same negative pressure setting over a wide range of gas supply pressures.
The valve is normally held closed by the spring (see #14). When the pressure acting to the diaphragm (see #17) becomes sufficiently great for the lever fork (see #17) to overcome the spring (see #14) the lever fork pushes the valve pin allowing new gas to flow into the system.
An overpressure valve *(see #3)* that is factory set is fitted to ensure that during the standby mode the internal pressure of the system does not exceed 172 bar. As a result, the internal pressure within the SLS system will vary between the single stage regulator set pressure of 138 millibars and the overpressure valve set pressure of 172 millibars as the diver's ambient pressure will change during the upward or downward excursions.
As indicated previously, a pressure indicator of Rotowink type which changes from green to red if a significant loss of pressure occurs is fitted to the system *(see the drawing below)*. It is installed in a robust metal housing which is allowed to flood in order to reference the ambient water pressure. A fine mesh screen is fitted to prevent the ingress of dirt to its internal parts exposed to the water.



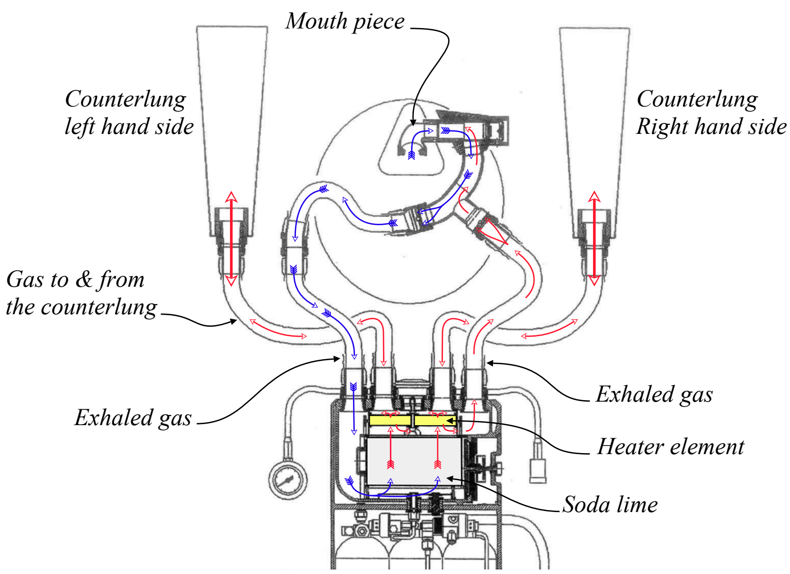
1 - Body	*6 - O rings*
2 - O ring	*7 - Mesh*
3 - O ring	*8 - Mesh retainer sleeve*
4 - Rotowink	*9 - Top cap*
5 - Lens	



Cut Rotowink

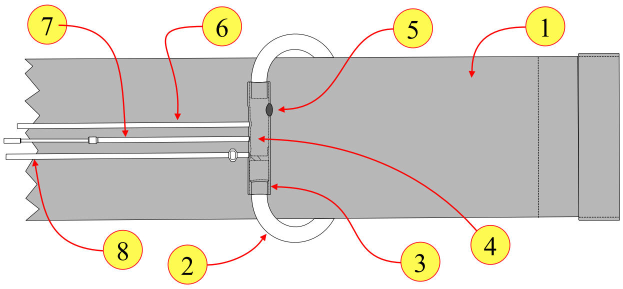
A - Gas pressure	*D - Spring*
B - Membrane	*E - Opening to ambient*
C - Connecting rod	*F - Rotating indicator*

Another difference the SLS Mk4 has with the last generation rebreathers used by militaries and trained scuba divers is that the counterlungs of most of these new systems are organized in such a way that one unit collects the exhaled gas and the second unit is filled with the renewed gas to inhale. Thus, one counterlung is before the cartridge of soda lime and the 2nd after it. Opposite to this design, the counterlungs of the SLS Mk4 are working together and are situated after the CO2 absorber. Also, they are connected by separate hoses and are not along with the main respiratory hoses. As a result, four breathing hoses are installed on the backpack instead of two with the last generation rebreathers.



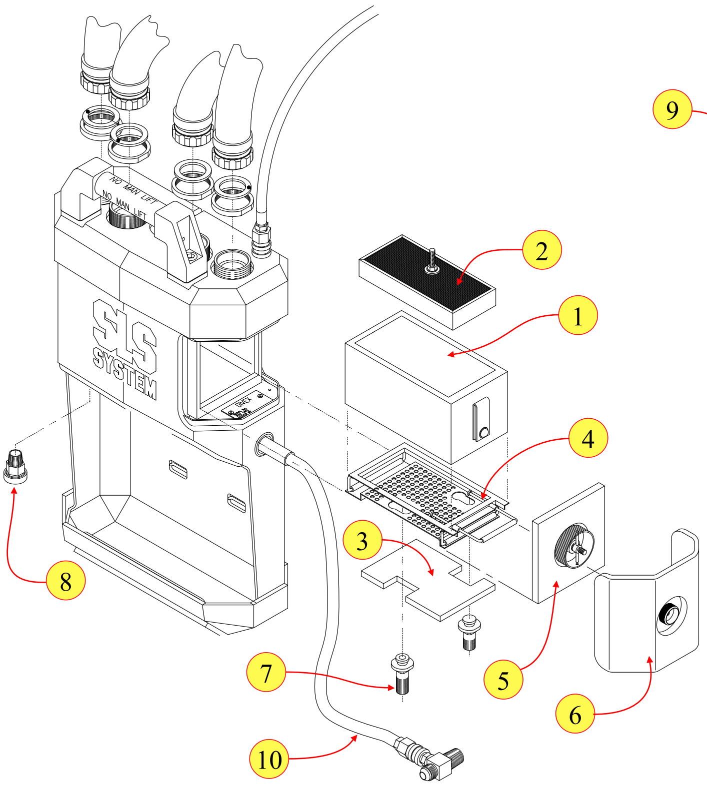
Also, as the SLS is designed to be used only in an emergency, the counterlungs must be protected from rubbing and shocks that may damage them. It is the reason they are packed in robust enclosures.
These enclosures are maintained closed by a series of Teflon lined loops through which the two nylon actuation cables are passed. This design allows the actuation cables sliding easily when they are pulled out by the handle. As a result, the enclosures fall open, and the counterlungs deploy ready for use.
Note that it is of ultimate importance that the cables are entirely removed from the rings to have a correct opening of the enclosures.

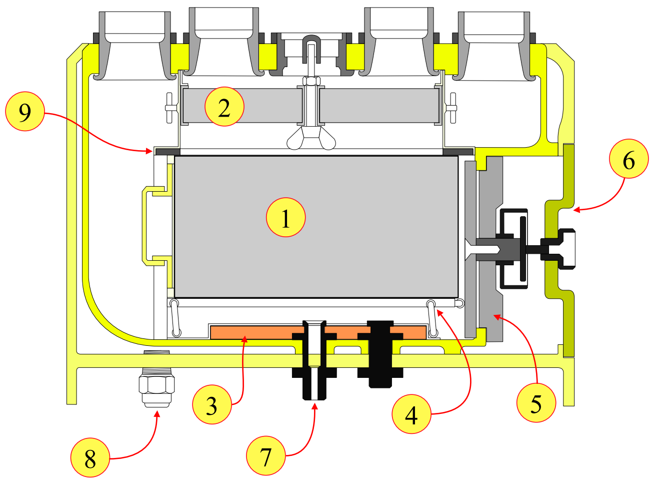
Note that the lengths of the actuation cables which are connected to the actuation handle must be adjusted in such a way that the two-stages regulator and the counterlungs are actuated simultaneously (see the drawing below). This handle is protected by a flap which is terminated by a red colour band *(see item "A" on the photos below)*



1 - Webbing	*5 - Screw*
2 - Actuation handle	*6 - Cable actuation counterlung*
3 - Handle sleeve	*7- Cable actuation regulator*
4 - Cable holder	*8 - Cable actuation counterlung*

The refillable scrubber canister assembly *(See #1 below)* is a rectangular box which contains 125 gramme of soda lime that allows absorbing CO_2 for 30 minutes maximum *(see the endurance table on the next page)*. It is inserted into the back pack through a waterproof lateral door *(see #5 & #6)* and is pressed against its gaskets by a lift mechanism *(see #4)*. Note that this opening allows accessing the thermal regenerator and the absorbent sponge *(see #3)* which collects moisture resulting from condensation and breathing.





1 - Scrubber canister	*6 - External door*
2 - Thermal regenerator	*7 - Injector*
3 - Absorbent sponge	*8 - Relief valve*
4 - Lift mechanism	*9 - Gasket*
5 - Waterproof door	*10 - Hot water inlet*

The preparation of the SLS Mk4 requires some precautions. Also, Some preventive maintenance has to be performed to ensure that the system is always ready for use.

- The procedure and safety precautions for charging the bottles are those used with quads and scuba cylinders. Also, as previously indicated, Divex says that they must be emptied before filling them again.

- The determination of the mix to be used should be done according to the table and method explained previously. Also, the endurance of the system depends on the pressure of heliox stored in the bottles and the duration of the CO_2 absorbent, which is 30 minutes maximum. As a result, Divex says that there is no advantage in charging the cylinders to their maximum pressure (300 bar) for shallow dives. The table below can be used to select the pressure necessary for the planned depth of intervention:

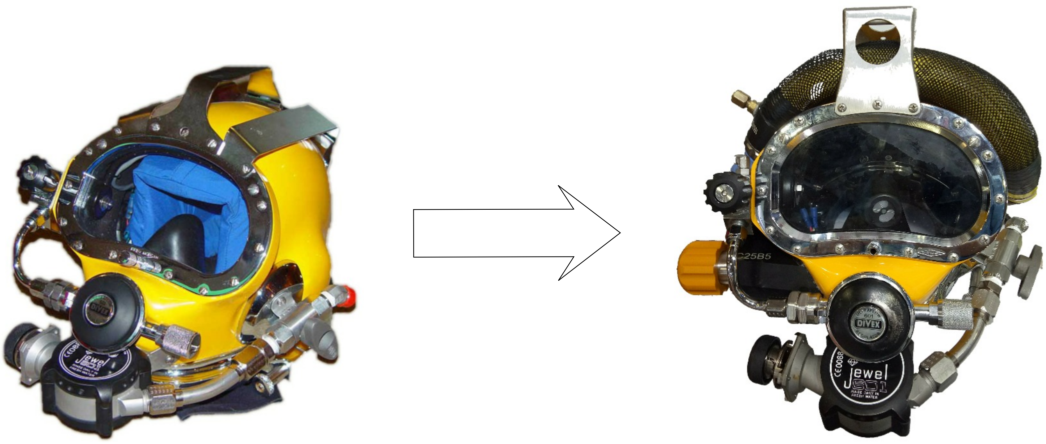
Depth	*Charging pressure*	*Duration (minutes)*	*Depth*	*Charging pressure*	*Duration (minutes)*
50 msw	*300 bar **	*30 min **	*200 msw*	*150 bar*	*10 min*
50 msw	*175 bar*	*30 min*	*250 msw*	*300 bar*	*19.5 min*
50 msw	*100 bar*	*17 min*	*250 msw*	*200 bar*	*12.5 min*
100 msw	*300 bar **	*30 min **	*300 msw*	*300 bar*	*17.5 min*
100 msw	*250 bar*	*30 min*	*300 msw*	*200 bar*	*11 min*
100 msw	*100 bar*	*12 min*	*350 msw*	*300 bar*	*16 min*
150 msw	*300 bar*	*28 min*	*350 msw*	*200 bar*	*10 min*
150 msw	*150 bar*	*14 min*	*400 msw*	*300 bar*	*13.5 bar*
200 msw	*300 bar*	*22 min*	*400 msw*	*250 bar*	*11 min*
*Note: The values with an asterisk * are limited to 30 minutes due to the scrubber canister duration.*					

- The manufacturer recommends replacing the scrubber canister every 24 hours even though the system has not been actuated. The reason is that there is possible aggregation (sticking together) of the soda-lime granules within the moist bell environment.
- Precautions are indicated by the manufacturer for the compression and decompression of this item. It is to prevent the external pressure damage to the o rings of the pipework, the cylinders, and other items composing the SLS Mk4 system:
  - The SLS system backpack must be disconnected from the helmet prior to locking it in or out of a chamber complex or prior to compression or de-compression of a diving bell or a chamber with the SLS system inside.
  - The gas cylinders must be charged prior to the compression of the backpack

Of course, the SLS system is designed for one use only. For this reason, it must be fully reconditioned after any actuation. This reconditioning includes the change of the soda-lime and a detailed inspection of all the components.
Note that the procedures for the maintenance and inspection of this equipment can be found on the manufacturer's website at the following address: https://www.jfdglobal.com/

2.3.7.4 - COBRA (Compact Bailout Rebreathing Apparatus)

The COBRA (Compact Bailout Rebreathing Apparatus) is the new system from DIVEX that replaces the SLS Mk4. It provides better ergonomics, allows more time to return to the bell, and can be used at depths up to 450 msw in seas at temperatures between -1 Cº and + 34 Cº.
This device, that is based on the same concept as its predecessor, is composed of a backpack that is connected to a specific helmet with the similar operational principle of a conventional semi-closed circuit breathing apparatus, in which the exhaled gas is captured in counterlungs and is then re-breathed by the diver, after removal of the carbon dioxide (CO_2), and injection of fresh heliox to maintain a mix adapted to the depth of the diver. Note that, as with the SLS Mk4, the helmet is originally a conventional Divex "Ultrajewel 601" to which the necessary elements for the rebreather are adapted *(see below and in point 2.3.6.1)*.

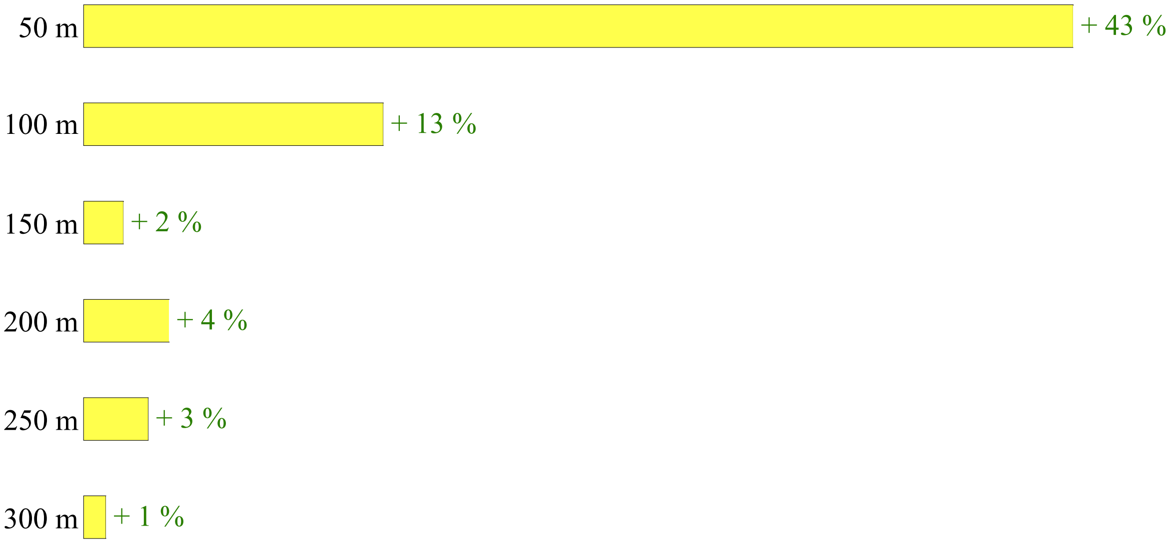


Similarly to the SLS 4, the “backpack” consists of the main housing containing the gas injection system, the CO_2 scrubber canister and the thermal regenerator that temporarily stores the heat within the breathing gas to avoid losing it to the water as the breathing gas passes into the counterlungs.
These modules have been improved, so the operations to change the soda lime of the scrubber are much simple. Also, the feeding of the positive pressure that maintain the breathing loop integrity when the rebreather is offline to allow for the first breath at activation is increased, which allows for a more rapid descent.
A major difference with the SLS Mk 4 is that the counterlungs are encapsulated inside the main housing instead of being on the harness straps. This configuration protects them better against potential damages than the flexible external protectors of the SLS Mk 4. Also, their deployment is now automatic, so the diver does not have to pull an actuation handle to open their enclosure as with the previous model. As a result, the activation of the system is performed with only the rotation of the dedicated handle of the helmet that deploys the mouthpiece at the same time it opens the gas circuit. Note that this configuration also eliminates the two big shoulder counterlungs hoses, so the mobility of the diver is improved.

The gas injection system is composed of two composite or steel gas storage cylinders that supply the 1st & 2nd stages of the regulator, the injection orifice, and the demand valve. As with the SLS Mk 4, the system is provided with a “Rotowink type” pressure indicator, which changes from green to red if a significant loss of pressure occurs. There is no electronic component in place to calculate and dose the mix, such as those found in modern exploration rebreathers used by militaries and sportive divers. Instead, the appropriate percentage of oxygen of the breathing gas is calculated by the technician in charge according to the planned depth of excursions and stored in the cylinders before the dive. So, this system, which is designed to be available at all times within the excursions limits planned for the dive, is similar to the one used with the SLS Mk4. However, the cylinders are installed on each side of the gas injection and reclaim modules instead of underneath them with the SLS Mk4.

Another improvement is that this new system can be activated and deactivated as required. That allows the diver to perform pre-dive function tests as with the gas cylinder of an open circuit bailout. Also, the weight of the system, which is calculated to be neutral in the water, is 26 kg in air. So, it is lighter than the twin-set bottles 10 litres commonly used, and sufficiently compact to be appropriately stored in the bell.

According to the data from DIVEX, the comparison of the possible breathing duration of the COBRA with those of the SLS Mk4 demonstrates improvements at all depths at the following approximate percentages:



In conclusion, this new system of bailout erases the majority of the inconveniences of the SLS Mk 4 without losing its advantages. It provides an increased safety level to the diver and should be adopted for all dives below 50 m and in cold waters.

Note:
Courses regarding the use and the maintenance of this system are organized in the several subsidiaries JFD and can be booked at this address: https://www.jfdglobal.com/services/training-services/course-booking/

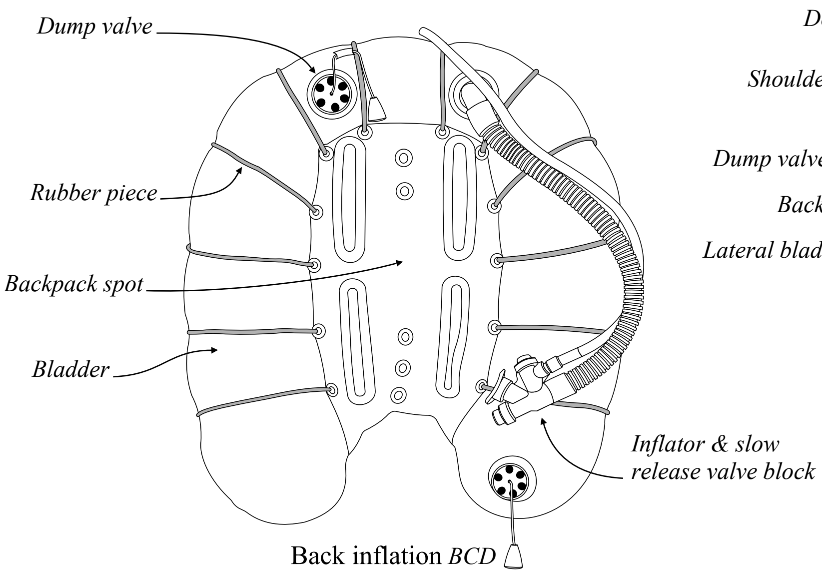
2.3.8 - Buoyancy Control Devices (BCDs)

Recreational scuba divers and militaries commonly use buoyancy control devices. However, they are still not always adopted for saturation, and surface orientated commercial diving operations, despite some noticeable progress.
It is important to note that these tools give the possibility to set a neutral buoyancy allowing the diver not to drop and easily control his depth when performing excursions that are not on the seabed. Also, they can be helpful in the case of the recovery of an unconscious or injured diver. It must be remembered that in the case of a team of three divers, recover a casualty who is not in a condition to move by himself with only the help of the umbilical that is pulled from the bell is a difficult task, even though the rescue diver and the bellman are active and experienced. Also, in the case that the team in the bell is limited to two persons, the rescuer intervening in the water is the bellman, and there is nobody in the bell to pull the umbilicals. For these reasons, we can say that these devices are beneficial and should be part of the tools available to the diver when it is possible to implement them.

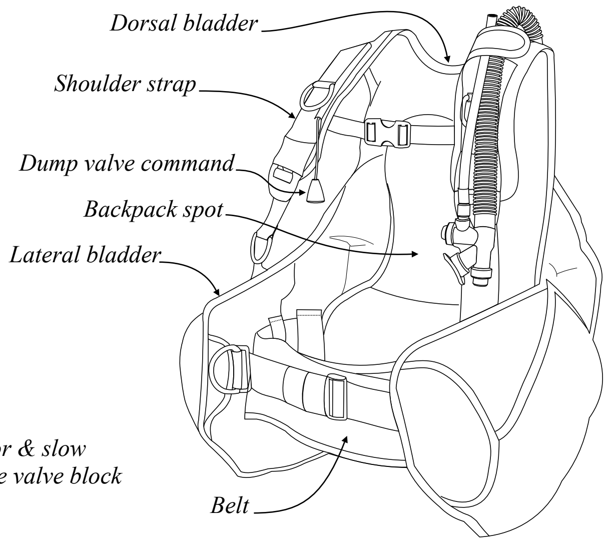
2.3.8.1 - Description

They are composed of a bladder or a sealed bag where the gas is injected through an inflator which is connected to a low-pressure gas supply of a 1st stage regulator connected to a cylinder or situated on the side block of the helmet. The gas trapped in the bladder is released using quick release valves (dump valves) and slow release valves that are used to control the buoyancy. They can be classified into two main families:

- “Stabilizing jackets”, also called “vest BCDs,” are buoyancy control devices that are shaped as a vest. With this design, the trapped gas is distributed around the belly, the torso, the back, and the shoulders. They are generally fitted with adjustable straps. This repartition of the gas makes them very safe when they are fully inflated at the surface as the body of the diver is kept vertical. However, note that these devices will never be used at the surface during saturation diving operations.
- “Back inflation buoyancy control devices”, which are also called "Wings," are installed around the backpack, thus are inflated in back of the diver and may be fitted with rubber bands that retract them when they are not in use. These models are often used by sportive scuba divers practicing deep incursions with extra cylinders as some models can provide lift capacities above 40 kg. However, large volume bladders are unnecessary for saturation divers as, due to the supply from the umbilical and the proximity of the bell, they do not need to carry these cumbersome extra gas bottles.



Back inflation *BCD*



Stabilizing jacket

2.3.8.2 - Precautions to be in place for the implementation of BCDs

- Formation of the divers:

Buoyancy Control Devices are dangerous tools when the divers have not been trained to use them, which may be the case with some commercial divers. Note that there is no IMCA module for the use of BCDs, and even though the procedures for the implementation of such items or inflated dry suits is taught in a lot of diving schools, several experiences show that it is not the case of all schools. For this reason, the diving superintendent must ensure that the divers have had such training. That can be done through the control of certificates or a test. Note that the following documents, but not limited to, can be considered a proof of competence:

- The logbook of the diver should normally record the formations the diver has received. Also, the suits and buoyancy control devices used during the projects should be indicated.
- Military or sportive diving certificates or licenses may prove that the diver is familiar with buoyancy control devices. Note that regarding this point the description of the formation undertaken should be provided.

If there is no evidence that the diver is familiar with buoyancy control devices, he cannot be authorized to dive with such equipment.
Of course, the company can implement a test or a formation. However, that should not be organized without the support of a recognized diving school and diving instructors.

- Selection of the model:

There are a lot of models of Buoyancy Control Device. However, most of them are initially designed for sportive or military divers, and may not be suitable for commercial saturation diving. For this reason, a lot of precautions should be in place when selecting the model. Also, the selection of the BCD should be made by experienced divers and diving supervisors. The people in charge of choosing such devices should focus on the following elements, but not limited to:

- The BCD must not disturb the use of other safety devices such as bailout systems (bottles or rebreathers).
- There must not be conflicts with the hoses and wires of the helmet, the attachment of the umbilical, and the hot water connection and manifold.
- The device should be fitted with dump valves and a slow release valve which are situated in the upper parts of the bladder. Their commands must be readily accessible. Note that the inflator is often fitted at the end of a ringed hose with the slow release valve *(see the drawing on the previous page)*. This hose should be arranged in such a way that it does not conflict with another equipment and is readily accessible at all times. If it is not the case, it should be replaced by an inflator similar to those used with dry suits (*see # 1 on the photo to the side)*. Also, if the BCD is fitted with an optional bottom dump valve, it should be situated in a convenient place and the person selecting the equipment must ensure that it cannot be opened unexpectedly. Thus, if this extra valve can be the source of a safety problem, it should be removed.
- BCDs used for commercial diving must be made of materials that are strong enough not to be damaged during working operations in an aggressive surrounding.
- The buoyancy control device should not deprive the diver of breathing gas if his bailout system is activated. For this reason, it is preferable to supply it from one or two separate dedicated small bottle(s) as it is the case with a lot of military models.

BCDs mounted on twin bottles sets used for shallow saturation diving in one of the bells of UDS Lichtenstein

- Pre-dive checks and maintenance:

BCDs are safety equipment that must be checked before each dive. For convenience, these checks may have to be performed by the technicians outside the bell:

- Webbing, cloth, and sewing threads should be in perfect condition without noticeable wear or scratch.
- The bladder and valves should be tested for leaks, and defective spares should be replaced. Note that most manufacturers say the lifetime of a bladder is approximately 10 years from the date of manufacturing.
- The inflator should be easy to trigger and should immediately return to the closed position when released.
- Note that the small bottles and their regulators may have been flooded. For this reason, they must be frequently visually inspected. They should be removed from service and adequately tested and refurbished if corrosion is detected. Note that these bottles must not be filled inside the saturation system.

Preventive maintenance should be performed:

- The BCD should be rinsed with fresh water internally and externally after every dive.
  Regarding the internal parts of the BCD, the seawater that is inside the bladder should be removed and replaced by approximately two litres of fresh water and the BCD should then be inflated and shaken to rinse it appropriately. This fresh water is then removed. Note that this operation can be repeated several times.

- Note that a Buoyancy Control Device (BCD) transferred from the saturation system through the tool transfer lock should be emptied; otherwise, it will be fully inflated when it arrives at the surface. A precaution to avoid this is to remove one dump valve.
- Pre-project training may be organized in a swimming pool that is filled with chlorinated water. For such a case, manufacturers recommend to thoroughly rinse the BCD, as repeated exposure in such water can damage the construction materials used.
- A buoyancy control device that must be stored should be dried externally and internally. A natural process of drying is recommended not to damage it. Also, manufacturers recommend to store it partially inflated.

2.3.9 - Knifes, fins, weight belt, and small equipment

Only devices from recognized manufacturers are considered suitable.

2.3.9.1 - Knife

The diver must have a knife that is designed to cut ropes, fishing lines, and textile slings.

- The blade that is suitable for this purpose has a specific profile and is sufficiently long (16 to 20 cm) to cut big ropes.
- This blade must be strong enough to not break during normal use. It should be made of specific stainless steel that does not corrode.
- The knife is secured in its sheath that is designed to secure it and easily release it.
- The diver must ensure that it is easily accessible. A small coiled lanyard should be installed to avoid losing it.
- The knife must be tested for efficiency before starting the bell run.
- Note that despite precautions, knives are often lost during diving operations. For this reason, a spare unit should be in the bell and several replacements must be available in the onboard store.

2.3.9.2 - Fins

Fins must be worn for all jobs that are not on the seabed. They should always be available in the bell even though the task is planned to be performed on the seabed and that the diver logically prefers using boots, as they can be useful in the case of an emergency or if the diver needs them due to the conditions encountered. The following elements should be taken into account when selecting them:

- Fins designed for diving operations from closed bells should be made of durable materials and not be too long to allow easy deployment of the diver, not take too much space in the bell, and not to disturb him during the work.
- Open heel fins are generally preferred as they can be worn on booties and are adjustable. However, the shoe size must not be too large and fit the feet of the diver. If it is not the case, the diver does not swim comfortably and may lose them.
- Note that despite numerous new models that are proposed for the market, fins used for commercial diving have not really evolved for more than fifty years. As an example, the model in the photo at the side is still one of the most used and was first commercialized under the name "Jetfin" in 1964. This model is made of rubber and appreciated for its durability despite its heavy weight and its reduced output compared to more modern models.

Fins should be inspected before each bell run:

- Note that rubber straps are fragile and often need to be changed. For this reason, spare straps must be available in the bell.
- Also, buckles may be damaged and should be carefully checked:
  - Metal buckles are robust. However, they may distort with time, or the rubber parts in which they are inserted may tear when they become too old.
  - Plastic fasteners are often mounted on pivots that are molded in the mass of the fin and that may become quickly worn to retain them in position. When such a problem happens, the fins cannot be repaired and should be scrapped. That explains the reason old models such as the one in the photo are still successful.
- Note that rubber loses its capabilities over time. As a result, items made of rubber stored for too long a time become sticky and lose their elasticity and thus may tear easily. Of course, the effects of the sun and the salt speed up this process. Nevertheless, it will happen to items ideally maintained and stored. Products such as talc powder slightly slow down such the process.
- Fins may be lost by divers even though they are in good condition. For this reason, there must be a replacement pair in the bell and several spare units onboard the vessel.

2.3.9.3 - Buoyancy control weights

Depending on whether the diver works on the seabed or not and is equipped with a buoyancy control device, weights should be used to adjust his buoyancy. A balanced buoyancy is ideal when the diver is working above the floor and needs to swim. However, remember that a saturation diver who becomes positively buoyant is exposed to an uncontrolled ascent, and so is in danger.
These weights of one or two kilograms and sometimes one pound can be molded lead blocks or granules in sealed bags. They can be put on a specific belt made of textile or rubber, or clipped to the harness of the diver, or inserted into dedicated pockets of the harness or the buoyancy control device. Note that in the old time weights could be trapezoidal medals installed at chest level. However, this system seems to no longer be used for saturation diving.

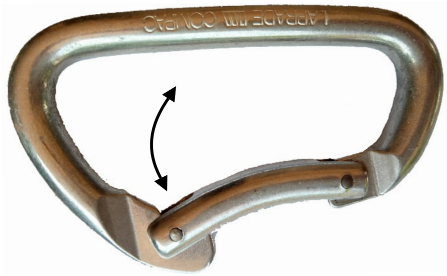
Belts are still used for scuba and commercial surface oriented diving as, depending on the job undertaken, they may have some advantages.

However, they are not the best option for saturation diving and teams still using them are very rare.
If this option is selected, the belt must be robust enough not to be torn during a dive, designed not to be opened (lost) unexpectedly, and be adjusted in such a way that it cannot slide. Specific buckles that can be quickly closed and opened are proposed by manufacturers. Nevertheless, classical pin buckles are still the most selected and the preferable option.
The weights that are installed on the belt must be measurable and secured on it in such a way that they cannot be lost.
Belts are not complex items. However, when preparing the dive, the diver should focus on the sewing or the rivets that secure the buckle and the holes in which the pin of the buckle is inserted. Also, as explained previously, rubber does not keep its capabilities over time and may become stiff and fragile.

As a result of this discussion, weights secured in dedicated secured pockets of the harness seems the most comfortable and safest solution. Thus, the preferable option for saturation diving.

2.3.9.3 - Rescue Lanyard

A lanyard that is designed to secure an injured or an unconscious diver to the rescue diver should be provided to each diver. The rescue lanyard should be a strong polyester rope (approximately 1 cm diameter) with a spliced eye at each end or a similar small soft sling of approximately 1 m long with a carabineer is ready for use in each eye.
Climbing type carabineers similar to the model below, which is designed to be quickly inserted and remain always closed as a result of its particular shape, are the best option for this essential safety tool.



2.3.9.4 - Compass

With the progress of survey systems, divers are guided to the target using beacons. However a compass is a good help to follow or report a direction. These instruments should be able to withstand the pressures attained in saturation. For this reason, liquid filled compasses are recommended.
Note that a lot of diving compasses designed for recreational scuba divers are originally designed for depths above 100 metres.

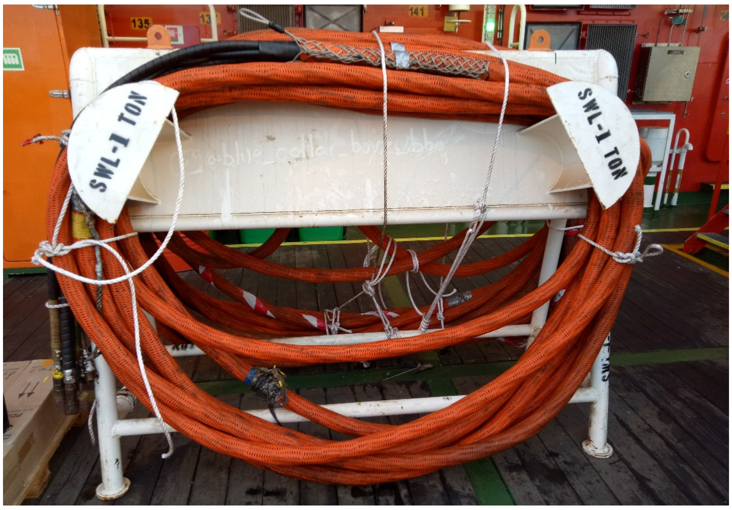
2.3.10 - Main bell umbilical

2.3.10.1 - Description

The main bell umbilical is an essential part through which the following functions are transferred to and from the bell:

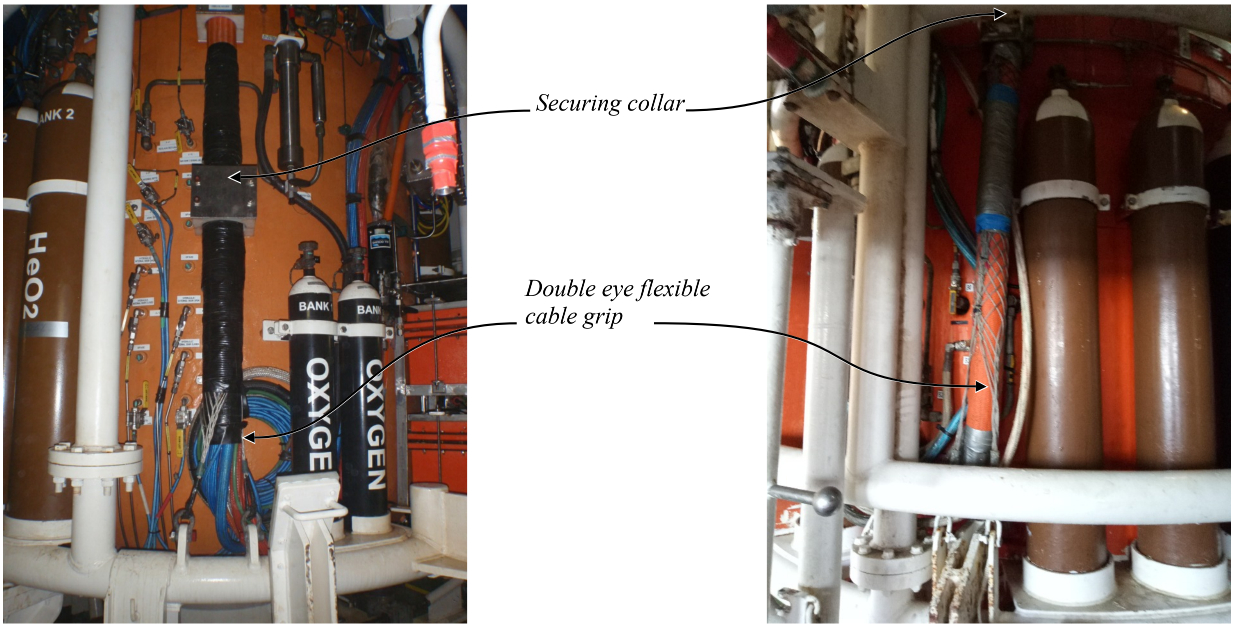
- Gas supplies and exhausts:
  - Bell pressurization and exhaust
  - Diver #1 & #2 gas supply
  - Bellman/Standby diver (diver #3) gas supply
  - Divers' gas reclaim exhaust
- Depth, atmosphere control, & temperature control
  - Depth external bell & diver #3
  - Depth internal bell
  - Depth diver #1
  - Depth diver #2
  - Analysis bell
  - Hot water supply
- Electrical supplies
  - External lights
  - Internal lights
  - Scrubber
  - Diver #1 hat light
  - Diver #2 hat light
  - Diver #1 camera
  - Diver #2 camera
  - Bell internal camera
  - Bell external cameras
  - Sensors divers' monitoring system
  - Hypergas analyser (hydrocarbons analyser)
  - Onboard batteries & through water comms battery
- Video, sensors, & communication signals
  - Diver #1 video signal
  - Diver #2 video signal
  - Signals sensors divers monitoring systems
  - External bottom camera signal
  - External topside camera signal
  - Internal camera signal
  - Sound powered phone communications
  - Microphone diver #1 signal
  - Earphone diver #1 signal
  - Microphone diver #2 signal
  - Earphone diver #2 signal
  - Microphone standby diver (diver #3) signal
  - Earphone standby diver (diver #3) signal
  - Microphone bell intercom signal
  - Earphone bell intercom signal
  - Hypergas analyser signal

Wires and hoses are maintained together by a polyethylene braided sock that protect them from shocks and abrasion. The hoses are made of rubber and high-performance thermoplastic polymers. Similar materials are used to isolate the electrical and communication wires.

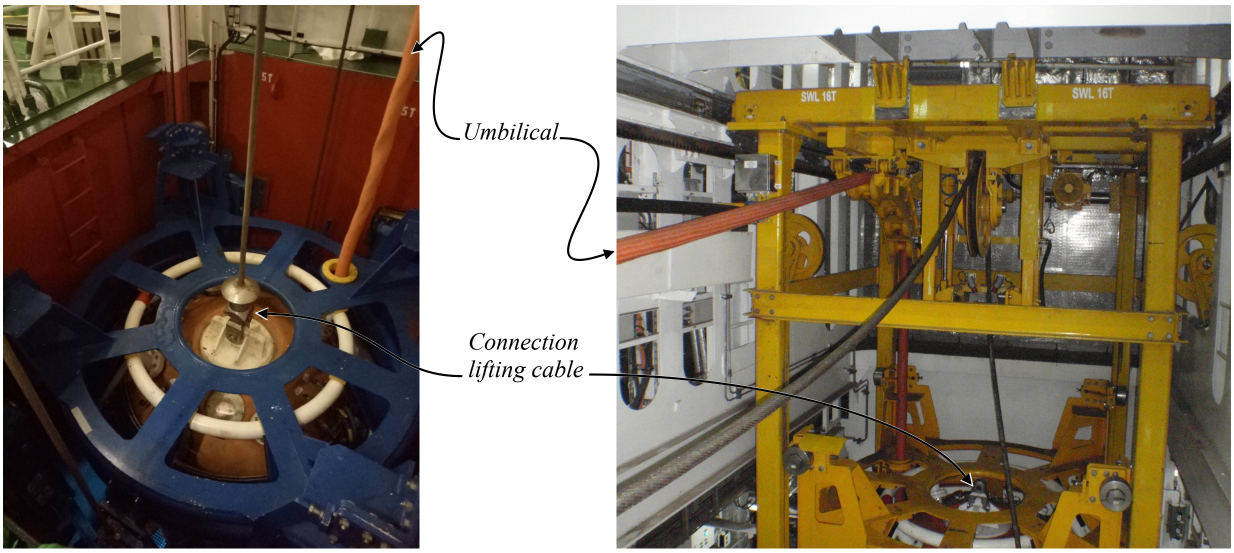


2.3.10.2 - Installation and protection

IMCA D 024 says that The umbilical must be securely attached to the bell by means of a strength member or strain relief fitting so that neither the individual components or any bell penetrations are subject to load. The leads of the hoses and cables at the bell end should be arranged to avoid chafing or kinking.
To fulfill this requirement, most umbilicals of modern systems are secured to the protection frame of the bell by double eye flexible cable grips. Note that in the examples below each umbilical is attached to the bottom frame and also secured along with the bell by dedicated metallic collars. As a result, the hoses and wires moving out the polyethylene braided sock are protected from tractions that may damage them. Also, the connecting wires and hoses are secured along with the wall of the bell and have sufficient ample curves to protect them from kinking. Note that contacts with obstacles should be absorbed by the protection frame of the bell that is arranged at a sufficient distance to ensure that wires and hoses should not be affected by shocks, chafing, and other damages resulting from such undesirable events.



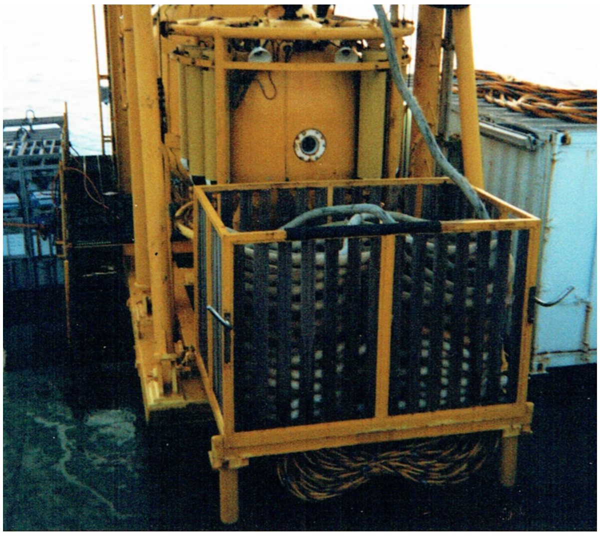
The external braided sheath of the umbilical can be damaged by frequent rubbing with the lifting and guide cables. Also, it can become very dirty as these cables are coated with a layer of grease that protects them from corrosion. To protect the umbilical and avoid conflicts with the lifting cables during the deployment and the recovery of the bell, the manufacturers of the last generation systems secure them to the side of the bell and as far away as possible from any cable. Also, they provide dynamic tensioning systems that permanently recover the excess of slack of the umbilical. As a result, the umbilical is kept in perfect condition.



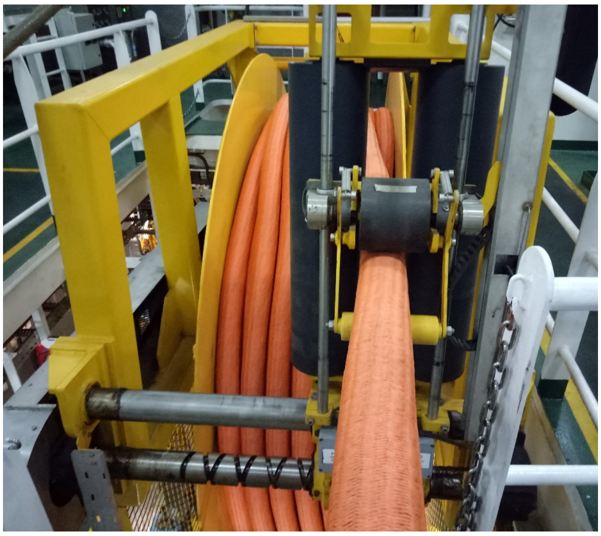
Note that the umbilicals of some systems from the previous generation are sometimes connected to a pad-eye that is welded on the top of the bell and close to the lifting point of the pressure vessel. Also, they are not equipped with dynamic tensioning systems. That results in umbilicals with sometimes an excessive slack that are rubbing with the cables and are made dirty by the grease that protects these cables. To avoid having too much slack in the water with such systems a solution frequently used is to fasten the umbilical along with the lifting cable by the means of whips. The distance between the whips depends on parameters such as the underwater currents and whether the surface support uses a dynamic positioning system.

Old systems are designed with umbilicals that are recovered and deployed by rollers and manually stored in a rectangular or a rounded basket. The manual storage of such an umbilical is a strenuous task that employs at least two people.

Modern systems are designed with a winch that coils the umbilical ideally and deploys it at the speed of the cable winches. The winch is also a part of the dynamic tensioning system. Note that IMCA says that it should be fitted with a mechanical braking system to stop the umbilical paying out under load when the winch motor is in use (over-running), in neutral, or at rest.



Umbilical basket (old generation systems)



Umbilical winch (Last generation systems)

2.3.10.3 - Bell recovery using the umbilical.

IMCA D 024 says: *The umbilical should only be used as a means of secondary recovery if it is specifically designed for that purpose. If so, it must be tested in line with the requirements in the handling system section.*

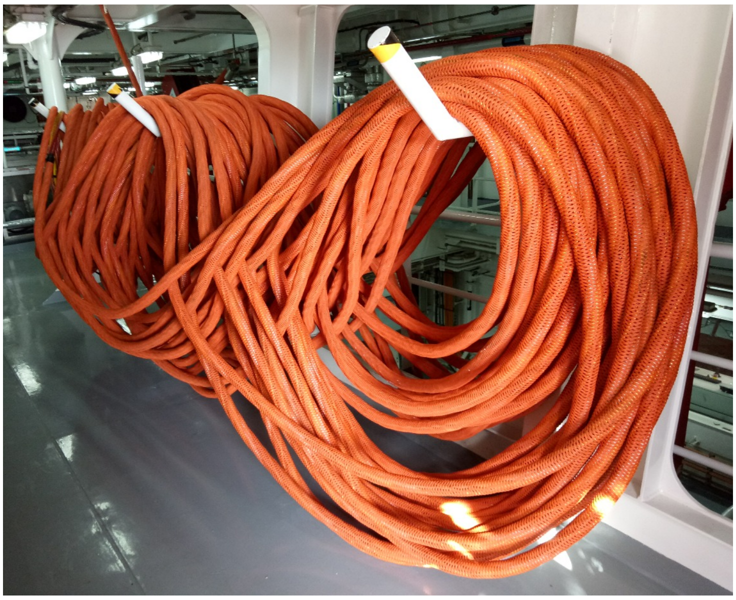
The capabilities of the umbilical to withstand a load must be documented by the manufacturer and never be exceeded. Note that umbilicals designed to lift the bell in the air are very rare. Nevertheless, the majority of the umbilicals in service are sufficiently strong to pull the bell to the proximity of the surface where it can be then connected to a lifting gear. However, this option must never be used without explicit confirmation from the diving system and umbilical manufacturers and the lifting tests indicated in IMCA D 024.

2.3.10.4 - Emergency umbilical

In the case that the main umbilical has been severed, an emergency umbilical can be connected to reinitiate the essential functions of the bell. Of course, this umbilical is designed for emergency recovery only and cannot be used for normal diving operations.

Note that IMCA D 024 says that it is only an option. As a result, IMCA considers that dives can be undertaken even though this equipment is missing. Nevertheless, serious companies and clients impose an emergency umbilical ready for use on the worksite. As already said, emergency umbilicals are designed to provide at least the functions indicated in point 2.3.2.6. As a reminder, it must be fitted with at least a hot water hose with a connector 3/4” NPT male, and breathing gas hose with a connector 1/2” NPT male. However, most emergency umbilicals are also fitted with a 1/4” hose with a male connector NPT for the internal depth, a power supply line, and a comms line. Also. NORSOK requests an additional 1/4” hose with a male connector NPT for the gas analysis.

IMCA says that this umbilical must be stored in suitable conditions, so on a specific frame from which it can be easily deployed *(see the photo below)*. The tests and certifications to be carried on are the same as for the main bell umbilical.



2.3.10.5 - Maintenance

The bell umbilical and its attachments must always be in perfect condition and checked before and after the dive. Also, IMCA D 024 provides the following guidelines regarding the certification and the audit of such a device:

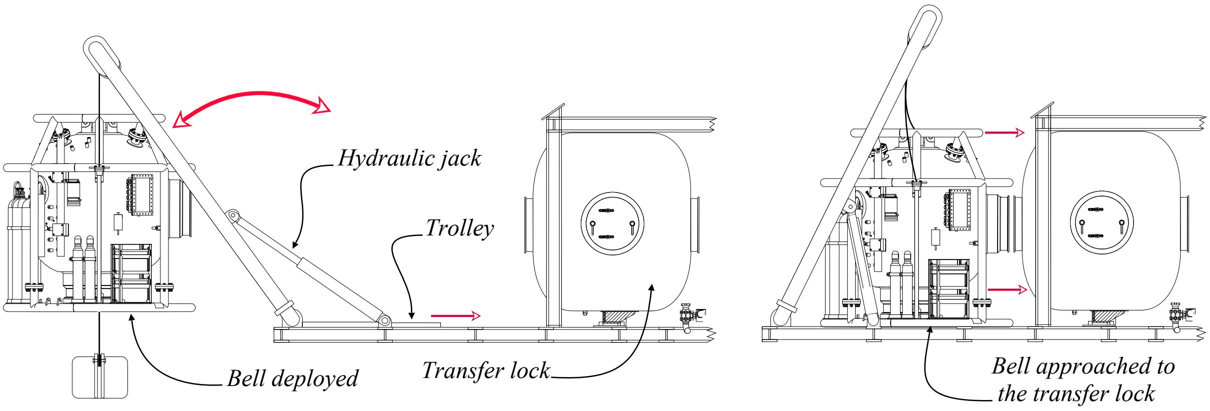
- The continuity and resistance of all cables must be checked every six months. Also, the other electrical components of the umbilical should be examined and function tested at the same time.
- Hose components and their protective devices should be carefully monitored, and function tested every six months. Also, they must be tested to their maximum working pressure every two years. Besides, they must be hydro tested to 1.5 times their maximum working pressure when they are new or as recommended by the manufacturer or the certification body.

2.3.11 - Bell launch and recovery and connecting systems

2.3.11.1 - Kinematics of launch and recovery systems

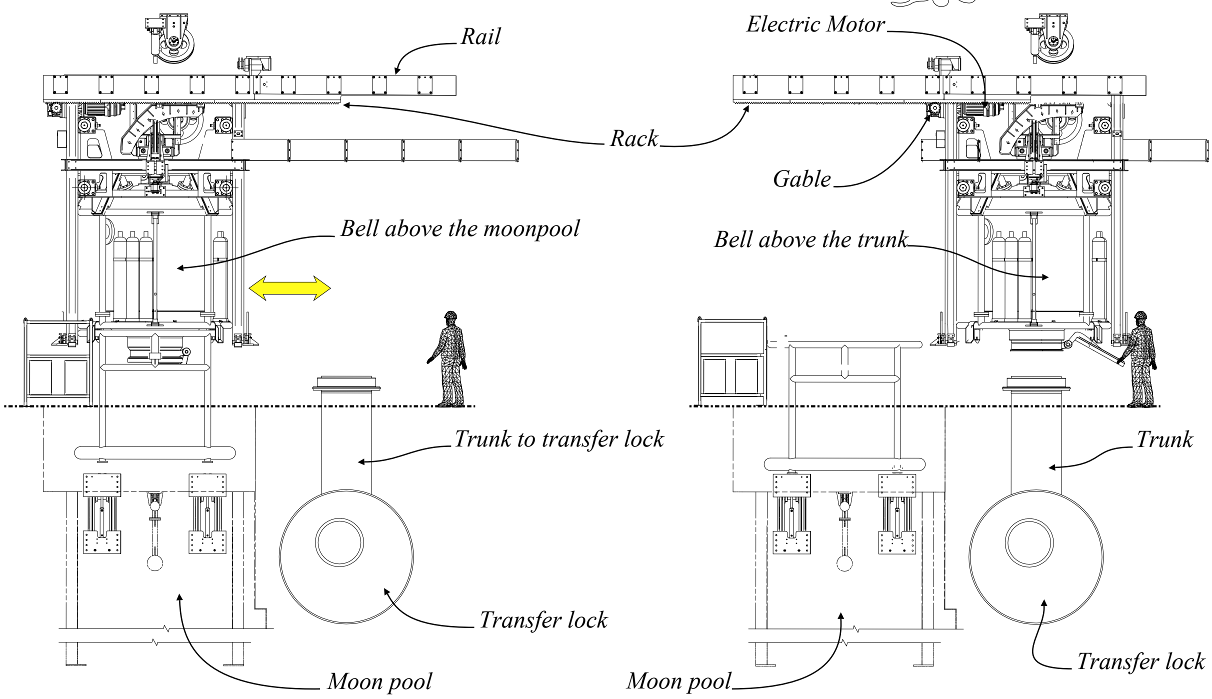
Two main design are commonly found: “A” frames or “trolley systems”.

- “A” frame systems are generally found on portable systems or systems designed with a bell deployed over the side of the vessel. However, it may happen that they are installed over a moon pool. This configuration is also used for the deployment of wet bells, diving baskets, ROVs, and other devices. The winches and the main umbilical reel that can be of complex or straightforward designs are often installed above the chamber to which the bell is connected. The advantages of these systems are their simplicity and robustness. They can be used with bells that connect to the transfer lock by the lateral or bottom door.
  The A-frame is deployed above the sea and returned to the inside of the vessel by strong hydraulic jacks. When the bell connects laterally, a trolley mounted on rollers which are guided by two rails included in the chassis is used for the final approach of the flanges. The procedure to connect the bell laterally to the system consists of lowering the bell on the trolley, then approach it gradually to the flange of the transfer lock. The trolley is generally actuated by a hydraulic jack. The cables and the umbilical are gradually slightly slacked during the approach. Note that on some very old generation systems, there were no trolleys and the bell was resting on skates that were guided and sliding in two slots inserted in the chassis. A winch was used to approach the bell to the transfer lock. It seems that systems with such design are no more manufactured.



As an example of a system designed with A-frame (see #1), the picture above shows a portable saturation system of the previous generation with the bell deployed above the water (see #2). Note that the umbilical is paid-out or recovered by a grooved wheel (See #3) into which the umbilical that is stored by hand in a basket (see #4) is pressed by a roller. Note that a lot of systems similar to this one are still in service.

- A bell traversing trolley system is a self-contained unit, mounted within parallel rails built into the ship’s structure. The trolley moves on the tracks through the action of an electric motor that rotates a gable on a rack *(see the drawing next page)*. These systems are more complex than A-frame ones and for this reason, they are not often used with portable systems. They are the preferred ones with built-in saturation systems as they allow a smooth transfer of the bell, and particularly a precise connection of the flanges. As with A frames, they can be used with bell that connects to the system laterally or by the bottom door. The last generation systems are equipped with a computer that controls the disconnection, descent, ascent, and reconnection of the bell.



The photo above shows an example of a system designed with a traversing trolley. Note the rails (see #1) to which the trolley (see #4) is hung. Also, note the rack (see#2) and the gable that moves the trolley along the rails and is motioned by an electric motor (see #3). The Bell is at depth and for this reason the trolley (see #4) is above the moon pool (see #5). The moon pool can be closed using doors that are folded on each side (see #6).

2.3.11.2 - Winches and wires

Most last generation launch and recovery systems are equipped with winches designed to fulfill the following functions:

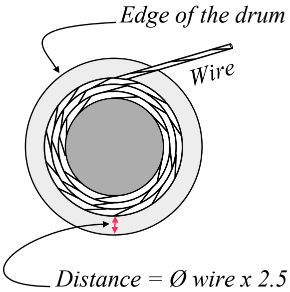
- Lowering and recovery of the bell
- Anti-gyration of the bell
- Secondary recovery
- Umbilical deployment

The lowering and recovery of the bell are performed by the main winch which cable is connected to the center of the bell.

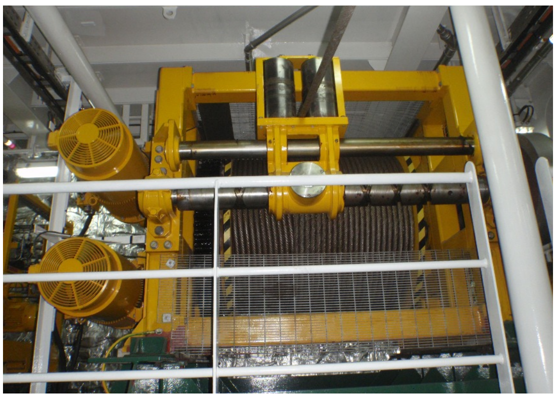
Regarding this winch and the cable used, IMCA says the following:

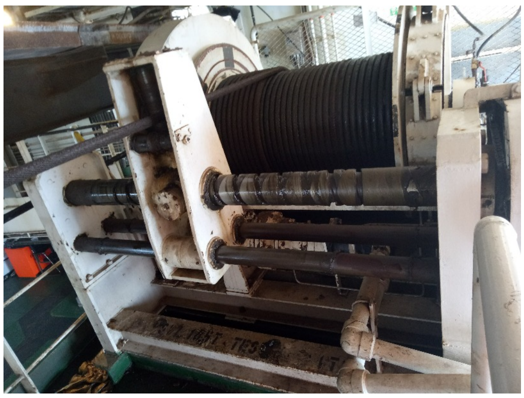
- The winch used must be certified suitable for man-riding and its raise & lower control must be designed to return to the neutral position when it is released by the operator. Also, the raise, neutral, and lower positions must be indicated so the operator knows how to operate the command. Note that regarding this point, modern systems are driven from a separate console which controls are operated electronically.
- An automatic brake which secures the winch when the operating lever is at the neutral position or if there is a loss of power must be in place. Also, a secondary automatic or manually operated braking system must be fitted and ready for use in case the main brake fails.
- Some systems are equipped with a clutch mechanism. There must be a system that prevents this mechanism from becoming disengaged during the operations.
- The winch must be fitted with two independent sources of power. The secondary source must always be available in case of failure of the primary source of power. Also, winches used to lift diving bells, including cursor winches, must be equipped with a main and a secondary motor *(so, two motors as on the photo below)*. IMCA also says that this requirement does not apply to winches used for secondary recovery.

- The winch drum must be able to accept the full length of wire being used. It means that there should be a space between the outside of the top layer of wire and the edge of the drum flange of at least 2.5 times the wire diameter as is that case of the winch below and also explained in the drawing on the side.
  Also, unless access is physically restricted, guards should be fitted to the winch and drum to stop anything (clothing, fingers, etc.) being drawn into the machinery. When the winches are installed at the proximity of other equipment, this requirement is often fulfilled using grating installed all around the winch as on the photos below. Other systems have winches installed on their top with no protection. However, their access is only possible by a ladder or a door.



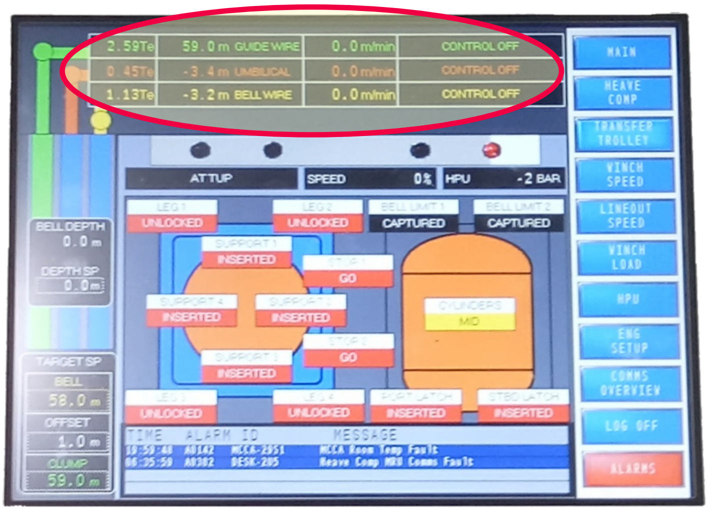
- Arrangements should exist to ensure that the wire being recovered on to any man-riding winch is correctly spooled. In the case of main bell winches this is often by means of a mechanical spooling device *(see below)*.





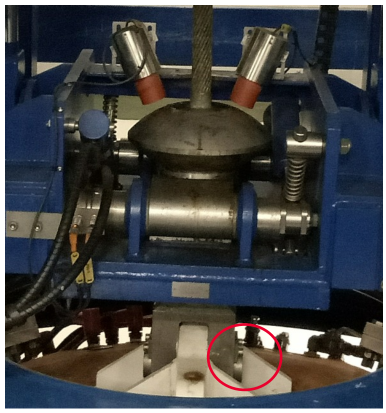
Note: The principle of work of a mechanical spooling system consists of a bidirectional reciprocating screw with two screw threads with opposite rotating directions that are crossing. A trolley equipped with rollers that direct the cable is fitted on this rod. This trolley is guided to a side of the winch by the rotation of the screw. When the side of the winch toward which the trolley is pushed is reached, the rotation of the rod pushes the trolley to the reciprocating thread, and it is moved to the opposite direction. Etc.

- A notice giving the operating instructions for the winch, including the actions necessary if power is lost, must be displayed where the winch operator can see it.
  Also, to avoid paying out umbilical in excess, there must be a device allowing the winch operator to see how much of the main bell lift wire and main bell umbilical have been paid out. It may be by line-out meters *(see on the photo below)* or by marking the bell wire and umbilical at 10 metre intervals or less.



- The winches must be visually examined and function tested at their maximum Safe Working Load (SWL) at least every 6 months. Also, an independent static load test on each brake system at 1.25 times maximum SWL should be performed at the same period.
  In addition, a static load test on each brake system at 1.5 times maximum SWL plus a dynamic test at 1.25 times maximum SWL followed by Non Destructive Evaluation (NDE) of critical areas must be performed every year.
- The lift wire(s) must be non-rotating and the connection of the wire to the bell must be of a suitable type. It should have two retaining means for the removable pin (as an example ,a nut locked with a split pin).





- Unless the wire is to be renewed every 2 years, it should be pressure lubricated every 6 months, at least from the bell back to the maximum depth of immersion in the period. If it has been laid up for a substantial period then it should have been pressure lubricated before lay up.
- There have been a number of problems in the past with high tensile bell wire ropes which appear to lose strength even when properly stored. For this reason, a test to destruction should be carried out when any high tensile bell wire rope is first put into service to establish the actual breaking force of the wire at that time. Provided the test result does not fall below the manufacturer's Maximum Breaking Force (MBF), future destructive test results should be compared to that original figure (the base value), rather than to any claim (or test certificate provided) by the manufacturer.
  If the test to destruction when the wire is first put into service does indicate a Maximum Breaking Force (MBF) below that of the manufacturer, then the manufacturer's MBF should always be adopted as the base value against which to monitor future deterioration in breaking force.
  However, if the result falls 10% below the MBF, then the rope should be discarded.
  The sample tested to destruction should prove an adequate safety factor exists. This usually is eight times the safe working load.
- The inspection and maintenance of the cable should be organized as follows:
  - A static test at 1.25 times SWL plus a function test at SWL as an integral part of lifting system and a visual examination of visible sections must be performed at least every six months.

- A test to destruction to prove an adequate safety factor should be applied to a length of the rope that has been cut (usually, 2 - 3m above the connection to the bell) at least every 12 months.
- When this test is completed (thus, every 12 months), the technician re-terminate the cable *(see the photo below)*, and a static load test at 1.5 times SWL is performed.

- As it is necessary to be able to trace the testing history of a main lift wire, all certification, including original manufacturer's certificate, initial test certificate and any annual test certificates should be available for inspection.

- Note from IMCA SEL 022/M 194, section 13:
There should be an annual removal of a length of wire rope from just beyond the first sheave from the bell termination with the bell below the surface, allowing for swell, to be discarded. A length sufficient to provide test samples for two tensile tests should be cut from the bell end adjacent to the termination. In certain circumstances the competent person may waive the recommendation to cut all the way back to the first sheave. In systems where there is a single vertical fall directly from the winch to the bell it will be necessary to cut right back to the winch.
A sample should be tested to destruction to verify that the required factor of safety is maintained. Should the test prove unsatisfactory due to problems with test procedures or where the wire rope fails within a length equal to six wire rope diameters (6 d) from the base of the socket or cone, a second test may be carried out.
This alternative test should not be used as a way of avoiding discard where a valid test is performed which indicates low strength.
The ultimate strength test to be carried out on a sample from the part subject to the most severe dynamic loading will be used to verify that a factor of safety of 8:1 is still being maintained and if not the wire rope should be discarded. Even if the factor of safety is being maintained but the result falls 10% below the base value adopted following the test carried out when the rope was first put into service, it should be discarded.
One of the tensile test samples should be dismantled and the internals examined.

IMCA says that there must be a secondary means of recovering the diving bell to the surface, bringing it on board and mating it to the chamber system. This means of recovery must be independent of the main recovery system. Also, IMCA says that this requirement is intended to refer to the means of lifting (wires, lifting gear, winch, etc.). It is not intended to say that a second A-frame, gantry or set of supporting steelwork should be provided.
To answer to this requirement, the secondary recovery of the bell is usually performed by the clump weigh winch which technical requirements are the same as those of the main winch. The only difference is that, as indicated previously, a second motor is not required for the secondary recovery winch. Nevertheless, some manufacturers provide their secondary means of recovery with two motors. It is the case of Parkburn which built-in launch and recovery systems (LARS) of UDS Lichtenstein and Picasso that are taken as references in this description *(see below)*.

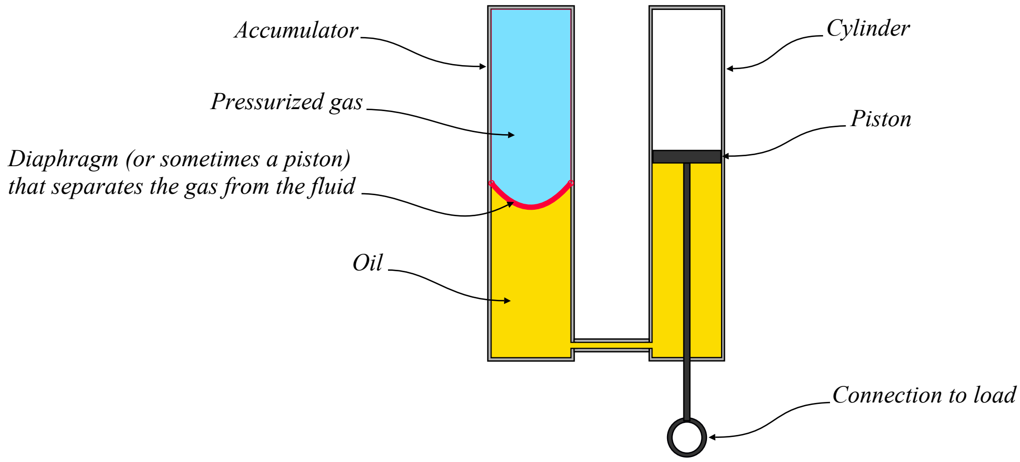
Note that IMCA takes into account the fact that the secondary means of recovery may not be the clump weight system. In this case, it is said that if the winch(es) and the guide wires of the clump weight are not designated as man-riding then they are required only to meet the normal standards for lifting equipment applying at the site.

Umbilical winches must be built with the same requirements as wire winches. Note that nothing is said regarding synchronization with the main winch. However, manufacturers provide this option in addition to the system to avoid paying out umbilical in excess or the opposite. Also, as already discussed in point 2.3.10, IMCA says that the main bell umbilical should not be designated as a secondary means of recovery for the bell unless both it and its handling system are specifically designed for that function.

2.3.11.3 - Heave compensation

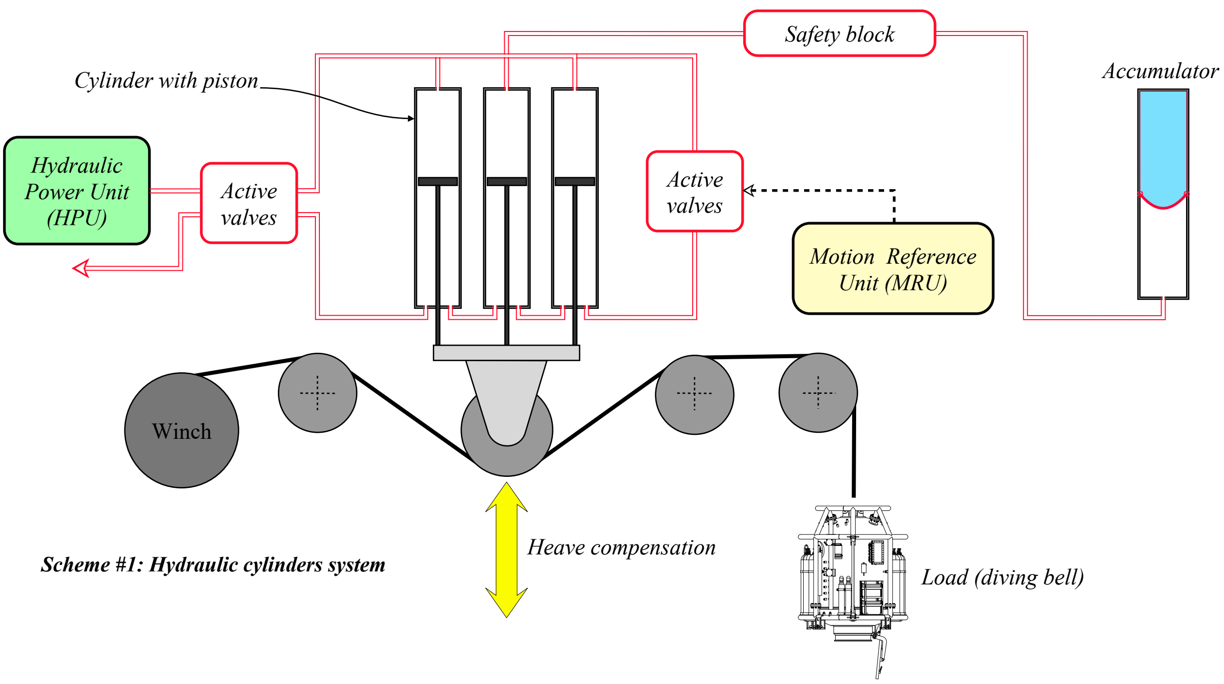
When there is an established swell, the vessel moves up and down, and the bell follows the motions of the ship. As a result, when the bottom door of the bell is opened, and depending on the amplitude of the movement, The ambient pressure changes permanently, which results that the level of the water inside the bell is unstable and that the divers inside the bell are obliged to correct the balance of their ears constantly. Also, entering and leaving the bell is dangerous due to its vertical movements that can be of several metres. To compensate this problem some diving LARS systems are fitted with heave compensators which function to keep the bell motionless, so it is always at the same depth.
Heave compensation systems are usually divided into "Passive Heave Compensation" (PHC) and "Active Heave Compensation" (AHC). However, note that a lot of mechanisms combine the two systems.

Passive Heave Compensation (PHC) systems accumulate the energy of a movement and use it to compensate for the change of position between the vessel and the load underwater. These systems work similarly to shock absorbers and often consists of hydraulic cylinders and gas accumulators that keep the circuit under pressure. Note that their efficiency is limited. Externally, they often consist of cylinders that are connected between the hook of the crane and the load.
As an example, the scheme below shows a hydraulic piston passive heave compensator. With this system, the gas, that is separated from the oil by a reinforced diaphragm, is pressurized to hold the desired load.



Active Heave Compensation (AHC) systems utilize a Motion Reference Unit (MRU), which is an inertial measurement unit with multi-axis motion sensors that actively measures all the movements of the vessel. Based on the data collected, A computer calculates the necessary counter motion of the system and controls it in real time. As a result, the length of the cable is permanently adjusted to counteract the vertical movements of the vessel, and there is no variation of the distance of the bell from the bottom; thus, its depth is kept constant.
The systems that adjust the length of the cable can be based on hydraulic cylinders, and also rotary hydraulic motors or electric motors that directly move the winch.

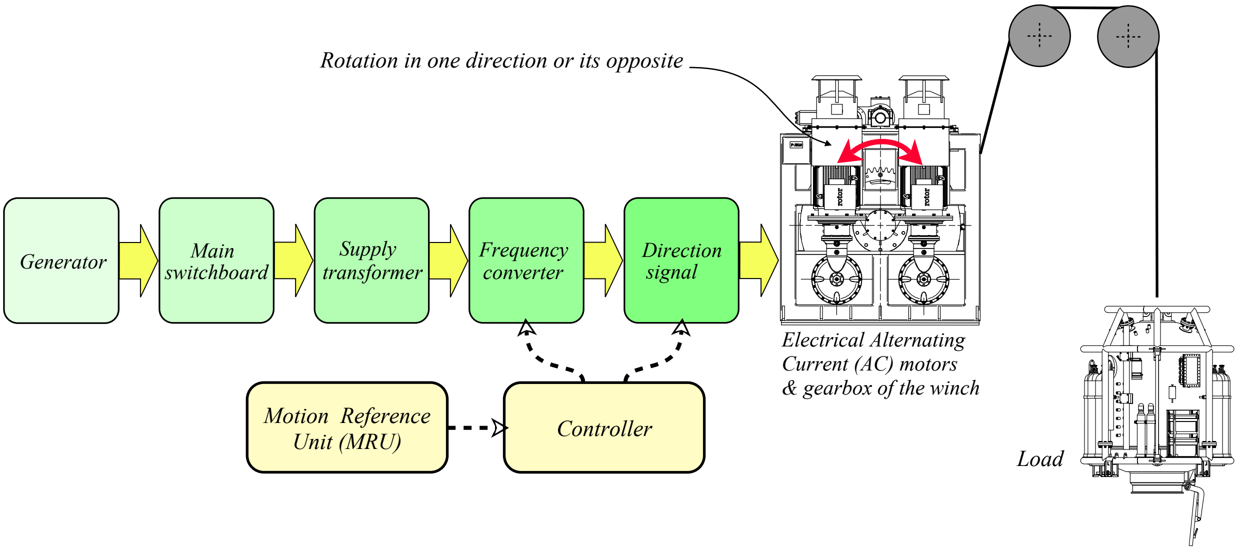
Hydraulic cylinder systems are based on pistons that extend and retract according to the direction of the fluid coming from the Hydraulic Power Unit (HPU) through a series of electronically piloted control valves that direct this fluid according to the orders from the MRU (See scheme #1 below). The cylinders are working independently from the winch, which is usually inactive. They can be installed vertically or horizontally. The function of the accumulator is to maintain a constant pressure in the system.



Scheme #1: Hydraulic cylinders system

Rotary hydraulic systems are based on the same principle as hydraulic cylinders. The difference is that the cylinders are replaced by the motor of the winch that acts in one direction or its opposite in function of the direction of the fluid sent from the HPU through the electronically piloted control valves.

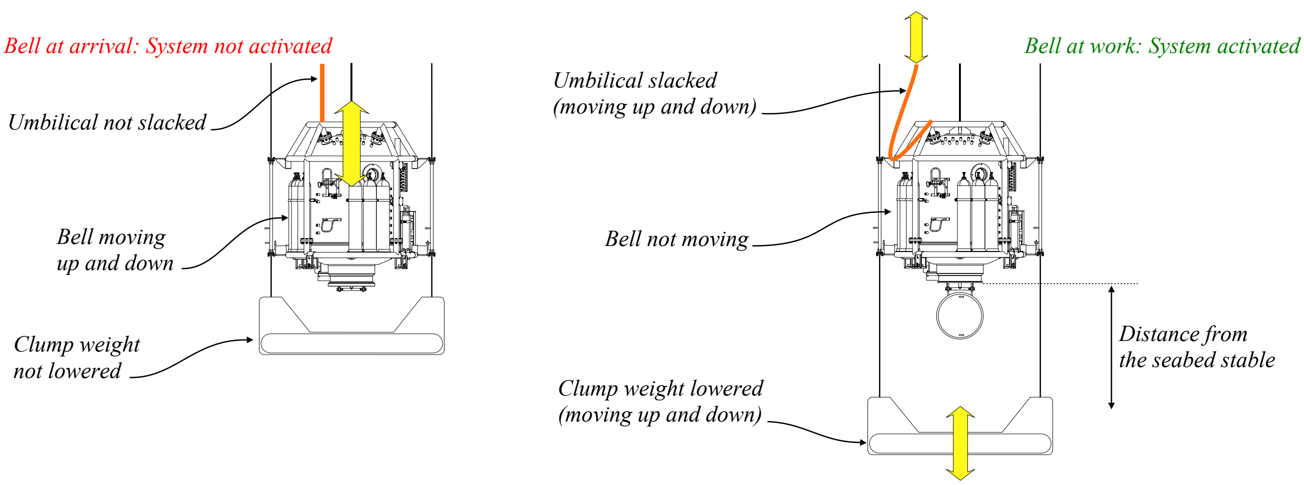
Electrically driven heave compensation systems are often selected due to their high efficiency as well as the fact that they can be easily fed by the generators of the last generation diesel-electric vessels. Also, it is said that they are more silent than other hydraulic systems. In addition, they do not need an oil reservoir and Hydraulic Power Unit (HPU), which may save some space and attract contractors who do not want to deal with oil replacement and potential leaks.
The advantage of electricity is also that it can act directly to the motor and allows the same torque at a slow speed as that at rapid speed. However, the electricity produced by the generators must be adjusted to the needs of the electric motor of the winch. The scheme below shows an example of a chain of conversion of the electrical current produced by the generator and where the motion reference unit (MRU) intervenes to allow heave compensation.



Definitions:

- *An electric switchboard is a device that directs electricity from one or more sources of supply to several smaller regions of usage. It is an assembly of one or more panels, each of which contains switches that allow electricity to be redirected.*
- *A transformer is a device used to change the voltage of an alternating current in one circuit to a different voltage in a second circuit. Transformers consist of a frame-like iron core that has a wire wound around each end. As a current enters the transformer through one of the coils, the magnetic field it produces causes the other coil to pick up the current. If there are more turns on the second coil than on the first coil, the outgoing current will have a higher voltage than the incoming current. This is called a step-up transformer. If there are fewer turns on the second coil than on the first, the outgoing current will have a lower voltage. This is called a step-down transformer.*
- *A frequency converter is a device that converts alternating current (AC) of one frequency to alternating currents of other frequencies. As the speed of an AC motor is dependent on the frequency of the AC power supply changing this frequency allows changing the motor speed. As a result, the rotational speed of the motor can be adjusted using this means instead of using a gearbox, which allows saving energy*

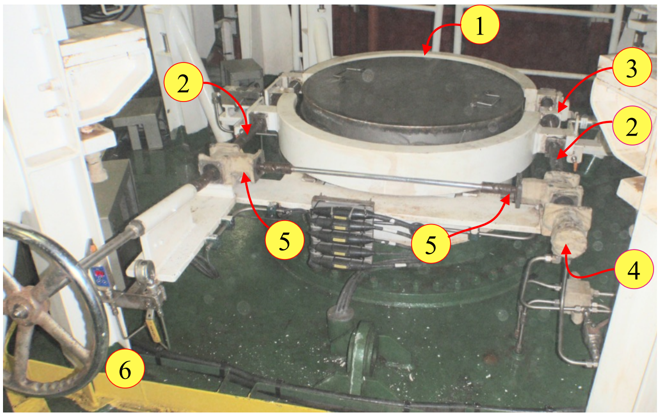
Note that heave compensation systems are designed to be activated only when the bell is at depth and should be deactivated when the bell is recovered to the surface. Also, before starting the system, the operator, must pay out sufficient length of umbilical and lower the clump weight to allow a sufficient distance for the system to work and avoid damaging these elements when they are moving up and down (remember that the bell does not move). New systems perform this operation automatically. Note that some models of clump weights that are designed to allow the divers entering into the bell cannot be used for this purpose with heave compensation systems.

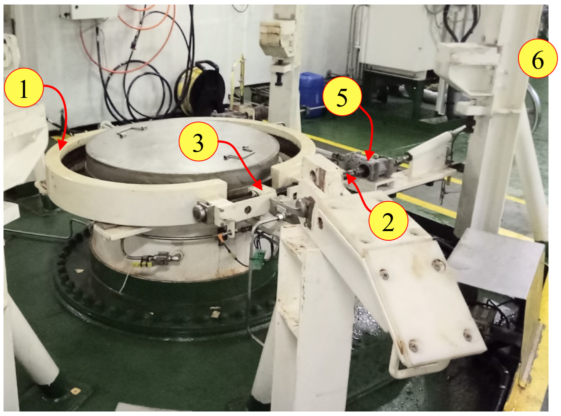


2.3.11.4 - Connection to transfer lock

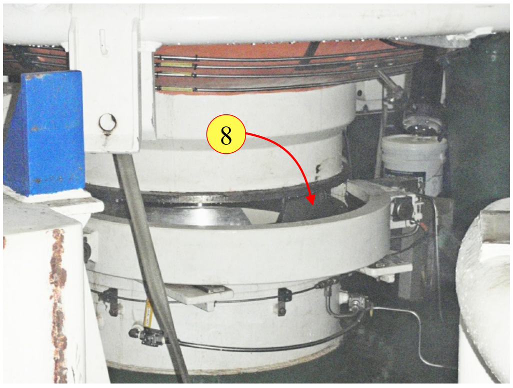
As already indicated, the transfer to or from the transfer lock can be performed through a trunk that is lateral or connected to the bottom opening of the bell.
This connection is of primary importance as if it fails during the transfer under pressure, the divers will be killed as a result of an explosive decompression. Such accident has already happened on Byford Dolphin in 1983 *(see "Explosive decompression accident" in the document "Saturation diving accident")*.
For this reason the connection and disconnection of the bell to the saturation system must be performed with a lot of precaution, and the system must be designed to never open during the transfer under pressure. IMCA D 024 says: *A safety interlock system must be fitted to the clamping mechanism securing the bell to the chamber. This interlock must make it impossible to open the clamp if there is still pressure inside the trunk and impossible to obtain a gas tight seal on the trunk if the clamp is not properly closed.*

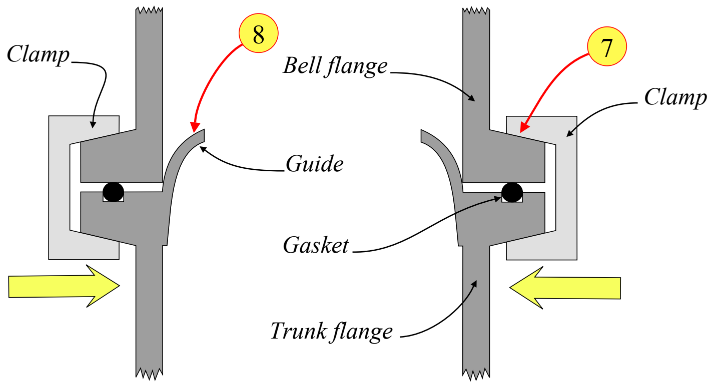
The connecting clamp consists of two half-clamps with internal profiles in bevel *(see #1 below)* that are approached around the flanges by two thread bars *(see #2 below)* secured on their middle at the central axis of the flanges *(see #3)* and designed with threads of opposite direction. As a result, 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 these bars are actuated by a motor, which can be hydraulic or pneumatic *(see #4)*, and through a series of gears *(see #5)*. Also, a wheel *(see #6)* allows to open or close the clamp manually in the case of a breakdown of the motor.



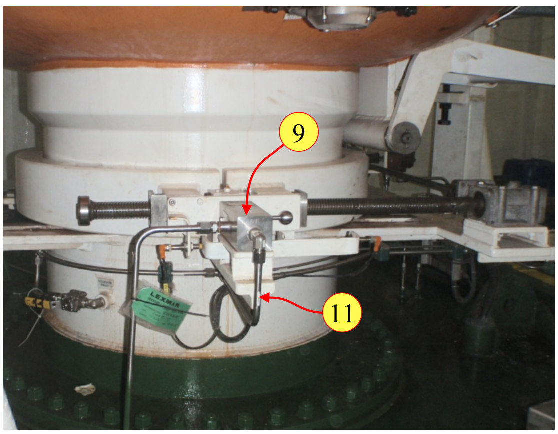


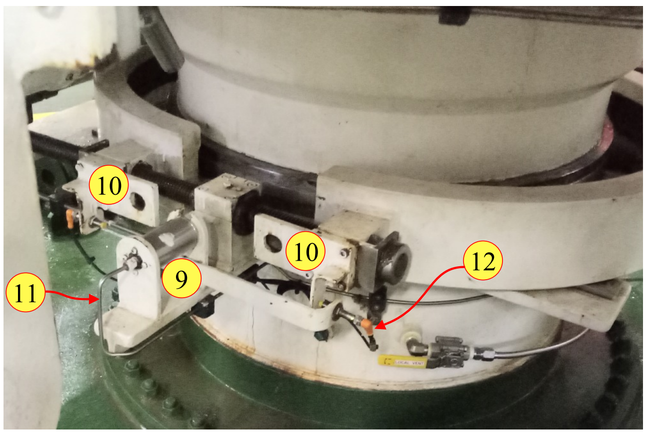
Note that in addition to the profile in bevel *(see #7 in the drawing below)* of the faces that are in contact with the clamp, the flange of the chamber may have a specific profile to guide the flange of the bell exactly to the ideal position *(see #8)*.





When the transfer trunk is under pressure, the clamp is locked by pins that are pushed out of their cylinders *(see #9)* through two overlapping holes *(see #10)* by the pressure established in the trunk. This locking mechanism is connected to the trunk through small pipes *(see #11)*. Springs in the cylinders retract the pins when the pressure in the trunk is released. Sensors are in place when additional electronic safety systems are fitted *(see #12)*. Note that other locking systems exist.



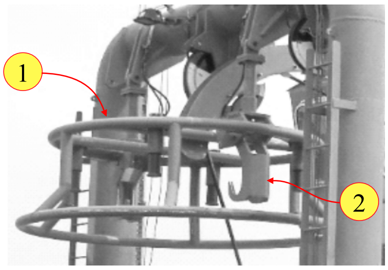


2.3.11.5 - Anti-swinging systems

Depending on the kinematics of the LARS, this part of the mechanism can be more or less complex.

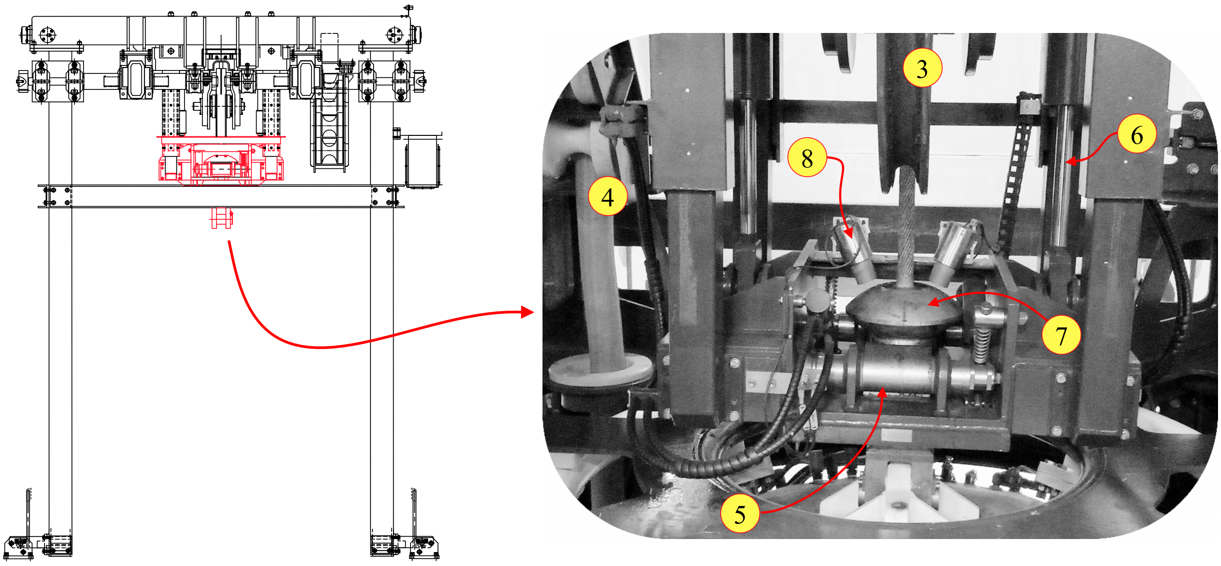
Old systems were not provided with blocking mechanisms and the bell was merely hung to the main hook. As a result, the bell was swinging in any direction and was difficult to control during the launching and the recovery phases.
To correct this problem blocking mechanisms have been fitted at the top of the launch and recovery systems.

With some systems, these mechanisms can be quite simple and may consist of a circular tubular structure which is kept at the top of the frame *(see #1 on the photo)* and is in contact with the top of the guards of the bell.
Two latching hooks *(see #2)* that are locked underneath the topside horizontal tubes of its protector frame secure the bell to the structure during the transfer, which limits its swinging movements and allows slacking the main cable if necessary during the adjustment of the bell above its final lowering point.
To lower the bell, the main cable is recovered in tension to slack the latches that are then opened. When the latches are confirmed opened, the bell is slowly lowered.

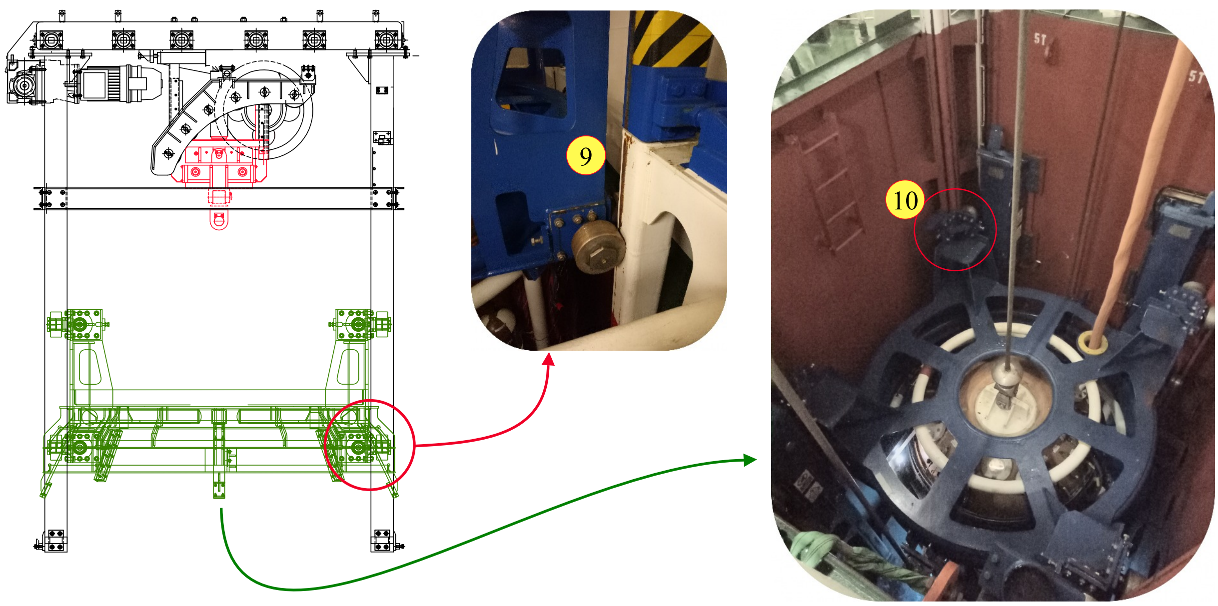


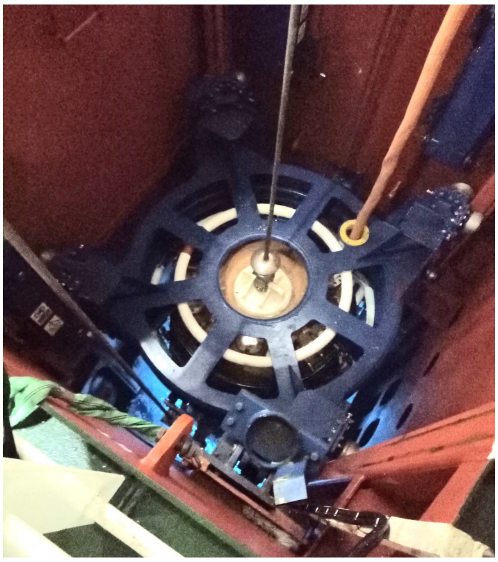
Last generation systems used with built-in trolley are generally much more complex as they are designed to limit any movement of the bell during the transfer to and through the moon pool. An example of such mechanisms are those in place on the LARS system from Parkburn already described previously.
This system is composed of 2 main parts:

- The parts that remain on the trolley: They are the pulleys of the main lifting cable (see #3 below) and the umbilical (see#4), the latching system (see #5), and two cylinders (see #6) that allow lowering and lifting the bell to and from the flange of the entry lock while the latching system secures the bell to the trolley through a blocker with a specific shape installed on the connection to the bell (see #7). Sensors (see #8) are fitted to inform the operator when the bell is fully lifted and hung by the main winch.



- The cursor, a circular piece which purpose is centralizing the the bell during its descent through the moonpool It is fitted with rollers *(see #9 & #10 below)* that perfectly maintain it in the middle of the moon pool during the descent. The cursor stops at the end of the moonpool *(see the photos on the next page)*.



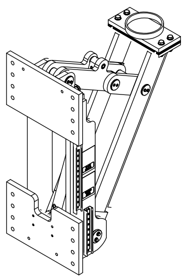


Bell and its cursor in the moonpool

Cursor at the end of the moonpool

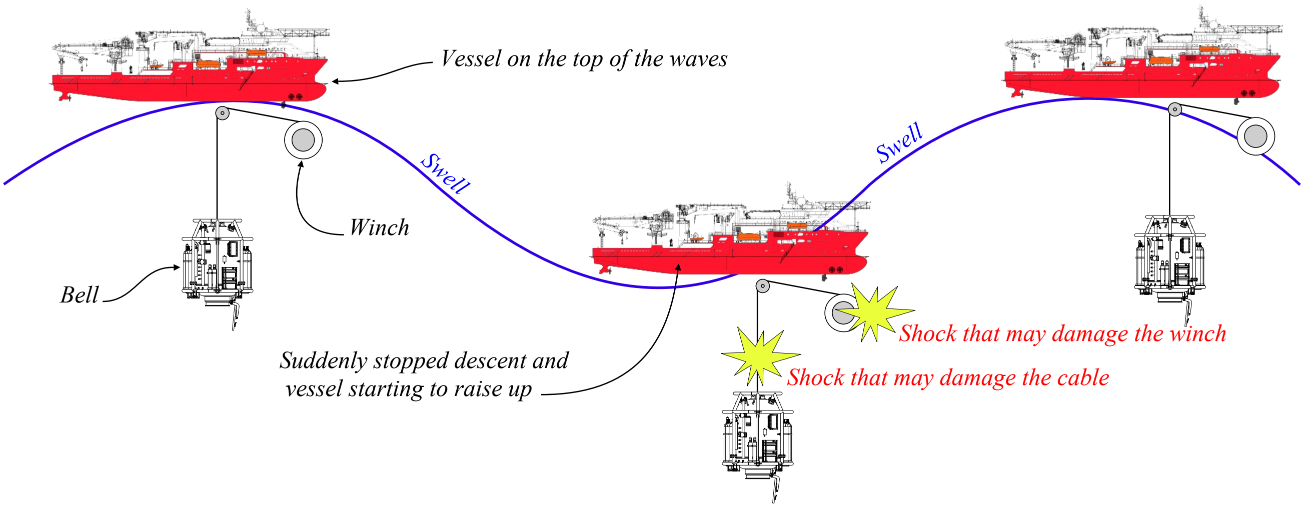
2.3.11.6 - Retaining legs in moonpool

Depending on the design of the system, retractable legs may be installed in the moonpool to secure parts of the system such as clump weight and standoff frame that may be stored there to save some space and have them ready to go as fast as possible.
These legs are articulated structures that are deployed and retracted by hydraulics jacks *(see the drawing aside)* Sensors are normally provided to inform the operator of their position and prevent any lowering operation if they are not fully retracted. They are visible on the photos above where they are in the closed position because the bell is moving down or is at work. They will be deployed only when the bell will be back on deck.
Note that this mechanism is optional and not found on all systems using moonpools.

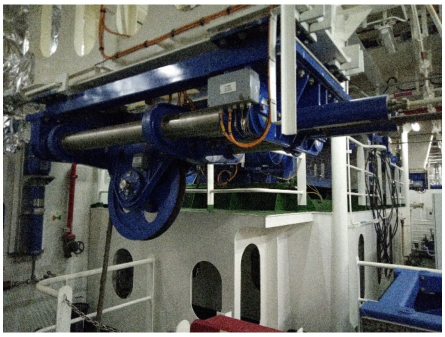


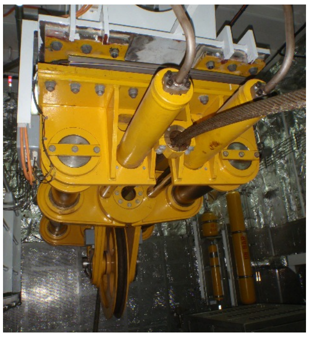
2.3.11.7 - Load limiters

Load limiters use a similar principle as passive load compensators. However, their function is to act as shock absorbers to protect winches and the deployed cables from the shocks resulting from a suddenly stopped motion. Such a situation may happen in the case of a descent suddenly stopped and more often as a result of vertical movements from the vessel heaving in the swell *(See the scheme below)*.

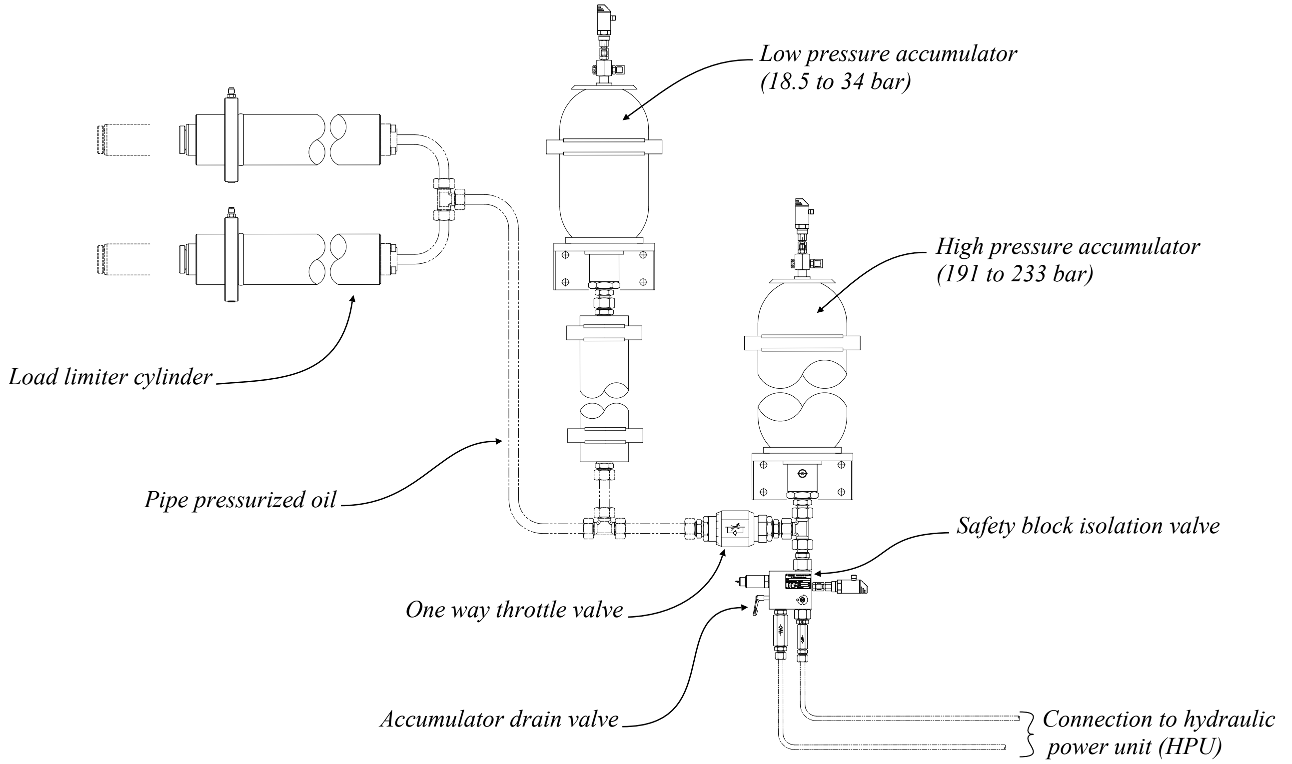


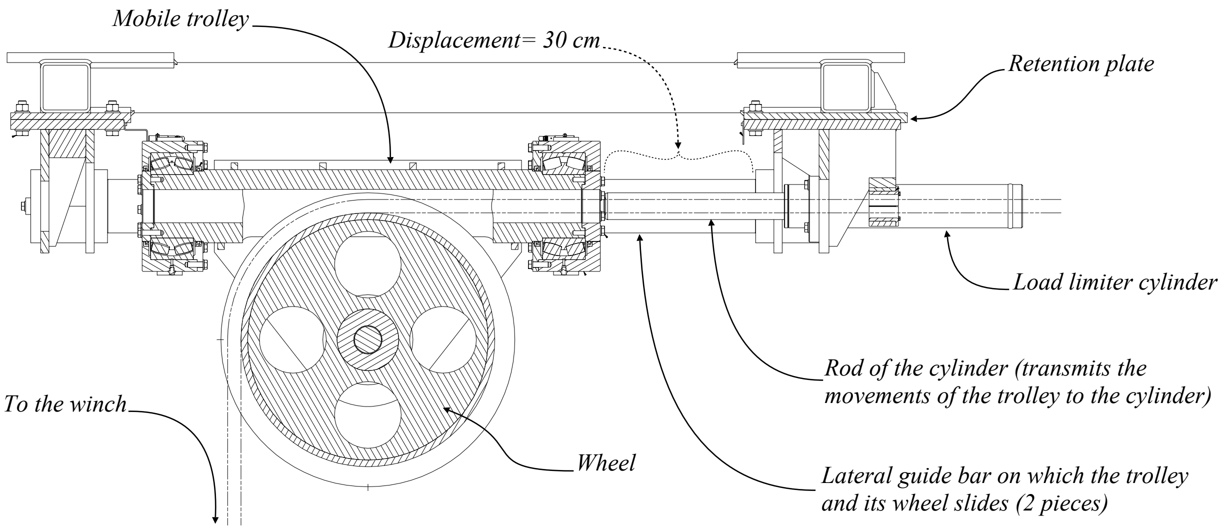
On UDS Lichtenstein and Picasso, load limiters are installed above the winches they protect and are at the same level that the top of the trolley. They are designed to work horizontally with a displacement of 30 cm.





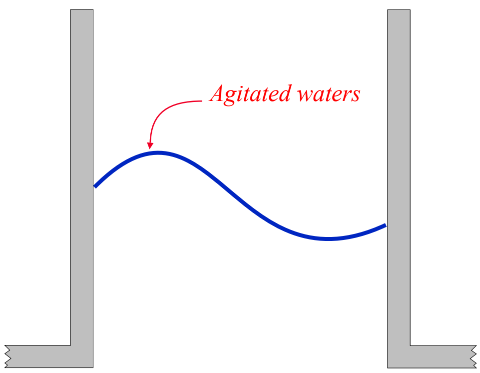
The principle of work of these devices is based on oil-filled cylinders that are maintained under pressure by hydro-pneumatic accumulators similar to those used for passive heave compensation, as previously described in point 2.3.11.3.



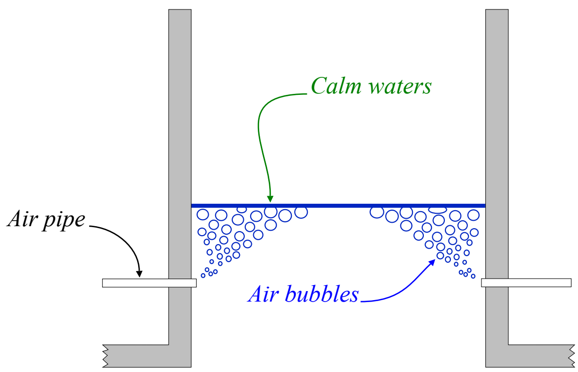


2.3.11.8 - Moonpool aerator system

Aeration of the moonpool is a mechanism that is designed to send air into the moonpool to make the water surface inside it calm when the sea conditions become severe and that waves and vortexes form in it due to the vessel movements, which may result in difficult and dangerous launching and recovery of the bell. The principle of the system is based on the fact that when air is blown into the water, the density of the water change which makes the waves break. This mechanism consists of several pipes arranged around the moonpool that blow compressed air into it.
Note that this system is optional. Thus, it is not available on a lot of vessels.



Moonpool without aerator

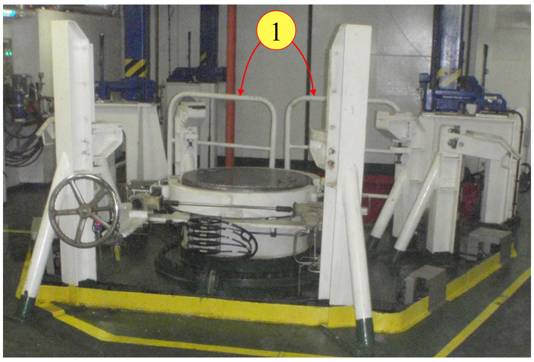


Moonpool with aerator

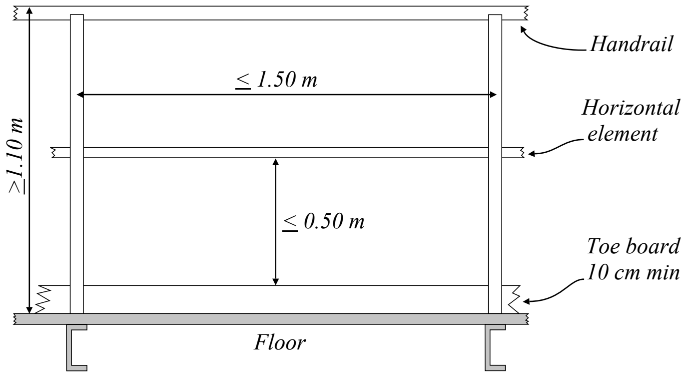
2.3.11.9 - Protections to prevent a man overboard

Barriers should be installed to prevent a man from falling into the sea during the launching operations and when the bell is at depth. These items can be permanently installed or mobile when the opening must be used to transfer the bell to the sea *(see #1 below)*. Note that side protections should at least conform with the requirement from standards similar to EN ISO 14122-3. "*Safety of machinery. Permanent means of access to machinery. Stairs, stepladders and guard-rails"* that requires the following:

- The handrail should have a diameter between 25 and 50 mm.
- The minimum height of the handrail should 1.10 m.
- The distance between the centres of two posts should be 1.50 m or less.
- The distance between each of the horizontal element should not exceed 500 mm.
- Toe boards should have a minimum height of 100 mm and their distance from the walking surface should not exceed 10 mm.



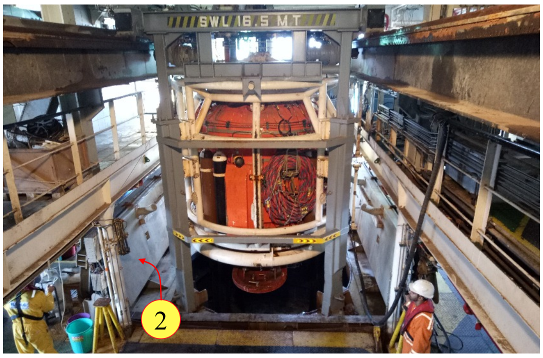
Mobile barriers of the moonpool of UDS Lichtenstein



Barriers are sufficient protections when the dive station is sufficiently high above the sea level. As an example, it is the case of UDS Lichtenstein and Picasso which moonpools openings are at more than 6.5 metres above the sea level. However, in the case of a launching deck that is at 3 metres or less above the sea level, the launching station can be flooded during rough weather conditions and people may be caught by waves when passing at the direct vicinity. For this reason, launching stations situated on the side of the vessel are usually isolated by additional barriers restricting access to them to avoid such an accident.

However, this is difficult to do in the case of a moon pool which opening is on a deck used to transit and perform some maintenance activities. Also, waves coming inside the vessel may damage some equipment. As a response to this problem, manufacturers provide doors that can be closed to isolate the moonpool. It is the case of the system onboard HOSQ Shaddad which is also designed and built by Lexmar *(JFD Group)*.

This closing system consists of four doors that are folded each side of the moon pool when the diving operation is in progress (see #2 below) and that are deployed and secured above the opening, using dedicated jacks (see #3), when the vessel is sailing and during rough weather conditions. That protects the personnel and equipment and gives the possibility to prepare future work and perform maintenance activities during unfavourable weather conditions.



Launching of the bell: Doors folded each side

Doors folded: Note the actuating jack


Doors closing (sliding on the sides of the moonpool)

Doors closed

2.3.11.10 - Control consoles

In this document, a "control console" is a panel accommodating a set of commands for mechanical or electronic equipment that is designed to control the deployment and recovery of the bell from only one location. Its design depends on the complexity of the system it is supposed to manage. As a result, it can be very basic or extremely complex as with some last generation systems such as those designed by Parkburn for UDS Lichtenstein & Picasso.

With old generation systems, the control console consists of a series of bi-directional joystick valves and switches that are grouped on a panel at the direct proximity of the winches. That allows reducing the lengths of pipes and wires and the technician can have a direct view of all elements involved in the launching and recovery of the bell, such as the winches, Hydraulic Power Unit (HPU), bell umbilical, etc.
This panel is fitted with manometers such as oil pressure and temperature and some alarms such as lack of oil in the HPU or too elevated temperature. However, with the majority of such systems, the information provided is at a very minimum, and the operator has reduced tools to diagnose the condition of the system. Also, the distance of wire and umbilical paid out are often calculated using marks on the umbilical and the cables as described by IMCA in point 2.3.11.2.
This panel is generally installed in a small cabin situated in the direct proximity of the bell and above it *(see "A" on the photo below)*, so the operator can manage it at the same time as the other parts of the system involved. Communication to the dive control should be performed through wired hand free connections and radio as a backup.
Such systems are still in use with a lot of saturation systems, which are mainly portable systems. Also, they are sometimes fitted to new fabrications. Their advantage is their robustness and easy maintenance.

The consoles described above are mostly purely mechanical and electrical. Thus, there is no intervention of the electricity to operate a mechanical device and vice versa.
Another type of consoles are those that are based on electro-mechanical systems. Electro-mechanical refers to devices which involve an electrical signal to create mechanical movement or vice versa. As an example, electromagnetic relays, which using a small voltage current allow controlling a more powerful electrical circuit by mechanically switching sets of contacts, and solenoids, by which it can actuate a moving linkage such as an electrically operated valve.
As all their commands are wired, such consoles do not need to be at the vicinity of the elements they control and can be installed in the dive control from which the operator may communicate with the diving supervisor without the need of an intercom. Also, it often installed in a directly adjacent room. Note that when the operator is not in the same room and the direct vicinity of the diving supervisor, hand-free wired communications and a backup radio should be provided.
The room in which the console is usually installed is at bell level or above it. Thus, the operator has a clear view of the bell when he is transferring it. Also, screens showing the strategic points of the LARS, such as the winches and the connecting flange, should be provided in the room.

The panel aside is composed of electrical commands such as:

- *Winch controls*
- *Trolley control*
- *Rams and bell clamp controls*
- *HPU controls*
- *Lock pin controls*

Essential information is provided:

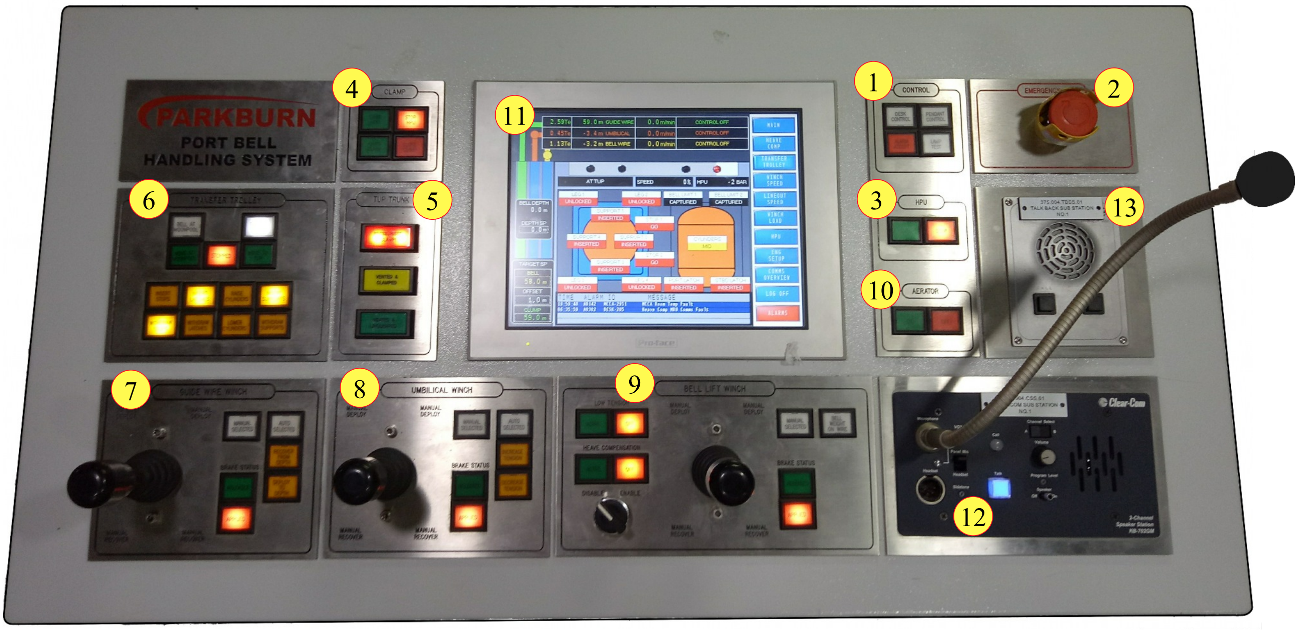
- *Cable and umbilical distance paid out*
- *Bell winch load*
- *Ram pressure*
- *System pressures*
- *Temperatures*
- *Whether the trunk is pressurized*
- *Warnings HPU #1 & #2*

The last generation consoles are still based on electro-mechanical devices. However, they are fitted with a computer terminal where the operator inputs orders which are controlled by the software system prior to be implemented. Also, the computer provides status messages from the essential parts of the system. The communication with the computer is performed through a Human Machine Interface (HMI), which is a touch screen. More traditional electromechanical commands are installed throughout the command panel.
We can imagine that with the progress of the electronics industry, such types of consoles are going to replace those of the previous generations. For this reason, a study of how the software intervenes in the management of the deployment and the recovery of the bell is interesting. The console used for this study is designed by Parkburn and installed on UDS Lichtenstein. Note that other models may be different, but they use similar principles.

- Step 1 - Powering and general description

Powering the Diving Bell Handling Equipment is made through the Motor Control Centres that also feed the Bell Master console. Note that these elements are separated from the console
The Bell master console is started by pressing the pushbutton “desk control” that is situated in the section “Control” of the console, which is at the top of the right-hand side aside from the emergency stop pushbutton *(See #1 on the picture below)*. Note that this master console is composed of several sections that allow controlling automatically or manually all the elements that compose the Launch and Recovery System (LARS). These sections are identified as follows:

- Control *(see #1)*
- Emergency stop *(see #2)*
- Hydraulic Power Unit (HPU) *(see #3)*
- Clamp *(see #4)*
- Transfer Under Pressure (TUP) trunk *(see #5)*
- Transfer trolley *(see #6)*
- Controls guide wire winch *(see #7)*
- Controls umbilical winch *(see #8)*
- Controls Bell lift winch (with the Active Heave Compensation command) *(see #9)*
- Aerator *(see #10)*
- Human Machine Interface (HMI) *(see #11)*
- Main intercom *(see #12)*
- Second intercom *(see #13)*



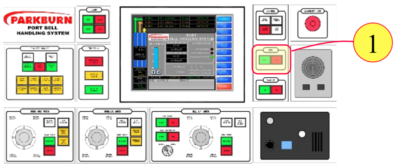
The Master console is designed to centralize all information regarding the status of the Launch and Recovery System. The Human Machine Interface (HMI) *(see #11 above)* provides the following details:

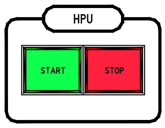
- Whether the system is active
- Status of the heave compensation system
- Condition of the Local Area Network (LAN). Note that a LAN is a computer network that interconnects computers within a closed area such as a boat, a series of offices, or the elements of a dive system.
- Condition of the Electrical supply of the Motor Control Center (MCC) which is an assembly of electric and electronic elements that controls some or all the electrical motors of a system from a central location.
- Condition of the Active Front End (AFE) distribution. An AFE is a rectifier that allows bi-directional power exchange between AC and DC sides. It is also used to minimize the amount of harmonic distortion of the electrical supply.
- Winch status
    - Whether the control is activated and the mode selected (manual or auto.)

- Tension mode applied (low or normal)
- Paying out or picking up wire
- Details of the emergency stop warnings that are halting the winch
- Winch's encoder or/and load cells bypassed or not

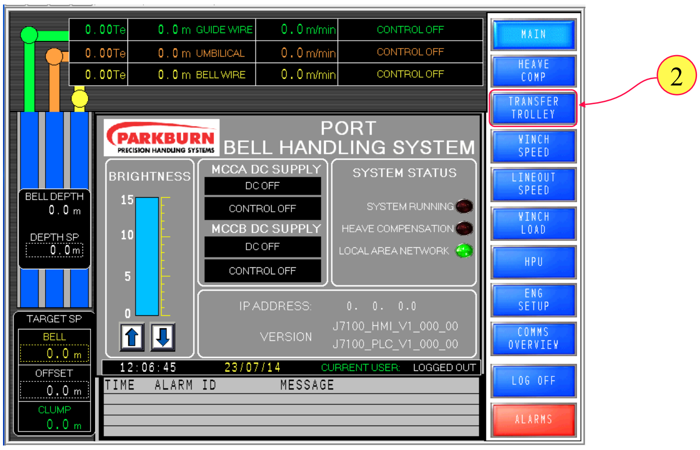
- Tension applied to the cable of the winch
- Distance of cable out (Line out)
- Speed of cable delivery or recovery
- Position of the bell during the operations
  - At home
  - On the deck
  - In the moonpool
  - In the splash zone
  - At the direct proximity of the cursor
  - Near the ship (within 5 m below the ship)
  - Clear of ship
  - Near the final depth selected
  - At depth

When the master control starts, the computer analyses the status of all the elements that compose the system, and in the case of a problem a message of alert is displayed on the HMI screen.
To continue to activate the LARS system, the operator must start the Hydraulic Power Unit (HPU). This pushbutton is situated in section "HPU," which is just below the section "Control" *(see #1 below)*.



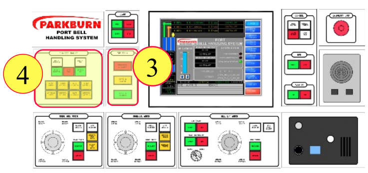


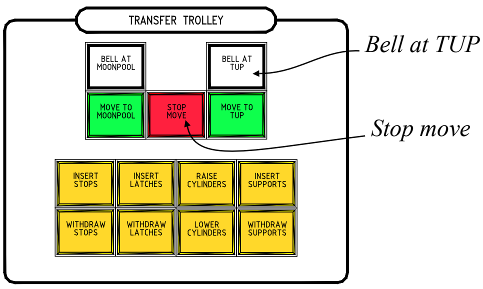
Usually, a message should be displayed on the HMI that reminds the operator that the sea fastenings that secure the LARS must be removed. This removal should have been done manually as with the previous generation LARS.
The status of the HPU can be then displayed on the screen by pressing the menu "HPU" on the right-hand side of the screen. Then the operator can change the display to monitor the transfer trolley. It can be performed by pressing the dedicated touch that is displayed on the right-hand side of the screen *(See #2 below)*.

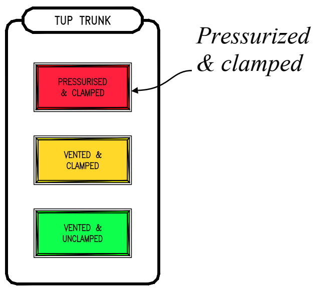


- Step 2 - Transfer Under Pressure (TUP)

When the bell is clamped to the saturation system, and the Transfer Under Pressure (TUP) trunk is pressurized, the light "Pressured & clamped" at the TUP Trunk Control section *(see #3)*, which is at the top of the left-hand side of the panel is illuminated. Also, the light "Bell at TUP" and the pushbutton "Stop move" in the section "Transfer Trolley" beside the section TUP Trunk are illuminated *(see #4)*.
As a result, the bell cannot be disconnected from the system as long as the trunk is pressurized because the sensors prevent any action as long this part of the system is under pressure. Thus the TUP can be performed safely.
Note that this section is provided with two other pushbuttons that are illuminated in green: "Move to up" and "Move to moonpool." A white light is also provided to indicate when the trolley arrives at the moonpool.

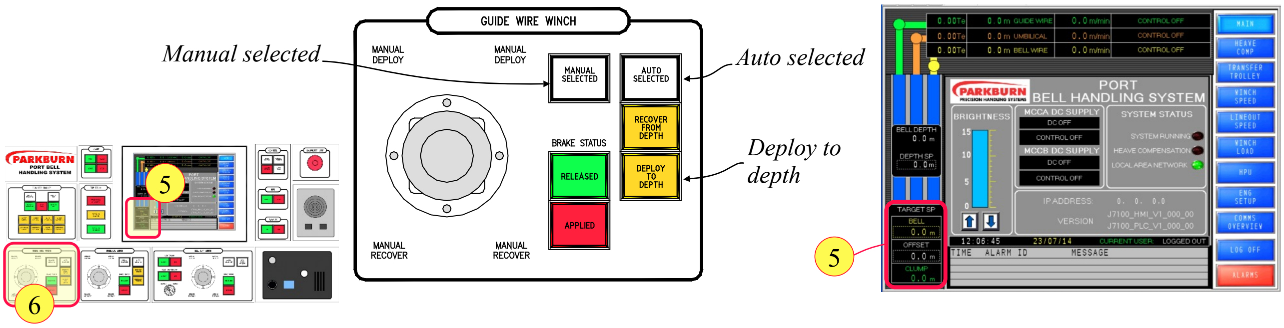


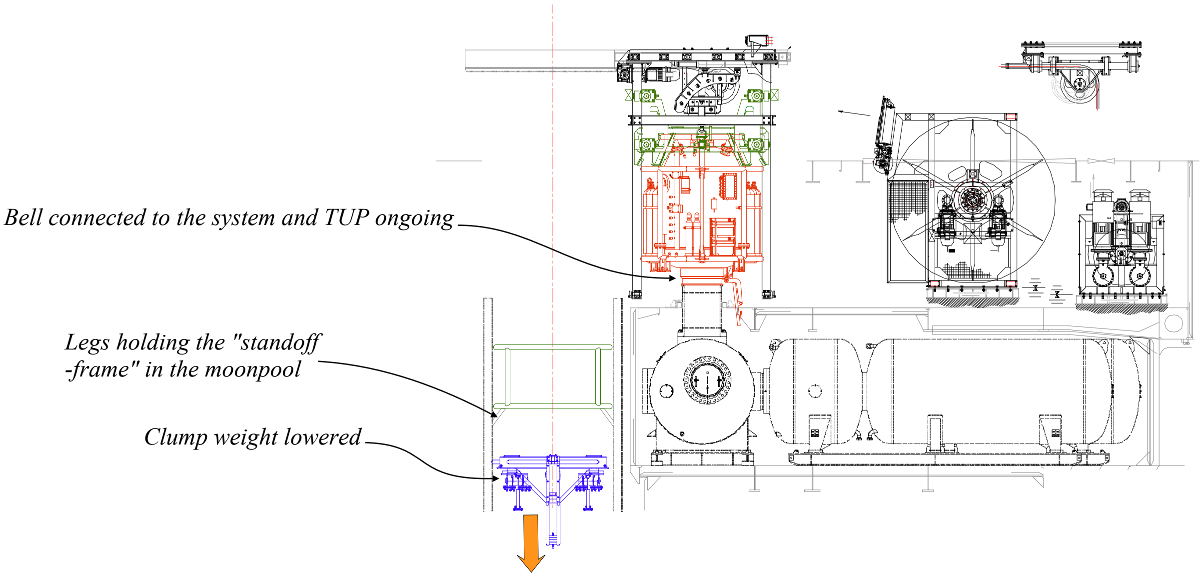




- Step 3 - Clump weight deployment

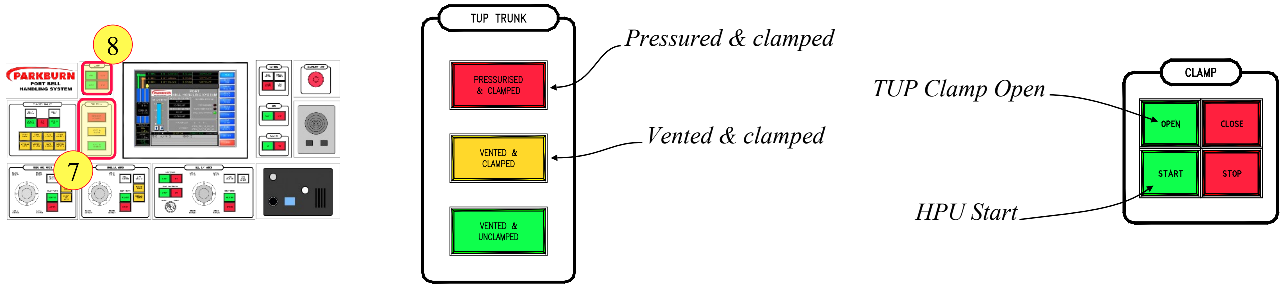
The clump weight must be deployed at depth prior to the remaining operations. If it is not, the software does not allow for continuing the operations.
Before implementing the clump weight and the bell, the operator must set up the required bell depth using the menu "target SP" of the HMI display *(see #5)*.
The clump weight can be deployed automatically or manually:
Using the pushbuttons "Auto selected" & "Deploy to depth" in the section "Guide Wire Winch" *(see #6)* which is on the bottom of the right-hand side of the panel. As a result, the clump weight deploys to the required depth according to the depth previously selected for the bell.
If the operator prefers a manual deployment, the button "Manual selected" should be pressed. In this case, the control of the clump weight is performed using the joystick. However, the winch will automatically stop when the depth previously selected will be reached



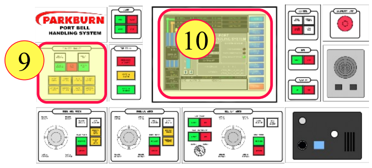


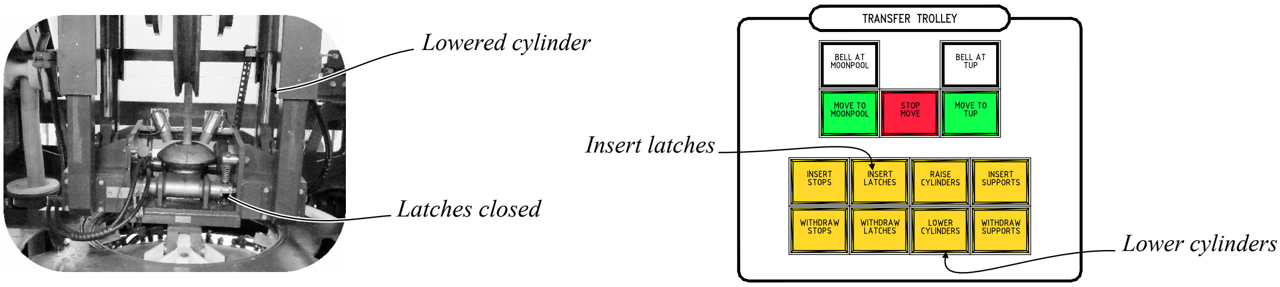
- Step 4 - Disconnection of the bell

As indicated previously, the system prevents the bell from being removed from the trunk as long as the transfer under pressure is ongoing.
When the trunk has been vented, the amber light "vented & Clamped" in the section "TUP trunk" *(see #7)* is illuminated and the red light "Pressured & clamped" is shut down. That indicates that the bell and the transfer lock are secured and that the system allows disconnecting the bell.
That can be done pressing the button "HPU Start" & "TUP Clamp Open" in the section "Clamp" that is situated at the very top of the right-hand side of the console, near the logo Parkburn (see #8).
The TUP clamp opens and the green light "vented & unclamped" opens while the amber light "vented & clamped" shutdown (these lights are in the section "TUP trunk").

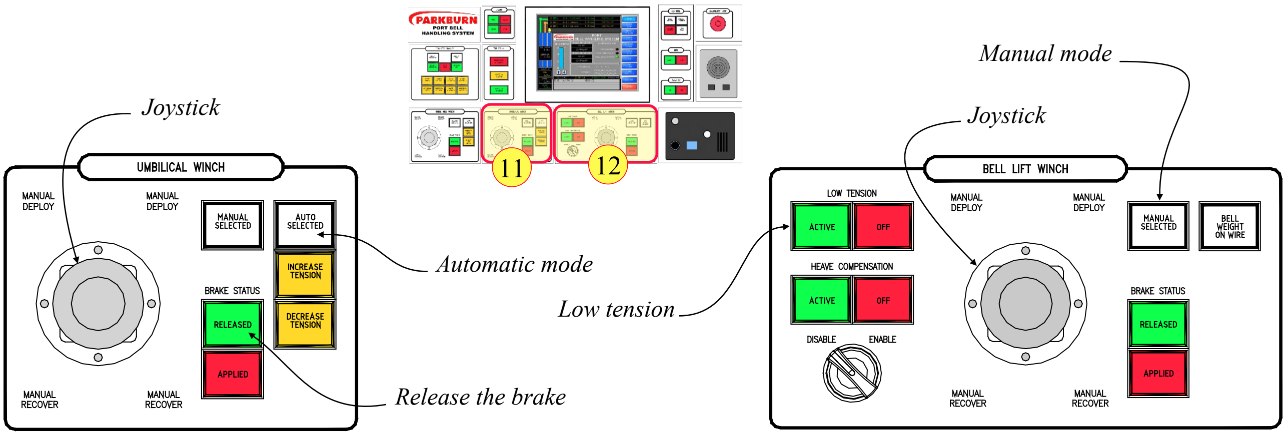


When the TUP clamp is opened, a warning light is illuminated on the HMI screen.
Then, the mating cylinders are lowered to pick up the bell using the pushbutton "lower cylinders" in the section "transfer trolley" *(see # 9)* that is highlighting. Also, a warning is displayed in the trolley status on the HMI *(see #10)*.
The Latches are then inserted using the button "Insert latches". A confirmation message appears on the HMI screen.

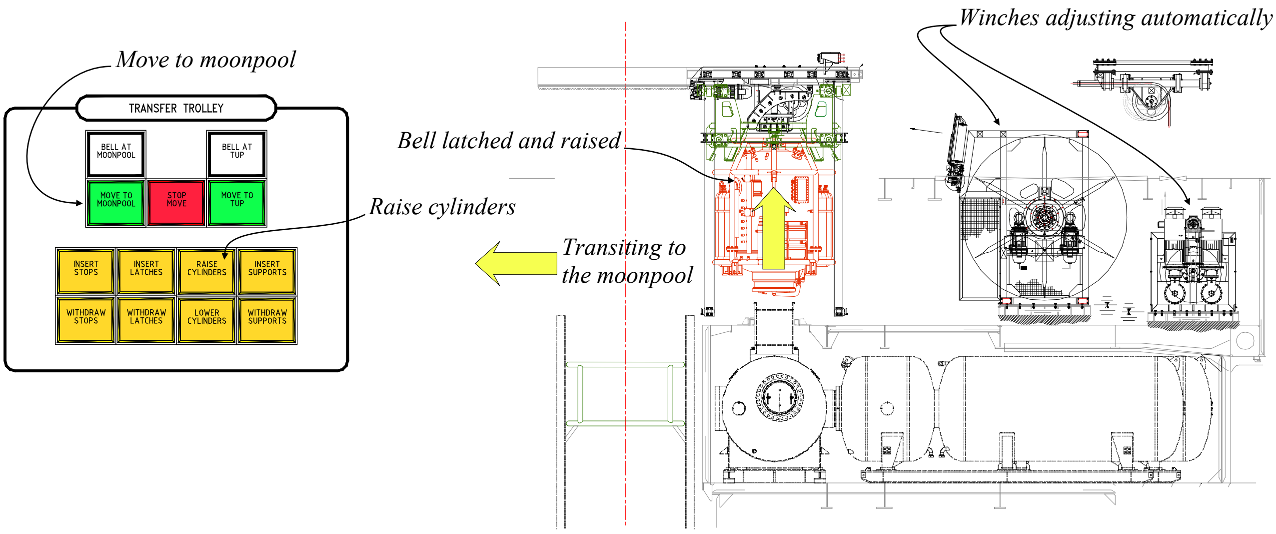




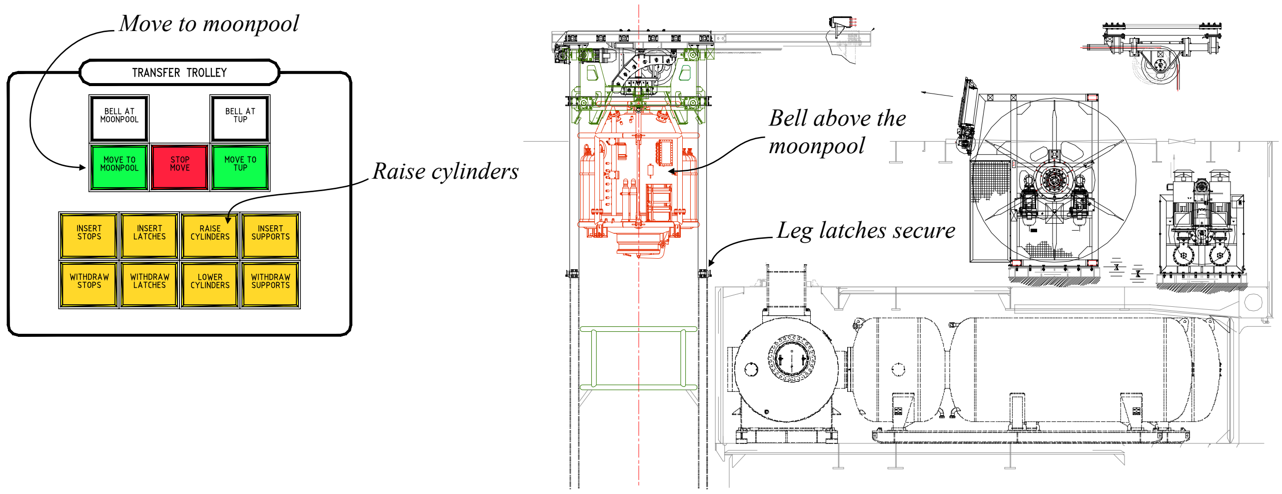
Before raising the bell, the winches of the main cable *(see #11)* and the umbilical *(see #12)* must be implemented. Their commands are fitted with joysticks and are in the sections near the "Guide wire winch". Automatic or manual modes can be selected.
If the mode "automatic" is selected for the umbilical winch, it automatically stabilizes at the preset tension. Note that to allow the winch to establish the pre-set tension, the operator should release the brake by pressing the corresponding green button.
The umbilical winch can also be run in manual mode for maintenance purposes and recovery in the event of an instrumentation fault. In this case, the joystick is used to control it.
To implement the main wire winch, the operator activates the option "Low tension." That allows the movement of the Transfer Trolley. The Bell Winch drives run and hold zero speed at the low tension torque limit.
When this phase is completed, the bell can be raised.



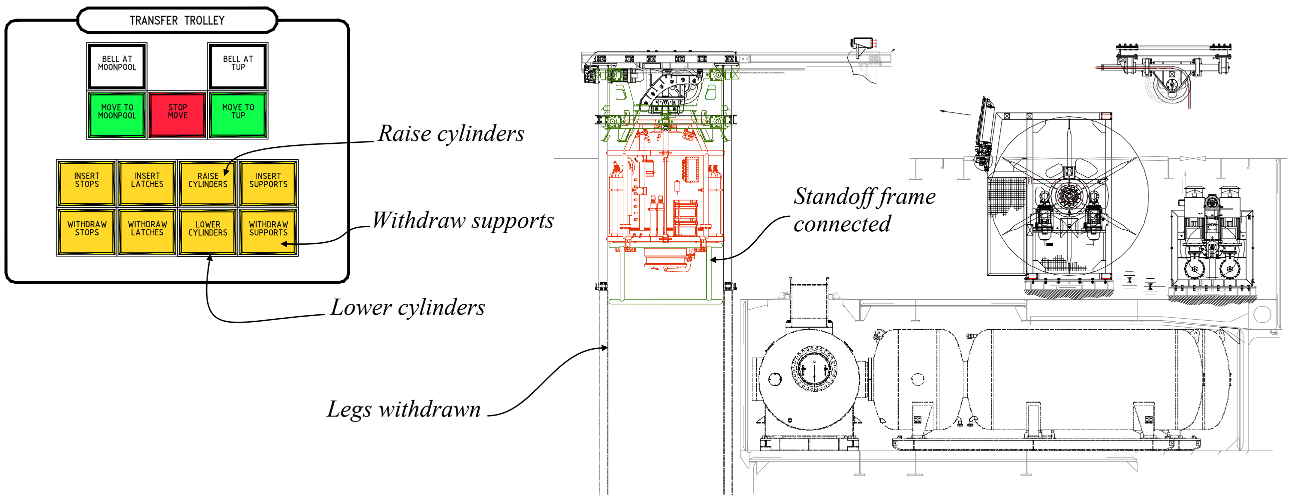
To lift the bell off the connecting flange. The operator must hold the pushbutton "raise cylinders" in the section " transfer trolley." Usually, the main cable winch automatically recovers the excess of slack. The push button is illuminated by a yellow light when the cylinders are fully retracted. Also, that can be visually checked through the window that allow to see the bell and the flanges, and using the corresponding menu on the HMI screen.
When the cylinders are fully retracted, the trolley can automatically move to its final position above the moonpool. To implement this, the operator presses the button "Move to moonpool" in the section "Transfer trolley" and confirms the new status on the HMI screen. Both winches are paying out adequately when the trolley is moving. The button "Move to moonpool" is flashing during the transfer to indicate the operation is ongoing.



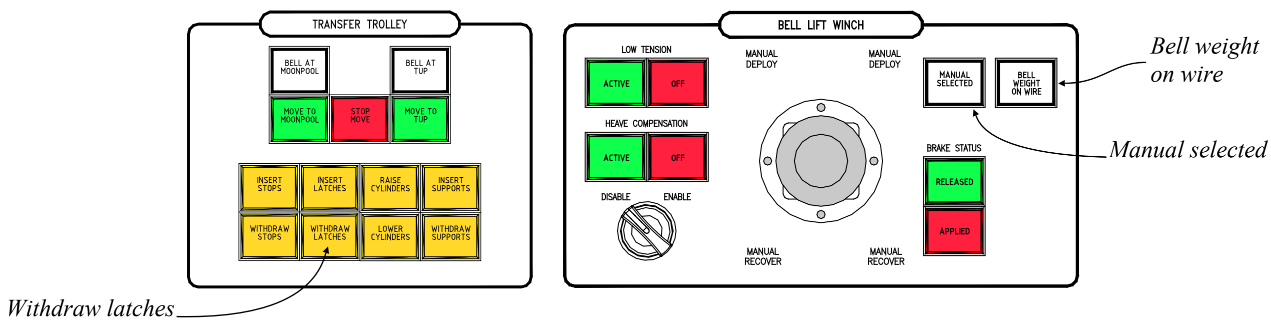
When the trolley reaches the final position, the flashing ceases and the adjacent light “bell at moonpool” flashes.
At this moment the operator locks the trolley in its final position by pressing the buttons “insert lock” and then “move to up” that are in the same section.
During this time, the supporting team manually closes the leg latches of the trolley to ensure that it cannot move back.



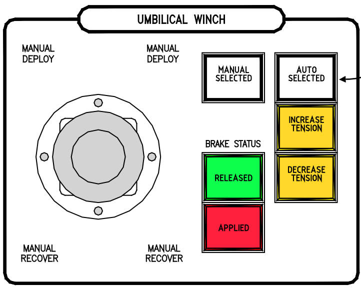
- Step 5 - Preparation above the moonpool and launching
The standoff frame and the cables of the clump weight must be connected before sending the bell to the work site. To do it, the operator pushes and holds the button “Lower cylinders” In the section “Transfer trolley”.
When the bell is in contact with the standoff frame, the supporting team inserts the locking pins manually. When the pins are secured, the operator pushes and holds the button “Raise cylinders” (in the same section) to lift the bell and its standoff frame off their support.
During these operations, the slack of the main wire and the umbilical are automatically adjusted.
When the bottom of the standoff frame is off the supports that are deployed in the moon pool to hold the standoff frame can be retracted. That is done by pressing the button “withdraw supports” in the section “Transfer trolley”. The button “Lower cylinders” is pressed again to lower the bell to its launch position.

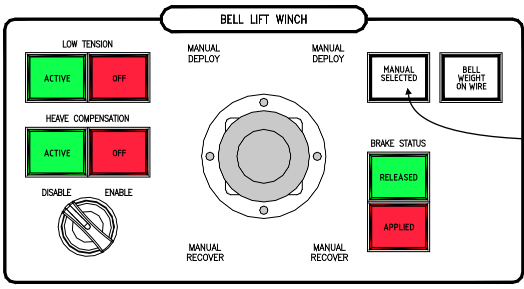


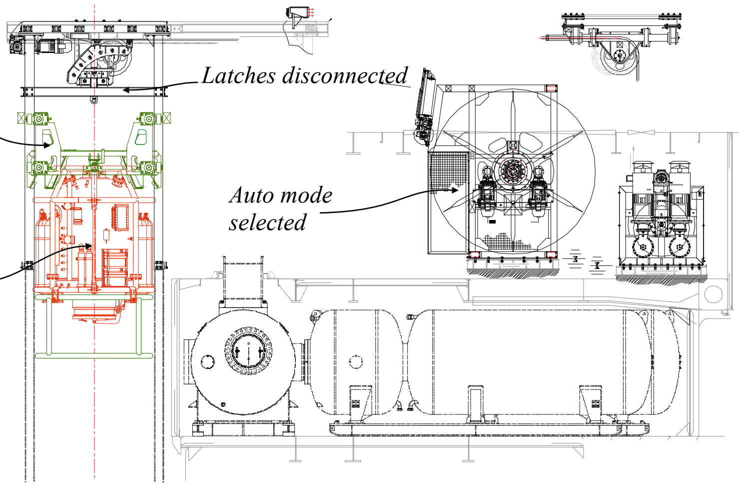
To launch the bell, the operator needs to withdraw the latches. To do it, he presses the button “Manual selected” in the section “Bell lift winch” and then the button beside named “Bell weight on wire”.
As a result, the wire winch take up the tension and holds the bell (note that the pushbutton flashes when the operation is in progress).
The joystick is then used to raise the bell until the limit sensors detect it. Note that the bell status is automatically displayed on the HMI screen.
Then, the operator presses the button “Withdraw latches” in the section “Transfer trolley.” When the latches are cleared, the new status is confirmed on the HMI screen.



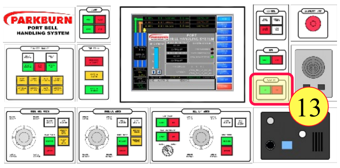
Before lowering the bell, to operator ensures that the umbilical deployment is on “Auto mode.” Then the bell is lowered to the level from where the cables of the clump weight can be connected. At this moment, the wires of the clump weight are manually connected and secured to each side of the bell by the supporting team.
When the cables are confirmed secured, the bell can be lowered manually through the moon pool. It can be achieved by pressing the relevant “manual selected” pushbutton and using the Joystick.

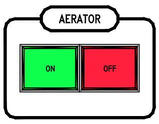


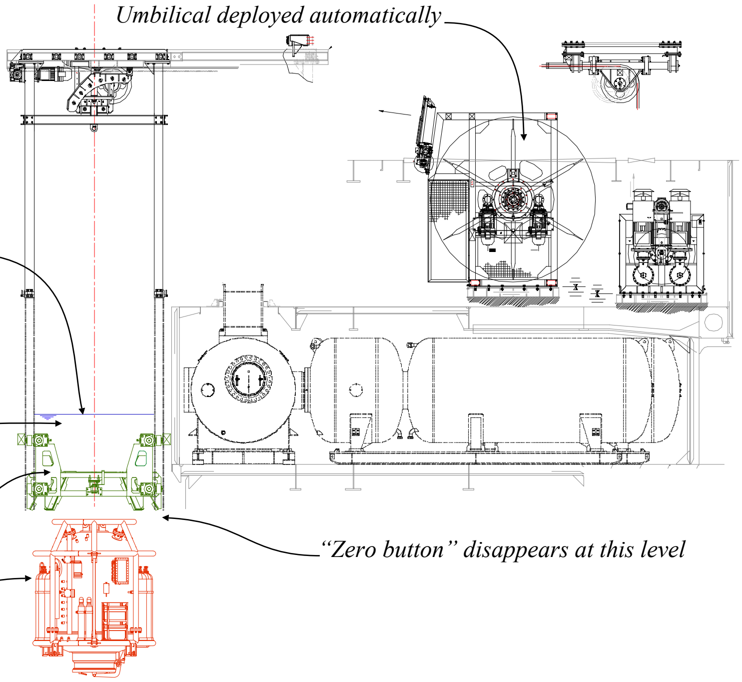




When the bell is in the moonpool, the “zero button” appears on the HMI screen and the operator presses it to set up the depth of the bell when it reaches the surface of the sea. This button then disappears when the bottom of the boat is passed.
If the weather conditions create too many waves and vortex into the moonpool, the aeration can be switched on to create a massive bubbling that will break the waves. This function is available on the right-hand side of the panel, under “Control” and “HPU” *(see # 13)*



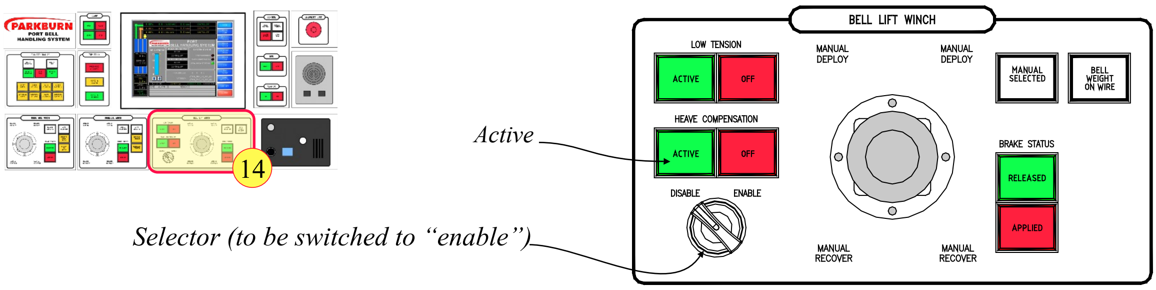




Note that the cursor is stopped at the end of the moonpool. Also, if it has been activated, the aeration is stopped when the bell is entirely outside the moonpool.
The lowering speed that was previously slow is then increased. It will decrease again at the proximity of the planned storage depth. Note that the umbilical is deployed automatically with the ideal tension. The speed of the bell, tension of the cable and the depth can be monitored at any time on the HMI screen.
When the bell is at depth, the winch of the deployment cable is shut down by pressing the button “Manual selected.”

- Step 6 - Heave compensation

When the bell is at the storage depth, heave compensation can be activated if necessary. To do it, a selector that is available into the section “Bell lift winch” *(see #14)* must be switched to “enable” and the green button situated above and labeled “Heave compensation active” must be pushed to raise the bell 3m above the initial depth.
Note that the umbilical winch is not activated. As a result that has for effect to create a 3 m loop in the umbilical and add a distance of 3 m between the bell and the clump weight, allowing the movements of the boat without affecting the bell and its umbilical.
When the correct depth has been reached the message “Line out ok for heave compensation" is displayed on the HMI screen. The alternative method proposed by the manufacturer is to lower manually the clump weigh 4 m deeper and pay out manually the corresponding extra umbilical.
On the HMI screen, the menu “Heave comp” provides information regarding the displacements of the bell.
Note that heave compensation cannot be activated at depths shallower than 50 metres. Of course, this function must be deactivated prior to recovering the bell.

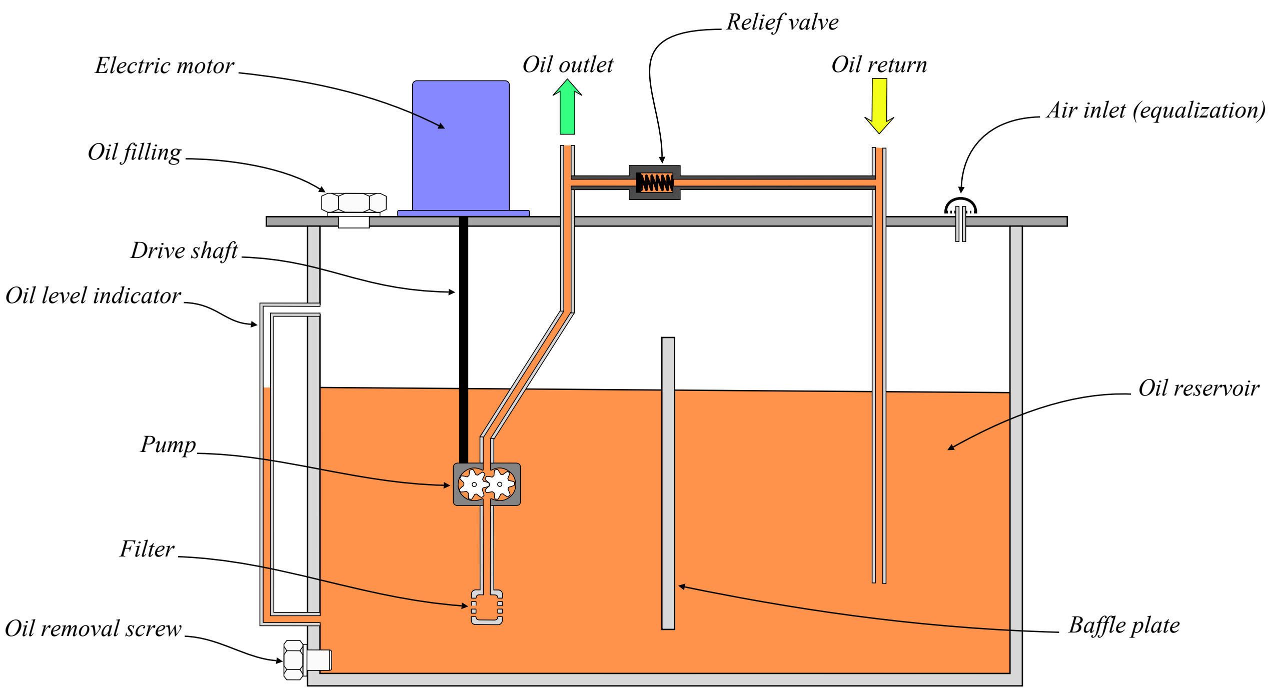


To recover the bell, the inverse process has to be performed.

To conclude on control consoles
The study of the launching process of the bell using a digital console that is described above shows that the operator is obliged to follow the established procedure to launch the bell. As a result, mistakes such as disconnection of the TUP trunk when it is under pressure or a forgotten phase are not possible as the system blocks any further operation as long as the correct procedure is not followed. Thus, we can say that computerized control systems provide additional safety precautions which result that the divers are better protected during the transfers under pressure and the descent and recovery of the bell.
However, the models of consoles from the previous generations are robust and easy to maintain. For these reasons, we can expect to cross them within the next twenty years.
Note that, despite efficient supports from the manufacturers, the major problem of the last generation control consoles is to find technicians who are competent in electronic and computer systems, in addition to the traditional mechanical skills.

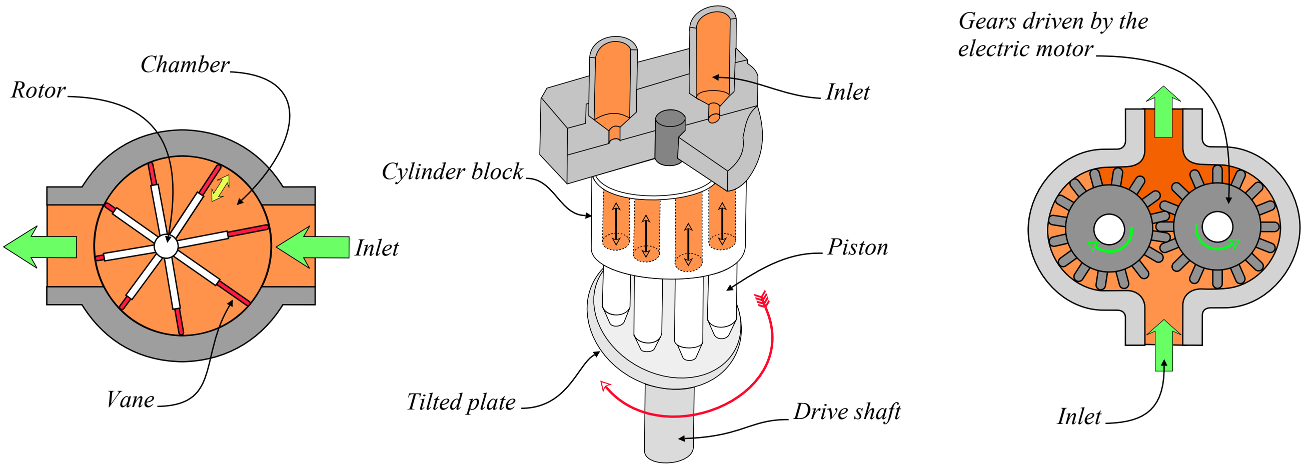
2.3.11.11 - Hydraulic Power Unit (HPU)

Hydraulic jacks and motors cannot be operated if there is no pressure in the circuit that feed tem with oil. It is the function of the Hydraulic Power Unit, also called Hydraulic Power Pack.
The Hydraulic Power Unit is composed of a hydraulic pump that is driven by an electric motor, an oil reservoir, pipework with pressure relief valves and a filter.



The pumps usually used are positive displacement pumps that are sufficiently powerful to power the tools they supply. Three types of pumps are commonly found:

- Gear pumps produce a flow of oil by using the teeth of two meshing gears to move the fluid. They are reputed robust and can transmit high amounts of hydraulic fluid.
- Piston pumps are also used for this purpose. They contain one or more pistons that convert the rotary shaft motion into an axial reciprocating motion. They are composed of a tilted plate that rotates, causing the pistons to move up and down, and thus, take the fluid and expel it each shaft rotation *(See the scheme below)*.
- Vane pumps are also found. They consist of a rotor rotating inside a circular cavity where its center of rotation is eccentric. Several vanes are in place at the periphery of this rotor, creating chambers that vary in volume as the rotor turns. The intake of the pump is where the chambers are the largest. The outlet is where the size of the chambers is smaller.



Vane pump *Piston pump* *Gear pump*

The the oil reservoir is designed to:

- Hold enough fluid to adequately supply the hydraulic system: For this reason, it must have a sufficient volume to supply the elements connected to it and collect the returning fluid from these elements. Note that fluids expanse when they are hot, and this phenomenon must be taken into account when the volume of the tank is calculated.
- Provide communication to the external atmosphere, and sufficient space above the fluid to let the air compressed when it is hot to escape to the atmosphere and vice versa.
- Provide a surface that is large enough to transfer the heat from the fluid to the ambient environment by radiation and convection.
- Avoid fluid turbulence at the pump inlet: It is the function of the “baffle plate” that forces the fluid from the return line to take an indirect path to the pump inlet. The baffle plate also limits the movements of the stored hydraulic oil linked to the sea conditions encountered by the boat.
- Provide a gauge to check the volume of oil, and means of access to top-up it if necessary, and change it when it is too old or dirty.

The filter is usually installed at the pump inlet. Also, a relief valve is usually installed at the pump out let. Note that other relief valves may be provided in the hydraulic circuit

Important note:
The hydraulic power unit of the Launch And Recovery System (LARS) must not be for any other purpose than the supply of the elements of the LARS, and this according to the original design indicated by the manufacturer and agreed by the certification body. So, a separate Hydraulic Power Units must be provided to supply the working tools of the divers.

2.3.11.12 - Maintenance

IMCA D 024 gives the following guidelines regarding the planned audits for the maintenance of the system.

Items	*Visual examination + function test + Load test 1.25 SWL*	*Wire destruction test*	*Load test 1.5 SWL*	*Other*
Relief valve	6 months	2 ½ years		
Pneumatic hoses	6 months	2 years		
Electrical winch testing	6 months			
Communication	6 months			
Emergency breathing apparatus	6 months	2 ½ years	5 years	
Bell clamp safety interlock	6 months	2 years	When installed	
Fire fighting portable system	6 months			Manufacturer specification
Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
Fire detection	12 months			
LARS overall testing	Static: 6 months Dynamic: 1 year		12 months	1 year: NDE critical areas
Weight of the bell (Outside and in the water)	12 months			
Main winches (function and load test)	6 months		12 months	NDT critical areas: 12 months
Main lift wire	6 months	12 months	12 months	History of certificates must be available
Secondary winch	6 months		12 months	
Secondary lift wire	6 months	12 months	12 months	History of certificates must be available
Lifting attachment points	6 months		12 months	NDT critical areas: 12 months
Cross haul system general			6 months (test in the water)	
Heave compensation	6 months (test at max SWL)	6 months		
Hydraulic systems (general)	Hydraulic systems (Intercooler/heater)	6 months		
Hydraulic oil analysis or replacement				12 months

The pre-operation checks must be performed at least daily during the diving operations. The manufacturer of the system presented (Parkburn) provides the following guidelines that should be followed regardless of the commercial brand of the system used.

- General inspections:

- Ensure that all communication links are operating correctly.
- Ensure that all personnel are aware of the intention to operate the equipment.
- Ensure that all associated equipment is operating correctly.
- Inspect all structures and proprietary items for damage.
- Inspect all fastenings to ensure that all are present and appear to be correctly tightened.
- Ensure that all protective guards are correctly fitted.
- Ensure that all safety devices are operational.
- Ensure that any maintenance authorizations have been completed.
- Ensure that there are no outstanding issues, which could affect the safe operation of the equipment.

- Ensure that equipment movement paths are clear of all obstructions, and foreign bodies.
- Ensure that the all sea fastenings have been removed.

- Mechanical system

The following checks should be carried out with the system isolated at main circuit breakers:

- Carry out a visual inspection of the Diving Bell Lift Winch. Ensure all deck mountings are secure and torque loaded. Ensure no debris is present in gear trains. Check that the Lift Winch cable and all terminations are sound and that the wire is secured to the bell. Check that all guards are fitted.
- Carry out a visual inspection of the Guide Wire Winch. Ensure that all deck mountings are secure and torque loaded. Ensure no debris is present in gear trains. Check that the Guide Wire cable passes through all sheaves, clump weight and onto the Moon Pool anchor point. Check that mountings are secure and torque loaded. Check that all guards are fitted.
- Carry out a visual inspection of the Umbilical Winch. Ensure that all deck mountings are secure and torque loaded. Ensure that there is no debris is present in gear trains. Check that the Umbilical cable and all terminations are sound and that the Umbilical cable is securely attached to the Dive Bell. Check that all guards are fitted.
- Carry out a visual inspection of the Trolley and Moon Pool Guide Rails. Check that mechanical stops, locking mechanisms, and proximity sensors are present and sound. Note: if the LARS uses an A-frame, carry out a similar inspection to be sure that the frame can deploy safely. So, the fixations of the structure and the jacks to the frame, and those of the pulleys.

- Hydraulic system

- Pipework should be safely supported in order to avoid vibration or movement. Fittings are assembly elements and should not be used to support pipework.
- Flexible hydraulic hoses should be long enough for free-movement, but short enough to avoid snagging on other equipment.
- Inspect all hydraulic hoses and pipework for signs of damage.
- Check the integrity of all hydraulic connections.
- Ensure that the system contains hydraulic oil and has been vented.
- Ensure that all accumulators have been pre-charged to the required pressures.

- Electrical systems

- Inspect all controls and instrument panels for signs of damage.
- Use the Lamp Test facility at the Control Desk to verify that all lamps are operational.
- Check the integrity of all electrical connections.

2.3.12 - Gas reclaim system of the bell

2.3.12.1 - Purpose

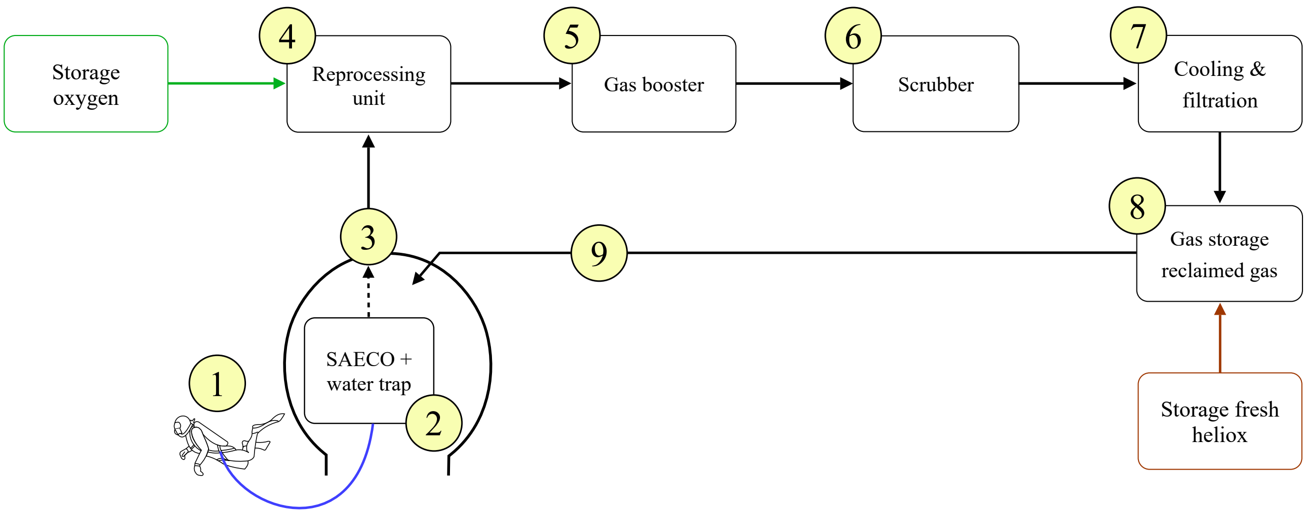
Heliox (He + O_2) is used in saturation as it is the best gas to avoid narcosis and is comfortable to breathe. However, helium is very expensive and cannot be fabricated. For this reason, it is of utmost importance to recycle it. It is the function of the gas reclaim system of the bell which recovers the gas mixture breathed by divers, re-process it and delivers it into the supply system. This system that has been already mentioned in the previous points is a closed circuit that allows recovering up to approximately 90% of the gas injected in the breathing circuit. The 10% loss is the result of helmet and bell flushing and undetectable leaks. Note that the new rules of gas purity require the removal of contaminants.
Also, the reclaim system allows staying a long time at sea as only the oxygen and the helium lost are to be renewed. Without such a system, the vessel is obliged to return to the shore very often as the consumption of gas is multiplied by the depth the divers are living and working. As an example, a diver at work at 60 meter consumes 245 litres per minute, so 14700 l per hour. Thus for a 24 hrs operation with two divers in the water, the consumption can reach 705600 litres per day. As a conclusion, a failure of the reclaim system can affect a project and for this reason, its condition must be monitored. The general layout of the equipment is as follows:

- In the bell

1. Exhaled gas is recovered from the divers through reclaim valves, mounted on helmets. The exhaust umbilicals are connected via SAECO valves (supply actuated exhaust cut-off valves), also called "Pressure Operated Safety" (POS) valves, situated in the bell and which description can be found in point 2.3.2.
2. The gas then passes via a water trap to the exhaust which is maintained at a slight differential pressure by a back pressure regulator (see in point 2.3.2). The bell-man can monitor this pressure on a gauge situated in the bell.
3. The gas is then passed to the surface through a non-return valve and the main umbilical of the bell.

- At the surface

4. The gas enters the reprocessing unit, where it is filtered, stored in receivers, and oxygen is added to make the correct mix.
5. The gas is then passed to an Electric Gas Booster where the pressure is increased.
6. It is then scrubbed to remove the CO_2 and other impurities
7. Then, the gas is dried by cooling and filtered.
8. It is then stored. Eventually, fresh heliox is added to compensate the gas lost during the dive.
9. Then, the gas is passed via the umbilical to the bell gas supply manifold and then to the diver's regulator.



Some small differences may be found from one system to another. However, the basic concept remains the same. Also, as such systems are complex, it is preferable to describe them in details using existing models as support. For this reason, the model currently in use on UDS Lichtenstein and Picasso which has been designed and built by LEXMAR, a company of JFD group is taken as an example.

2.3.12.2 - Bell Unit

I. As indicated above, the breathed gas of the diver is expelled through the exhaust valve of the helmet that is described in point 2.3.6 and the exhaust hose of the umbilical. This exhaust hose, is connected to the "Supply Actuated Exhaust Cut-Off " (SAECO) valve, which is also called "Pressure Operated Safety" (POS) valve *(see #1 in the figures A & B on the next page)*. The exhaust hose can be isolated by a ball valve *(see #2)*.

II. The SAECO/POS valves allow the exhaled gas from the diver to return to the surface. Please, remember that this valve is designed to close in the event the supply pressure drops below a pre-set value. This pre-set value is controlled by the back-pressure regulator *(see #3 in the figures A & B on the next page)*

III. The Back Pressure Regulator loader regulates the divers exhaust gas pressure in the umbilical. A valve controls the amount of gas going to the flow meter *(see #4 in the figures A & B)*.

IV. A flow meter controls the amount of gas being tapped off from the divers supply to load the Back Pressure Regulator (BPR) at the desired flow rate (0.5 L/min) to the BPR reference port *(see #5 in the figures A & B)*. That sets the reference pressure for the bell BPR which in turn determines the pressure in the exhaust hose for the diver excursion umbilical and the Bell water trap. A slight flow is required so that the BPR load can be varied to compensate for any required setting changes.

V. The Back Pressure Regulator (BPR) that controls the negative pressure in the exhaust umbilical to the optimum value to give a minimum breathing resistance is fitted with a bleed valve which allows regulating the pressure from the BPR loader *(See #6 in the figure A)*.

VI. A pressure gauge *(see #7 in the figures A & B below)* allows to monitor the pressure in the water trap, which is the same as the pressure umbilical which is the same as the pressure in the exhaust umbilical if the exhaust hose isolating valve and POS valve is open.

VII. The bell exhaust, which can be isolated by a valve *(See #8 in the figures A & B)* allows the gas of the bell to enter in the water trap and being drawn through the Back Pressure Regulator (BPR) to the Reprocessing Unit (TRU), which is situated in the vessel, where it will be recycled.

VIII. The "water trap" collects most of the water present in the gas expelled by the divers *(See #9 in the figures A & B)*. It consists of an acrylic housing, a compound pressure gauge, an overpressure relief valve, a negative pressure relief valve, and drain and isolation valves. It is designed to be drained regularly without affecting the working process of the reclaim system *(see in the figure C)*. This item should be mounted in a prominent position so the bellman can have an unobstructed view and is able to check its status at any time.

IX. From the back pressure regulator, gas passes through hull stop valves *(see #10)*which function is the isolation of the circuit during maintenance or in the case of an emergency. As usual there is one valve inside the bell and a 2nd valve outside the bell.

X. From the hull valves, the gas passes through a check valve *(see #11 in figure A below)* situated at the external of the bell which function is to prevent reverse flow of gas from the bell umbilical into the bell equipment: As an example, when the bell is being depressurized.

XI. Then the expelled gas flows to the external water trap (see #12 below) that collects any additional free water which has not been trapped at the main water trap or condenses when the gas passes from the internal to the external of the bell as a result of its cooling. Water should be anticipated in this filter, so it is essential to drain it when the bell is recovered out of the water.

Figure A

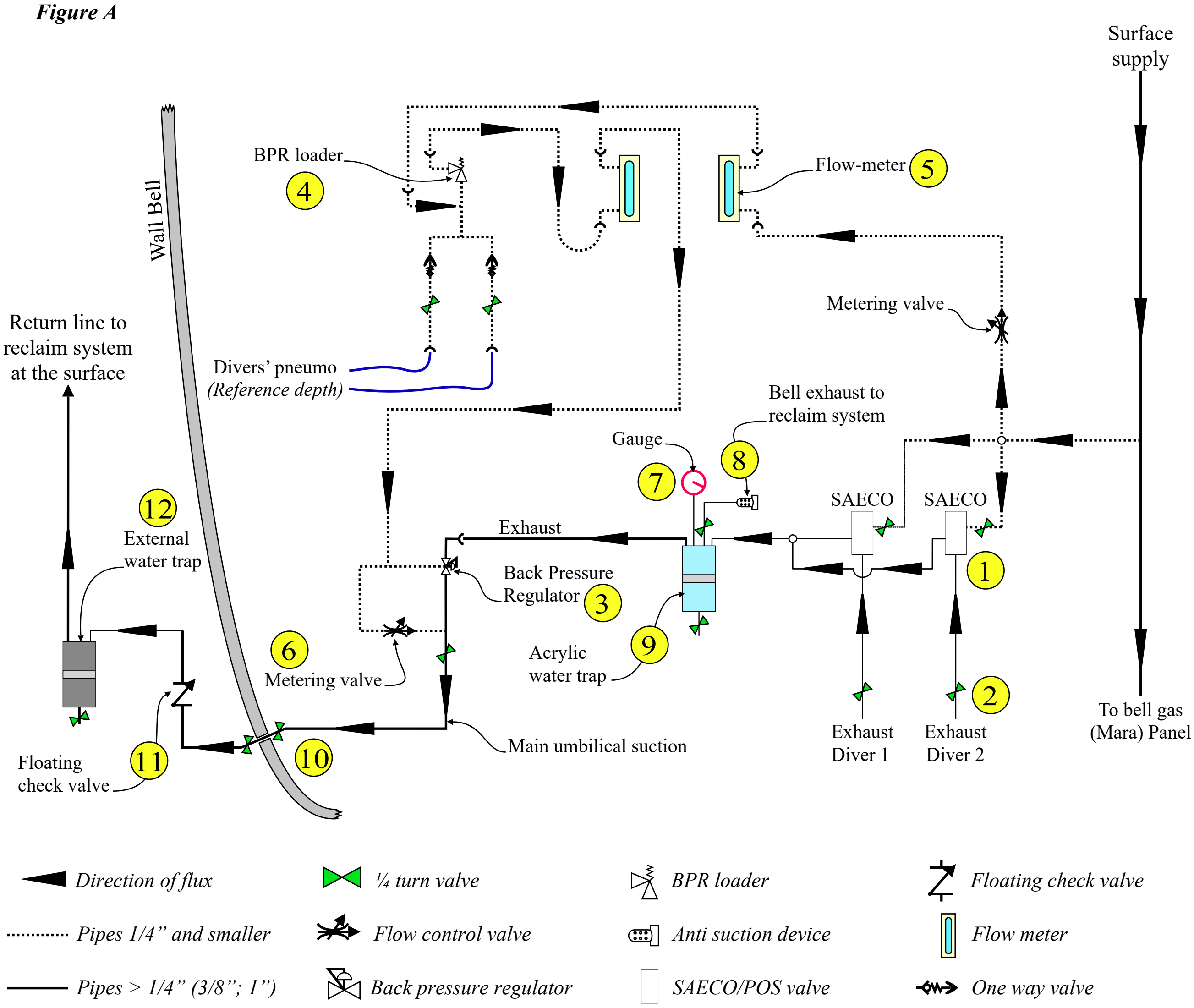


Figure B

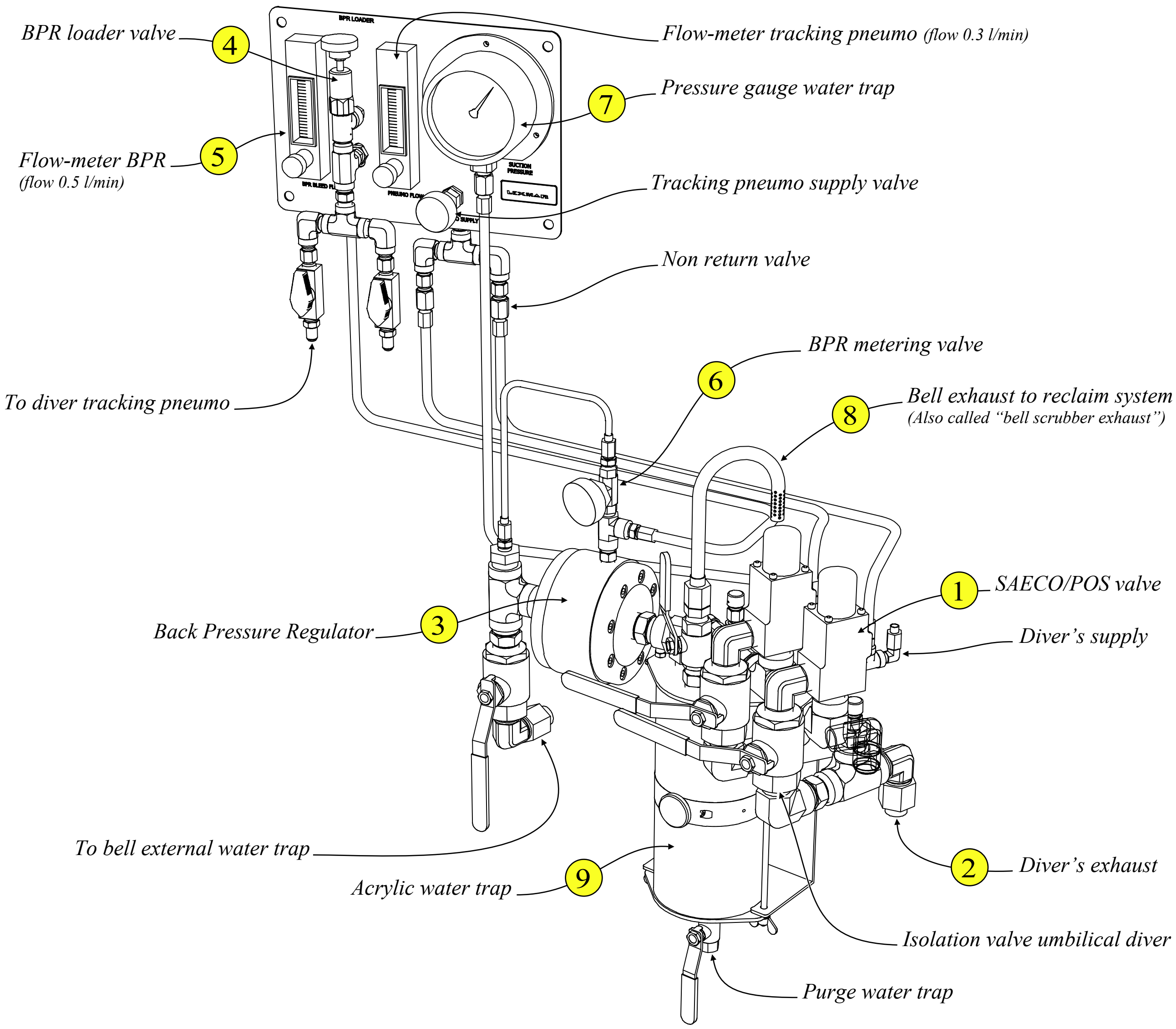
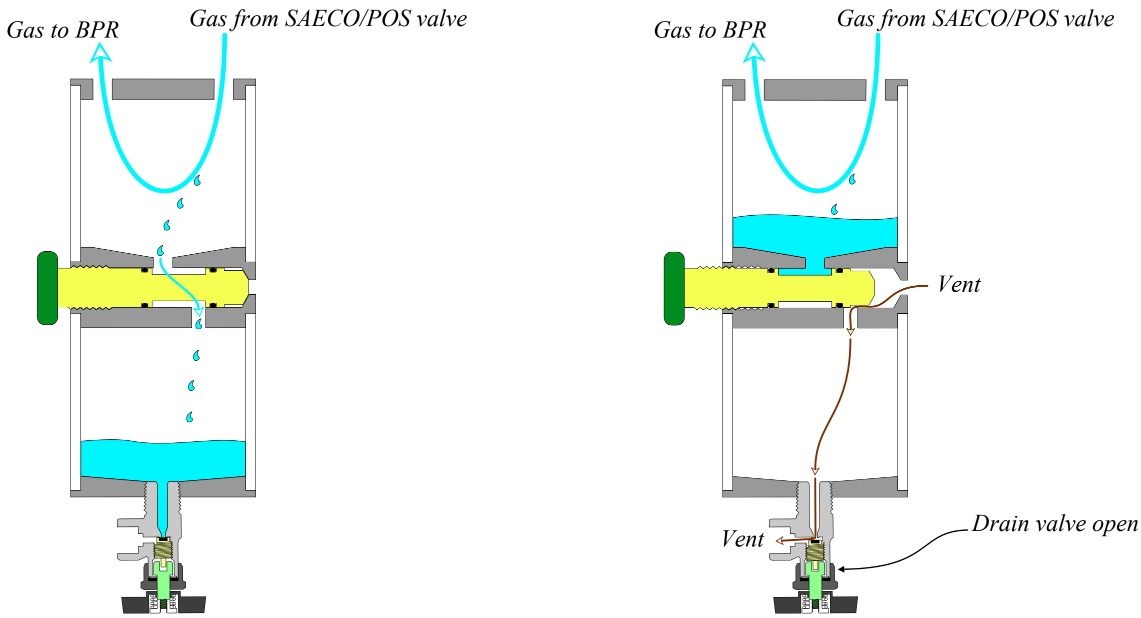


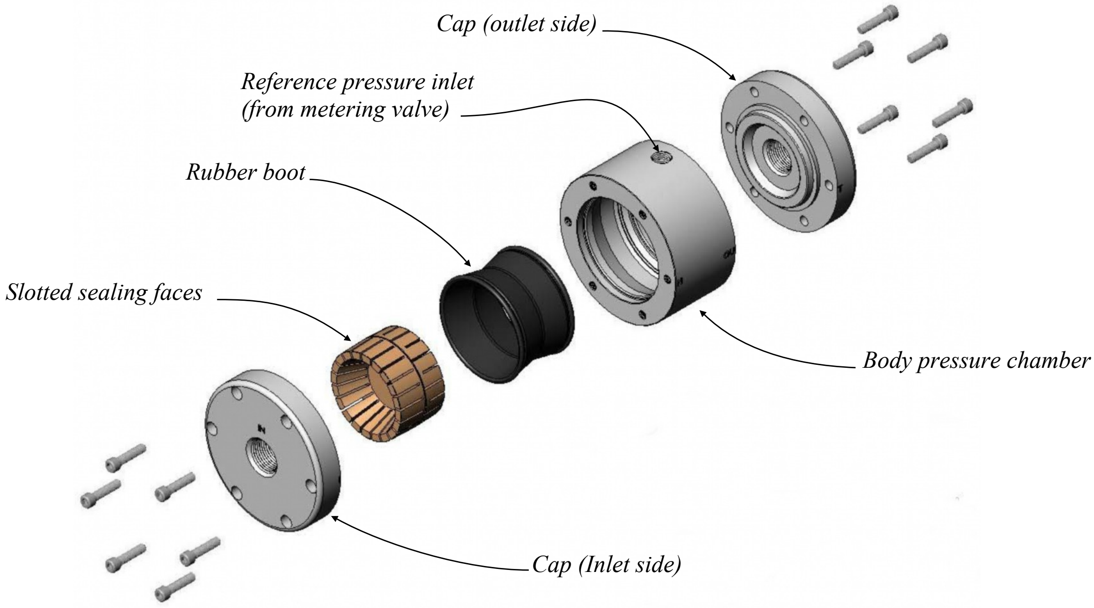
Figure C



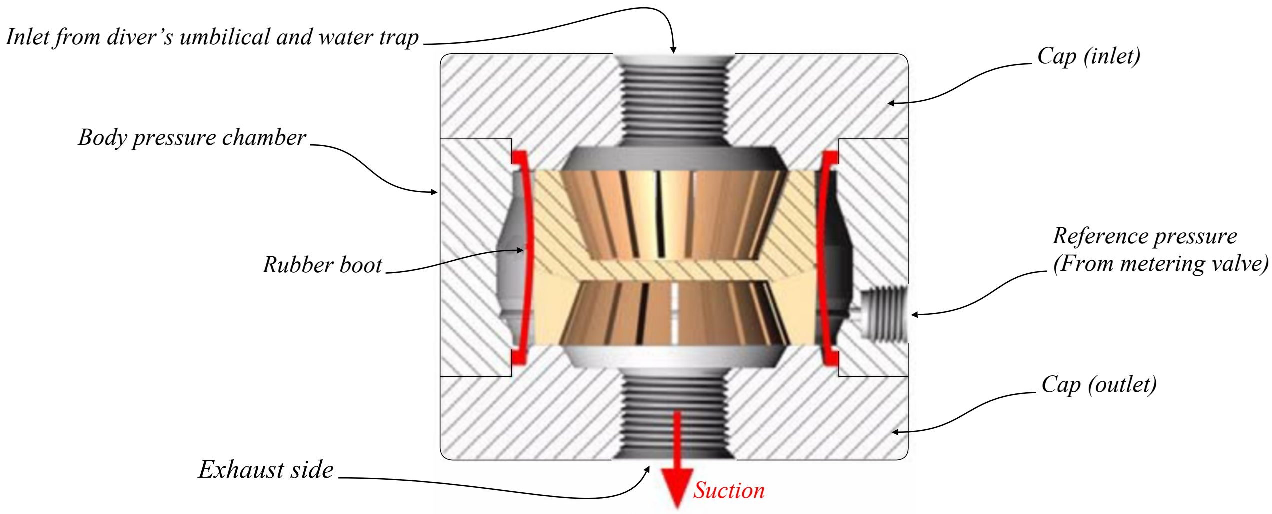
Water trap during normal operation:
With the plunger in the normal (in) position, the trapped water passes to the lower part of the cylinder.

Water trap draining:
The isolation valve is pulled out, the upper and lower halves of the water trap are isolated and the lower half is vented to bell ambient pressure. The drain valve may now be opened to remove water while the upper half continues to collect water from the flowing gas.

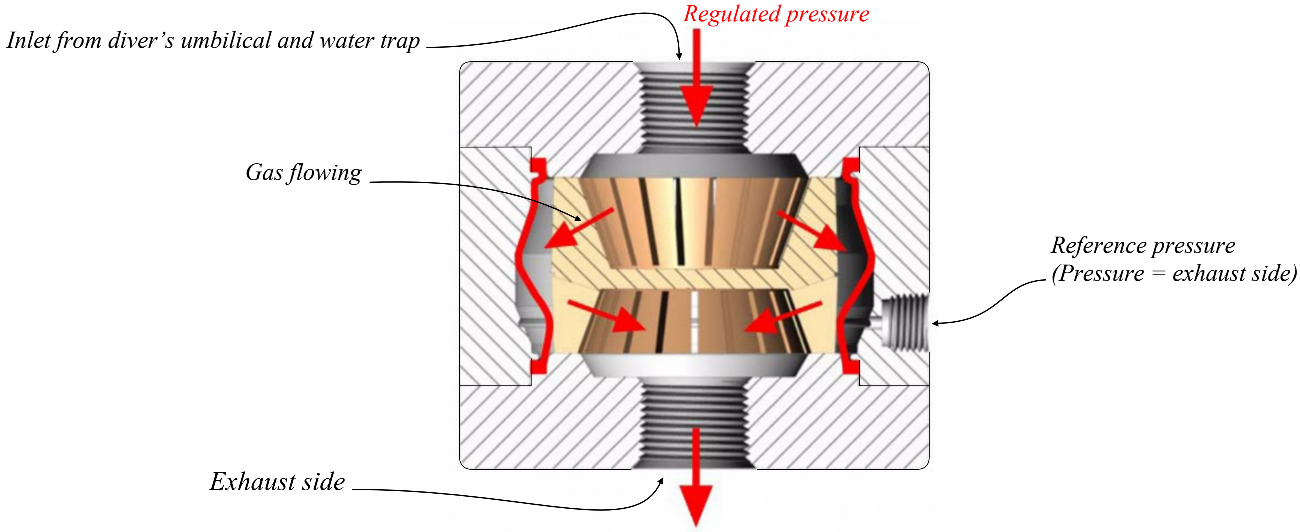
- Back pressure regulator:
The back pressure regulator controls the pressure in the diver's umbilical to give a minimum breathing resistance. It is generally composed of two slotted sealing faces enclosed by a rubber boot. This assembly is housed inside a sealed pressure chamber into which a reference pressure may be applied. The model described below is designed by Divex. However, the system provided by Lexmar is very similar, so it uses the same principle.



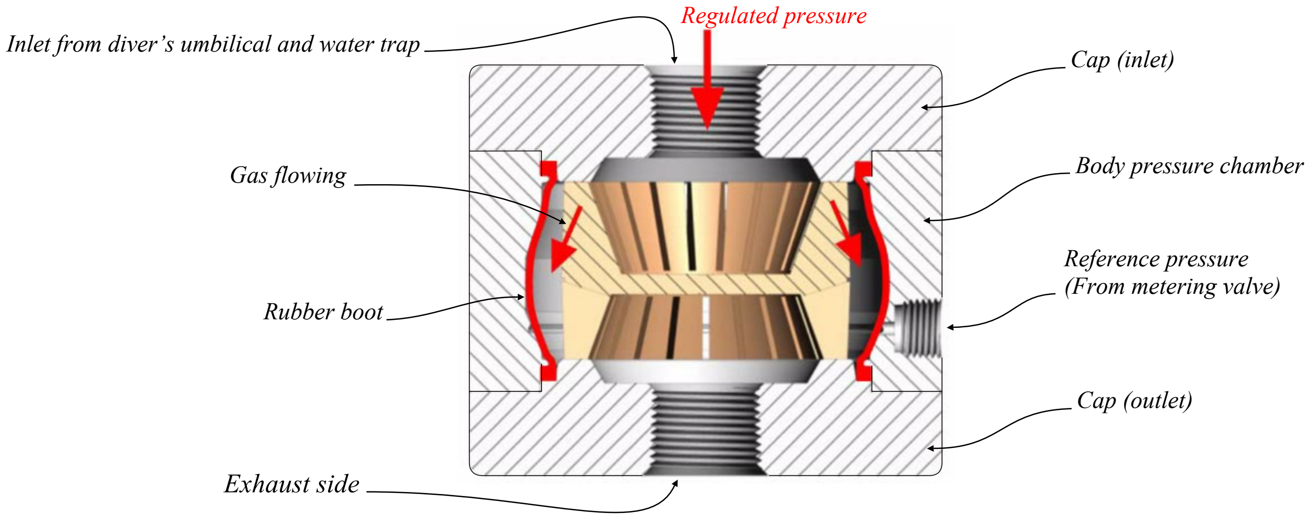
Initially, a suction is applied to the discharge side of the regulator and a reference pressure to the chamber.
If the pressure at the inlet side is below the reference pressure, the rubber boot is held in place by the pressure and no flow occurs.

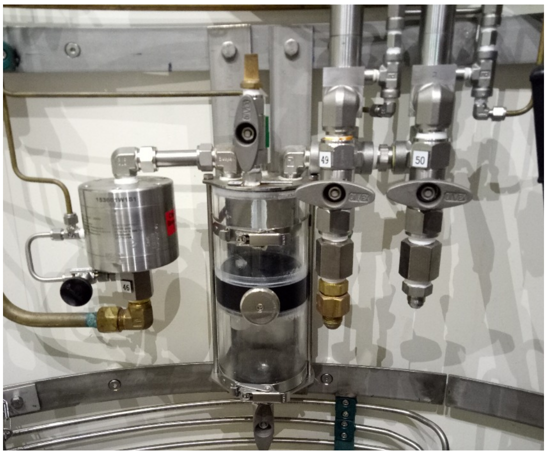


If the inlet pressure rises fractionally above the reference pressure, the diaphragm lifts, allowing the gas to flow. In this way the pressure in the exhaust umbilical is held at a level equal to the reference pressure.



A further increase in gas flow will result in increased opening of the regulator as shown





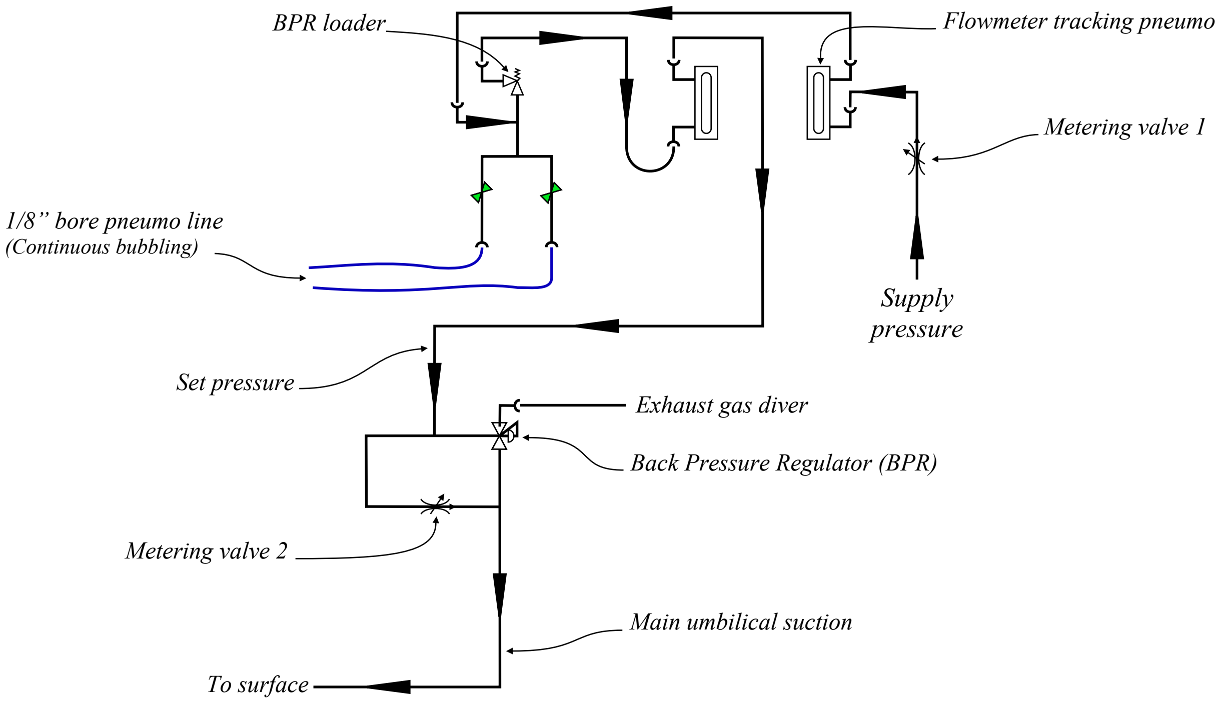
Back pressure regulator & water trap DIVEX

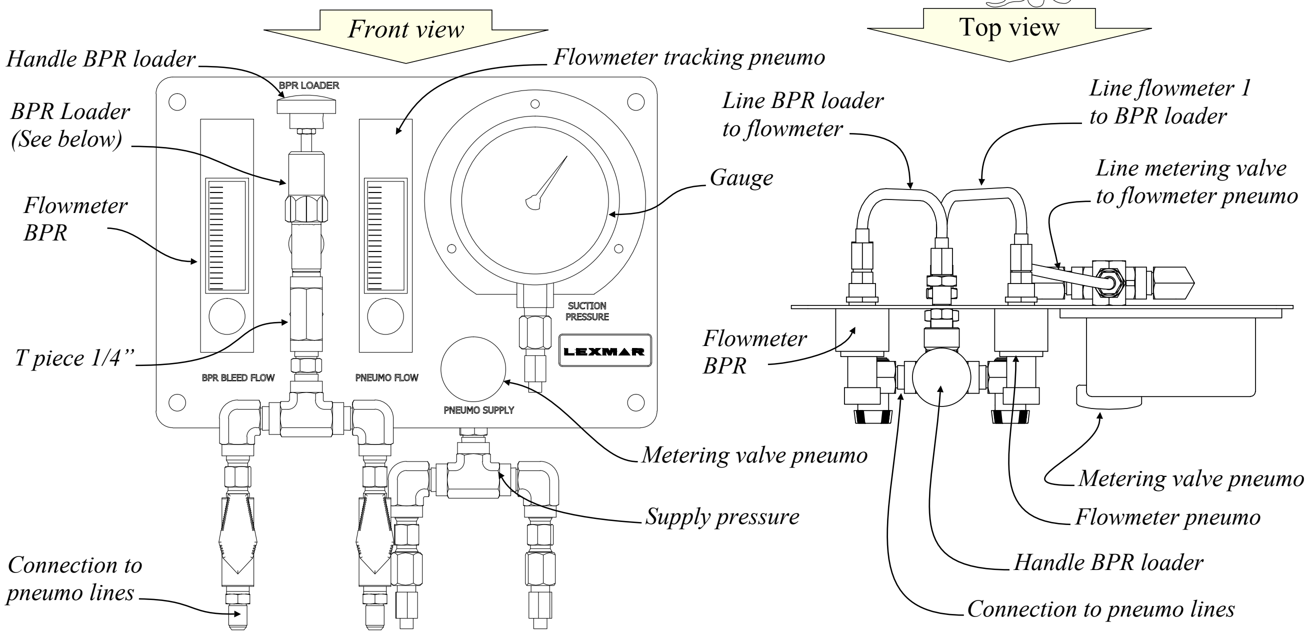
Back pressure regulator & water trap LEXMAR

- Diver tracking system:

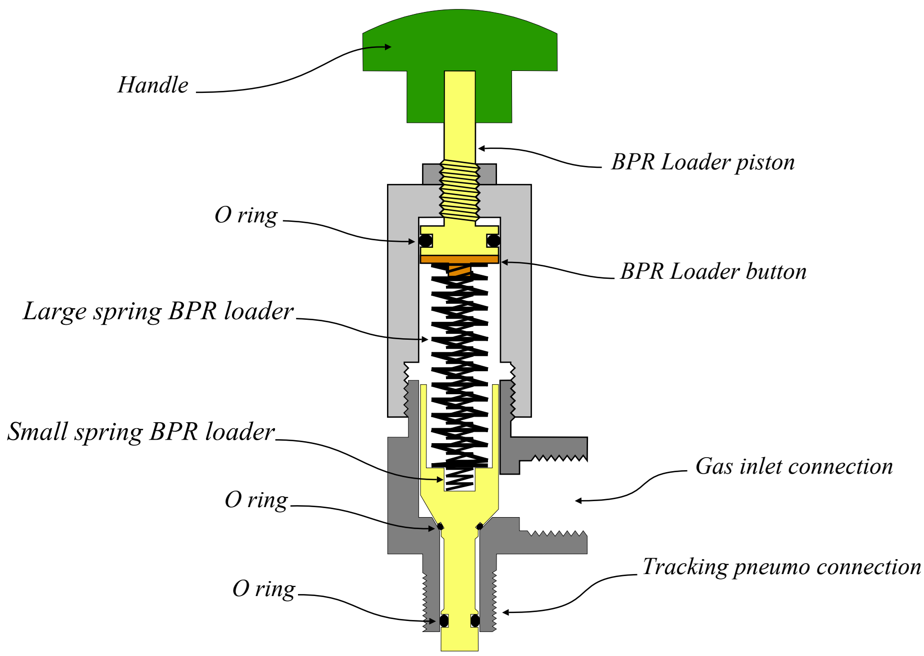
The diver tracking system adjusts the Back Pressure Regulator (BPR) loading accordingly to the depth of the diver to obtain a minimum breathing resistance from the reclaim valve. Note that the pressure in the return umbilical is adjusted approximately between 1 and 2 bar below the diver ambient pressure.

In addition to the equipment in place in the bell, a 1/8" internal diameter pneumo line is added to the diver umbilical. A slow gas bleed is drawn from the bell gas supply to this pneumo. As a result, gas bubbles emerge continually from this line at a slow rate. Note that an excessive flow will adversely affect gas recovery figures: Only a very small trickle of bubbles from the pneumo line should be evident to the diver.





The loader is a modified inward relieving relief valve which controls the set pressure for the BPR.
As suction is first applied to the system, gas will be drawn from the BPR loader line, reducing the pressure until it reaches the set pressure of the loader when it will lift, allowing gas to flow to prevent further depressurisation. In this way, a fixed reference pressure is available for the BPR.
The pressure in the diver pneumo line is applied to a piston (having the same area as the valve opening) on the bottom of the BPR loader. As the diver changes depth, the change in pressure in the pneumo line will produce a force on this piston which will in effect change the set pressure of the loader.



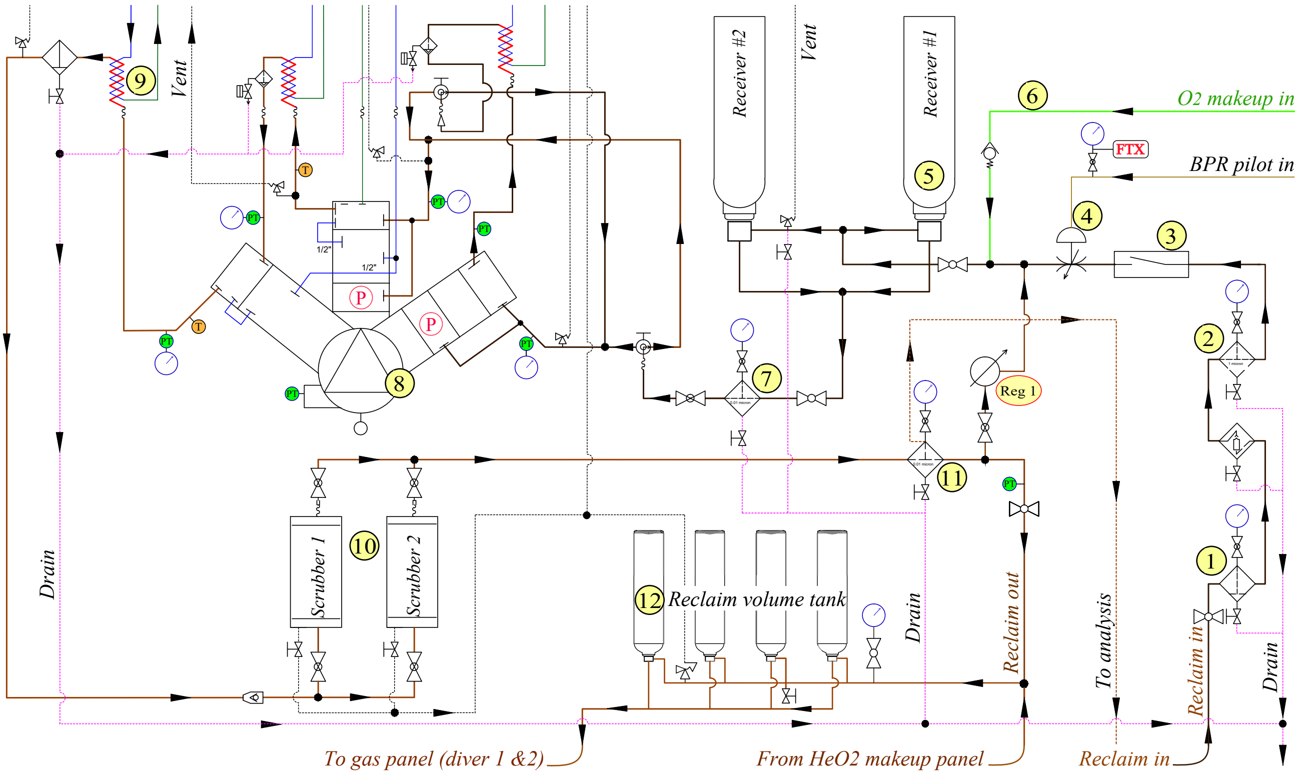
Functions of the diver tracking system components:

Diver pneumo	Monitors the diver's depth.
Metering valve pneumo	Adjusts the supply gas to purge the diver pneumo. It is often adjusted at 0.3 litres/min; a maximum of 0.4 litre/min is recommended.
Flowmeter pneumo	Indicates the flow through metering valve pneumo.
Back Pressure Regulator loader	Maintains a constant pressure difference between diver ambient and BPR setting.
Back Pressure Regulator (BPR)	Controls the exhaust umbilical pressure to be equal to the BPR loader setting.
Metering valve BPR	Controls the gas bleed through the BPR loader to give stable operation. It should be set to 0.5 litre/min.
Flowmeter BPR	Records the flow through metering valve BPR

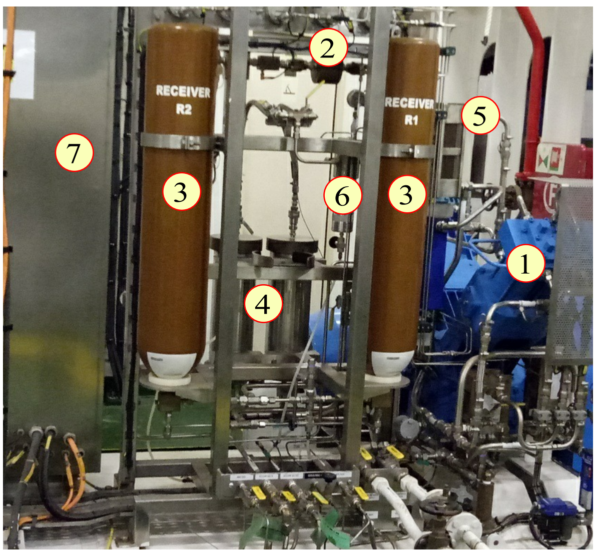
2.3.12.3 - Topside unit

The gas from the bell is drawn to the Topside Re-Processing Unit (TRU) through the bell umbilical.
The Topside Re-Processing Unit (TRU), recompresses the recovered gas, scrubs it to remove the CO2 and other contaminants, and adds oxygen to restore the correct PPO2 of the breathing gas supply.

- The inlet section consists of a water trap *(see #1 below)*, filter 1 micron with moisture separators *(see #2)*, flow switch *(see #3),* back pressure regulator *(see #4)*, and two receivers which smooth out fluctuations in the flow to the compressors *(see #5)*. Oxygen enrichment is also carried out in the inlet section (see #6).
- The gas is then sent to another 0.01 micron particle filters which is fitted with biological filters *(see #7)*
- The Compressor (gas booster) consists of one electric driven three piston compressor which brand is Hycomp for the system studied . It is described more on the next page *(see #8)*.
- The gas from the compressor is water-cooled through heat exchangers *(see # 9)*. It is discharged to the scrubbers where soda lime (9 litres each) and Purafil remove the carbon dioxide and other contaminants *(see #10)*. A further filtration 0.01 micron removes water particles or solid material *(see # 11)*. The gas is then stored in the “reclaim volume tank” *(see #12)* from which it is sent to the divers.
- Finally, the topside unit also houses electrical and computer systems necessary for the control and driving of the Hycomp compressor motors. Note that computers are monitored through a human machine interface (HMI).



¼ turn valve	Gauge	Needle valve	Water trap	Filter
Flow switch	Heat exchanger	Back Press. Reg	Pressure regulator	Relief valve
FTX Flow transmitter	T T° transmitter	PT Press. Transmitter	3 way valve	Check valve



#1: Compressor (booster)

#2: Back Pressure Regulator

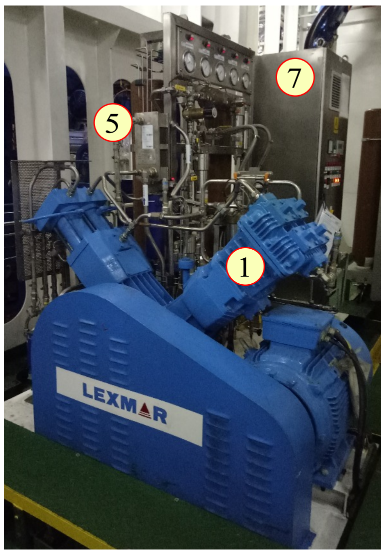
#3: Receivers (No 1 & No 2)

#4: Scrubbers

#5: Heat exchanger

#6: Micron filter

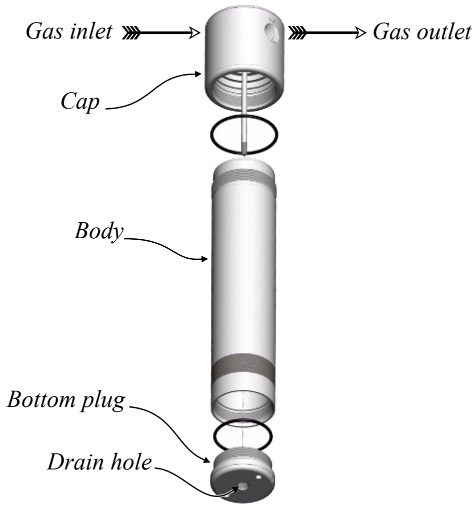
#7: Electrical enclosure



#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*

- Filters and moisture separators:
  The filter elements coalesce the small liquid droplets into larger liquid droplets which drain to the bottom of the housing.
  Two types of filtration are provided:
    - Filter 1 – 1 micron
    - Filter 2 – 0.01 micron
    - Filter 3 – 0.01 micron

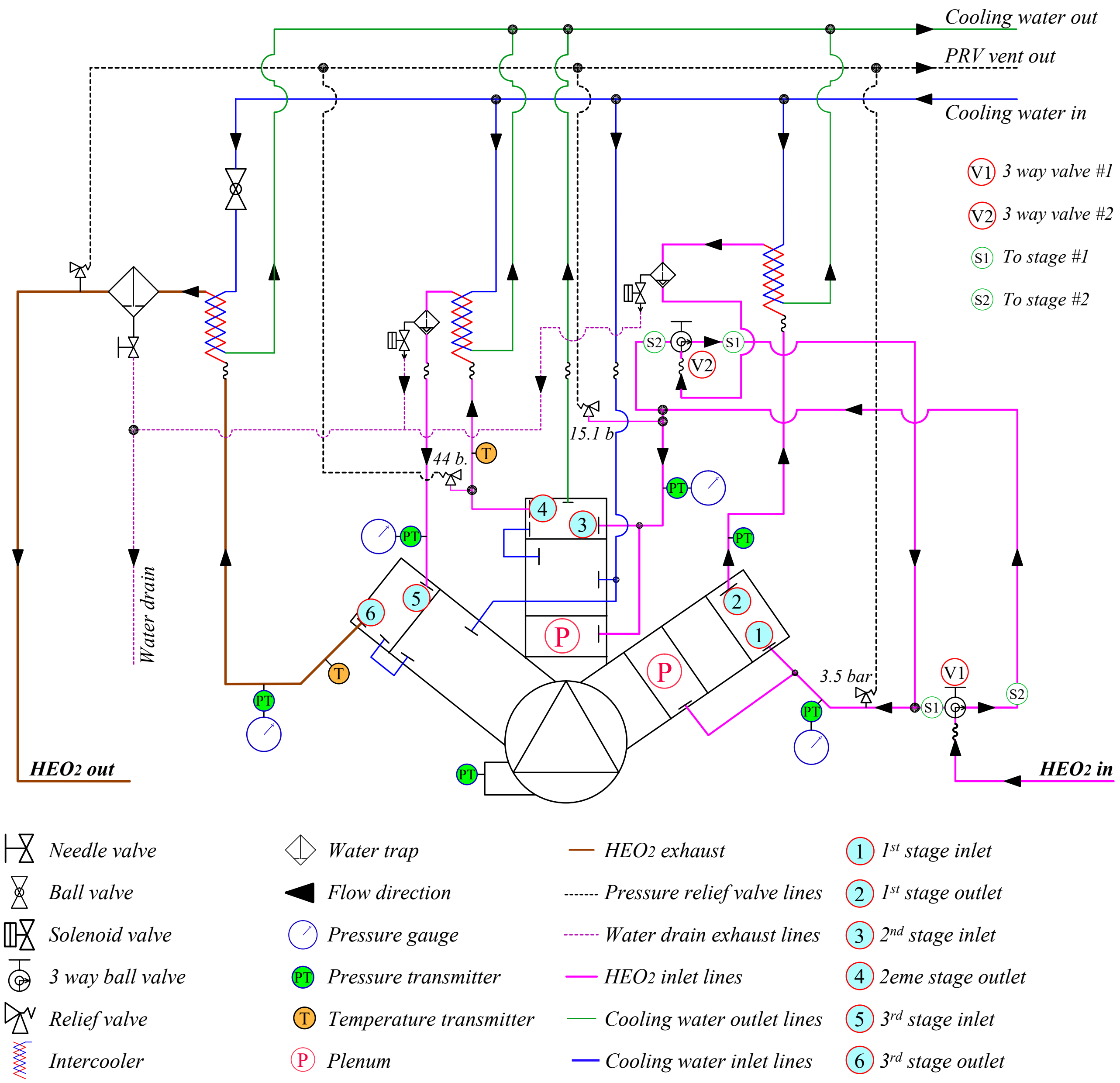
  A filter housing is generally composed of three main parts, as shown in the drawing on the side.
  All water traps and filter housings should be drained every hour or so.
  It is recommended that filter elements be replaced at intervals of 500 operating hours.
  Water traps prevent water from flooding the topside unit. Note that in addition to the moisture expelled by the divers, water incursion may happen in the case of a loose fitting.
  A drain valve allows any accumulated water to be removed. Note that the water trap should be checked and drained at least every hour.



- Oxygen injection:
  Oxygen from storage enters the panel by passing through isolation valve and O2 gauge and is injected into the gas after passing through the Back Pressure Regulator on the Topside Reprocessing Unit (TRU). The flow is controlled by setting a regulator for desired pressure of the oxygen supply to the system which is on the "oxygen make-up panel" in Dive control.

- Flow switch:
  The flow switch senses the divers exhaled gas flow through the system. This switch controls two functions.
  I. It activates the alarm in the control panel when the flow of gas through the topside unit stops.
  II. It stops the addition of oxygen in the absence of flow.

- Back Pressure Regulator (BPR):
  The topside BPR controls the pressure in the main bell reclaim hose in the umbilical. It has a similar design as the one used in the bell. The bias pressure to the BPR is controlled from the "Reclaim panel" in the Dive Control.
- Compressor (booster):
  A compressor is a mechanical device that increases the pressure of a gas by reducing its volume. A gas booster is a compressor that is designed to increase the pressure of a gas that is already above ambient pressure.
  The compressors used in reclaim systems act as boosters as the gas received from the bell is already above the ambient pressure at the surface. However, most systems utilize machines that are capable of compressing gas at atmospheric pressure, or that is as low as 0.1 bar above atmospheric pressure. Note that the inlet gas pressure of each stage of the compressor must conform with the specifications it has been calculated for and that the machine will be damaged if the inlet gas pressure is higher than recommended.
  Compressors are more described in another chapter. However, the machines commonly used in reclaim systems are membrane and piston compressors. As a result of a more reduced cost, piston compressors are the most used with modern reclaim systems. As an example in the diving system taken as reference for this description, the gas from the bell is pumped by a 3 stage compressor driven by a variable speed-controlled electrical motor and is designed with inter, and after-coolers. It is capable of receiving input pressures from as low as 0.1 bar and supplying an output pressure of up to 55 bar. Also, it can sustain flows of up to 135 L/min at bottom pressure for a diving depth of up to 300 MSW. The speed range of this compressor is between 400 and 800 RPM.
  Note that its 1st stage can be deactivated or activated through manual 3-way valves. It must be bypassed for operations in the range of depths deeper than 160 MSW; the determining factor is the maximum allowed input pressure of 3.4 Bar at stage 1 inlet. Of course. a relief valve preventing the introduction of gas above 3.5 bar protects the 1st stage.



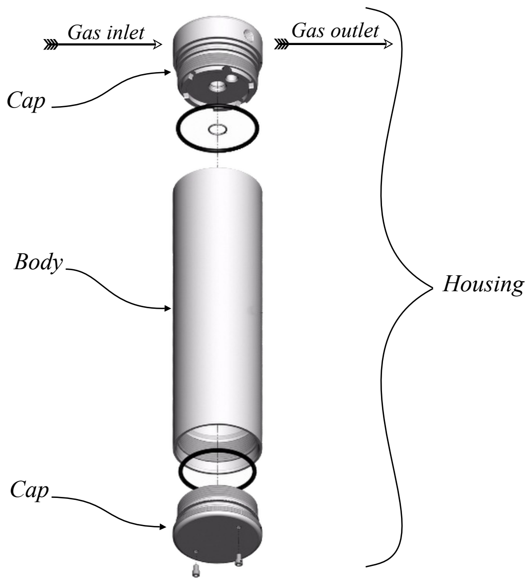
Additional technical information regarding the compressor taken as an example:

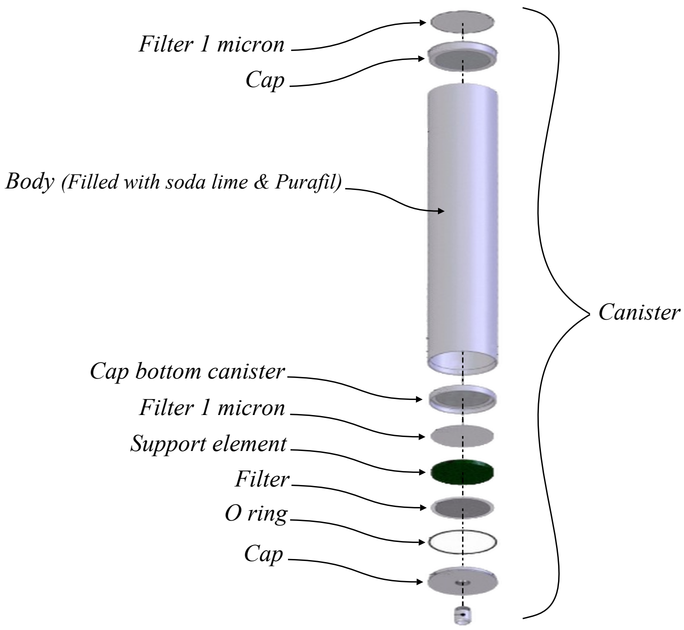
- Dimension of the compressor are L: 2650 mm, H: 2225 mm, W: 1750 mm and its weight is 2500 kg.
- This machine is protected by a computer that monitors its functions and shut it down in the case of incorrect parameters. A Human Machine Interface (HMI), which is on the electrical enclosure, allows controlling it.

- Power requirements are 440 Vac/ 60 Hz/ 40 KW.
- Suction gauges, which indicate the gas pressure into the compressor are provided at the inlet of each stage. A gauge is also provided to indicate the discharge pressure.
- Max inlet pressure: 31 bar / Max outlet pressure 55 bar. As already said, the inlet pressure must never be above the recommended value or the compressor can be damaged. High and low pressure switches are provided to shut down the compressor in the event of high discharge pressure or low inlet pressure.
- A Shut-off valve that isolates the compressor’s suction gas from the inlet section is also provided.
- Gas temperature switches are provided to shut down the compressor in the event that the discharge gas temperature rises above the normal operating temperature. This may occur if the cooling water supply to the compressor is disrupted.
- Intercoolers fitted with water traps are installed to cool the gas and protect the compressor from damage due to carry-over water entering the inlet stages. Cooling water supply: 20 litres/minute & 3 to 6 bar / Max cooling water supply temperature: 32 ºC. Note that an automatic draining system is provided. However, the manufacturer recommends to regularly check that it is functioning.
- An oil pressure switch shutdowns the electrical motor in the case of low oil pressure.

- Automatic inlet gas pressure management
In the installation taken as example, the computer mentioned above monitors the inlet pressure and automatically adjusts the compressor rotation speed to keep this inlet pressure to a constant value.
When there is insufficient mixed gas returning from the divers and the reclaim volume tank, a heliox make-up system automatically keeps the volume tank pressure to a preset value, and an alarm is triggered on the reclaim panel in the dive control.

- Scrubber assembly
Two scrubber units that consist of housings into which a canister assembly filled with soda lime (also called soda sorb) and Purafil are provided.
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 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)*.





- Bypass regulator
Excess gas volume which is being delivered is re-circulated back to the suction side of the compressors at the inlet to the gas receivers.
This re-circulation line is fitted with a pressure regulation system. The bypass regulator *(see “Reg 1” in the scheme that represents the entire topside unit at the beginning of this topic)* is loaded by the gas that flows in the line from the scrubbers to the "reclaim volume tank". This gas passes through an orifice. Downstream of this orifice is a pressure regulator which is set to open at a value below that set on the return line BPR. If the pressure downstream of the return line BPR falls below its set point, the bypass regulator will sense this drop in pressure and open, with this regulator open the BPR load pressure will also fall and allow the BPR to open, bypassing into the "receivers" the gas flowing from the scrubbers.

2.3.12.4 - Control console unit

The control console is situated in “dive control. It is generally composed of four parts:

- Analysis panel
- Oxygen make-up panel
- HeO2 make-up panel
- Back pressure regulator loader panel

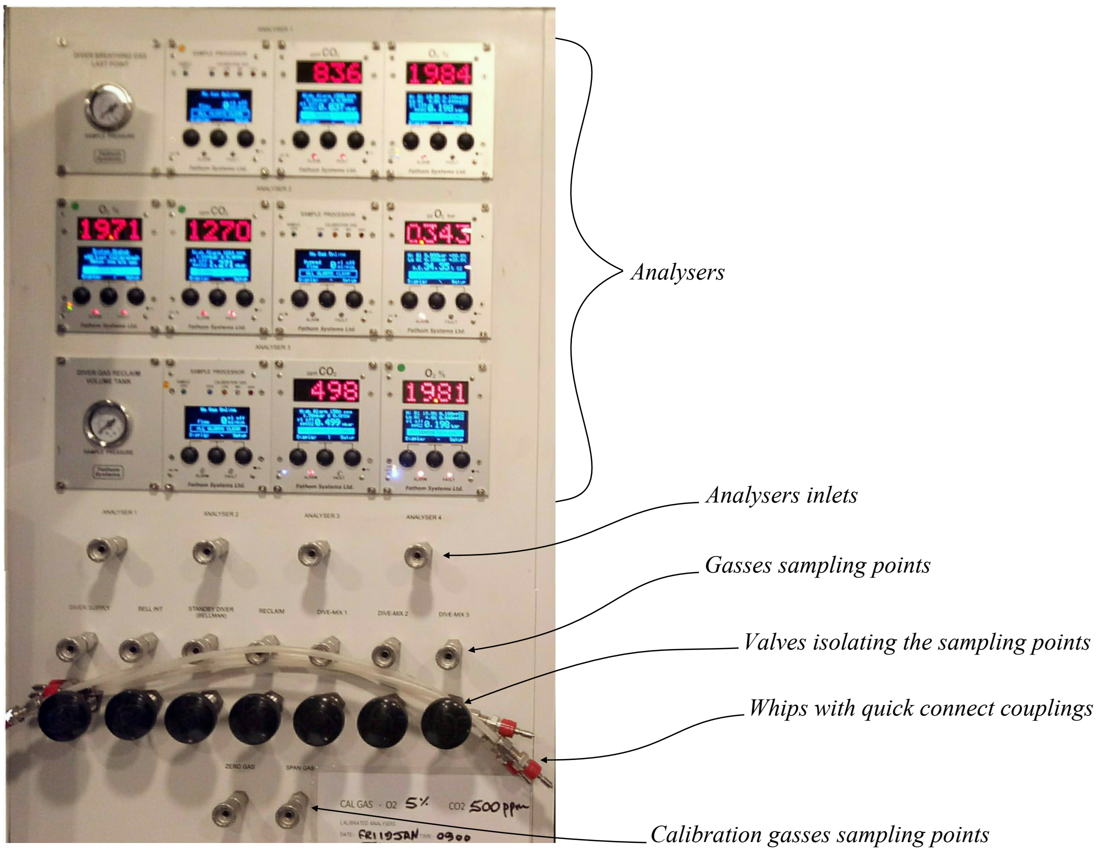
- Analysis panel:

The analysis panel is essential to ensure that the reclaim system works accordingly to what is expected and to monitor the gasses that are ready to be in line. IMCA says the following:

- *There must be an oxygen analyser with an audible and visible high and low alarm fitted in line on the downstream gas supply to the divers*
- *If diver gas reclaim is being used, there must be a carbon dioxide analyser with audible and visible high level alarm fitted to the down-stream side of the diver gas supply. The adjustment of gas sample flow rate must not affect any other analyser fitted*
- *There must be a means by which the diving supervisor can monitor the bell atmosphere for oxygen and carbon dioxide levels. This may be by a manual procedure carried out by the bellman or by a remote reading in dive control*

The analysers used on control panels are separate devices which are designed for a dedicated gas. They are typically grouped together and at the direct proximity of the diving supervisor. Flexible whips with quick connect couplings are used to connect these O2 and CO2 analysers to the various sampling sources that are regulated by flowmeters. These sampling points are usually organized as follows:

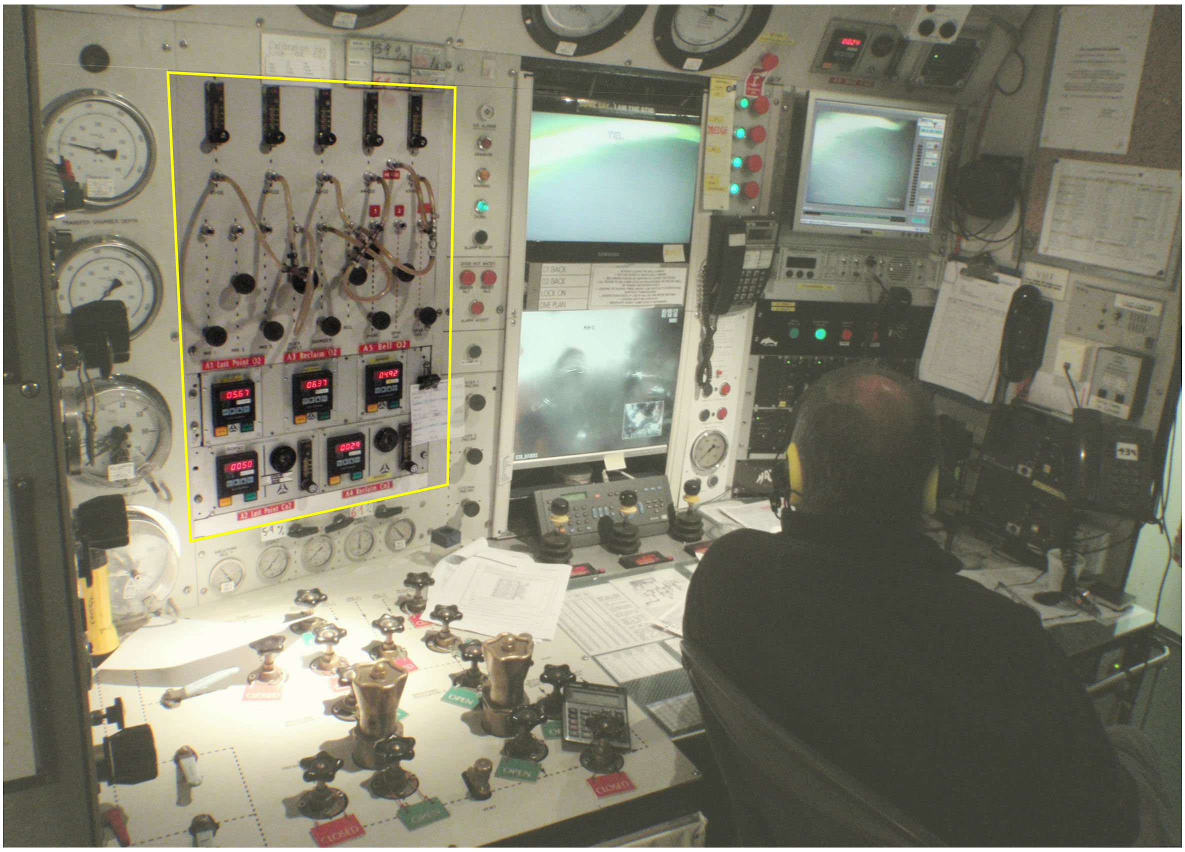
- Span & zero gas sampling points: Analysers must be frequently calibrated, and it is recommended to use a zero gas and a span gas to do it. For this reason, these gases must be available at all times. Note that:
    - A “zero gas” is a neutral gas, that does not contain any molecule of the gas the analyser to calibrate and is designed to detect, which is used to set the zero of this analyser. As an example, pure nitrogen or helium are often used to perform the zero calibration of an oxygen or carbon dioxide analyser.
    - A “span gas” is a gas in which there is a precisely known concentration of a detectable gas which is exposed towards an analyser designed to detect it in order to calibrate it.
- Divers supply sampling point allows to control the gas delivered to the divers in the bell.
- Bell Internal sampling point allows monitoring the atmosphere of the bell.
- Standby diver sampling point provides a control of the gas ready to be delivered to the stand by diver..
- Reclaim sampling allows monitoring the reclaimed gas before its delivery to the bell.
- Mix #1, #2, and #3 sampling points allow controlling the stored gasses that are ready to be introduced and which have been fabricated by the life support technician or specifically manufactured.
- Depending on the diving system, other sampling points may be available.



Analysers should provide the operator with a clear and accurate display of the gas concentrations within the bell and the gas supply lines being monitored. The values are displayed as follows.

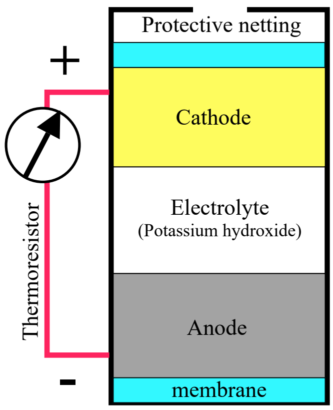
- Concentration of a gas: Percentage (%) and part per million(PPM) are commonly used.
- Pressures: Bar and millibar (mbar) are today the most employed units of measure (1 bar = 100000 Pa). However, PSI (pound per square inch) and Atmosphere (atm) are the preferred units in several areas. Note that NORSOK 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 majority of analysers in use with saturation systems are robust machines that act individually. They usually have only one type of display and are fitted with an audio alarm which is generally reinforced by warning lights *(see in the photo below)*. Note that the analysis of the bell atmosphere is today remote on the wide majority of saturation systems. However, depending on the number of sampling points and analyser available, it is not always possible to analyse the CO_2 and O_2 at the same time.



Oxygen analysis may be carried out using a fuel cell analyser or a magneto-dynamic cell (also called paramagnetic).

- Fuel cell analysers are the more widely used because they are robust, lightweight and suitable for remote readings.



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” O_2EII). 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.

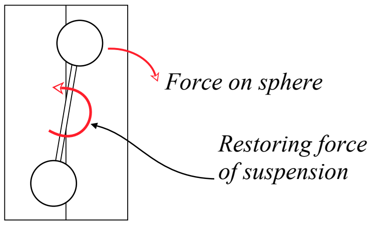
If the fuel cell is placed in a chamber, it can only be calibrated when the chamber is on the surface, or by reference to another analyser sampling the gas on the surface.

A fuel cell in the chamber can only be used as a guide to the PPO_2. 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.

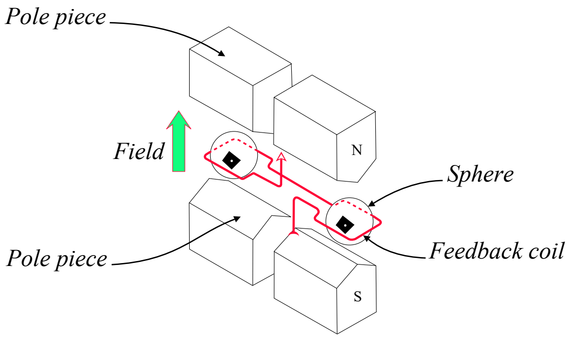
Since the fuel cell is a battery, it will run out, normally in about six months, but depending on the concentration of oxygen in the gas analysed, it will often be less. Erratic reading is an indicator that the cell needs to be changed.

- Magneto-dynamic (Paramagnetic):
  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).

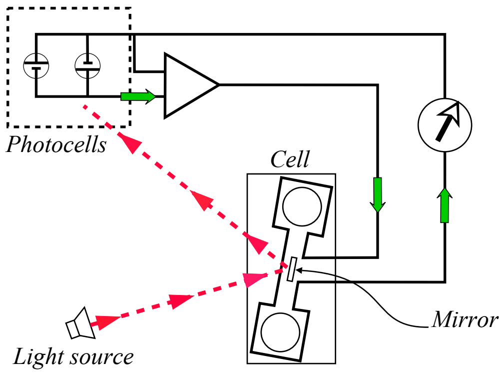
Magneto-dynamic oxygen analysers are based upon Faraday's method of determining the magnetic force developed by a strong non-uniform field on a diamagnetic test body suspended in the sample gas. The test body of all measuring cells oxygen analysers consists of two nitrogen filled quartz spheres arranged 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.



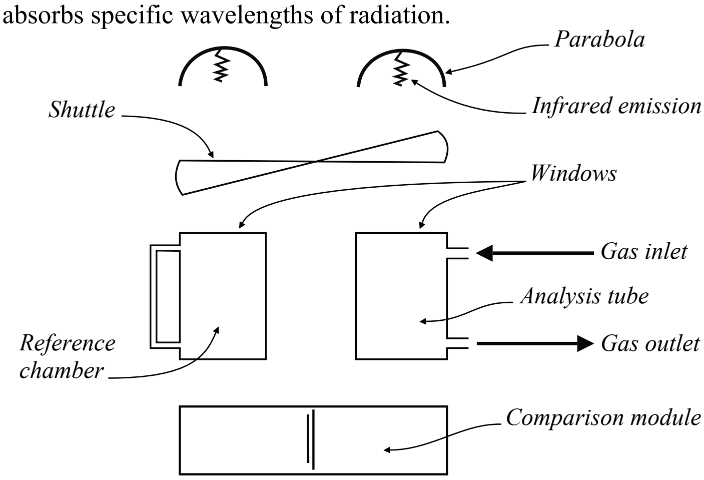
Carbon dioxide analysers rely on the fact that each gas absorbs specific wavelengths of radiation.

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.



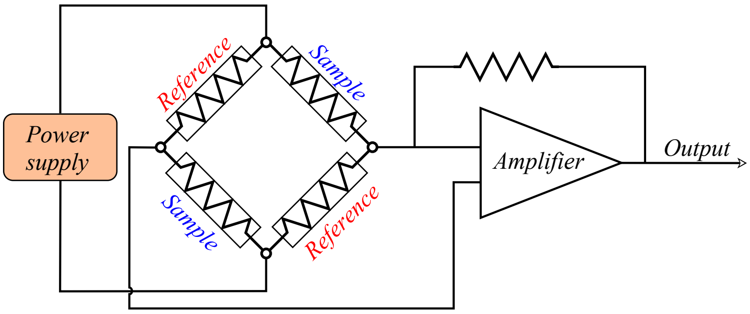
Some analysers require a set up procedure which should be repeated at regular intervals according to the manufacturer's instructions or if it becomes impossible to calibrate the instrument.

Because measurement depends on temperature, it is essential that the analyser warms up to a stable temperature before use. Readings are commonly given in parts per million.

Oxygen and Carbon dioxide can also be detected using thermal conductivity detectors (also called universal detectors):

The system 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.



The system can have an accuracy and display precision of around 0.1% when precise temperature compensation is made, and is reputed stable and robust.

Thermal conductivity is used to detect various gases such as:

- Oxygen
- Carbon dioxide
- Carbon monoxide
- Nitrogen
- Hydrogen
- Methane and various hydrocarbons
- Water vapour

The last generation analysers are designed in the same manner than the previous generation. However, electronic continues to progress and offer more functions. Also, manufacturers, such as Fathom systems, a company based in the United Kingdom, group the analysers in modules that are designed to analyse the O_2 and CO_2 at the same time and can display some measurement 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.

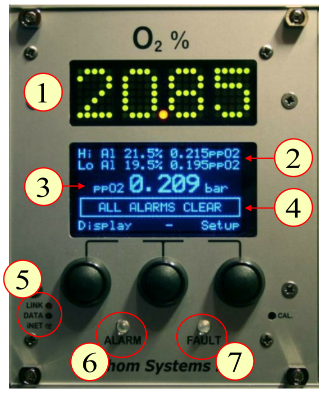
III - Accepted Alarm: An alarm that has occurred has been acknowledged or accepted by the operator (by pressing the appropriate front-panel button). In this case, and provided there are no other active alarms, the display changes to solid red, the alarm LED remains on red (not flashing) and the audible 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:

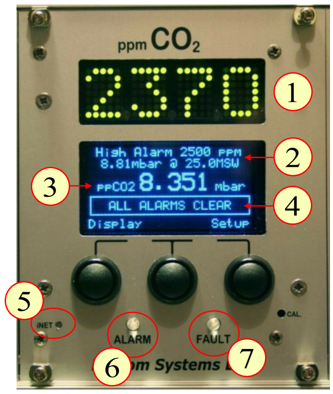
- Incorrect supply voltages
- Failure of sensor sub-systems or components
- Sensors not correctly calibrated
- Missing data communications with external devices / systems
- Internal temperature too high

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*

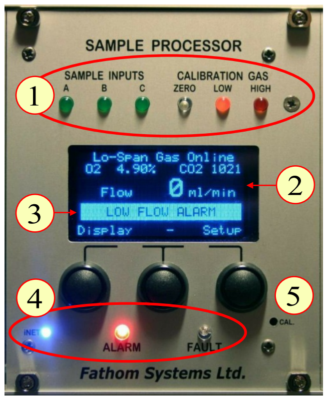


With the new systems described for example, the sample and calibration gases being sent to the CO2 slave and O2 master analysers are managed by the "sample processor", which is a slave module.
With this module, the classical flowmeter that is usually operated manually is replaced by a sensor that measures 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).

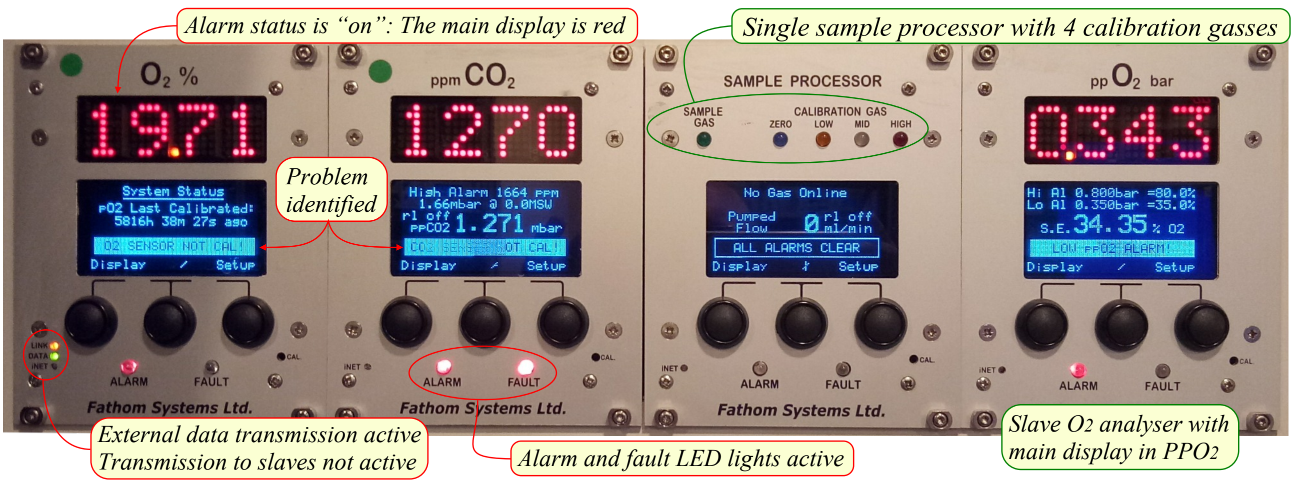
B - The 3-inputs version allows one of three different samples to be selected by the user, and 'switched' internally by the Sample Processor unit. As a result, six quick-connect couplings are available on the rear of the device: One for the zero gas, one for the low span calibration gas, one for the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

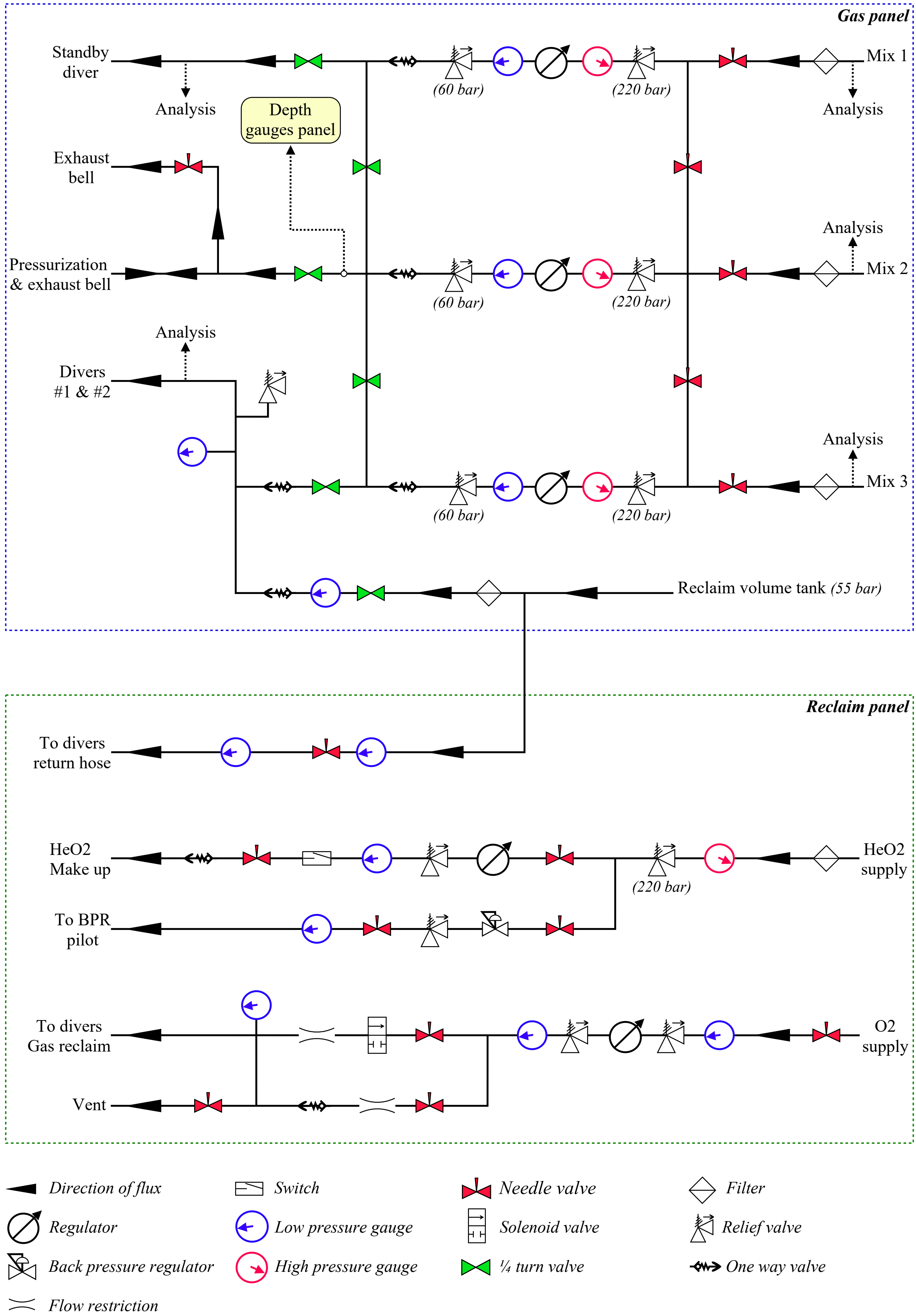


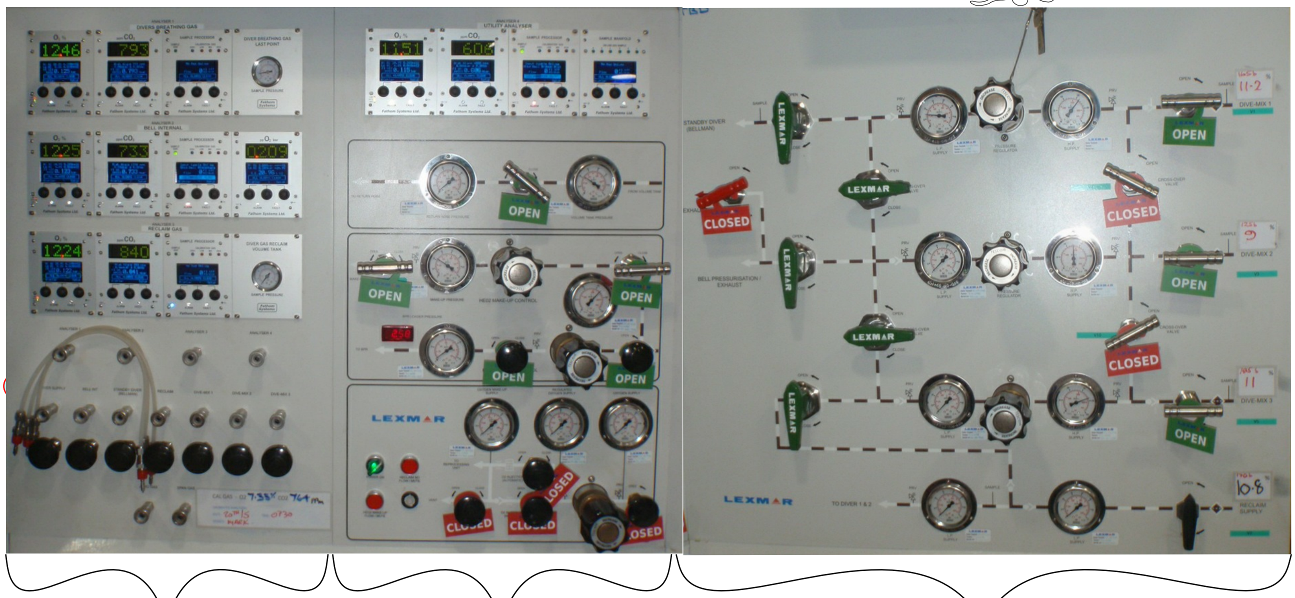
3-inputs sample processor

The photo below shows one of the modules from an analysing panel of a dive system that was not yet fully operational. As a result, the analysers were not calibrated and were raising alarms: We can note the following:



- Oxygen make-up, heliox make-up, and back pressure regulator loader are part of the "reclaim panel", which is supplied by the "gas panel". As indicated previously, they are situated near the analysis panel in the dive control.
  The scheme below shows the connections between the two panels and the elements of the system they supply. Note that the divers and the bell can be supplied with stored mixes *(Mix 1, Mix 2, Mix 3, HeO2 supply)* or with the gas from the reclaim volume tank. As a result, the divers are not deprived of gas in the case of a problem with the reclaim system.





Analysis panel *Reclaim panel* *Gas panel*

Panel monitoring the divers' return hose pressure (inlet TRU) and the "volume tank" pressure (outlet TRU), with a cross-over valve allowing to run the system in a closed-loop.

Heliox make-up control & back pressure regulator loading control panel

Oxygen make-up panel

- The "oxygen panel" controls the flow of make-up oxygen into the system.

As already said, the system is based on high pressure stored oxygen which is injected into the circuit through an adjustable regulator and across a fixed multi orifices injector that restricts its flow to a calculated rate. As a result, a controlled bleed of oxygen is supplied into the system. The flux of oxygen depends on the inlet pressure to the multi orifices injector and the heliox pressure in the circuit where the oxygen is bleed. Thus, too high or low inlet oxygen pressure may result in too much or not enough oxygen in the system. It is the reason that "reclaim tables", where the pressure of the inlet oxygen is indicated according to the depth planned for the operation, are provided. Note that these tables are called "diving tables" by the manufacturer. Gauges are provided to manage the inlet and outlet pressures.

Lexmar says that if the setting of the regulator is correct, the oxygen flow does not require further adjustments during the dive. Also, the quantity of gas stored in the system is sufficiently large that a change of oxygen uptake rate of the diver will result in a negligible effect during the dive. However, in the case of a change in the proportion of oxygen is noticed, the regulator may have to be slightly increased or decreased to return to the planned value.

As this system is based on a constant bleed, there must be a device to stop oxygen delivery when the gas flow through the system has stopped unexpectedly. It is achieved by the flow switch, already described in point 2.3.12.3, that closes the oxygen flux automatically in the case that the gas flow in machinery is stopped.

Hyperlink Tables of contents

The oxygen make-up panel is designed as follows:

A - The isolation valve allows opening or closing the oxygen supply *(see "Bb5")*.

B - The oxygen supply gauge indicates the pressure available to the system *(see "Gb1")*.

C - The regulator controls the oxygen pressure to the orifice *(see "Reg 3b")*.

D - The solenoid stops oxygen addition when gas flow through the system has stopped *(see "b1")*.

E - The regulator outlet gauge, also called "regulated oxygen supply", indicates the oxygen pressure available to the solenoid valve *(see "Gb2)*.

F - The oxygen orifice regulates the flow of Oxygen to the topside unit *(see "b2")*.

G - The oxygen make-up supply pressure gauge shows the pressure out of the solenoid valve *(see "Gb3")*.

H - The supply receiver pressure gauge indicates the pressure in the supply volume tank in the machinery van *(see "Gb7")*.

I - The exhaust hose (or return hose) pressure indicates the bell divers exhaust hose pressure at the inlet of the Topside Reprocessing Unit (TRU) *(see "Gb8")*.

J - Automatic injection valve: It is kept open during normal diving operations *(see "Vb6")*

K - Manual O2 injection valve *(see "Vb8"): It* can be used to increase the amount of O_2 in the system rapidly, but never be used when divers are in the water. The vent valve must be closed while this valve is open.

L - The manual O2 injection orifice is mounted after the O2 injection needle valve to control the amount of oxygen being manually injected into the system *(see "b3")*.

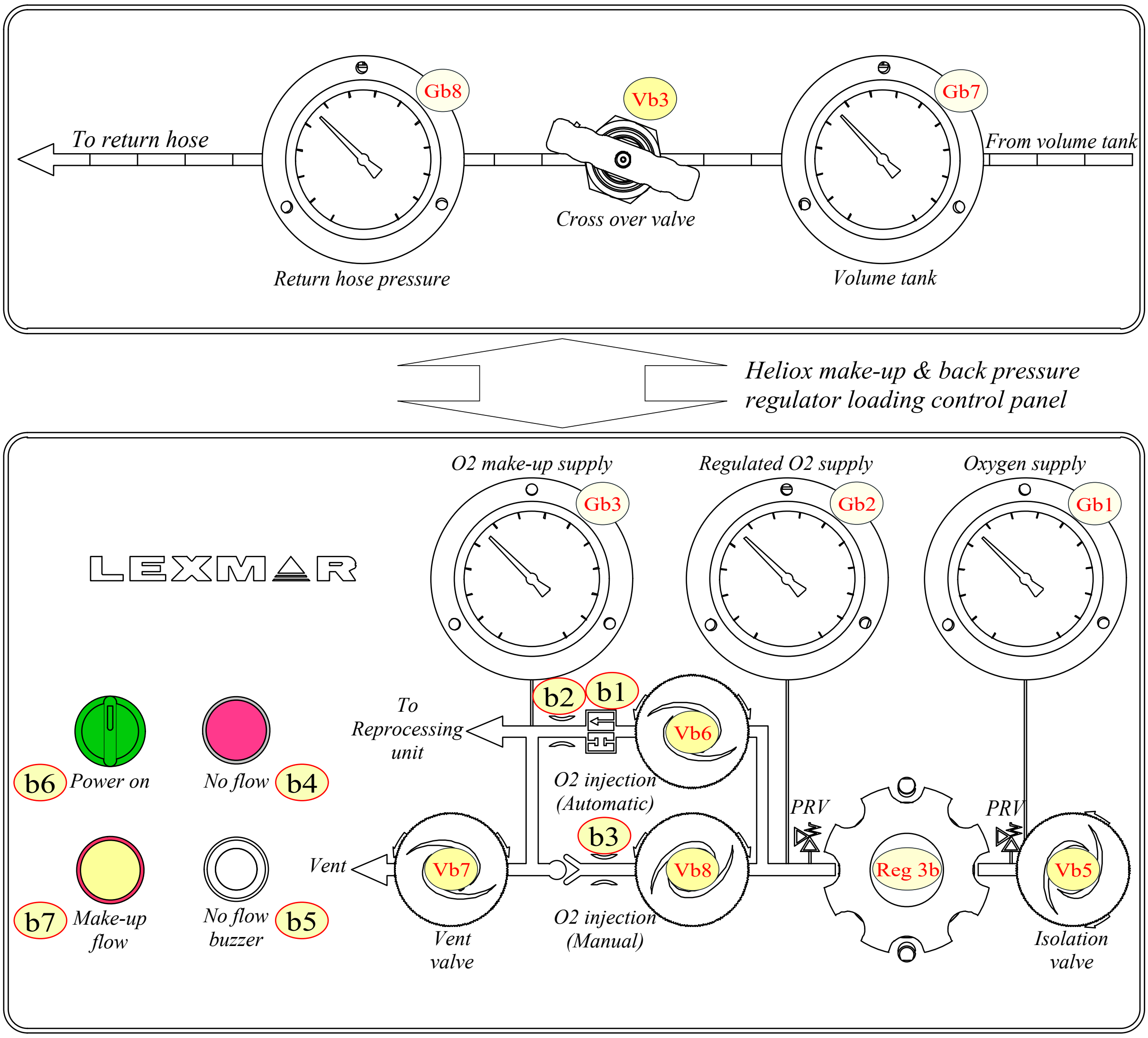
M - Manual vent valve: This valve must remain open to vent any leakage of oxygen that may pass through the manual O_2 injection valve while it is closed. Also, it must be closed for manual injections and then reopened when the injection is completed *(see "Vb7")*.

N - The "No flow" LED light indicates that there is no gas flow as a result of the flow switch of the Topside Reprocessing Unit in the "normally closed position" *(see "b4")*.

O - No flow audible buzzer *(see "b5")* will sound to indicate that there is no gas flow as a result of the flow switch of the Topside Reprocessing Unit in the 'normally closed position'. This buzzer can be muted.

P - Power ON / OFF switch allows turning on or turning off the power of the Reclaim Management Panel *(see "b6")*. A green light is illuminated whenever power is on to the Reclaim Management Panel.

Q - Make up flow light is illuminated when make-up gas is flowing into the volume tank.*(see "b7")*.

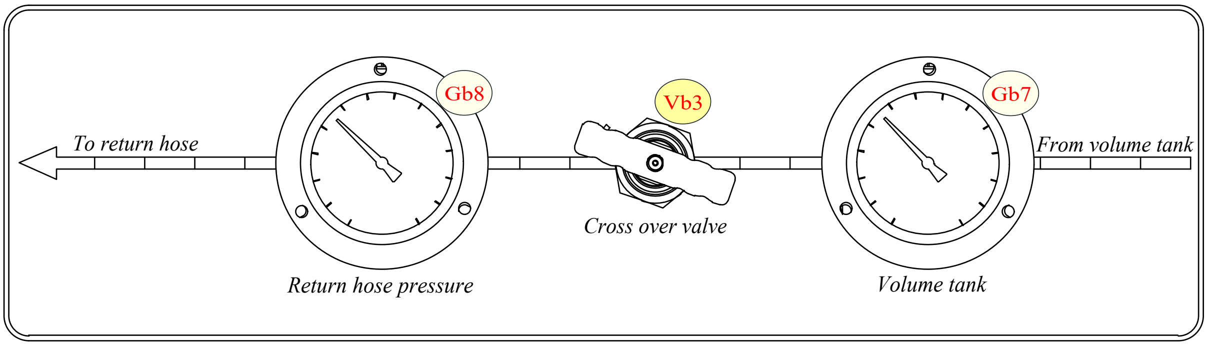


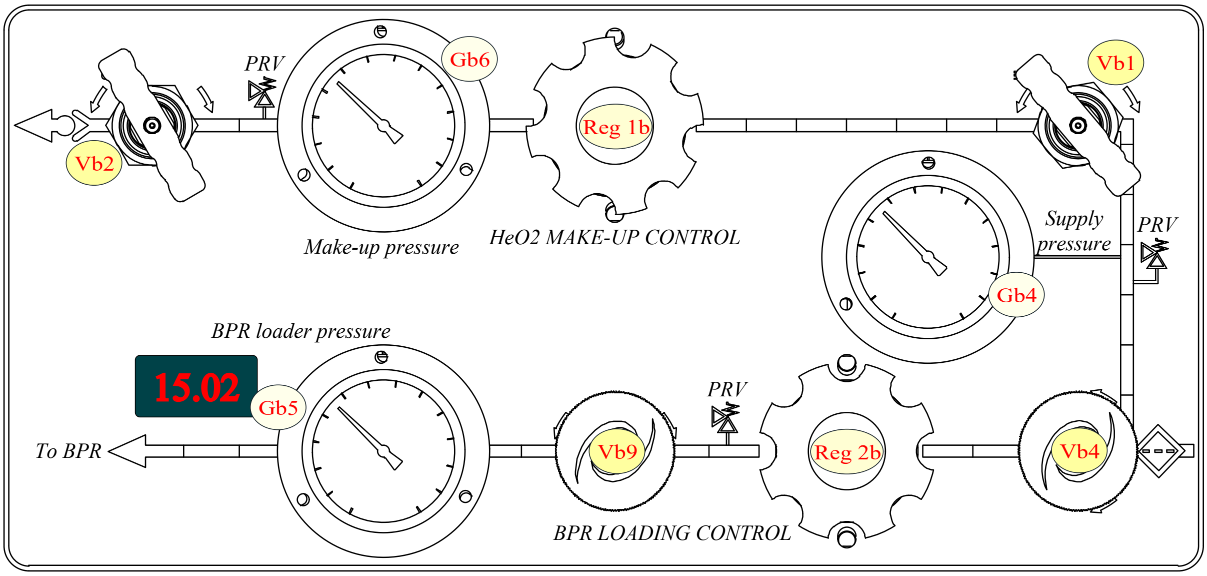
Remember that LEXMAR says the following:

- In operation, the Oxygen shut-off valve *(see "Vb5" in the drawing on the previous page)* is opened and the oxygen regulator *(See "Reg 3b")* set to the value recommended in the divers reclaim table.
- Manual Oxygen make-up should never be carried out while diving is in progress.
- When reclaiming oxygen manually, the supply exhaust cross-over valve *(see "Vb3" in the drawings on the previous page and below)* should be open, and the compressor should be running to provide circulation and mixing through the system.

- The HeO2 make-up gas panel provides both gas to increase the working depth of the system and make-up for any losses either at the surface or at the diver.
  1 - The HeO2 regulator is a high flow, self-venting regulator which controls the make-up gas pressure available to the volume tank *(see "Reg 1b" in the drawing below)*.
  2 - The "HeO2 supply gauge" indicates the HeO2 pressure available to the make-up system *(see "Gb4")*.
  3 - The "HeO2 supply valve provides manual shut-off control of HeO2 to the regulator *(see "Vb1")*.
  4 - The "HeO2 make-up pressure gauge" indicates the pressure available to the volume tank. The reading on this gauge is the minimum volume tank pressure desired *(see "Gb6")*.
  5 - The "HeO2 outlet valve" "Vb2" provides manual isolation of the HeO2 supply system to the volume tank.

- The "Back Pressure Regulator (BPR) loader panel" enables the BPR in the topside reprocessing unit to be remotely loaded. This panel houses the following components:
  1 - The BPR loader supply valve enables manual opening and closing of HeO2 to the BPR regulator *(see "Vb4" in the drawing below)*.
  2 - The BPR loader regulator allows controlling the BPR load pressure *(see "Reg 2b")*.
  3 - The BPR loader isolation valve provides manual isolation of the BPR loader shut-off valve *(see "Vb9")*.
  4 - BPR loader pressure gauges (analog and digital) indicates what pressure is being felt on the BPR loader. That will vary according to the regulator setting *(see "Gb5")*.
  5 - The cross over valve *(see "Vb3")*, which is already mentioned for manual oxygen reclaiming, allows the flowing of gas directly from the supply to the exhaust side of the system and being stirred up and mixed. It is opened or 'cracked' during initial pressurization of the system or when the compressors are required to be run without the helmets or bell being affected. This valve is also identified in the previous drawing.





2.3.12.5 - System start-up and operational procedures

Reclaim systems are sophisticated equipment. For this reason, the study of the starting procedures published by the manufacturer is the best method to understand how they work.

- Precautions prior to starting the set up procedures:

1. The operator must ensure that the appropriate gases are online. This operation is performed through the gas panel: Three mixes from the gas storage should be online. They are suitable diving mixes for the depth planned and should be analysed using the analysis panel. One mix is selected to supply the gas reclaim system, and the two other mixes can be used as backup, for bell pressurization, and to supply the standby diver umbilical.
2. The selected make-up gas is supplied to the "reclaim panel". Note that in the event that the topside unit operation is interrupted, it will automatically become diver gas supply.
3. Pure Oxygen is required for oxygen make-up.
4. Pure helium should not be connected to the system under any circumstances.
5. The operator ensures that all the valves of the control panels are closed and that the hand-knobs of the regulators have been returned to zero (fully turn the hand-knob anticlockwise and then turn it back ¼ turn)
6. The operator prepares the compressor:
   - He ensures that suitable electrical power is available for the compressor drive motors. It should be 440 Vac/ 60 Hz/ 40 KW for the model taken as an example.
   - He also checks the level of oil and that the cooling system of the compressor is ready for use.
   - The depth of the dive should be indicated to the technician so he can prepare the compressor and switch off the 1st stage of the compressor if the dive is planned at 160 m or below.
   - When the electrical power is supplied, the compressor can be started when the "Start" push button on the electrical panel is pressed.
   - As already said the compressor taken as an example is provided with a computer management system that optimises its performances and protects it from incorrect procedures. This computer is operated through a Human Machine Interface (HMI) that is on the electrical enclosure *(see below).*
     The HMI serves as a graphic interface between the operator and the controlling system
     The various measured values can be read on the screen, and parameters can be entered from there.
     Also displayed are the error messages as and when they occur, as well as warning messages.

7. The scrubbers must be prepared: The Sodalime canisters must be changed and the time required to replace them should be indicated on the control console panel. Note that each scrubber contains 9 litres of soda lime.
   One or two scrubbers are online depending on the duration of the bell run and the number of divers in the water. If only one scrubber is used, the isolation valves of the second one are closed, so it can be online when necessary. The procedure for the change of Sodalime (or Sodasorb) is as follows:
   - Slowly open the new canister inlet, on the bottom of the tower body.
   - Ensure that the flexible hose is connected through the quick connect then slowly open the new canister outlet, on the top of the tower cap.
   - Slowly close the inlet to the used canister; it is on the bottom of the tower body.
   - Slowly close the outlet from the used canister; it is on the top of the tower cap.
   - Slowly open the drain valve at the base of the used canister.
   - Disconnect the quick connect from the top of the used tower when the remaining pressure has been vented.
   - Unscrew the top cap by hand.
   - Remove the internal Sodasorb canister using the handle.
   - Remove the top gauze and empty the contents.

- Fill the canister to two thirds full with Sodasorb (or soda lime).
- Add 100 ml of Purafil (half a cupful).
- Fill to top with Sodasorb (Sodalime).
- Replace top filter gauze.
- Lower the inner canister slowly into the tower body. Ensure that it is seated on the lower seal.
- Inspect the top cap O-ring, clean or replace as required, replace top cap. It is O-ring sealed and seals when hard hand tight.
- Close drain valve at base and reconnect the quick connect hose to the top of the top cap.
- Slowly open inlet valve on the bottom, to pressurize the Scrubber Tower then close the Inlet valve.
- Check for leaks. If no leaks, the refilled canister is ready for use.

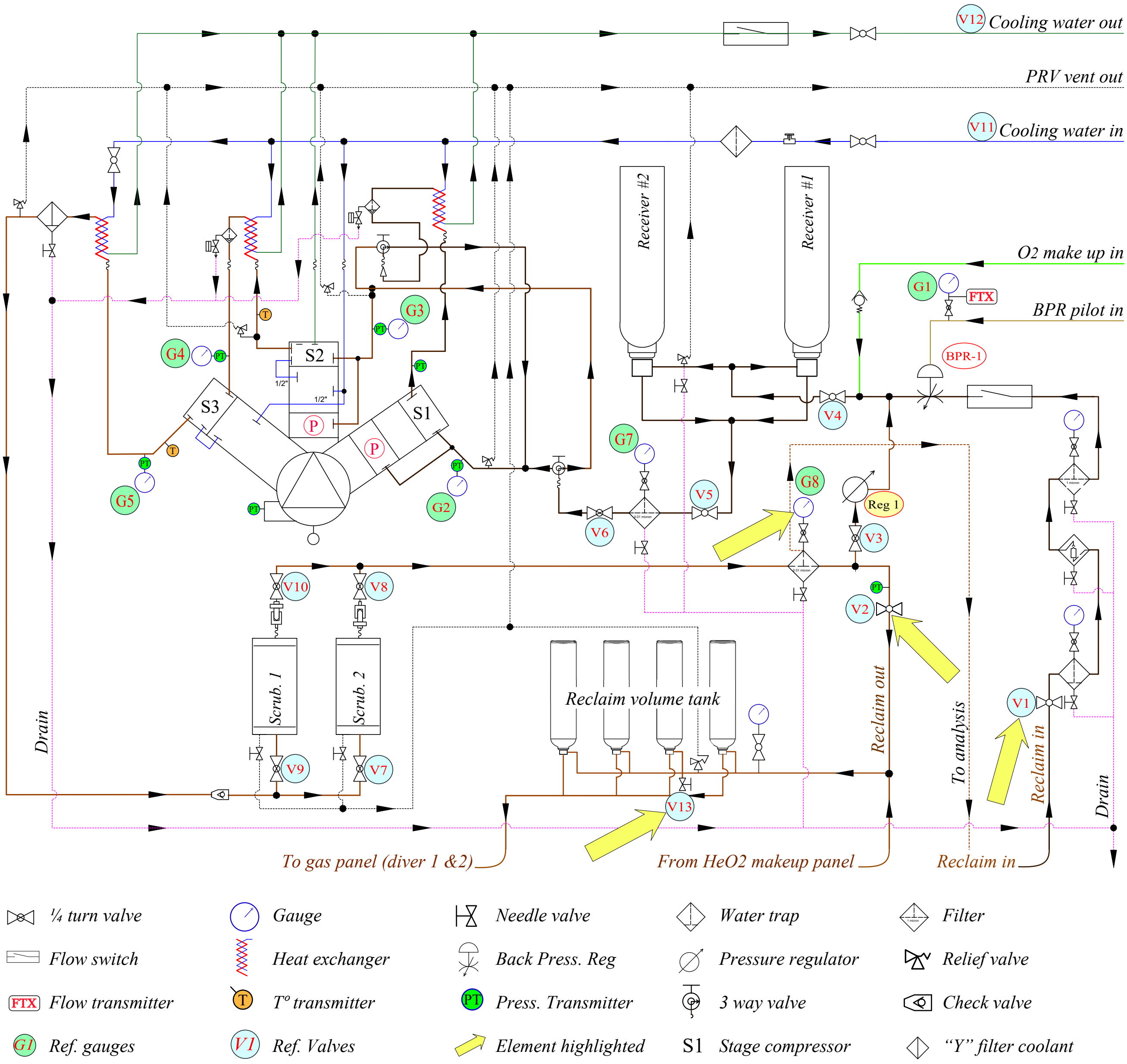
- Top side system setup

1 - Start the compressor:

If the pressure of the reclaim volume tank is below 45 bar, the outlet valve V2 *(See in the drawing below)* on the TRU must be closed prior to starting the compressor. When the compressor is started, the operator waits for the machine to reache its normal speed, then the outlet valve V2 on the TRU is opened again.

<u>If the volume tank is at a pressure above 45 Bar, the compressor cannot be started</u> due to the high resistance of this pressure. If this is the case a message will come up on the HMI saying “Press. too hi for start” and the amber “warning” pilot light will be on.

- To start the compressor the outlet valve V2 *(See in the drawing below)* on the TRU must be closed, then the the volume tank must be vented using the dedicated valve *(V13)* until the pressure on gauge G8, which is the gauge of the 3rd filter, *(See in the drawing below)* reads below 45 Bar.
- Once the pressure is below 45 bar, the operator can start the compressor and waits for the machine to reach its normal speed, then the outlet valve V2 on the TRU can be opened again.
- When the compressor is started, the volume tank can be pressurized to the required value



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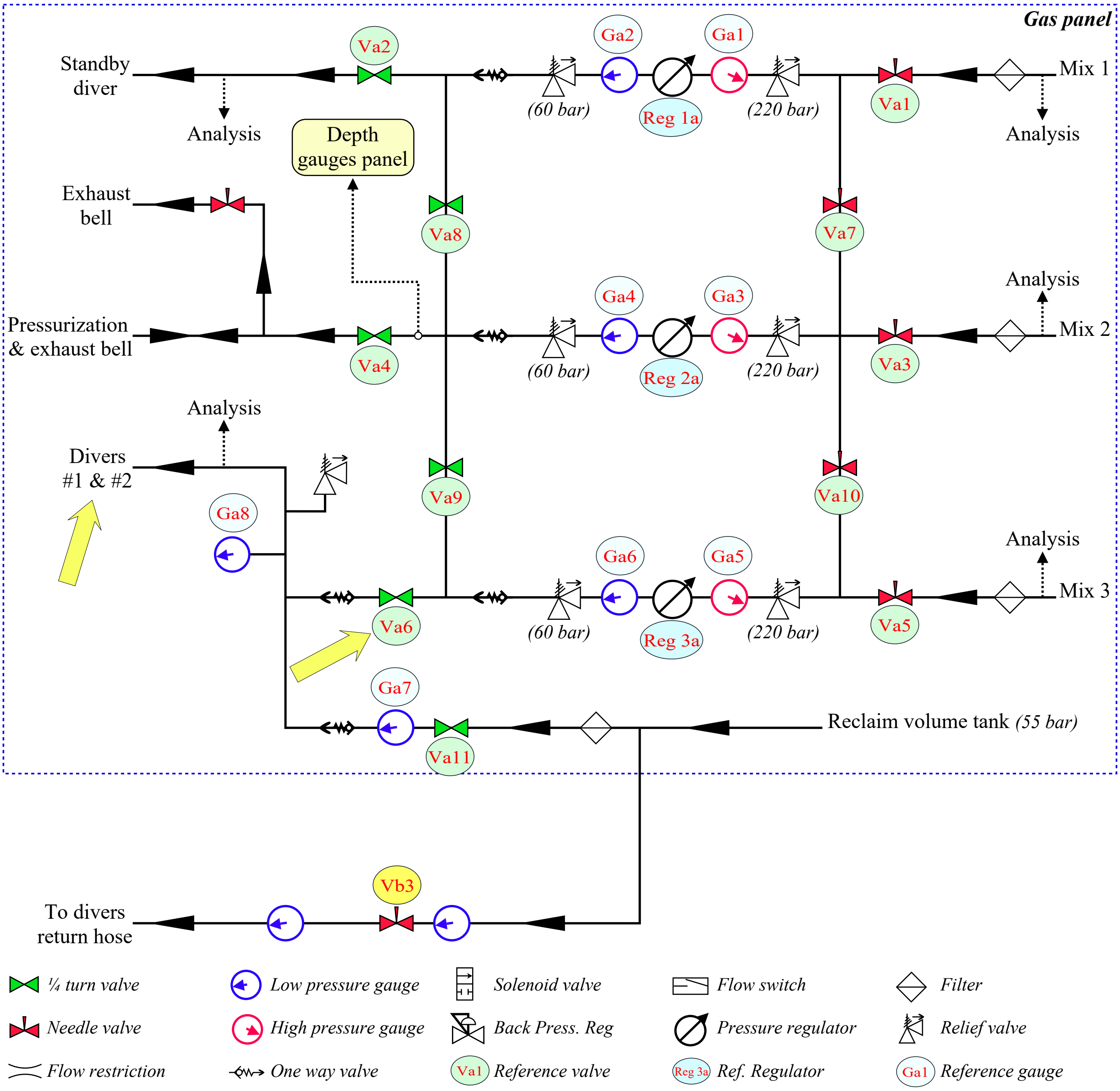
2 - Charge the “reclaim volume tank”:

- On the “gas panel” in the dive control:
    - The operator selects the mix to be used as the source in the reclaim system among mixes 1 *(valve Va1)*, mix 2 *(valve Va2)*, or mix 3 *(valve Va5)*.
    - Then he opens the corresponding valves of mix 1 *(valve Va1)*, mix 2 *(valve Va2)*, or mix 3 *(valve Va5)*, and sets the regulators “Reg 1a”, “Reg 2a”, “Reg 3a” to the correct pressures *(see in the drawing below)*.
    - When the regulators are adjusted to the desired pressures, he uses the cross-over valves Va7-Va10 or Va8-Va9 to supply the "makeup supply valve" Va6 with the mix selected and also have the “standby diver” and “bell pressurization” lines ready for use.
    - When the regulators are set up and the selected mix is supplied to the makeup supply valve “Va6”, and he opens this valve. As a result the selected gas flows to “divers 1 & 2” line.



- On the “reclaim panel” in the dive control:
    - The operator sets the make-up regulator *(see “Reg 1b” in the drawing on the next page)* to the desired “reclaim volume tank” pressure.
    - Then he opens valves “Vb1” and “Vb2”. These valves should be kept open throughout the diving mission. Note that the pressure can be read on the pressure gauge G8 on the TRU *(see in the corresponding drawing)*.
- On the Topside Reprocessing Unit (TRU)
    - The technician ensures that the “Reclaim gas out valve” V2 and “HEO2 makeup inlet valve” V1 are open.
    - He enters the “reclaim volume tank” pressure as an alarm setpoint through the human Machine Interface (HMI). As a result, a warning light is visible if the actual pressure is 3 bar above the set point.

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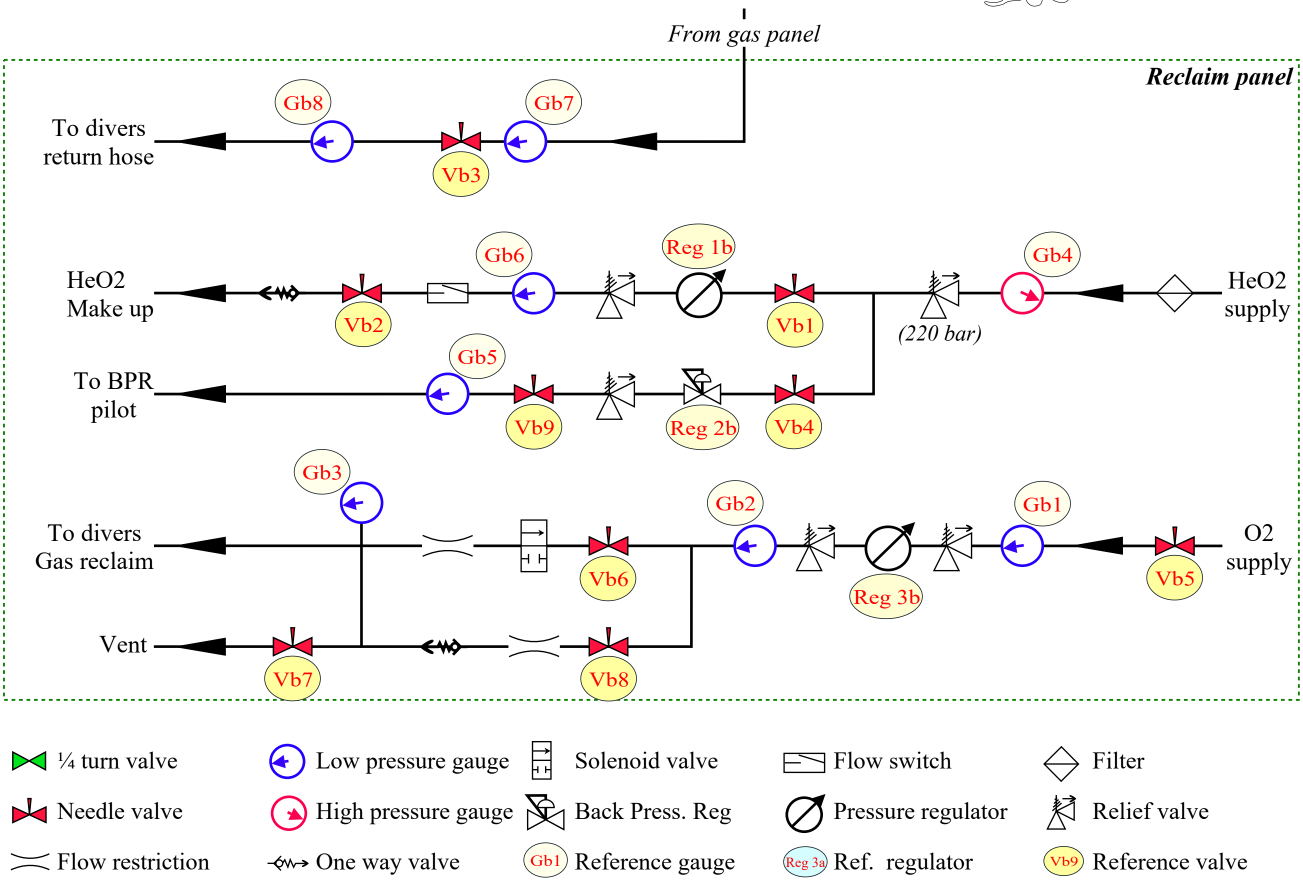


3 - Charge the return line and set up the BPR pilot pressure:

- On the “reclaim panel” in the dive control:
  - The operator opens the supply valve Vb4 and exhaust valve Vb9 *(see in the drawing above)*.
  - Then, he slowly opens the cross-over valve Vb3 until the entire umbilical reaches the bottom depth pressure. Note that the pressure can be read on the pressure gauge G6 on the TRU. When the pressure is reached the valve Vb3 is closed.
  - When the valve Vb3 is closed, the operator sets the BPR *(see “Reg 2b”)* to the requested pressure indicated in the “reclaim table”.

4 - Set the bypass BPR pressure:

- On the Topside Reprocessing Unit (TRU) and using valve Vb3 on gas the reclaim panel:
  - To prevent the compressor from speeding up during the set-up stage, the operator sets the bypass pressure to 15.5 Bar on the Human Machine Interface (HMI) on the TRU.
  - Then, he starts the compressor and keeps the compressor suction pressure to at least a pressure equal to the bypass pressure set point according to the “reclaim table” with the cross-over valve Vb3 on the gas reclaim panel.
  - When the pressure on the G8 gauge on the TRU is at the required volume tank pressure, the operator stops the compressor
  - The inlet valve V1 on the TRU is closed
  - The operator sets the bypass pressure as a set point on the HMI on the TRU according to the “reclaim table”.
  - The operator opens the Back Pressure Regulator “Reg 1” one turn
  - The compressor is started and with “Reg 1” the operator regulates the compressor suction until this pressure has stabilised at the bypass pressure set point according to the “reclaim table”.
  - The operator sets the required bypass pressure according to the dive table as a set point on the HMI.

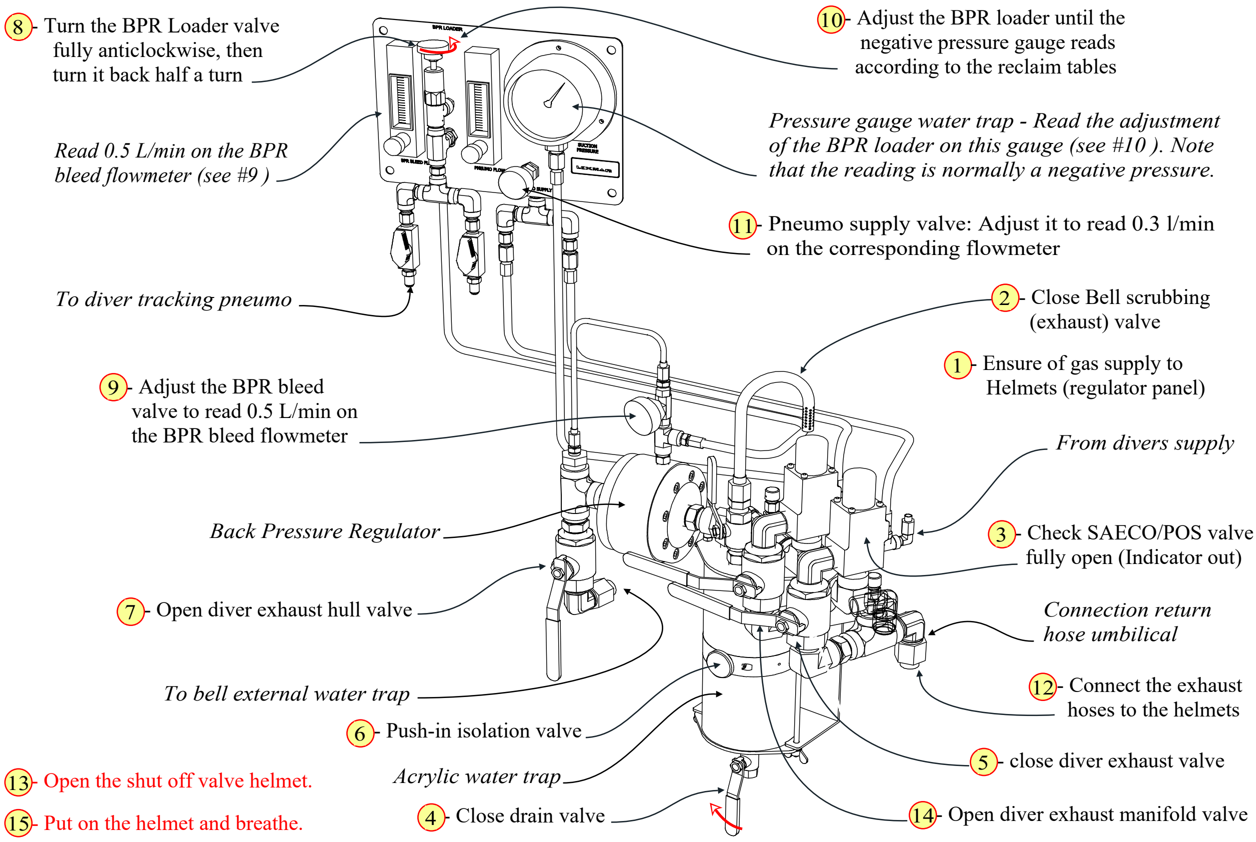
5 - Set the O2 to the required level:

- On the Topside Reprocessing Unit (TRU):
  - The reclaim gas inlet valve V1 is opened.
- On the “reclaim panel” in the dive control:
  - The operator slowly opens the cross-over valve “Vb3” and leaves this valve in this position.
- On the Topside Reprocessing Unit (TRU):
  - When the compressor suction pressure has reached a value higher than the bypass pressure set point, the operator starts the compressor. As a result, the gas is circulating through the volume tank
- On the “reclaim panel” in the dive control:
  - The Oxygen regulator *(see “Reg 3b)* is adjusted to the desired pressure for the planned dive.
  - The valve Vb3 is then closed

6 - Setting up in the bell

Note: The numbers below are those of the drawing

1. Ensure that Diver has gas supply to helmet (regulator adjusted to the value indicated in the “reclaim table”).
2. Close the bell scrubber valve.
3. Check that the SAECO/POS valve is fully open (The indicator is out).
4. Close water trap drain valve.
5. Close the diver exhaust manifold valve.
6. Push in the water trap isolation valve.
7. Open the diver exhaust hull valve slowly.
8. Turn the BPR Loader needle valve anticlockwise until it stops rotating, then turn back half a turn.
9. Adjust the BPR bleed (metering) valve to read 0.5 L/min on the BPR flowmeter (once set do not re-adjust).
10. Adjust the BPR loader until the negative pressure gauge reads according to the “reclaim tables” *(If using a different brand of helmet than Divex, the manufacturer’s recommendations)*. The Diving Supervisor must advise the divers of the desired negative pressure.
11. Adjust the pneumo supply valve to read 0.3 l/min on the corresponding flowmeter (0.4 l/min maximum)
12. Connect the exhaust hose to the helmet.
13. Open the “shut off valve” of the helmet.
14. Open the diver exhaust manifold valve.
15. Put on helmet and breathe on recovery.

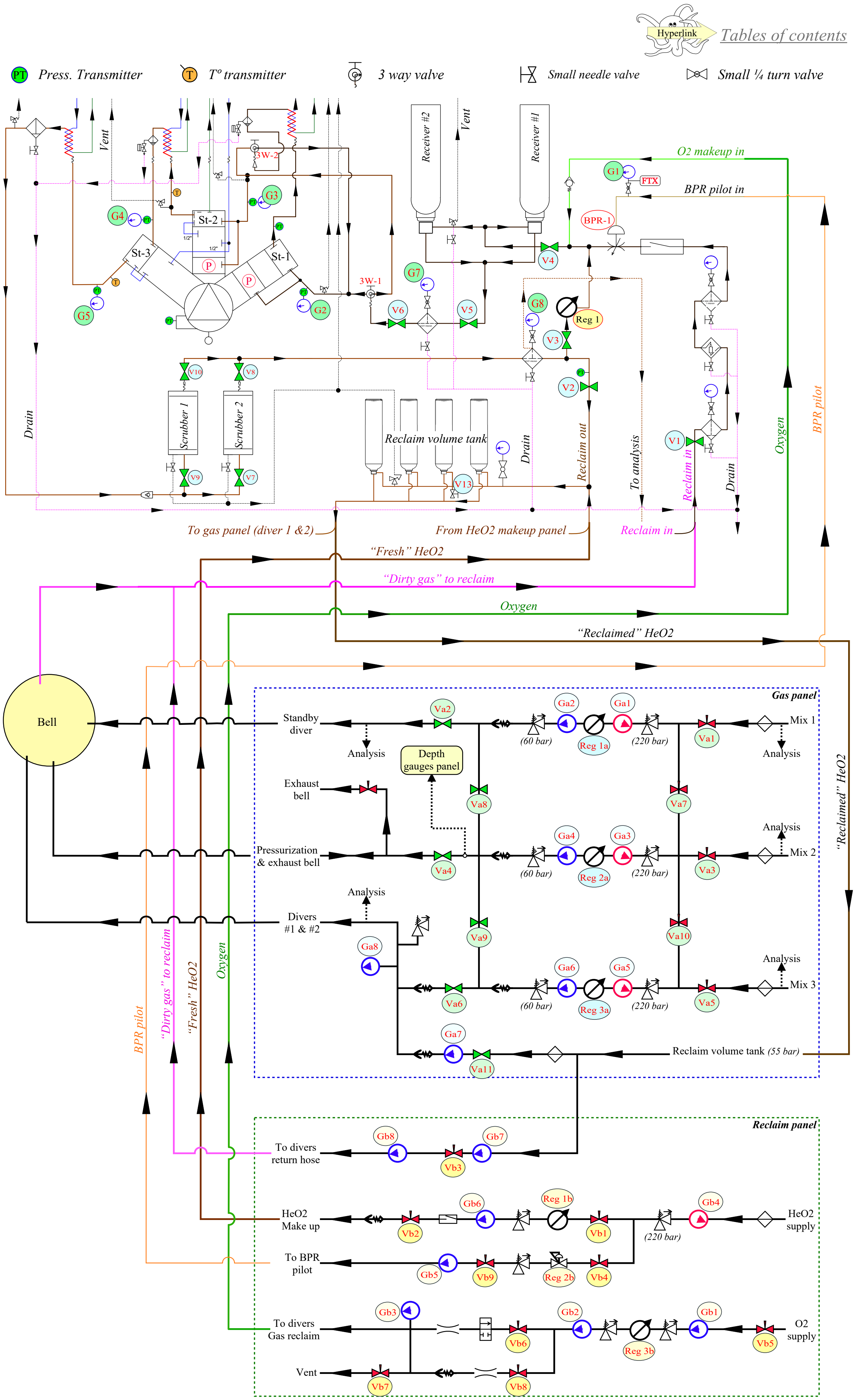


- Important note from the manufacturer of the equipment taken as example regarding shallow diving procedures:
  Diving at depths less than 40 MSW (130 SFW), makes further demands on the system. At shallow depths, the compressors are exposed to the highest-pressure ratio and, as such, shallow diving makes the greatest demands on the compressors.
  For this reason, the regulator settings advised should be rigidly adhered to. Low range gauges are also required for the BPR loader and umbilical suction. It might even be advisable to go for a shorter main umbilical, bypassing the umbilical winch, in order to reduce pressure losses.

2.3.12.6 - General view of the reclaim system

The drawing on the next page gives a general view of the reclaim system and highlights the connections between the panels in the dive control and the Topside Reprocessing Unit (TRU). The legends are those previously used.

¼ turn valve	*Low pressure gauge*	*Water trap*	*Flow switch*	*Filter*
Needle valve	*High pressure gauge*	*Back Press. Reg*	*Regulator*	*Relief valve*
Flow restriction	*One way valve*	*Back Press. Reg*	*Heat exchanger*	FTX Flow transmitter


Hyperlink
Tables of contents
Press. Transmitter
T° transmitter
3 way valve
Small needle valve
Small ¼ turn valve
Receiver #2
Receiver #1
Vent
O2 makeup in
BPR pilot in
BPR-1
FTX
St-1
St-2
St-3
3W-1
3W-2
Scrubber 1
Scrubber 2
Reclaim volume tank
Drain
Reclaim out
To analysis
Reclaim in
Oxygen
BPR pilot
To gas panel (diver 1 &2)
From HeO2 makeup panel
"Fresh" HeO2
"Dirty gas" to reclaim
"Reclaimed" HeO2
Bell
Gas panel
Standby diver
Exhaust bell
Pressurization & exhaust bell
Divers #1 & #2
Analysis
Depth gauges panel
Mix 1
Mix 2
Mix 3
(60 bar)
(220 bar)
Reclaim volume tank (55 bar)
Reclaim panel
To divers return hose
HeO2 Make up
To BPR pilot
To divers Gas reclaim
Vent
HeO2 supply
O2 supply

2.3.12.7 - Reclaim tables

Lexmar has designed "Reclaim tables" for the correct setting of the equipment *(Note that the manufacturer calls them "diving tables")*. These tables that cover dives from 30 m to 300 m are displayed on the next page.
The elements which are taken into consideration in these "reclaim tables" are those listed in the table below.
They are also described in the method recommended by the manufacturer to set up the system that is explained in the previous pages, and it is crucial not to confuse them with others. For this reason, a description of their function and their situation in the system are provided with the reference numbers used in the drawings displayed on the previous pages.

Elements indicated in the tables	*Description*
Depth	It is the depth of the bell at the lowest level (bottom door). It is the reference from which the other values should be selected when using the tables.
HeO2 make-up regulator "volume Tank" (Bar)	It is the regulator "Reg 1b" which is on the "reclaim panel". The pressure to read is displayed on the gauge "Gb6", which is directly downstream. This regulator feeds the "Reclaim volume tank" of the TRU with "fresh" heliox. Thus when the valve "Vb2" is open, the pressure read on the gauge "Gb6" should be the pressure of the "reclaim out" of the TRU and of the "volume tank", except if their pressure is above the pressure delivered by the regulator *(the regulator "Reg 1b" is isolated by a non-return valve).*
TRU BPR Setting (bar)	The setting of the Back Pressure Regulator "BPR-1" which is on the TRU is made through the regulator "Reg 2b" which is on the "reclaim panel". The setting pressure can be read on the gauge "Gb5" which is directly downstream the regulator "Reg 2b". It can also be read on the gauge "G1" which is upstream "BPR-1" on the TRU.
Compressor Suction Pressure (Bar)	It can be monitored through the "Human Machine Interface" (HMI) and gauge "G2" if 1st stage "St-1" of the compressor is activated, or gauge "G3" if the 1st stage is deactivated.
Stage 1 active	This column indicates whether the 1st stage must be activated or not. Activation /deactivation of the first stage "St-1" is performed through the three-way valves "3W-1" & "3W-2". It can be monitored through the HMI and the inlet gauges G2 (1st stage inlet pressure) or G3 (2nd stage inlet pressure).
Bypass BPR Pressure (bar)	The bypass BPR is the regulator "Reg 1" which is situated on the TRU and allows to bypass into the receivers the excess of gas flowing from the scrubbers to the volume tank, which is the final storage before delivery. It is said in the setup procedure that the pressure of setup can be monitored on gauge "G8" on the TRU. Also, as valve "Vb3" , which is on the "reclaim panel" has to be opened to establish a close circuit during the setup, the pressure of setting can be monitored on gauges "Gb7" & "Gb8" during this time.
Bell Divers Supply Regulator bias (bar)	It is the divers (1& 2) regulator that is situated on the "gas management panel" in the bell. It is also described in point 2.3.2.7 (items 8 & 27) of this document.
Bell BPR Setting bias (msw)	The bell Back Pressure Regulator (BPR) is adjusted through the BPR loader (see #8 in the bell setup procedure) which is situated in the bell. The pressure is read on the pressure gauge which is connected to the water trap and is mounted on the same panel as the BPR loader (see #8 in the setup procedure). Note that this gauge provides positive (overpressure) and negative (depression) values and that the reclaim tables provide negative values as the line should be in a slight depression.
Oxygen regulator setting	It is the regulator "Reg 3b" of the oxygen supply line which is on the "reclaim panel". The reading should be performed on the gauge "Gb2", which is immediately adjacent downstream.

To read the tables, select the planned bell storage depth and read across the corresponding values.

Lexmar also indicates the following elements:

- Weight seawater: 1.025 kg/litre
- Bypass BPR pressure: 0.30 bar below compressor suction pressure
- Required flowrate: 135 lpm at bottom pressure

Depth (MSW)	*Make-up Regulator "volume Tank" (Bar)*	*TRU BPR Setting (Bar)*	*Compressor Suction Pressure (bar)*	*Stage 1 Active*	*Bypass BPR Pressure (bar)*	*Bell Divers Supply Regulator bias (bar)*	*Bell BPR Setting bias (msw)*	*Oxygen Reg'r Setting 1 Diver*	*Oxygen Reg'r Setting 2 Divers*
30	18.6	1	0.9	Yes	12	12	-15	19	40
35	19.3	1.4	1	Yes	0.7	12	-15	19	40
40	19.9	1.9	1.1	Yes	0.8	12	-15	19	40
45	20.6	2.3	1.2	Yes	0.9	12	-15	19	40
50	21.2	2.7	1.25	Yes	0.95	12	-15	19	40
55	21.9	3.2	1.3	Yes	1	12	-15	19	40
60	22.5	3.6	1.4	Yes	1.1	12	-15	19	40
65	23.2	4	1.5	Yes	1.2	12	-15	19	40
70	23.8	4.5	1.6	Yes	1.3	12	-15	19	40
75	24.5	4.9	1.75	Yes	1.45	12	-15	19	40
80	25.2	5.4	1.9	Yes	1.6	12	-15	19	40
85	25.8	5.8	1.95	Yes	1.65	12	-20	19	40
90	26.5	6.2	2	Yes	1.7	12	-20	19	40
95	27.1	6.7	2.1	Yes	1.8	12	-20	19	40
100	27.8	7.1	2.2	Yes	1.9	12	-20	19	40
105	28.4	7.5	2.25	Yes	1.95	12	-20	19	40
110	29.1	8	2.3	Yes	2	12	-20	19	40
115	29.7	8.4	2.4	Yes	2.1	12	-20	19	40
120	3.4	8.8	2.5	Yes	2.2	12	-20	19	40
125	31.1	9.3	2.6	Yes	2.3	12	-20	19	40
130	31.7	9.7	2.7	Yes	2.4	12	-20	19	40
135	32.4	10.1	2.8	Yes	2.5	12	-20	19	40
140	33	10.6	2.9	Yes	2.6	12	-20	19	40
145	33.7	11	3.05	Yes	2.75	12	-20	19	40
150	34.3	11.4	3.2	Yes	2.9	12	-20	19	40
155	35	11.9	3.3	Yes	3	12	-20	19	40
160	35.6	12.3	8.6	NO	8.3	12	-20	19	40
165	36.3	12.8	8.85	NO	8.55	12	-20	19	40
170	37	13.2	9.1	NO	8.8	12	-20	19	40

Depth (MSW)	*Make-up Regulator "volume Tank" (Bar)*	*TRU BPR Setting (Bar)*	*Compressor Suction Pressure (bar)*	*Stage 1 Active*	*Bypass BPR Pressure (bar)*	*Bell Divers Supply Regulator bias (bar)*	*Bell BPR Setting bias (msw)*	*Oxygen Reg'r Setting 1 Diver*	*Oxygen Reg'r Setting 2 Divers*
175	37.6	13.6	9.25	NO	8.95	12	-20	19	40
180	38.3	14.1	9.4	NO	9.1	12	-20	19	40
185	38.9	14.5	9.6	NO	9.3	12	-20	19	40
190	39.6	14.9	9.8	NO	9.5	12	-20	19	40
195	40.2	15.4	10	NO	9.7	12	-20	19.3	40
200	40.9	15.8	10.2	NO	9.9	12	-20	19.7	40
205	41.5	16.2	10.4	NO	10.1	12	-20	20	40
210	42.2	16.7	10.6	NO	10.3	12	-20	20.3	40
215	42.9	17.1	10.8	NO	10.5	12	-20	20.7	40
220	43.5	17.5	11	NO	10.7	12	-20	21	40
225	44.2	18	11.15	NO	10.85	12	-20	21.3	40
230	44.8	18.4	11.3	NO	11	12	-20	21.7	40
235	45.5	18.8	11.55	NO	11.25	12	-20	22	40
240	46.1	19.3	11.8	NO	11.5	12	-20	22.3	40
245	46.8	19.7	11.85	NO	11.55	12	-20	22.7	40
250	47.4	20.1	11.9	NO	11.6	12	-20	23	40
255	48.1	20.6	12.45	NO	12.15	12	-20	23.3	40
260	48.8	21	13	NO	12.7	12	-20	23.7	40
265	49.4	21.5	13.6	NO	13.3	12	-20	24	40
270	50.1	21.9	14.2	NO	13.9	12	-20	24.3	40
275	50.7	22.3	14.8	NO	14.5	12	-20	24.7	40
280	51.4	22.8	14.2	NO	13.9	12	-20	25	40
285	52	23.2	14.55	NO	14.25	12	-20	25.3	40
290	52.7	23.6	14.9	NO	14.6	12	-20	25.7	40
295	53.3	24.1	15	NO	14.7	12	-20	26	40
300	54	24.5	15.1	NO	14.8	12	-20	26.3	40

2.3.12.8 - Routine maintenance and inspection

Periodic maintenance and test should be carried out on a regular basis according to IMCA D 018 and D 024. They are displayed and the end of this document. However, the following rules apply:

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***
High pressure vessels	6 months	30 months	5 years	
Welded pressure vessels	6 months	30 months		
Relief valves	6 months	30 months		Manufacturers recommendations
Pipework	6 months	24 months	5 years (1st install.)	
Power failure closure oxygen makeup	6 months			
Sensors, alarm & electrical systems.	6 months			Manufacturers recommendations
Analysers	6 months			
Output purity of compressors	6 months			
Delivery and rate of pressure compressors	6 months			
Various mechanical equipment	6 months			Manufacturers recommendations

Maintenance should also be scheduled according to the requirements of equipment manufacturers:

- Topside Reprocessing Unit:

- Filters:
  - They must be drained at least every 4 hours. It is said that, depending on the environmental conditions, Filter 1 (1 micron) should contain about a cup of condensate maximum and that the two others (0.01 micron) should not contain more than a spoon of condensate.
  - It is recommended to change the filters at intervals of 500 operating hours.
- Scrubbers:
  - Cartridges of scrubbers must be renewed after each bell run: A canister assembly 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.
  - Filter pads on the top and bottom of the canisters should be renewed every 500 hours.
- Drain valves and float valves:
  - They should be checked every 40 hours.
- Compressors:
  - Oil level should be checked before starting the machine and oil pressure regularly during the operations.
  - Oil + filter should be replaced according to the recommendation of the manufacturer:
    - It is essential to use the quality of oil indicated. Note that the type of oil to be used often depends on the environmental conditions. In addition, some compressors are lubricated with “synthetic oil” and other models accept only “mineral oil”. It must be remembered that manufacturers recommend not mixing a synthetic oil with a mineral one.
    - Environmental conditions and the quality of oil may also influence the frequency of the oil change: It is said that under Normal conditions (no extreme temperatures) some synthetic oils allow being renewed every 8,000 hours of run time or 12 months in the case of moderate use. This frequency drops to approximately 5000 hours with mineral oils. However, this frequency can be as low as every 1000 hours if the machine is exposed to extreme environmental conditions.
  - Coolant should be checked before starting the machine, and the temperature monitored during the operations. It may have to be changed at seasonal periods.
  - The machine should be checked for leaks every day.
  - A lot of manufacturers recommend checking the tension and the alignment of the belt every 2000 hours.
  - Suction, delivery, and pressure relief valves should be controlled according to the recommendations of the manufacturer. It is usually recommended every 1000 hours.
  - Some compressors have parts that are identified as more sensitive to wear than others. As a result, they have to be changed at indicated periods as a precaution.

- Bell:

  Bell equipment requires only a limited amount of maintenance, which may be carried out at a convenient time when the bell is the on surface and depressurized while carrying out the following checklists:
  - Bell internal system:
    - Acrylic water trap drained as required, during the dive (without interrupting gas recovery).
    - Water trap dismantled, cleaned and inspected every 500 hours
    - Check the condition and operation of SAECO/ POS valves and relief valves every 3 months.
    - Over a period of time the acrylic housing of the Bell internal water trap and the flow meters will become discoloured. This may be removed by washing in warm BIOX or other detergent and flushing with clean water. Note that the Flow meter must be internally dried when reinstalled on the system.
  - Bell external system
    - The Bell external water trap should be drained upon completion of each dive, or prior to the Bell being redeployed
    - Check operation of externally mounted check valve very 6 months.

4.3.12.9 - Trouble shooting

- System fault

Fault	***Fault diagnosis***	***Action***
High current, high discharge temperature, compressor drive motor amperage high and gas outlet temperature high, despite adequate cooling water flow.	Diving at deeper depths than 160 msw with both stages of the compressor on line.	Bypass the 1st stage of the compressor.
Low suction pressure	BPR loader pressure set too high.	Reset BPR loader pressure.
	Filters #1 & #2 chocked	Change the filters
High Pressure reading on the return hose	Return line set too high	- Load the regulator to 3 bar less than working depth. - Check LP receiver pressure. - Check compressor supply valve is open. - Check oil pressure and high temperature. - Switch the compressor off.

- Bell equipment fault

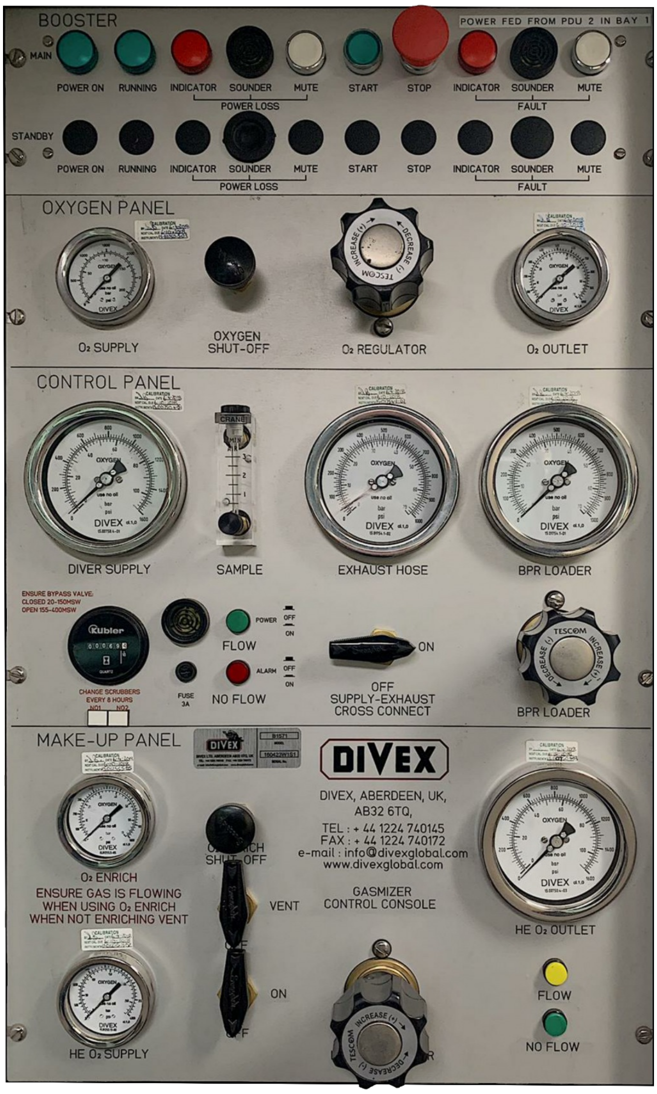
Fault	***Fault diagnosis***	***Action***
Volume tank relief valve popping off	Diver supply valve closed	Reduce volume tank pressure and slowly open diver supply valve.
Suction pressure loss at helmet: The diver loses suction at the valve and finds difficulty exhaling. As a result, the diver goes on “Open Circuit”.	Suction dropping off due to insufficient topside unit pumping capacity.	Ensure that the compressor is operating correctly
	SAECO/POS valve shut, closing off exhaust circuit. The bellman should check the pin on the SEACO/POS valve: The pin should be out.	Ensure that the diver has adequate supply pressure of 12 bar recommended in the reclaim table from the bell panel and the surface. Check whether the bellman has turned the diver’s supply gas off.
	Bellman may have shut diver exhaust manifold bell water trap	Open valve
	Hull exhaust valve may have been closed by mistake.	Open hull exhaust valve.
	Diver working above Bell & tracking pneumo not following the diver.	Reclaim should resume when diver goes below the Bell. Or Adjust diver tracking pneumo to give a bleed of approximately 0.3 to 0.4 litres per minute.
	BPR loader in the Bell not set up properly.	The bellman closes the diver manifold exhaust valve and sets up again the pre-dive checks. *(See points 5 & 14 in the bell setup procedure)*.
	Main umbilical hose collapsed, or/and main umbilical return shut off valve closed.	Replace hoses or cut back flattened area. Open main umbilical shut off valve slowly.

Fault	*Fault diagnosis*	*Action*
Suction pressure loss at helmet: The diver loses suction at the valve and finds difficulty exhaling. As a result, the diver goes on “Open Circuit”. *(Continuation of the previous page)*	Bell umbilical and external water trap filled with water.	- The dive may be continued by backing off BPR loader slightly in the dive control. - Set up to 1 bar below the recommended value. - Drain the umbilical and water traps at the end of the bell run and check for a loose fitting on the outside of the bell and on the helmet. - Ensure that divers’ helmet and mask are in good condition and not leaking water and the oral-nasal properly fitted to lower exhaust connectors. - Most importantly, the bellman must always drain the internal water trap when it is filled with water.
Volume tank pressure increase: Pressure increase in the system volume tank when make-up regulator is not flowing.	Diver using standby onboard gas instead of umbilical supply in the Bell.	Diver to be put on umbilical supply.
	Standby gas supply being used as umbilical supply and coming back up the exhaust hose to the volume tank.	Regulate standby gas below make-up regulator pressure.
Volume tank pressure increase: Pressure increase in the system volume tank when make-up regulator is not flowing. Gas escaping from the Bell into the exhaust circuit and the Bellman has to blow down regularly to prevent water coming up the Bell trunk.	Bell scrubbing valve open.	Close the valve *(see point 2 in the bell setup procedure).*
	Bell water trap drain valve open with isolation valve pushed in	Close the water trap drain valve *(see point 4 in the bell setup procedure).*
	Leaks at inward relieving valves on umbilical fitting below diver umbilical exhaust manifold	Check for gas being sucked into the valves. Also, check that the relief valves on top of the water trap are not relieving inwards. Removing the caps may be necessary for these checks.
	Metering valve BPR *(also called “bleed valve BPR”)* opened too far	Set “BPR bleed valve” as per bell setup procedure *(see point 9 in the bell setup procedure).*
	Hose to helmet disconnected and manifold valve knocked open	Close the valve of the diver’s umbilical exhaust *(see point 5 in the bell setup procedure).*
	O-rings on isolation valve damaged or water trap large O-rings leaking	Replace the damaged O-ring
Gas losses: A great deal of gas used for the dive but the diver assures the supervisor that he is on closed circuit and losing very few bubbles at his helmet	Loose fittings on the outside of the bell or the inside of the bell losing gas.	Check for leaks in the diver’s supply. Tighten loose fittings
	Diver tracking pneumo flow set far too high.	Set to correct flow in the bell of 0.4 litres/min. maximum. When the diver leaves the bell there should be one bubble every 10-20 seconds at the tracking pneumo end on his umbilical
No gas coming back from diver	Umbilical return line pressure too low.	Ensure that the umbilical return line is pressurised when lowering the Bell into the water.
		Ensure the proper setting on return line loader. Visually check end of hose at Bell for flattening.

2.3.12.10 - Divex bell reclaim system

The 1st Divex bell reclaim system has been proposed to manufacturers and owners of existing saturation systems during the eighties, and from this 1st launch, its general architecture has remained the same over the years. As a result, it is currently the most employed bell reclaim system in the world.
The general design of the Divex and Lexmar systems is very similar. As a conclusion, it is reasonable to say that the diving personnel using one of these systems should be able to adapt to the other one quickly. Note that Lexmar and Divex are two companies of the JFD group.
Apart from some minor details, the commands in the bell are the same and situated at the same places. However, there are some differences between the topside reprocessing units. Also, the control panels that are installed in the dive control provide similar functions, but their commands are arranged differently. For this reason, a comparison of these elements is necessary for a smooth transfer from one system to the other.

- The main difference of the topside reprocessing unit is the gas booster which is a two piston compressor that delivers 150 l/min with a maximum discharge pressure of 100 bar and is rated to 500 metres depth, while the compressor of the reclaim unit Lexmar model LME-RC-03-S-HY provides 135 l/min at a pressure of 55 bar. Note that the compressor provided by Lexmar is widely sufficient for the diving system it is installed on, because this system is rated for 300 m maximum. Also, the saturation procedures Normam 15 promoted in this manual are limited to 350 m, the US navy procedures to 300 m, and there are currently no published tables allowing deeper depths. As a conclusion dives to 500 m depth are to be considered experimental dives only.
  Note that the commands of the system Divex are electro-mechanical while the system Lexmar is managed through a computer. As a result, there is not a Human Machine Interface (HMI) where menus and alerts are displayed with the system Divex. Nevertheless, audio and visual alarms are provided on the machine and in the dive control.
  Note that similarly to the compressor used with the system Lexmar, the 1st stage of the compressor Divex is to be disconnected for dives below 150 metres depth.
- The reclaim control panel of the system Divex includes a module for the control of the compressor, which is not installed on the Lexmar one where a computer controls the system through the Human Machine Interface (HMI) which in on a separate console. The Last generation of Divex reclaim panel is organised as follows:



Booster panel:
It provides essential information and alarms regarding the booster.
Note that the line "stand by" is in the prevision of an optional second booster.

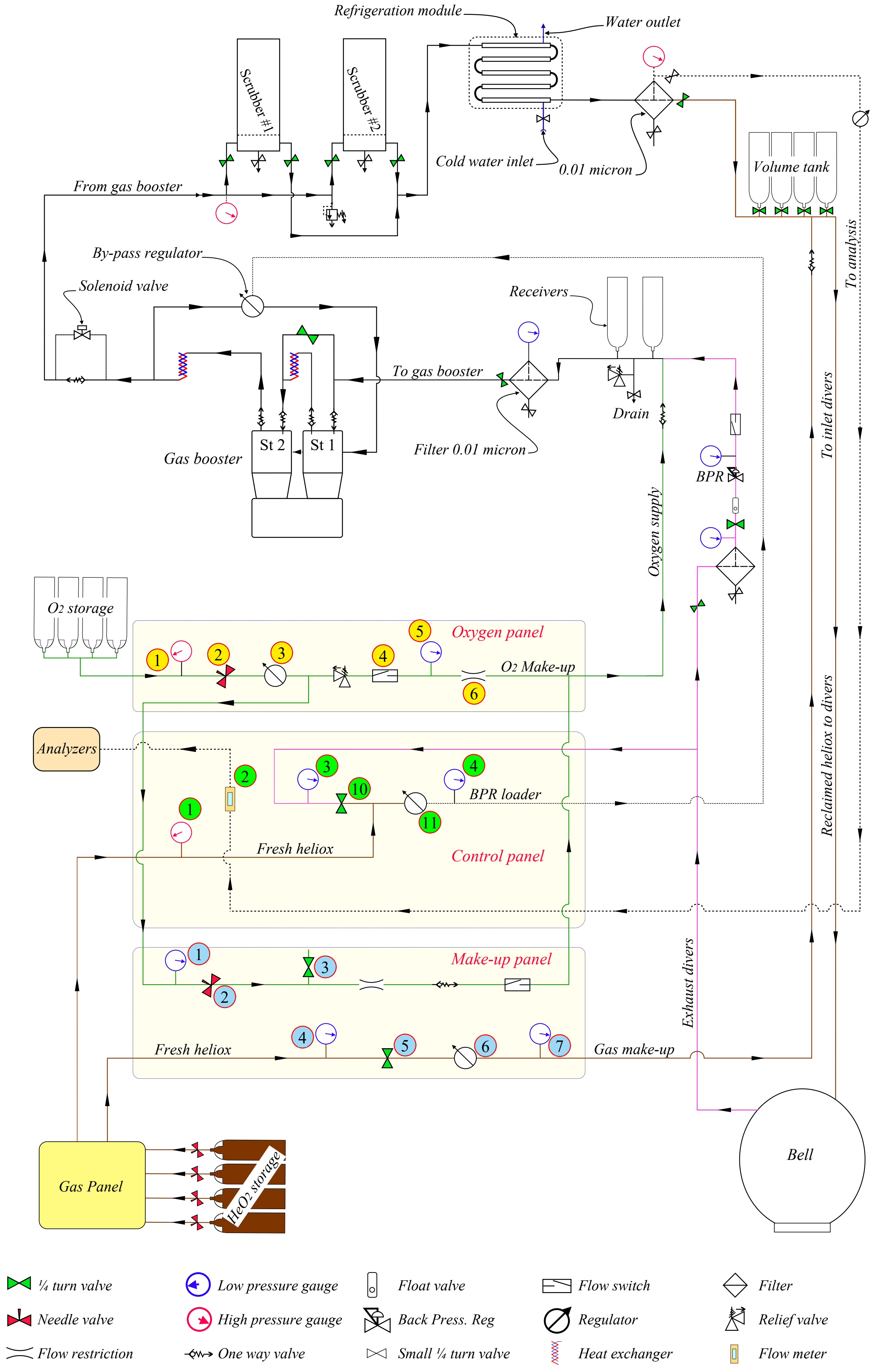
Oxygen panel:
Opposite to the panel from Lexmar, it is installed at the top of the reclaim panel and the manual enrichment of oxygen is not operated from this panel, but from the "Make-up panel".

Control panel:
Its 1st function is to control the back-pressure regulator of the topside reprocessing unit. On the system Lexmar, it is performed through the regulator reference "Reg 2b" (see in the drawings) which controls the BPR "BPR-1"
The 2nd function is to control the pressures in the exhaust hose from the bell and the outlet of the reclaim system and create a closed-loop when the cross over valve is opened. On the system Lexmar, it is done through the gauges "Gb8" & "Gb7", and the valve "Vb3".

Make-up Panel:
It groups the commands for the "heliox make-up control", thus on the panel Lexmar, the function of the gauges "Gb4" & "Gb6", the valves "Vb1" & "Vb2" and the regulator "Reg 1b" (see on the corresponding drawings).
Also, it allows performing manual oxygen injection and venting. On the Lexmar panel, these operations are performed through the valves "Vb8" & "Vb7".

For a better comprehension of this system, it is essential to read the explanations from the manufacturer and check the function of the items using a general drawing of the system which are available on the next pages.

- The general scheme below allows checking the functions of the elements described in the next pages. For this reason, the references numbers of the commands of the reclaim panel are those used in this description.

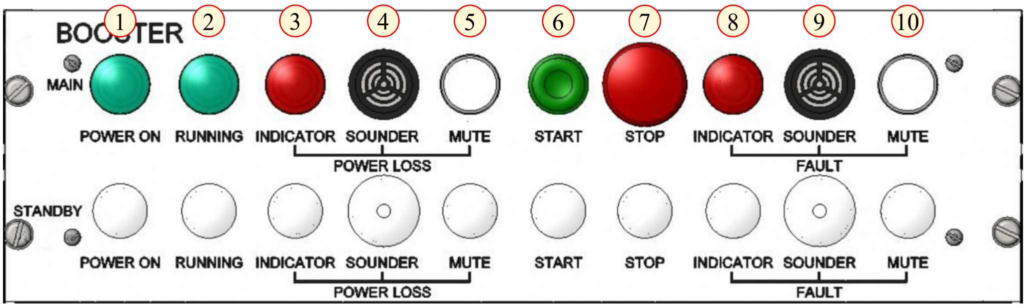


- Booster panel -

The booster panel provides the following commands:

1 - Power on indicator light
2 - Running indicator light
3 - Power loss indicator light
4 - Power loss sounder
5 - Power loss sounder mute
6 - Start push button switch
7 - Stop push button switch
8 - Fault indicator light
9 - Fault sounder
10 - Fault sounder mute

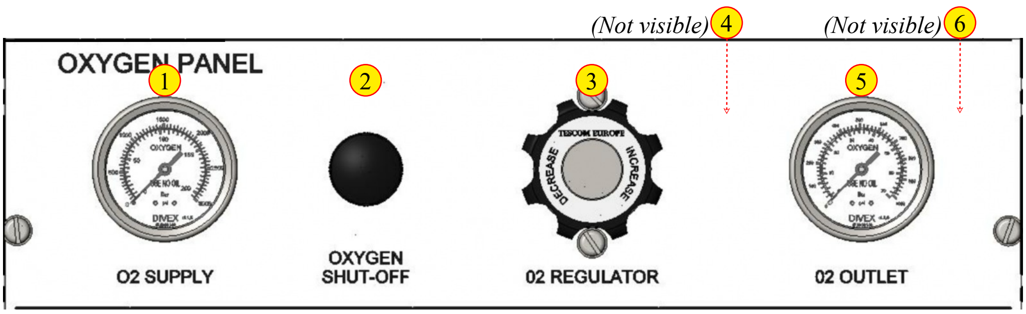
As indicated, a second set of controls can be added for an optional stand-by booster.



- Oxygen panel -

Oxygen panel provides the automatic functions and elements described with the Lexmar system. The commands are the following:

1 - O2 supply gauge – indicates the oxygen pressure available to the system. It corresponds to the valve "Gb1" of the Lexmar system
2 - Oxygen shut-off valve – provides manual isolation of the oxygen supply. It corresponds to the valve "Bb5" of the Lexmar system.
3 - O2 regulator – controls the oxygen pressure to the O 2 orifice. It corresponds to the regulator "reg 3b" of the Lexmar system.
4 - The O2 solenoid – stops oxygen addition when gas flow through the system has stopped *(Not visible)*.
5 - O2 outlet gauge – monitors the oxygen pressure available to the O 2 orifice. It corresponds to the gauge "Gb3" of the Lexmar system.
6 - O2 orifice – multi-orifice restrictor which regulates flow of oxygen to the Reprocessing Unit *(not visible)*.



- Control panel -

The control panel allows monitoring the system operations during a dive. The front panel layout is shown below. In addition to the functions indicated previously, a flowmeter is installed on it to monitor the flow to the analysers. This function does not exist on the Lexmar system where the gas to analyse is directly sent to the analysing panel.

This panel is composed of the following elements:

1 - Diver supply pressure gauge – indicates supply pressure available to the main umbilical. It corresponds to the gauge "Gb7" of the Lexmar system.
2 - Sample flow meter – monitors the sample gas flow to an external gas analyser.
3 - Bell exhaust hose pressure gauge - indicates pressure in the main umbilical exhaust hose. It corresponds to the gauge "Gb8" of the Lexmar system.
4 - BPR loader pressure gauge – indicates the pressure set on the (surface) BPR loader. It corresponds to the gauge "Gb5" of the Lexmar system.

6 - No flow sounder – sounds when gas flow stops.

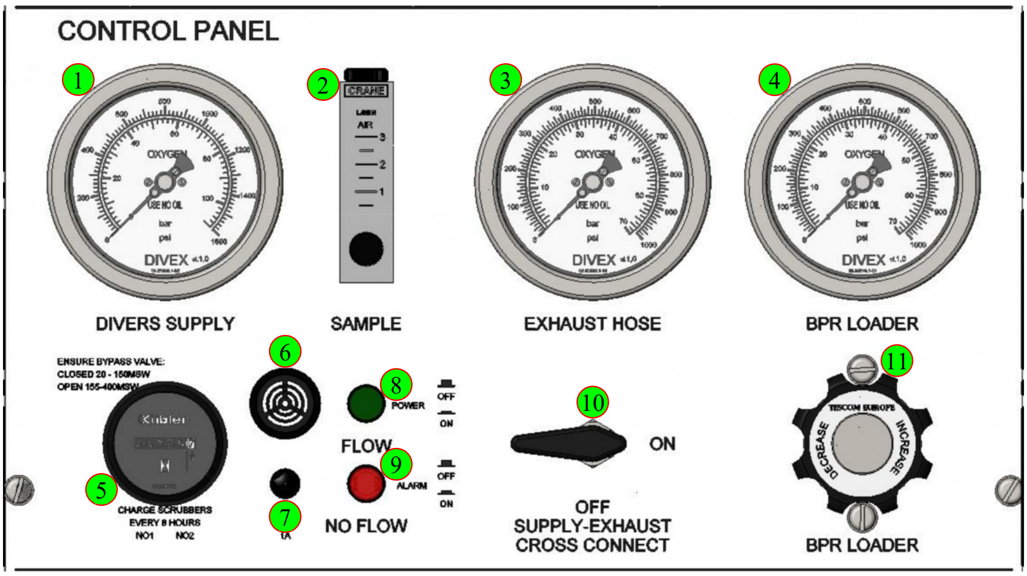
7 - Fuse holder – contains 3 amp fuses for protection of the 12 volt DC power system.

8 - Power switch/flow light – when depressed, the 12 volt DC system is energised. When the green light is on, gas is flowing through the system.

9 - Mute switch/no flow light – when the alarm switch is in the OUT position the alarm will sound if the gas flow stops. When the red light is ON, gas is not flowing through the system.

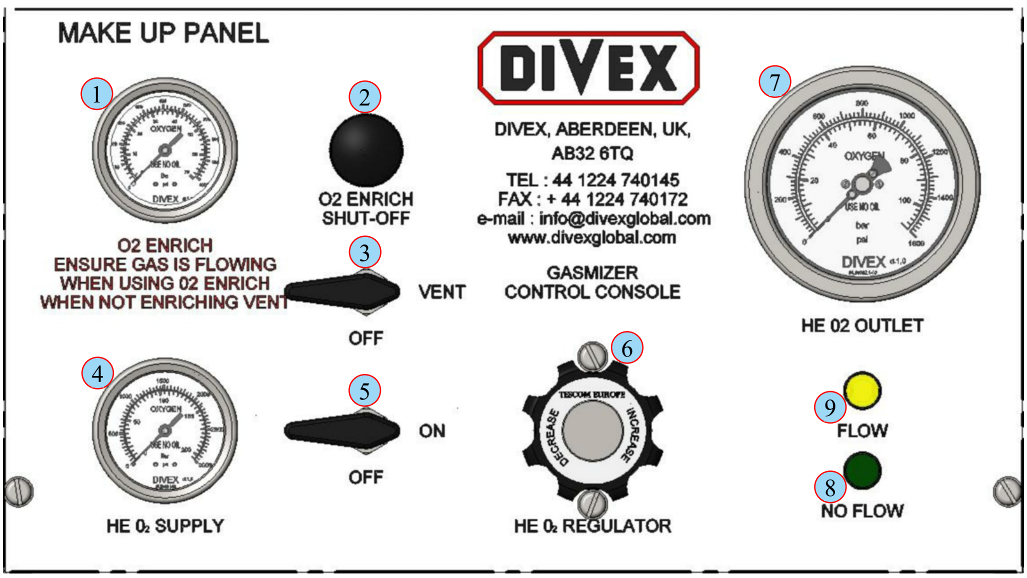
10 - Supply exhaust cross connect valve – allows gas to flow directly from the supply to the exhaust side of the system during initial pressurisation or when changing gas mixes. It corresponds to the valve “Vb3” of the Lexmar system.

11 - The BPR loader regulator – regulates the pressure set on the Reprocessing Unit back pressure regulator. It corresponds to the regulator “Reg 2b” of the Lexmar system.



- Make-up panel -

As indicated previously this panel provides the make-up gas section which is used to increase the working depth of the system and replace the gas lost, and the manual oxygen enriching section which is used to rapidly add oxygen to the system. As with the Lexmar system, this function must not be used during a dive.
Please remember that this gas comes from the O_2 regulator on the oxygen panel *(see in the general scheme)*.



1 - O_2 supply gauge – indicates oxygen pressure available to the panel.

2 - O_2 supply valve – provides manual shut-off of oxygen to the O_2 enriching orifice. It corresponds to the valve “Vb8” of the Lexmar system.

3 - Vent valve – is normally open to prevent accidental addition of oxygen into the system. It corresponds to the valve “Vb7” of the Lexmar system.

4 - The HeO_2 supply gauge – indicates the HeO_2 pressure available to the make-up system. It corresponds to the gauge “Gb4” of the Lexmar system.

5 - The HeO_2 supply valve – provides manual shut-off control of HeO_2 to the regulator. It corresponds to the valve “Vb1” of the Lexmar system.

6 - The HeO_2 regulator – is a high flow, self venting regulator which controls the make-up gas pressure available to the volume tank. It corresponds to the regulator “Reg 1b” of the Lexmar system.

7 - The HeO_2 outlet gauge – indicates the pressure available to the volume tank. The reading on this gauge is the minimum volume tank pressure desired. It corresponds to the gauge “Gb6” of the Lexmar system.

8 - The make-up gas flow light – indicates yellow when make-up gas is flowing into the volume tank.

9 - The make-up gas no flow light – indicates green when there is no flow through the make-up gas section.

- Oxygen content management tables:
The make-up panel is provided to allow the oxygen content of the breathing gas to be altered rapidly to a new diving depth. As a result of this depth change, it may happen that the partial pressure of oxygen has to be changed. For this reason, Divex provides tables that should be used to measure the time required to decrease or increase the oxygen content to the desired level.
Note that helium dilution may be achieved by venting the system, partially or completely and re-pressurizing with the appropriate gas mixture.

Table #1: For use with an Air or Electric Driven Gasmizer System. Using 3/4” supply & exhaust umbilicals length of 350 metres.

	Partial pressure oxygen						***Breathing time***		***Oxygen enriching time***				
	Time to drop 0.7 PPO2 to 02 PPO2 with NO oxygen injection (1 diver)						*Time to breathe the same molecule of gas @ 40 lpm*		*Time required to enrich oxygen content with a 40 bar oxygen supply pressure through both the O2 injection systems*				
Depth	***0.7 PPO2***		***0.2 PPO2***		***Time***		***System total***	***Time***	***0.25%***	***0.50%***	***0.75%***	***1.0%***	***1.25%***
msw	%O2	Litres	%O2	Litres	Min.	Hr:Min.	Litres	Min.	Min.	Min.	Min.	Min.	Min.
30	17.5	1700	5.0	485	1013	16:53	9700	60	3	7	10	13	16
40	14.0	1510	4.0	432	898	14:58	1,0800	54	4	7	11	15	18
50	11.7	1400	3.3	400	833	13:53	12,000	50	4	8	12	16	20
60	10.0	1320	2.9	377	786	13:06	13,200	47	4	9	13	18	22
70	8.8	1260	2.5	360	750	12:30	14,400	44	5	10	15	19	24
80	7.8	1210	2.2	344	722	12:02	15,500	43	5	10	16	21	26
90	7.0	1170	2.0	334	697	11:37	16,700	41	6	11	17	22	28
100	6.4	1140	1.8	325	679	11:19	17,900	40	6	12	18	24	30
110	5.8	1117	1.7	318	660	11:00	19,100	39	6	13	19	26	32
120	5.4	1090	1.5	311	649	10:49	20,200	38	7	14	20	27	34
130	5.0	1070	1.4	306	637	10:37	21,400	38	7	14	22	29	36
140	4.7	1050	1.3	300	625	10:25	22,500	37	8	15	23	30	38
150	4.4	1040	1.3	296	620	10:20	23,700	37	8	16	24	32	40
160	4.1	1030	1.2	293	614	10:14	24,900	36	8	17	25	33	42
170	3.9	1020	1.1	290	608	10:08	26,100	36	9	18	26	35	44
180	3.7	1000	1.1	286	595	9:55	27,200	35	9	18	27	37	46
190	3.5	990	1.0	284	588	9:48	28,400	35	10	19	29	38	48
200	3.3	986	0.95	282	586	9:46	29,600	35	10	20	30	40	50
210	3.2	979	0.91	280	583	9:43	30,800	34	10	21	31	41	52
220	3.0	970	0.87	277	578	9:38	31,900	34	11	21	32	43	54
230	2.9	967	0.83	276	576	9:36	33,100	34	11	22	33	44	56
240	2.8	958	0.80	274	570	9:30	34,200	34	11	23	34	46	58
250	2.7	955	0.77	273	568	9:28	35,500	34	12	24	36	48	60
260	2.6	948	0.74	271	564	9:24	36,600	33	12	25	37	49	61
270	2.5	945	0.71	270	563	9:23	37,800	33	13	25	38	51	63
280	2.4	938	0.69	268	558	9:18	38,900	33	13	26	39	52	65
290	2.3	934	0.67	267	556	9:16	40,100	33	14	27	41	55	69
300	2.2	933	0.65	266	556	9:16	41,300	33	14	29	43	58	72
310	2.2	931	0.63	265	555	9:15	42,500	33	15	30	45	60	75
320	2.1	924	0.61	264	550	9:10	43,600	33	16	31	47	63	79
330	2.1	923	0.59	263	549	9:09	44,800	32	16	33	49	66	82
340	2.0	918	0.57	262	547	9:07	45,900	32	17	35	52	69	86
350	1.9	916	0.56	262	545	9:05	47,200	32	18	36	55	73	91

Table #2: Note for use with an electric Gasmizer system (Based on results obtained at NUTEC, March 85) Using 3/4" supply & exhaust umbilicals length - 500 metres.

	Partial pressure oxygen						*Breathing time*		*Oxygen enriching time*				
	Time to drop 0.7 PPO2 to 02 PPO2 with NO oxygen injection (1 diver						*Time to breathe the same molecule of gas @ 40 lpm*		*Time required to enrich oxygen content with a 40 bar oxygen supply pressure through both the O2 injection systems*				
Depth	***0.7 PPO2***		***0.2 PPO2***		***Time***		***System total***	***Time***	***0.25%***	***0.50%***	***0.75%***	***1.0%***	***1.25%***
msw	%O2	Litres	%O2	Litres	Min.	Hr:Min.	Litres	Min.	Min.	Min.	Min.	Min.	Min.
20	23.3	2875.3	6.7	821.5	1711.5	28.5	12322.6	102.7	3.6	7.3	10.9	14.5	18.2
25	20.0	2555.7	5.7	730.2	1521.3	25.4	12778.7	91.3	3.9	7.9	11.8	15.7	19.7
30	17.5	2316.1	5.0	661.7	1378.6	23.0	13234.8	82.7	4.2	8.4	12.6	16.8	21.0
35	15.6	2129.7	4.4	608.5	1267.7	21.1	13691.0	76.1	4.4	8.9	13.3	17.8	22.2
40	14.0	1980.6	4.0	565.9	1178.9	19.6	14147.1	70.7	4.7	9.4	14.0	18.7	23.4
45	12.7	1858.6	3.6	531.0	1106.3	18.4	14603.3	66.4	4.9	9.8	14.7	19.6	24.5
50	11.7	1756.9	3.3	502.0	1045.8	17.4	15059.4	62.7	5.1	10.2	15.3	20.5	25.6
55	10.8	1670.9	3.1	477.4	994.6	16.6	15515.5	59.7	5.3	10.6	16.0	21.3	26.6
60	10.0	1597.2	2.9	456.3	950.7	15.8	15971.7	57.0	5.5	11.1	16.6	22.1	27.6
65	9.3	1534.2	2.7	438.3	913.2	15.2	16437.7	54.8	5.7	11.5	17.2	22.9	28.7
70	8.7	1484.0	2.5	424.0	883.4	14.7	16960.3	53.0	6.0	11.9	17.9	23.8	29.8
75	8.2	1439.8	2.4	411.4	857.0	14.3	17483.0	51.4	6.2	12.3	18.5	24.7	30.9
80	7.8	1400.4	2.2	400.1	833.6	13.9	18005.7	50.0	6.4	12.8	19.2	25.5	31.9
85	7.4	1365.2	2.1	390.1	812.6	13.5	18528.3	48.8	6.6	13.2	19.8	26.4	33.0
90	7.0	1333.6	2.0	381.0	793.8	13.2	19051.0	47.6	6.8	13.6	20.4	27.3	34.1
95	6.7	1304.9	1.9	372.8	776.7	12.9	19573.6	46.6	7.0	14.1	21.1	28.1	35.1
100	6.4	1278.9	1.8	365.4	761.2	12.7	20096.3	45.7	7.2	14.5	21.7	28.9	36.2
105	6.1	1255.1	1.7	358.6	747.1	12.5	20619.0	44.8	7.4	14.9	22.3	29.8	37.2
110	5.8	1233.3	1.7	352.4	734.1	12.2	21141.6	44.0	7.7	15.3	23.0	30.6	38.3
115	5.6	1213.2	1.6	346.6	722.1	12.0	21664.3	43.3	7.9	15.7	23.6	31.5	39.3
120	5.4	1194.7	1.5	341.3	711.1	11.9	22187.0	42.7	8.1	16.1	24.2	32.3	40.4
125	5.2	1177.5	1.5	336.4	700.9	11.7	22709.8	42.1	8.3	16.6	24.8	33.1	41.4
130	5.0	1161.6	1.4	331.9	691.4	11.5	23232.3	41.5	8.5	17.0	25.5	34.0	42.4
135	4.8	1146.8	1.4	327.7	682.6	11.4	23755.0	41.0	8.7	17.4	26.1	34.8	43.5
140	4.7	1133.0	1.3	323.7	674.4	11.2	24277.6	40.5	8.9	17.8	26.7	35.6	44.5
145	4.5	1120.0	1.3	320.0	666.7	11.1	24800.3	40.0	9.1	18.2	27.3	36.4	45.5
150	4.4	1107.9	1.2	316.5	659.5	11.0	25323.0	39.6	9.3	18.6	27.9	37.3	46.6
155	4.2	1096.5	1.2	313.3	652.7	10.9	25845.6	39.2	9.5	19.0	28.6	38.1	47.6
160	4.1	1085.8	1.2	310.2	646.3	10.8	26368.3	38.8	9.7	19.4	29.2	38.9	48.6
165	4.0	1075.6	1.1	307.3	640.3	10.7	26891.0	38.4	9.9	19.9	29.8	39.7	49.6
170	3.9	1066.1	1.1	304.6	634.6	10.6	27413.6	38.1	10.1	20.3	30.4	40.5	50.7
175	3.8	1057.0	1.1	302.0	629.2	10.5	27936.3	37.8	10.3	20.7	31.0	41.4	51.7
180	3.7	1048.5	1.1	299.6	624.1	10.4	28459.0	37.4	10.5	21.1	31.6	42.2	52.7
185	3.6	1040.4	1.0	297.2	619.3	10.3	28981.6	37.2	10.7	21.5	32.2	43.0	53.7
190	3.5	1032.7	1.0	295.0	614.7	10.2	29504.3	36.9	11.0	21.9	32.9	43.8	54.8
195	3.4	1025.3	1.0	292.9	610.3	10.2	30027.0	36.6	11.2	22.3	33.5	44.6	55.8
200	3.3	1018.3	1.0	290.9	606.1	10.1	30549.6	36.4	11.4	22.7	34.1	45.4	56.8
205	3.3	1002.5	0.9	286.4	596.7	9.9	30792.2	35.8	11.5	22.9	34.4	45.8	57.3
210	3.2	998.0	0.9	285.1	594.0	9.9	31364.7	35.6	11.7	23.4	35.0	46.7	58.4
215	3.1	993.6	0.9	283.9	591.4	9.9	31937.2	35.5	11.9	23.8	35.7	47.6	59.5
220	3.0	989.4	0.9	282.7	588.9	9.8	32509.6	35.3	12.1	24.2	36.4	48.5	60.6
225	3.0	985.4	0.9	281.5	586.6	9.8	33082.1	35.2	12.3	24.7	37.0	49.4	61.7
230	2.9	981.6	0.8	280.5	584.3	9.7	33654.6	35.1	12.6	25.1	37.7	50.3	62.8
235	2.9	997.9	0.8	279.4	582.1	9.7	34227.0	34.9	12.8	25.6	38.4	51.2	63.9
240	2.8	974.4	0.8	278.4	580.0	9.7	34799.5	34.8	13.0	26.0	39.0	52.0	65.0

	Partial pressure oxygen						*Breathing time*		*Oxygen enriching time*				
	Time to drop 0.7 PPO2 to 02 PPO2 with NO oxygen injection (1 diver						*Time to breathe the same molecule of gas @ 40 lpm*		*Time required to enrich oxygen content with a 40 bar oxygen supply pressure through both the O2 injection systems*				
Depth	***0.7 PPO2***		***0.2 PPO2***		***Time***		***System total***	***Time***	***0.25%***	***0.50%***	***0.75%***	***1.0%***	***1.25%***
245	2.7	971.0	0.8	277.4	578.0	9.6	35372.0	34.7	13.2	26.5	39.7	52.9	66.2
250	2.7	967.7	0.8	276.5	576.0	9.6	35944.5	34.6	13.5	26.9	40.4	53.8	67.3
255	2.6	964.6	0.8	275.6	574.2	9.6	36516.9	34.4	13.7	27.3	41.0	54.7	68.4
260	2.6	961.6	0.7	274.7	572.4	9.5	37089.4	34.3	13.9	27.8	41.7	55.6	69.5
265	2.5	958.7	0.7	273.9	570.6	9.5	37661.9	34.2	14.1	28.2	42.3	56.5	70.6
270	2.5	955.9	0.7	273.1	569.0	9.5	38234.4	34.1	14.3	28.7	43.0	57.4	71.7
275	2.5	953.2	0.7	272.3	567.4	9.5	38806.8	34.0	14.6	29.1	43.7	58.2	72.8
280	2.4	950.5	0.7	271.6	565.8	9.4	39379.3	33.9	14.8	29.6	44.3	59.1	73.9
285	2.4	948.0	0.7	270.9	564.3	9.4	39951.8	33.9	15.0	30.0	45.0	60.0	75.0
290	2.3	945.6	0.7	270.2	562.8	9.4	40524.3	33.8	15.2	30.4	45.7	60.9	76.1
295	2.3	943.2	0.7	269.5	561.4	9.4	41096.7	33.7	15.4	30.9	46.3	61.8	77.2
300	2.3	940.9	0.6	268.8	560.1	9.3	41669.2	33.6	15.7	31.3	47.0	62.7	78.3
305	2.2	938.7	0.6	268.2	558.8	9.3	42241.7	33.5	15.9	31.8	47.7	63.5	79.4
310	2.2	936.6	0.6	267.6	557.5	9.3	42814.2	33.4	16.1	32.3	48.3	64.4	80.5
315	2.2	934.5	0.6	267.0	556.2	9.3	43386.8	33.4	16.3	32.7	49.0	65.3	81.6
320	2.1	932.5	0.6	266.4	555.0	9.3	43959.1	33.3	16.5	33.1	49.6	66.2	82.7
325	2.1	930.5	0.6	265.9	553.9	9.2	44531.6	33.2	16.8	33.5	50.3	67.1	83.8
330	2.1	928.6	0.6	265.3	552.7	9.2	45104.1	33.2	17.0	34.0	51.0	68.0	85.0
335	2.0	926.8	0.6	264.8	551.6	9.2	45678.5	33.1	17.2	34.4	51.6	68.8	86.1
340	2.0	925.0	0.6	264.3	550.6	9.2	46249.0	33.0	17.4	34.9	52.3	69.7	87.2
345	2.0	923.2	0.6	263.8	549.5	9.2	46821.5	33.0	17.7	35.3	53.0	70.6	88.3
350	1.9	921.5	0.6	263.3	548.5	9.1	47394.0	32.9	17.9	35.7	53.6	71.5	89.4
355	1.9	919.9	0.5	262.8	547.6	9.1	47966.4	32.9	18.1	36.2	54.3	72.4	90.5
360	1.9	918.3	0.5	262.4	546.6	9.1	48538.9	32.8	18.3	36.6	54.9	73.3	91.6

Note: Table intentionally limited to 360 metres (Normam-15 saturation procedures limited to 350 m)

- Regulator setting guidelines:
These tables have a similar function as those published by Lexmar and explained in point 2.3.12.7.
Divex provides a set for 1 diver and another one for two divers.
The elements indicated in these tables are the following:

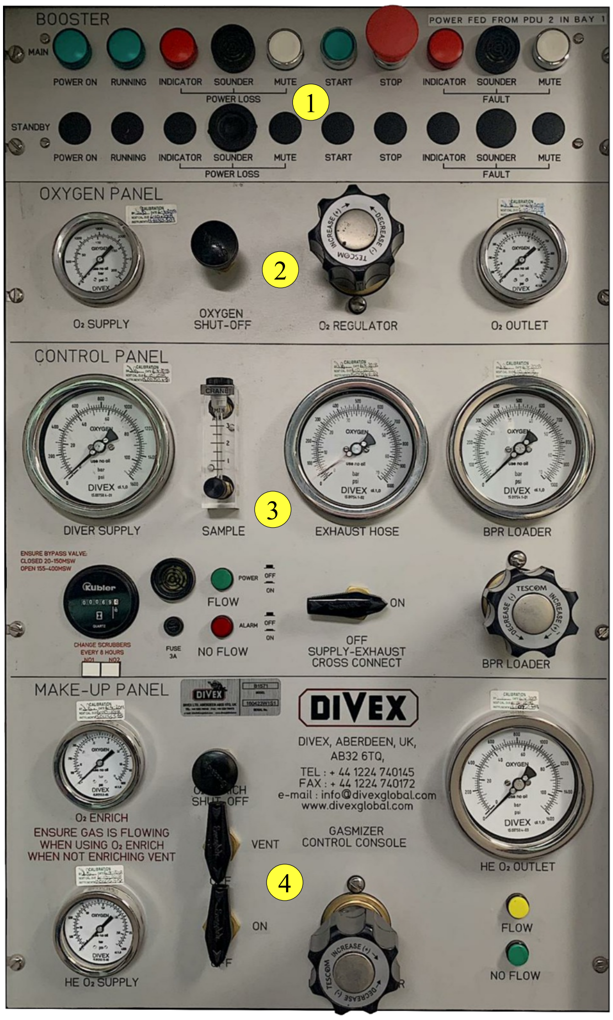
No	***Elements indicated in the tables***	***Description***
1	***Bell depth***	It is the depth of the bell at the bottom of the trunk
2	***BPR loader***	It is the Back Pressure Regulator loader on the "Gasmizer control console". It sets the main exhaust umbilical pressure.
3	***Make-up reg.***	It is the Make-up regulator on the "Make-up panel" of the "Gasmizer control Console". It sets the minimum "Volume tank" pressure
4	***O2 reg.***	It is the oxygen regulator on the "Oxygen panel" of the "Gasmizer control console". This setting will provide 1.2 litres per minute oxygen flow. Occasional adjustments maybe required depending on the diver work rate.
5	***Diver(s) supply (bell)***	It is the divers supply pressure setting on the Bell diver supply regulator.
6	***Bell BPR loader***	It is the bell BPR loader setting required for the Ultrajewel 601 Helmet.

Table 2: Regulator setting guidelines for 2 divers

1	2	3	4	5	6	1	2	3	4	5	6
Bell Depth	***BPR loader***	***Make-up Reg.***	***O2 reg.***	***Diver supply (bell)***	***Bell BPR loader***	***Bell Depth***	***BPR loader***	***Make-up Reg.***	***O2 reg.***	***Diver supply (bell)***	***Bell BPR loader***
msw	***Bar***	***Bar***	***Bar***	***Bar***	***Msw***	***msw***	***Bar***	***Bar***	***Bar***	***Bar***	***Msw***
30	1	18.6	39	14	-15	***200***	15.5	42	39	16	-21.5
35	1.4	19.3	39	14	-15	***205***	15.9	42.3	39	16	-21.8
40	1.8	20	39	14	-15	***210***	16.3	43	39	16	-22.1
45	2.2	20.7	39	14	-15	***215***	16.8	43.8	39	16	-22.4
50	2.6	21.4	39	14	-15	***220***	17.2	44.6	39	16	-22.7
55	3	22.1	39	14	-15	***225***	17.7	45.3	39	16	-23
60	3.3	22.7	39	14	-15	***230***	18.1	46.1	39	16	-23.3
65	3.7	23.4	39	14	-15	***235***	18.6	46.8	39	17	-23.6
70	4.1	24.1	39	14	-15	***240***	19	47.6	39	17	-23.8
75	4.5	24.8	39	14	-15	***245***	19.5	48.4	39	17	24.1
80	4.9	25.5	39	14	-15	***250***	20	49.1	39	17	-24.4
85	5.3	26.2	39	14	-15	***255***	20.4	49.9	39	17	-24.7
90	5.7	26.9	39	14	-15.2	***260***	20.7	50.7	39	17	-25
95	6.1	27.6	39	14	15.5	***265***	21.3	51.4	39	18	-25.3
100	6.5	28.2	39	14	15.8	***270***	21.7	52.2	39	18	-25.6
105	6.9	28.9	39	14	-16.1	***275***	22.2	52.9	39	18	-25.9
110	7.3	29.6	39	14	-16.3	***280***	22.6	53.7	39	18	-26.2
115	7.8	30.3	39	14	-16.6	***285***	23.1	54.5	39	18	-26.4
120	8.2	31	39	14	-16.9	***290***	23.5	55.2	39	18	-26.7
125	8.7	31.7	39	14	-17.2	***295***	24	56	39	18	-27
130	9.1	32.4	39	14	-17.5	***300***	24.5	56.8	39	19	-27.3
135	9.6	33.1	39	14	17.8	***305***	24.9	57.5	39.1	19	-27.6
140	10	33.7	39	14	-18.1	***310***	25.3	58.3	39.3	19	-27.9
145	10.5	34.4	39	14	-18.4	***315***	25.7	59	39.5	19	-28.2
150	11	35.1	39	14	-18.7	***320***	26.2	59.8	39.7	19	-28.5
155	11.4	35.8	39	14	18.9	***325***	26.7	60.6	40	19	-28.8
160	11.9	36.5	39	14	19.2	***330***	27.1	61.3	40.2	19	-29
165	12.3	37.2	39	15	-19.5	***335***	27.6	62.1	40.4	20	-29.3
170	12.7	37.9	39	15	-19.8	***340***	28	62.9	40.6	20	-29.6
175	13.2	38.6	39	15	-20.1	***345***	28.5	63.6	40.8	20	-29.9
180	13.6	39.2	39	15	-20.4	***350***	29	64.4	41	20	-30
185	14.1	39.9	39	15	-20.7	***355***	29.4	65.1	41.2	20	-30.1
190	14.6	40.6	39	15	-21	***360***	29.8	65.9	41.4	20	-30.2
195	15	41.3	39	15	-21.3	***365***	30.3	66.7	41.6	20	-30.3

Note: Table intentionally limited to 365 metres (Normam-15 saturation procedures limited to 350 m)

Note:
As a proof that this system has remained the same over the years, the comparison of the latest model proposed *(on the left side below)* with the one produced in 1985 under the commercial brand “Gas Services” *(on the right side below)* shows that the only noticeable difference is the booster panel that have been modified and was initially at the bottom of the unit.



1 - Booster panel:
It is the only element that has been changed.

2 - Oxygen panel:
There is no modification of this panel

3 - Control panel:
This panel has not been modified.

4 - Make-up Panel:
As with the other gas panels its commands and gauges remain identical to the model sold in 1985.

2.3.13 - Bell hot water machine

This point describes the machine that supplies hot water to the bell and the divers and is situated on the surface support. It is the continuation of the bell heating system described in point 2.3.2.7 and of the hot water suits discussed in point 2.3.4.

As already said in these previous points, the temperature of the surface of the sea varies according to the location and the season. However, the temperature at deep depths may fall below four degrees and does not vary according to the seasons. This permanent temperature slightly changes with the latitudes and may be close to zero degrees Celsius near the poles. Because the loss of heat is 24 times faster in water than in air, and that umbilicals have a limited isolation, the loss of energy is considerable and increases with the deployed lengths. As a result, powerful machines are necessary to heat the divers during the bell run that can be up to 8 hrs. These machines can be electrically or fuel-powered. Nevertheless, it seems that the majority of modern in-built saturation systems are based on electrical devices.

2.3.13.1 - Recommendation IMCA:

IMCA D 022 point 10.4 “heating systems” highlights the following facts:

- There is a considerable temperature drop in the umbilical. This temperature drop depends on the temperature at the machine, umbilical length, flow rate and sea temperature.
    - A lower temperature and a higher flow rate can transport as much heat as a higher temperature and a lower flow rate.
    - A higher temperature transfers heat more effectively to the diver, but increases the risk of scalding and hyperthermia which may happen if the water reaching the diver is at temperatures in excess of about 45°C. Also, if the temperature or flow rate is too low there is a risk of hypothermia.
- After some time in the water, the diver may not be able to assess his heating requirements adequately. Also, hyperthermia and hypothermia are gradual processes and may not be noticed by the diver focusing on his task.
- Respiratory heat loss is particularly hard to detect because the body only has temperature sensors in the skin, not in the lungs. Also, as already discussed in the presentation of the bell and helmet, the diver’s respiratory heat loss increases with depth, as the density of the breathing gas increases, and the gas must be heated for dives deeper than 150 msw (495 fsw).
- Note that according to DMAC 08 “Thermal stress in relation to diving”, the comfortable skin temperature in hot-water suits was shown to be about 34°C (Presentation Dr Kuehn).
- The supply to the bellman must also be considered as too much heat to the divers may deprive the bell.

IMCA D 024 gives in section 8 the following guidelines regarding the way hot water machines should be organised:

- The equipment used to generate and supply the hot water to the diver must be suitable for the purpose
- There must be an alternative and independent source for supplying heat to the diver
- If electricity is required to generate heating or pump it to the diver then there must be a back-up system in the event of primary failure (such as the vessel losing main power). This must be able to function for as long as it takes to recover the diver(s) to safety.
- The diving supervisor must have a display showing the temperature of the water being supplied to the diver
- A high and low temperature alarm (audible and visible) must be fitted to alert the diving supervisor if pre-set upper and lower limits are exceeded:
- All hot water machines need to have suitable provision of firefighting equipment in their vicinity. This may be by means of permanent ship or platform provided equipment or by means of portable extinguishers etc. It must be capable of dealing with any type or size of foreseeable fire hazard.
- If any hot water machines are situated in enclosed and unmanned areas then consideration should be given to fitting a fire detection system. This should be particularly considered for oil-fired units.

IMCA also says that manufacturers usually publish charts or tables for the adjustment of the hot water machines they sold. However, note that these documents may not be necessary with some last generation models.

2.3.13.2 - Description of a hot water machine

The machine used for this description is the electric water heater installed on UDS Lichtenstein and Picasso that was fabricated by Comanex (http://www.comanex.fr/), a well known company based in Marseille (France).
Note that because these vessels have two bells, three hot water units are provided. Each machine is designed to deliver heated seawater from 30ºC to 80ºC with a continuous flow up to 60 l/min (3.6 m³/hr) at a maximum pressure of 65 bar, which is sufficient to supply one bell during extreme conditions. Thus, one unit is provided for each bell, and the third one is to be online in the case of a breakdown.
The Machine is designed as follows:

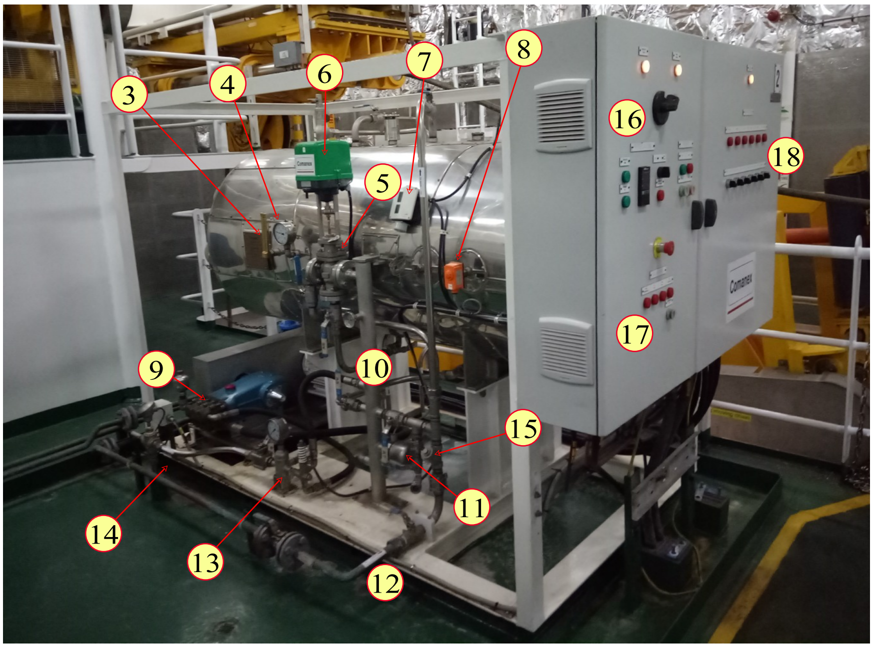
- The unit is composed of an isolated water tank of 830 litres capacity where the water is heated using six heat elements of 35 kW/h each (total = 210 kW/h). This tank allows regulation of the water temperature. Also, it stores sufficient hot water to supply the diver for 20 min in the case of a failure of the heating elements, which allows returning safely to the bell or starting the backup unit. A temperature controller automatically switches the heating elements on or off, and a safety thermostat stops them in the case of overheating.
  A 3-way valve mixes the hot water with cold sea water to adjust the selected temperature to the flow rate. The water is then pressurized to the desired pressure through a booster pump specially designed to handle hot sea

water. As a result, this device automatically delivers the water at the selected temperature at all times, and the charts used with the machines of the previous generation for the manual adjustment of flow rates according to the number of heating banks activated are unnecessary with this last generation machine.

- Depending on the option selected by the owner, the machine can be controlled by a computer through a Human Machine Interface (HMI) which is provided on its electrical enclosure and in the dive control, or manually through electrical panels in the dive control and on the machine.

The photo on the side shows the three hot water machines of UDS Picasso. They are installed at the direct proximity of the bell reclaim system, above the dive control.

Note the six heaters (see #1) at the extremity of each machine, and the motor of the pump with the protection of its transmission belt to the pump (see #2).

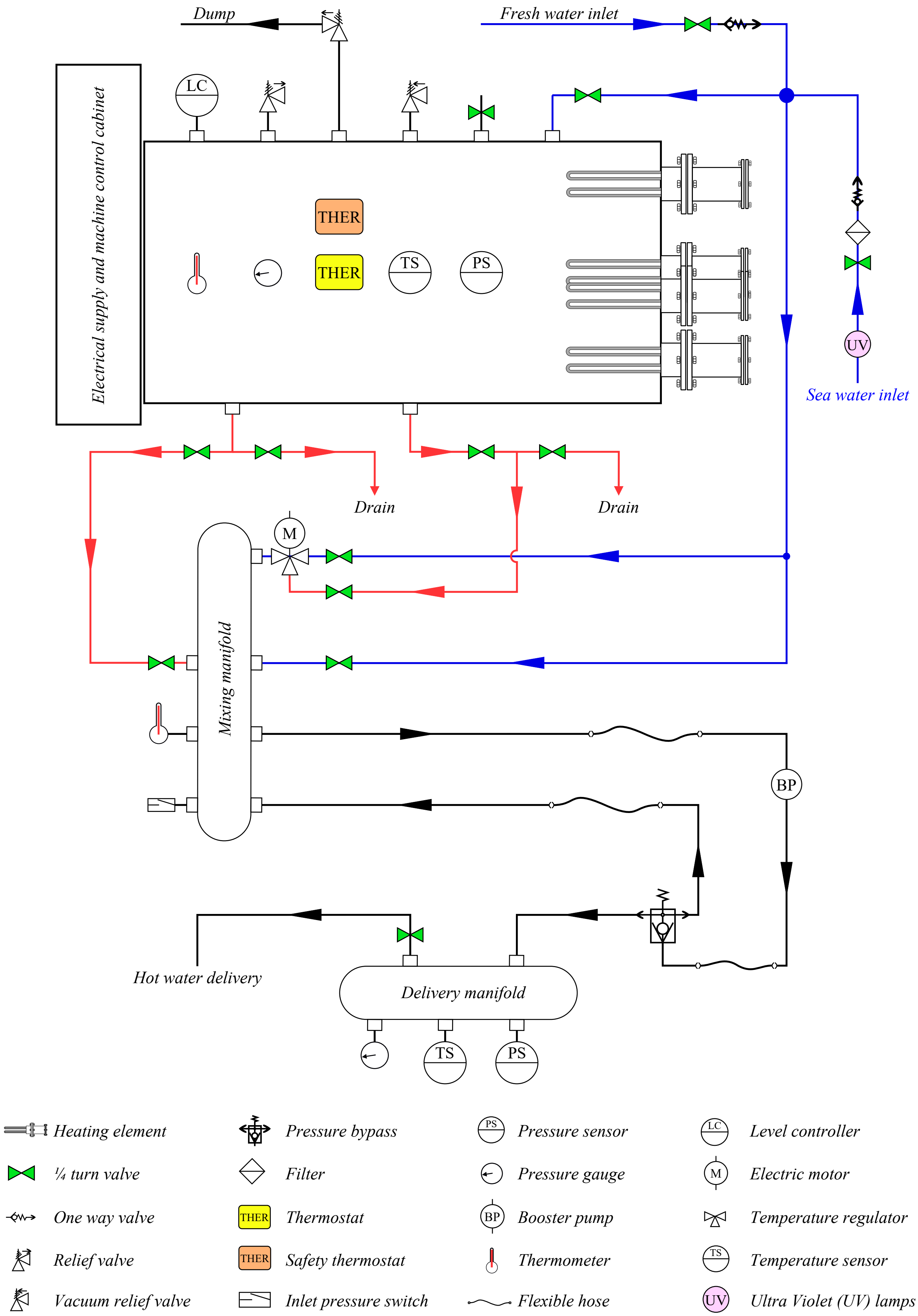


View of a hot water machine above from the other side:
- *Thermometer (#3)*
- *Pressure gauge (#4*
- *Regulation valve (#5)*
- *Regulation valve motor (#6)*
- *Thermostat (#7)*
- *Safety thermostat (#8)*
- *Pump (#9)*
- *Mixing manifold (#10)*
- *Flow controller (#11)*
- *Water inlet (#12)*
- *Delivery manifold with the temperature sensor, and the bypass regulator (#13)*
- *Hot water outlet (#14)*
- *Sea water filter (#15)*
- *Controls (#16)*
- *Alarms + emergency stop (#17)*
- *Heaters switches and their corresponding lights (#18)*

Control panels of the machines in the dive control:
- *On the left the system installed on the Picasso, on the right the system installed on Lichtenstein.*
- *The difference is that Picasso has a classical system that is electrical (see #19), and that Liechtenstein has a last generation system that is managed through computers which are controlled through a HMI.*

Note the two HMI which each one corresponds to a machine (#19 and #20). Also, note the emergency stop on the side of each HMI.

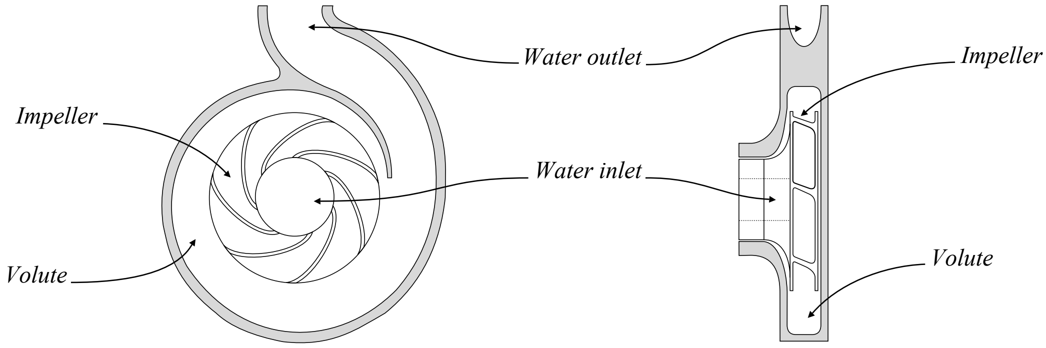
The elements of the machine described previously are more detailed on the scheme below.
Note that fresh water can be delivered to the hot water machine. However, fresh water is not used during the dives but mostly for the maintenance of the machine (Salt removal). Also, a Ultra-Violet (UV) light is added before the filter to neutralize pathogen organisms.



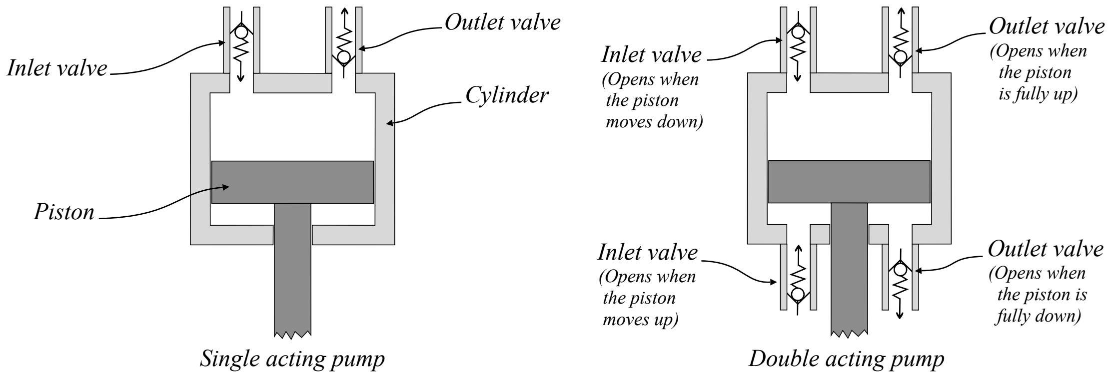
Important and not indicated previously: The control cabinet has a main and a backup electrical supply.

- Note regarding equipment that are specific to hot water machines:

- Vacuum relief valves
  Relief valves used on diving systems are generally designed to protect pressure vessels and other items against overpressure. Opposite to that, the function of a vacuum relief valve is to protect the tank from being in depression and then being crushed by the atmospheric pressure. In case the container becomes depressurized, this valve opens to equalize it with the surrounding pressure.
- Piston booster pumps
  Hot water machines are fitted with piston booster pumps instead of centrifugal pumps or of another design for following technical reasons:
  - Centrifugal pumps are commonly used in the marine and diving industries. These pumps are able to deliver high flow rates and are appreciated for their simple design that consists of an impeller that is rotated by a motor and is installed in a casing shaped in the form of a volute. The rotation of this impeller draws the fluid into the housing and transfers its kinetic energy to the liquid, which is then pushed to the discharge hose. However, due to their design, these pumps do not deliver high pressures or several stages (pumps) are necessary to achieve it, their flow rate is dependent on the delivery pressure, they may develop cavitation with warm water or low intake pressures, and they cannot auto prime if they are not pre-filled, which is the reason they are generally in the lowest parts of the boat.
    As a result, these pumps are ideal for supplying water to the machine, but not as a booster pump.



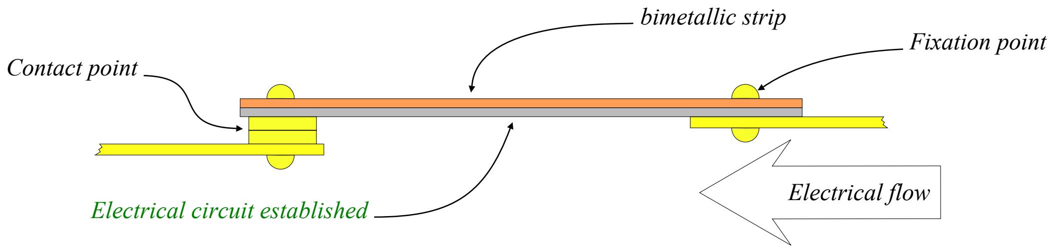
  - A piston pump is designed to draw a liquid in a cylinder and compress it using a piston that moves up and down. Inlet and outlet valves are alternatively open and close to fill the cylinder and release the liquid when it is pressurized. Thus, the principle of work of piston pumps is similar to piston compressors. Note that piston pumps can be simple or double acting. In the case of a double acting pumps, the liquid is drawn in and compressed when the piston moves up and down *(see below)*



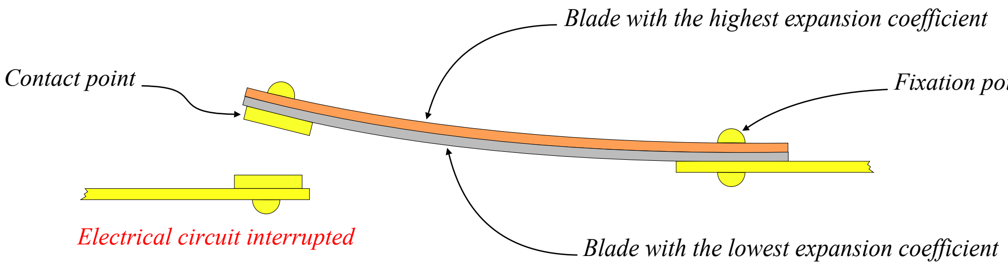
  The advantages of piston pumps are that they are less affected by variations of pressure than centrifugal pumps, they can deliver high pressures, and they are not affected by the heat. It is the reason they are also used with high-pressure water jets. Also, the pressure they deliver is not affected by their flow rate, and some models are able to auto prime.
  Their main inconvenience is that they deliver lesser flow rates than centrifugal pumps, and that this flow is pulsating. To finish, and as already said, their maintenance costs are more expensive.
  Piston pumps of the latest generation are equipped with a pulsation dampener. The system consists of a cylinder where a membrane separates a gas from the liquid that flows into it. The gas behind the membrane acts as a spring that flexes and absorbs the pulses, allowing a laminar flow downstream of the dampener. Note that this system is similar to the load limiters described in point 2.3.11.7.
  Also, to increase their durability, last generation pumps are fitted with ceramic pistons. The advantage of this material is that it has a highest resistance to corrosion, wear, and heat.
- Thermostat
  A thermostat is a device that controls the temperature of equipment by switching on or off the heating or cooling elements. On water heating machines, they are used to regulate the heat transfer from the heating elements to maintain the tank at the desired temperature.
  These devices can be mechanical and electronic and can be programmable. They work on the principle of the thermal expansion of solid materials. A lot of mechanical systems exploiting this principle can be found in the

form of strips that are coiled or not, bellows filled with gas, springs, etc. One of the simplest systems which are commonly used with thermostats is the "bimetallic strip" system:

- This mechanism consists of two pieces of different metals which have varying coefficients of expansion and are connected to form a single blade. These strips are arranged to create a bridge that can open and close in the electric circuit.
- When these metal strips are cold, the bridge is established, allowing the electricity to flow and activate the electrical elements *(see below)*.



- Depending on time and its intensity, the electricity flowing through these small pieces of metal heats them. As a result, the most conductive strip becomes hotter than the other, and because its expansion is different that the expansion of the coldest one, it bends the bridge and breaks the electrical circuit. As a result, the electrical elements are switched off.



- When the 2 strips return cold the bridge is reestablished and the electrical elements are energized again.

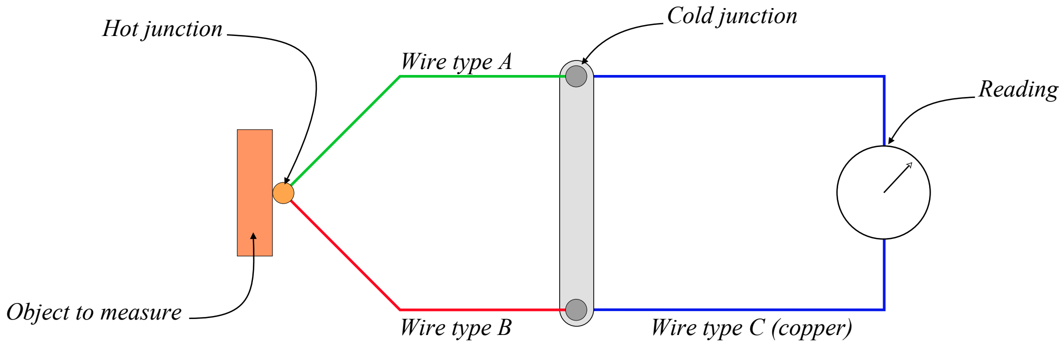
Electronic thermostats use the same principle, but they are controlled through a device called "thermistor". A thermistor is a resistor that reacts on temperature. Thermistors are also used for electronic sensors. Depending on the application two types of resistors can be used:
With a Negative Temperature Coefficient (NTC) thermistor, the resistance decreases when the temperature increases. NTC type thermistors are commonly used in thermostats, temperature sensors, or inrush current limiters.
With a Positive Temperature Coefficient (PTC) thermistor, the resistance increases when the temperature increases. This type of thermistor is generally used as a fuse.

- Temperature sensors:
Temperature sensors measure temperature and may be used to actuate switches. They are classified into two basic types: "Contact" and "non-contact" temperature sensors
  - "Contact temperature sensors" must be in physical contact with the object being sensed and use conduction to monitor changes in temperature. They are the models commonly used with hot water machines.

    Alcohol or mercury thermometers are based on the expansion of a fluid that it is exposed to heat. They consist of a liquid that is contained in a glass bulb which is connected to an expansion bulb by a capillary. Both connected bulbs are sealed at the extremities of the device. The space above the liquid is a mixture of nitrogen and the vapour of the liquid.
    These thermometers are commonly used, and one unit is fitted on the tank of the Comanex hot water machine described.

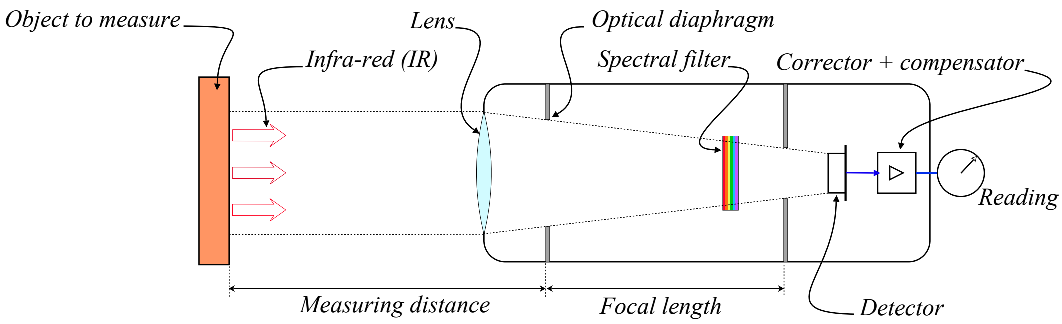
    The "bimetallic strip" system described above for thermostats is also used to design thermometers. In this case, the deformation of the blades, which is proportional to the heat, is used to display temperatures.

    Thermocouples and Resistance Temperature Detectors are typical examples of electrical-based contact temperature sensors.
    - A thermocouple is a device that creates electricity when heated. It is based on the thermoelectric effect that states that a temperature difference in a circuit made of two different conductors creates electricity and it does not with a circuit made of the same conductor.
    The thermocouple consists of two wires made from different metals that are welded together at one end, creating a junction called "hot Junction". This junction is where the temperature is measured. The other ends of the cables are connected in the "cold" junction which is maintained at a constant reference temperature.
    When the temperature of the "hot junction" change, it generates electricity through the loop. This electrical flow can be read using a voltmeter which reading is then translated into temperature using an appropriate formula.

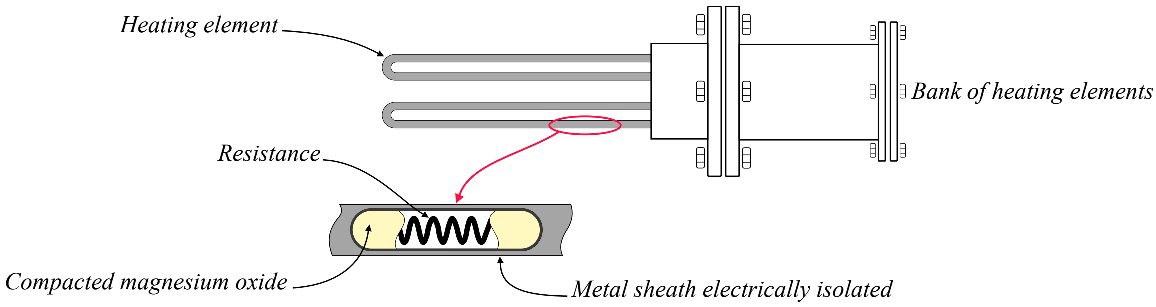


- A "resistance temperature detector" is a temperature sensor that contains a resistor that changes its resistance value as its temperature changes. The temperature sensor is made from a material whose resistance at various temperatures is documented and can be predicted. An electrical current is transmitted through this material and its resistance is measured and converted to temperature according to the resistance reading. Negative temperature coefficient (NTC) thermistors used for temperature sensing are part of this family.

◦ "Non-contact temperature sensors" detect the energy being transmitted from an organism, an object, a liquid or a gas, in the form of infra-red radiation (IR). The process is based on the fact that an element with a temperature above the absolute zero (-273.15°C = 0 Kelvin) emits an infrared radiation which is proportional to its temperature and can be measured. An infrared measurement device is composed of the following parts:
  - A lens that collects the emitted thermal radiation from a defined surface and a spectral filter.
  - A detector that converts this energy into an electronic signal
  - A correction system that is used to adjust the instrument according to the properties of the target.
  - A compensator that prevents the detector from factoring its own temperature into the output signal.



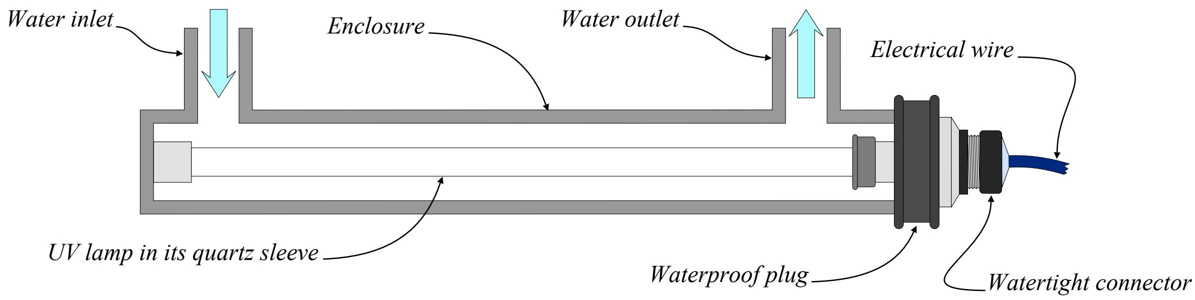
- Heating elements:
  Electrical diving hot water machines use immersed heating elements that heat the water of a tank as it is the case with the Comanex machine taken as an example for this topic. The volume of this tank and the number and the power of the elements vary according to the design of the device.
  A typical heating element is a coil, ribbon or strip of wire that gives heat similarly as a filament lamp. Thus it converts the electrical energy passing through it into heat that radiates out in all directions. The power of the heating element depends on the size and the materials used for this resistance.
  Heating elements are typically made of iron or nickel-based alloys. However, other alloys can be used. Nickel-chromium is often used with immersed heating elements because this material has a high melting point (1400ºC), a constant resistance, does not oxidize and does not expand too much when heated. This heating element is protected from the water by a metallic sheath. Also, magnesium oxide powder is widely used as a filling and isolator for electrical heating elements in contact with liquids. This material is employed because it has high thermal conductivity and low electrical conductivity.



- Ultraviolet (UV) rays:
  Divers in saturation live in a closed environment with an oxygen partial pressure of 400 mbar and above that is favorable for the proliferation of pathogens. Also, the duration of a saturation dive is up to six hours and long exposures to hot water rinses and alter the superficial layers of the skin which become more permeable to external agents like chemicals and micro-organisms. For these reasons, saturated divers are more vulnerable to

pathogens than surface orientated divers, and it is reasonable to ensure that pathogens that might have contaminated the hot water circuit are neutralized upstream to the Diver.
Ultraviolet (UV) radiations are known to alter the nucleic acids (DNA & RNA) of microorganisms and inactivate them. The effectiveness of this process is related to exposure time, lamp intensity and wavelength, as well as the number and varieties of the pathogens in the water.
Most lamps found in UV systems emit a wavelength of 254 nanometres, which is considered the optimum range for UV energy absorption by nucleic acids. The exposure time is reported in "microwatt-seconds per square centimetre" in some countries. However it is said that most scientists and engineers use units such as "millijoule per square centimetre" (mJ/cm^2) or "joule per square metre" (J/m^2). Studies have demonstrated that nearly all organisms are neutralized at doses above to 12 mJ/cm^2.

Ultraviolet lamps are generally installed in a pipe that is incorporated to the water circuit and is sufficiently narrow to neutralize the pathogens passing through. The bulb is housed in a quartz sleeve that protects it from the water. This pipe can be opened to change the bulb and being cleaned. Some installations use several units installed in series.



- Advantages of computer-controlled machines:
As indicated previously, the hot water systems studied in this presentation can be controlled from the electrical cabinet of the devices and from the dive control. However, the newest generation systems provide, more flexibility and more information than those of the previous generation. That can be demonstrated by comparing the command panels that are installed in the dive-control:

- The panel below, which is from the hot water machine of the previous generation is installed on UDS Picasso and provides the following indications and alarms:
  - #1 - Emergency stop hot water machine #1
  - #2 - Emergency stop hot water machine #3
  - #3 - Indicator heaters on
  - #4 - Water level fault
  - #5 - Heaters fault
  - #6 - Indicates that the control cabinet is on emergency power *(alarm)*
  - #7 - Buzzer *(audible alarm that switch on in the case of a fault)*
  - #8 - Indicator pump at work
  - #9 - Alarm pump
  - #10 - Alarm insufficient flow
  - #11 - Outlet temperature display
  - #12 - Adjustment outlet temperature
  - #13 - Mute audible alarm

  - With this system, the essential information is provided but it is not detailed.
  - The six 35 kW heaters are triggered and stopped at the same time by the controller, and the supervisor cannot operate them one by one.

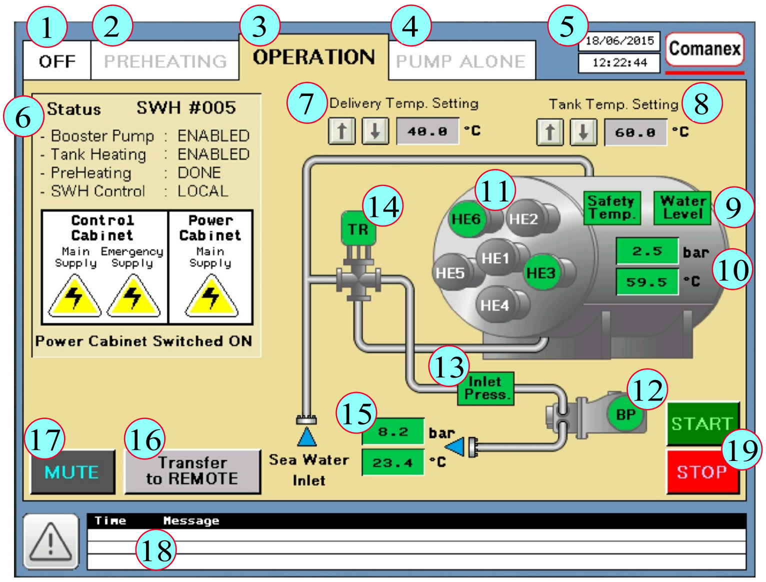
- It is true that it is possible to switch on or off some heating elements. However, in this case, the diving supervisor must ask the dive technician to do it from the panel of the machine where the six separate switches are installed *(See below and #14 in the photo of the machine on the previous page)*.
- As the commands of this machine are electrical, it is not possible to program-specific tasks that automatically optimise the functions of the device.

- As already explained, with the latest generation machines controlled by computer the electrical commands on the machine and in the dive control are replaced by Human Machine Interface (HMI) screens. These screens provide identical information on the machine and in the dive control. However, the HMI of the machine is the "master" and the one in the dive control the "slave". For this reason, to activate the screen of the dive control, the operator must enable it from the HMI installed on the electrical cabinet of the machine. In other words, the HMI in the dive control is an extension of the HMI of the machine.

UDS Picasso: Previous generation

Lichtenstein: New generation

Each HMI screen is designed as follows:



#1 - Command "off" HMI *(similar to the on/off of a computer)*
#2 - Selection "pre-heating panel" *(that is part of the pre-dive process of the machine)*
#3 - Selection "operation panel" *(it is this panel, which is used during normal operations)*
#4 - Selection "pump alone procedure panel" *(provides water from an external hot water source)*.
#5 - Date and time
#6 - Status:
Booster pump *(enabled or disabled)*
Tank heating *(enabled or disabled)*
Preheating *(not done or done)*
Status electrical supply *(control cabinet & power cabinet)*
Sea water heater control used *("local" indicates that the control is done from the machine)*
#7 - Delivery temperature setting
#8 - Tank temperature setting
#9 - Alarms temperature & water level tank
#10 - Temperature and pressure water tank
#11 - Heating elements *(green when active and red if in fault)*
#12 - Status & alarm pump *(green when active and red if in fault)*
#13 - Alarm inlet pressure
#14 - Status/alarm 3-way valve *(hot & cold water mixing)*

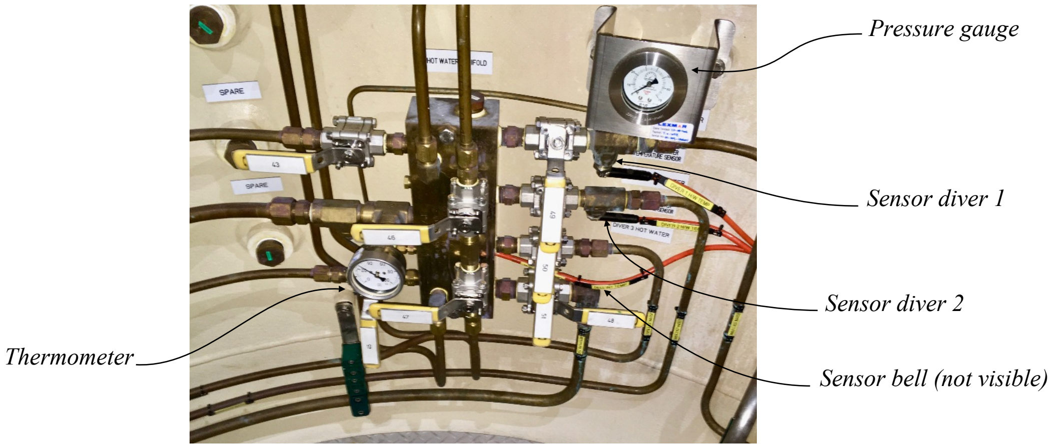
#15 - Temperature et pressure sea water inlet
#16 - Transfer to remote command *(activate the unit in the dive control)*
#17 - Alarm mute command
#18 - Alarm message records (time & description)
#19 - Machine start & stop commands

- With this system, the status of the main elements can be controlled at any moment. As a result, the operator is informed of what is performed by the machine from the water inlet to the delivery.
- The delivery temperature and the temperature of the tank, can be precisely set up
- The heating elements can be selected automatically or on demand from the cabinet or the dive control
- Alarm messages are documented and recorded

As a conclusion, computerized systems provide more flexibility and comfort in addition to the fact that the energy necessary to heat the diver is more optimised.

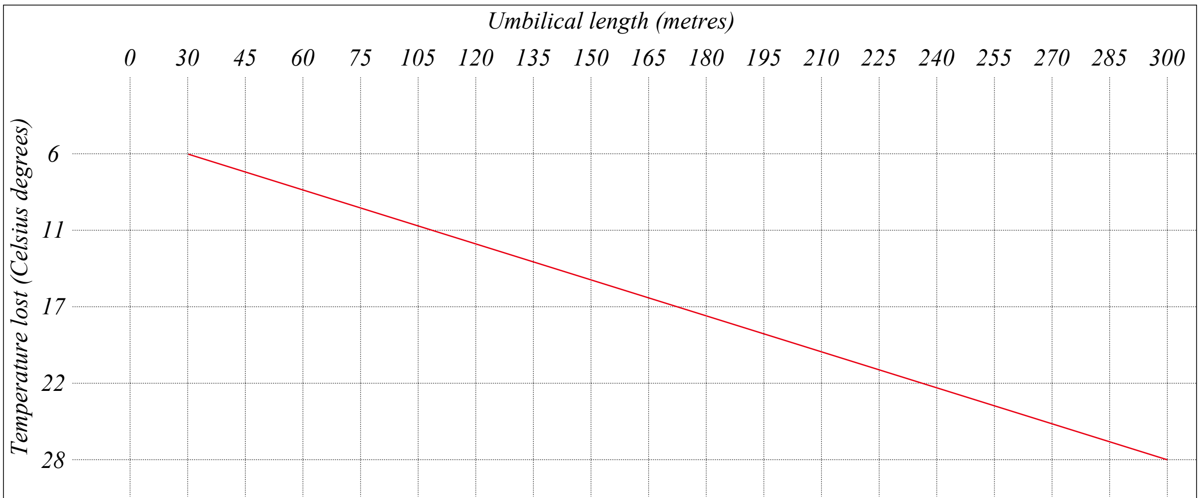
- Additional temperature controls

Already indicated with the heating system of the bell in point 2.3.2.7, sensors may be installed in the bell and linked to the dive control to alert the diving supervisor in the case of temperature, flow, or pressure change. That allows him to immediately adjust the temperature of the hot water machine to the desired temperature *(The system installed in Lichtenstein and Picasso is designed by Fathom)*. However, these sensors provide the temperature supplied at bell level and not at the end of the umbilical of the diver. For this reason, the supervisor is still obliged to extrapolate the needs of the diver according to the length of umbilical deployed from the bell.
In less advanced bells, temperature and pressure readings can be performed by the bellman using the thermometer and the pressure gauge installed on the hot water manifold. These readings are then reported to the diving supervisor.



2.3.13.3 - Settings

Before setting up the machine the necessary heat to provide, which is the addition of the desired temperature of the diver and the heat loss from the surface to the end of the umbilical, must be calculated.
Some manufacturers provide tables such as the one below to roughly evaluate the heat loss.



Approximate temperature loss through a 1/2" Synflex hose or equivalent, used with a surrounding seawater temperature of 2 - 5°C (source: Divex).

However, these tables are theoretical and cannot take into account the numerous variables that must be considered such as those listed below:

- The temperature of the surface of the sea varies according to the latitude, the season, and the weather conditions encountered. Also, note that rivers influence the temperature of the sea at the proximity of their mouth.

- The temperature of the sea is not affected by the weather conditions at deep depths but may vary according to the latitude.
- Cold currents may be encountered at any depth and speed up heat loss due to the increased convection.
- The configuration of the hot water system has an influence on the heat loss:
  - Heat loss will be different depending on whether the hot water machine and the umbilical are inside the vessel, or exposed to weather conditions.
  - The distance of the machine from the umbilical and the quality of isolation of the pipes also has an influence on the heat loss.
  - Heat loss may also depend on the configuration of the umbilicals and the quality of the hoses used.
  - As indicated in IMCA D 022 the water flow through the umbilical also influences the heat loss.

Experienced technicians and supervisors familiar with the diving system and the areas where the boat operates can establish heat loss charts more precise than those provided by manufacturers. Theoretical temperature loss can then be calculated using these tables. Nevertheless, if these charts cannot be created, the team can refer to those from the manufacturer.
Whatever table is used, some adjustments may be necessary when the bell arrives at depth. As indicated in the previous point, the water temperature and pressure can be read in the bell, and these data should be used to refine the setting of the machine. For these reasons, it is essential to set the machine in such a way that it will be available for supplying an increased demand for heat if requested.
Regarding this point, note that the manufacturer of the machine used as support for this study recommends to preset the tank 20ºC above the desired delivery temperature.
Note that the delivery temperature of the machine described is regulated by a motorised regulation valve that mixes hot and cold water to adjust the final temperature from 30 ºC to 60 ºC with a flow of 60 l/min *(see #5 & 6 in the photo)*. The temperature setting can be done and modified on the machine or in the dive control. When this setting is done, the device automatically adapts to deliver water at the temperature selected.
Similar systems can be found on other last-generation devices. However, a lot of old machines are not fitted with this option, and in this case, the water mixing must be done manually according to tables provided by the manufacturer. Also, the heating banks of a lot of modern, but less advanced machines, are not automatically switched on or off. In this case, the team will have to use the charts previously described that indicate the ideal combination of heating elements to obtain the desired temperature.
Note that, depending on the model, these machines generally require water supply at 2 to 3 bar minimum. Also, modern machines have a pressure by-pass fitted on the delivery manifold to protect the pump in the case of a blocked downstream flow. This valve can be set at the factory, or be adjusted according to the recommendations of the manufacturer.

Pre heating and "pump alone" procedure:
Hot water machines must be pre-heated prior to launching the operations. The duration of this procedure depends on the power of the device, the size of the tank to heat, the temperature of the seawater, and the desired delivered warmth.
This pre-heating phase can be speeded up or avoided with some machines that allow using the booster pump to transfer the hot water from another source. This function, which is available with the machine described as an example, also allows using this second source in the case of a breakdown of the heating system of the device.

2.3.13.4 - Oil-fired heaters

As mentioned previously, it seems that these machines become rare with built-in saturation systems and that they are more encountered with portable systems and surface orientated diving systems.

Their general design is similar to electric hot water systems except that the electrical heaters are replaced by a separate oil burner *(see #1 in the photo)* which heats freshwater or a fluid in a closed primary circuit that then heats the seawater through an exchanger. The heated seawater is then stored in a tank *(see #3)*. This process prevents salt deposits in the seawater canalizations. A separate fuel reservoir supplies this oil burner *(see #4)*.
Downstream from the tank, the delivery temperature is regulated by the 3-way regulation valve, already described with the electrical units, that mixes the hot and the cold water *(see #5)*.
The water is then circulated to the bell through the piston booster pump and the delivery manifold that is fitted with a temperature sensor, and a bypass regulator as with electrically heated machines *(see #6)*. Also, note that the mixing manifold is similar to the one described previously *(see #7)*.

Modern units such as the one in the photo on the right are provided with sensors that regulate the oil burner and allow the temperature control of the hot water machine from its panel *(see #8)* or from the dive control. Old generation units do not offer this option. As a result, the supervisor can monitor the parameters but cannot adjust the machine from the dive control and must ask the technician to do it.

The advantage of oil-fired heaters is that they can work with a limited electrical supply. It is the main reason they are appreciated by teams diving from vessels of opportunity or in cold and isolated areas.

However, due to the fact they burn fuel, these machines have numerous inconveniences that must be addressed. For this reason, IMCA D 024 / section 8, provides the following guidelines:

- Oil fired heaters must be located such that they present no risk to the dive system in the event of fire.
- Their position must also present no risk in terms of pollution or contamination of air supply intakes to the vessel or any breathing air compressors.
- They must be fitted with a spill tray which drains off to a safe area (to reduce risk of fire or pollution)
- Where possible the fuel supply should be hard piped.
- The local tank filler should be fitted with a dead-mans handle or automatic shut off valve which closes when the tank is full.
- The local tank must be fitted with an overflow system with a capacity greater than the filling supply system (i.e. capable of allowing a rate of overflow greater than the filling rate)
- The overflow system must dump to a safe area.
- The fire fighting systems are those indicated in point 2.3.13.1.

Another problem with this type of machine is that they emit a naked flame. Even though this flame is in a controlled space, that limits their use to areas that are not likely to a sudden gas release. Note that such conditions can be found on some oilfields.

2.3.13.5 - Routine maintenance and inspection

As for every device that is part of the diving system, periodic maintenance and test of the hot water machine should be carried out on a regular basis. IMCA D 024 says the following:

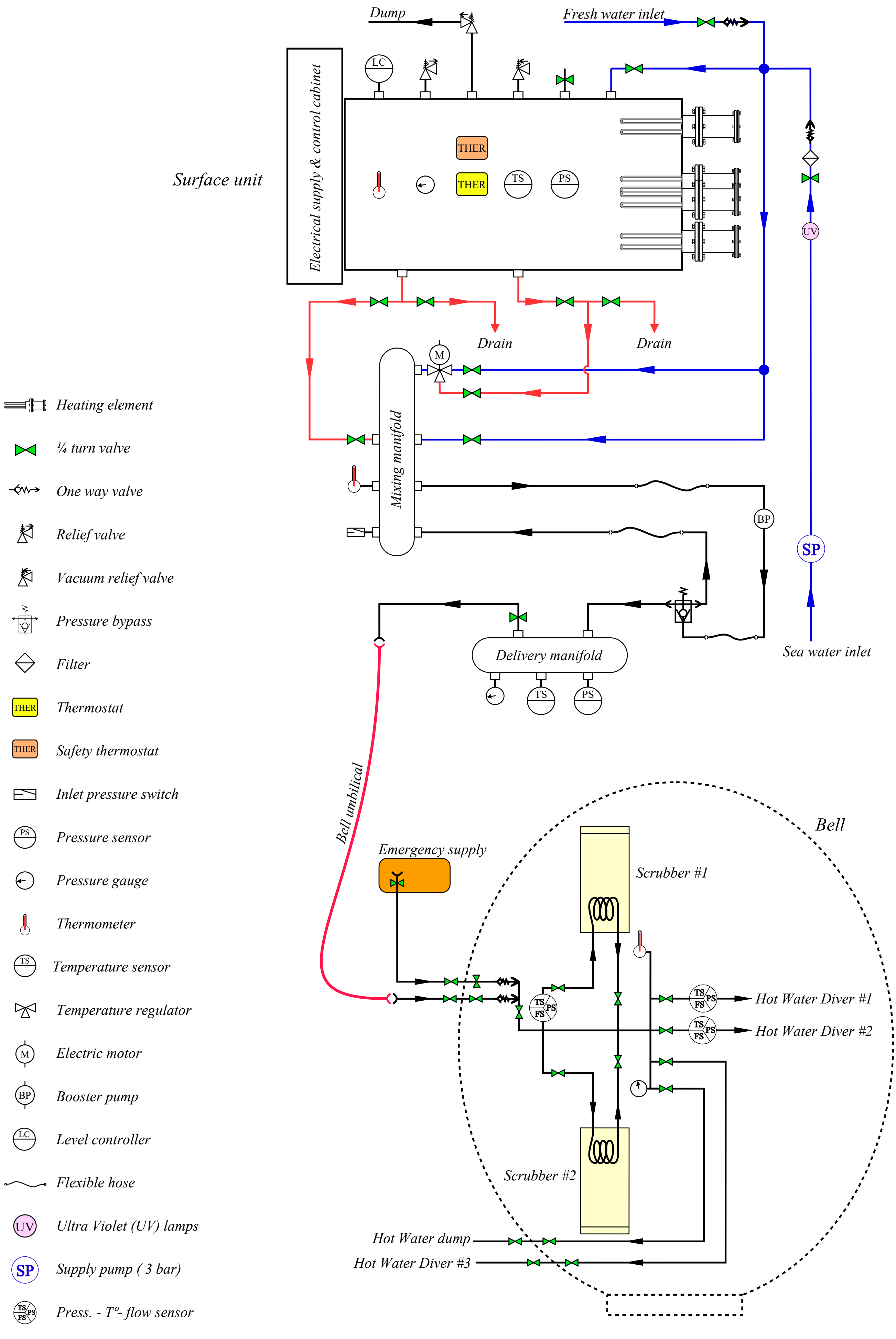
Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure*	*Other*
Fire fighting portable system	6 months			Manufacturer specifications
Fire fighting fixed system	6 months	12 months		Manufacturer specifications
Automatic fire detection	12 months			Manufacturer specifications
Hot water system	6 months			Manufacturer specifications
Pipework and fittings	6 months	24 months		
Gauges (calibration and test)	6 months			
Electrical systems	6 months			
Pressure vessels	6 months	15 months	5 years	
Alarms	6 months			
Relief valves	6 months	30 months		

Manufacturers provide the following guidelines:

- The machine must be visually checked before starting it.
- The seawater filter must be checked and cleaned daily, or in the case of loss of pressure or flow.
- The oil level of pumps and motor outputs must be checked every day. This oil should be replaced according to the recommendations of the manufacturer.
- The tension of the belt (electric motor - pump) must be checked every week, or in the case of unusual noise or vibrations.
- The circuits and pump must be rinsed with fresh water after the bell run. In addition, in the event of an extended shut-down period, the heating tank must also be cleaned with freshwater and drained.
- The zinc anodes fitted on the machine to prevent corrosion should be checked monthly.
- Because the failure of the automaton will prevent the use of the machine, the manufacturer of the system described recommends storing a backup device with its program as a precaution.
- It may happen that some parts are more sensitive to wear than initially planned. That can be linked to numerous reasons that may be difficult to investigate and not only the machine itself. In this case, it is prudent to increase the frequency of checks and the renewal of these sensitive parts.

2.3.13.6 - Overview of the heating system

As for other systems, this drawing allows a general view of the heating system of the bell and the divers.

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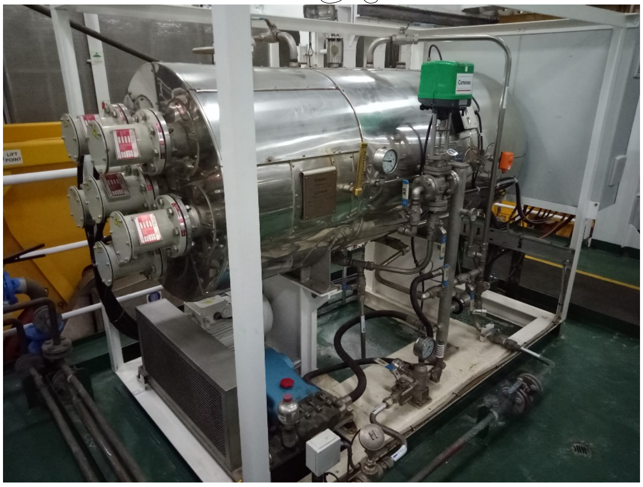
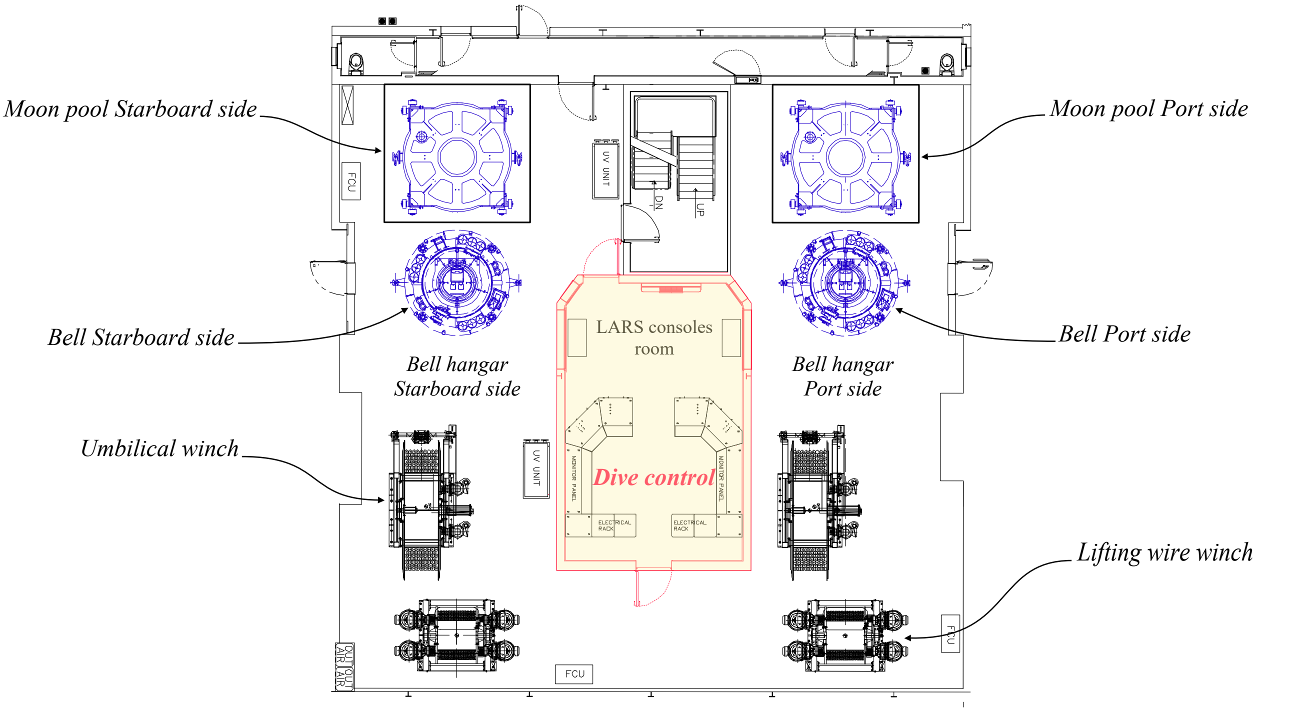


2.3.14 - Dive control

The dive control is the place from which the diving supervisor manages the diving operations. For this reason, it must be organized to allow him full control of the dive and of the elements that may interfere with it and to provide him a minimum of comfort. As a result, the commands of the systems previously described are grouped in with the communications to the essential parts of the vessel. The dive controls are generally installed above the launching area or at its level to allow a panoramic vision of the bell from the control console of the Launch And Recovery System (LARS), which is usually in a nearby room or the same room as the dive control. Their access should be comfortable and safe. IMCA D 024 provides precise guide-lines regarding the way a dive control should be organized that are followed by most manufacturers.

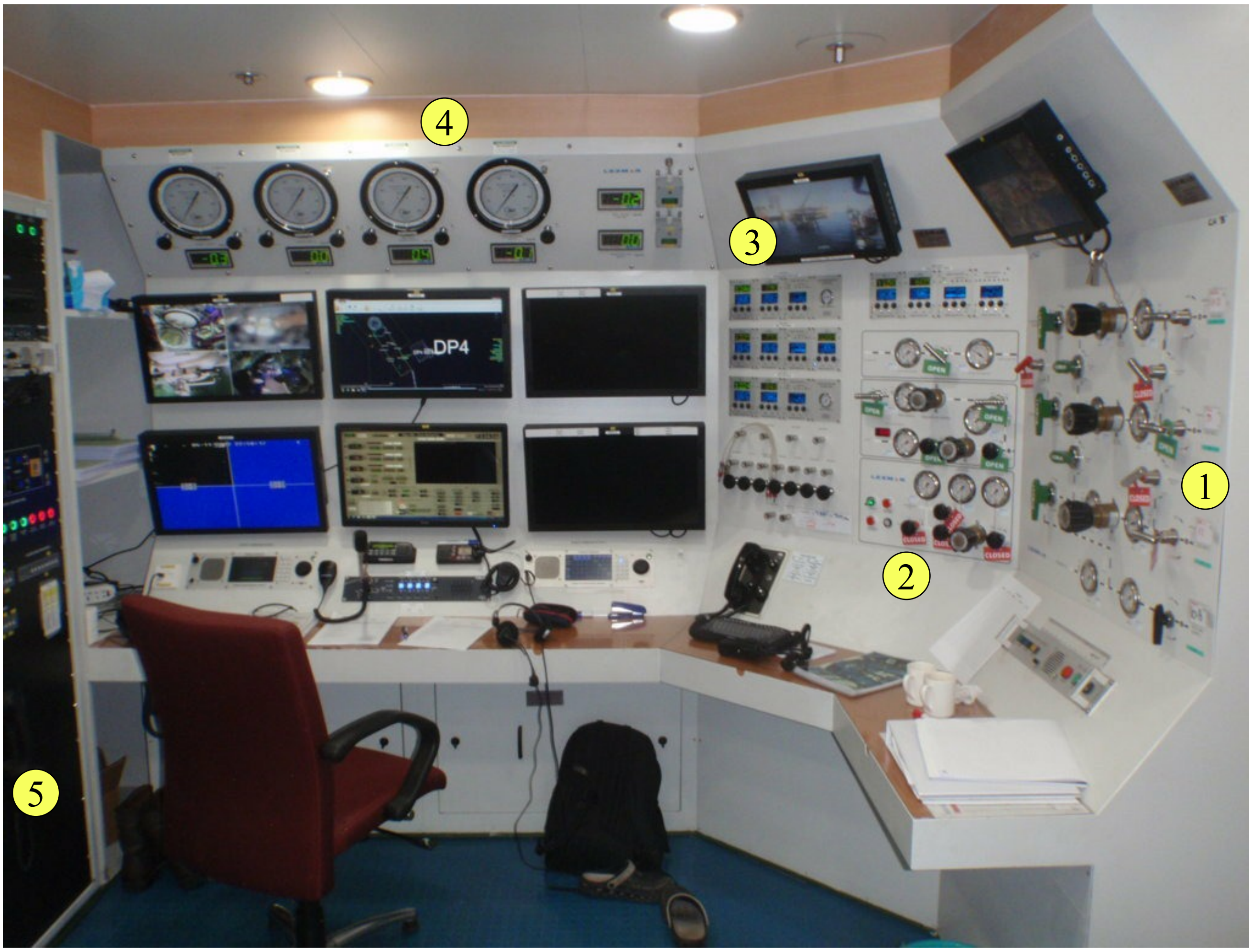
2.3.14.1 - General design

IMCA says that the diving supervisor must be protected from weather and other elements (including dropped objects) which may affect his concentration, and be kept suitably warm or cool.
Also, all gauges, displays, and relevant areas of control should be easily accessible and readable without difficulty. For this reason, the dive control and its controls must be adequately illuminated for operations during the day and night. In addition, the dive control should be suitably isolated from external noises that may disturb clear communications.
Usually, the dive controls of portable systems are organized in a dedicated 20 feet container which is protected from extreme temperatures and noises from the deck by several layers of appropriate isolation foam or wool. Also, it is warmed and cooled by relevant heating elements and air conditioning systems. However, due to their direct exposure to the weather conditions and the activities on deck, these dive controls are less comfortable than those of built-in systems that are installed in calm and weather protected areas of the vessel. It is the case of the dive control rooms of UDS Lichtenstein and Picasso which are situated between the moon pools at shelter deck level, so is inside the boat and in an area protected from external temperatures by appropriate isolating materials. As these vessels are provided with two bells, two fully separate diving panels allow controlling the starboard side bell and the port side bell. In fact, there are two dive controls grouped in one room *(see below)*.



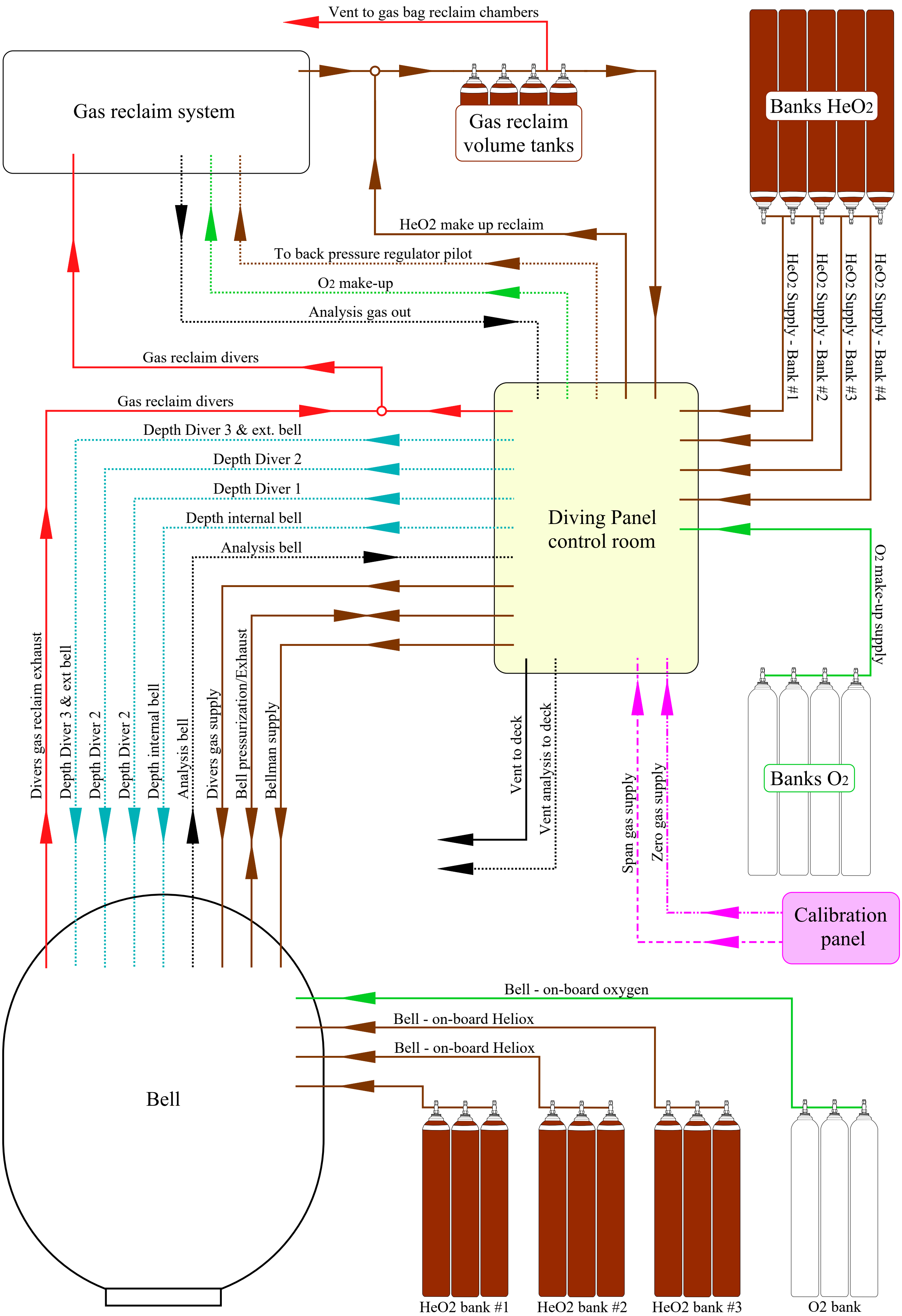
Each dive control panel is organised as follows:

1. The gas panel is already described in point 2.3.12 *"Gas reclaim system of the bell"*.
   As a reminder, the gas inlet panel is supplied with pre-mix supplies, gas reclaim make-up supply, and a supply from the divers reclaim system.
   Note that the pre-mix supplies and gas reclaim makeup are fed from the distribution panel in the gas storage room situated on the tween deck, or from the gas storage on deck. The pre-mix supplies and gas reclaim make-up supply are individually regulated to the required pressure for the diving operation.
   There is a valve system which directs the incoming gasses to the bell blow down hose, and the divers breathing hose in the bell's umbilical. The reclaim system can also be charged from this panel. The valve system prevents the reclaimed gas supply from being directed into the bell blow down hose.
2. The reclaim management panel, also described in point 2.3.12, allows the entire reclaim system to be monitored and operated from the dive control. It receives gas from the main gas supply panel. An O2 supply is also included for PPO2 control.
3. The gas analysis panel consists of the 4 x Carbon dioxide, 4 x Oxygen, analysers described in point 2.3.12. Below this panel is a patch panel fitted with quick connectors. This allows the dive supervisor to connect between the various supplies to individual analysers in order to provide calibration and zero gases, analyse the diver breathing gas, the bell internal atmosphere, the reclaim supply and any of the pre-mix supplies.
4. The diving monitoring panel accommodates the electronic depth gauges of the divers, bell (internal and external), bell trunk, and transfer lock. These gauges are readable from afar. Also, classical pneumo gauges are installed to double check the depth of the bell and the divers.
   Communication systems to the divers and the bell are in place. They are digital systems designed by Fathom systems http://www.fathomsystems.co.uk/. Also, a diver monitoring system, designed by the same manufacturer, groups all the essential information on a screen in the middle of the control panel. This system is described with others in the next points.
   Wired communications to the bridge, superintendent and client offices, and radios to contact the bridge, the personnel on deck or a boat cruising in the vicinity during the diving operations are also installed.
   A series of screens allows controlling the divers, the inside of the bell, the ROV, the position of the divers and of the vessel, the transfer lock and the strategic points of the deck are in place.
   Audible and visible alarms conforming to IMCA D 024 requirement are also installed.
5. Two side racks house the black boxes and video recording systems, the controls of the bell lights , The hot water controls, the power supply controls of the bell and diving panels with Uninterruptible Power Supply (UPS), The emergency sound powered phone, the through water communication system (wireless communications to the bell), and the intercom interface in which all intercoms are connected.

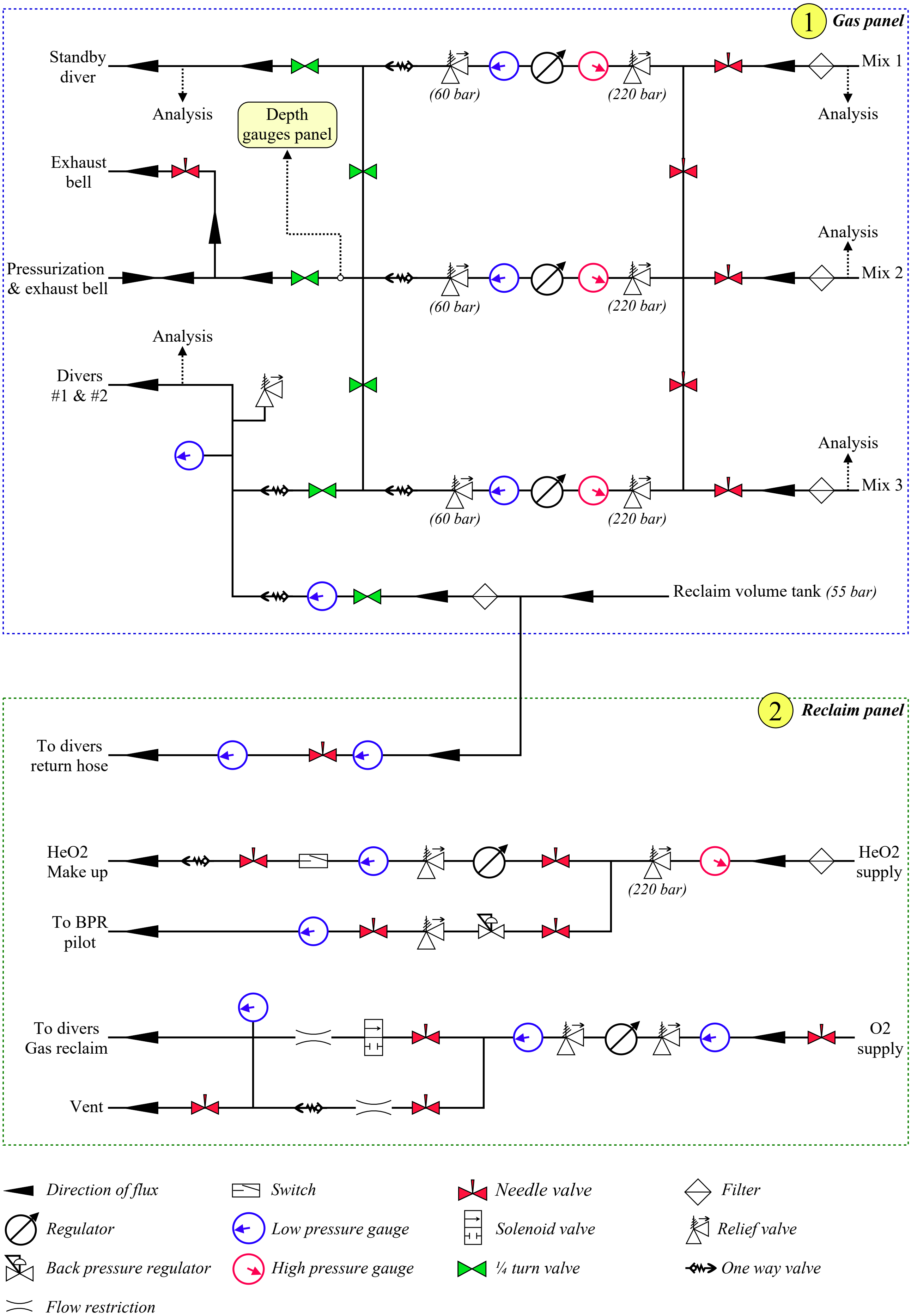


2.3.14.2 - Gas management panels

As already said, these panels control the distribution and the recycling of the gas to and from the bell. For a better understanding, it is essential to have an overview of the gas distribution to and from the dive control to provide sufficient breathing gas to the bell. It is the purpose of the scheme below.



As a complement of the scheme on the previous page, the drawing below, which is also displayed in point 2.3.12, shows the interconnections between the gas supply and gas reclaim panels and the function of the various supply lines.

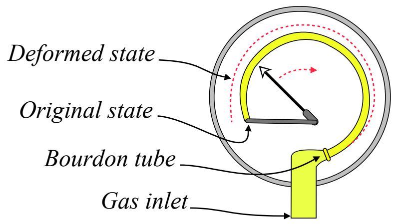


Note that the gas analysis panel is already fully explained in point 2.3.12 and is not explained again here for this reason.

Regarding gas supplies, IMCA D 024 says that sufficient sources of gas of breathing quality must be available and suitably arranged, so that if the online source to the diving bell or the diver fails an alternative source can be immediately switched on line. This point is confirmed by other organizations such as NORSOK, which also says that a minimum of two independent gas supplies is required to the panel supplying the main umbilical, and that the divers at work and the stand-by diver must have their own dedicated primary gas supply and a separate secondary gas source immediately available as a back-up.
Note that the diving systems taken as examples are widely beyond these minimum requirements as four distinct gas inlets are connected to the gas panel and should be in service in addition to the onboard gas of the bell. Also, the gas management panel of the bell described in point 2.3.2.7 is designed to open and isolate the supply lines according to the requirements indicated above.

Regarding gauges, IMCA D 024 says that there must be enough suitable gauges so that the diving supervisor is aware of the depth of the diving bell, each diver and of the supply pressures of each main and secondary breathing supply. These gauges must be protected by pressure limiting devices to avoid over pressurization that may damage them. Note indicated by IMCA, but very important, the gauges used with mixes containing more than 25% oxygen (22% with NORSOK) must be oxygen compatible and cleaned. The gauges used in last generation systems can be analogical or digital.

- Analogical gauges are usually bourdon tubes. They consist of a tube with the shape of an interrogation point and an oval cross-section which is open at one end and closed at the other one. The gas is directed inside this tube, and its pressure produces motion in the closed end of this tube, which is attached to a lever and a small mechanism that moves a needle. This needle indicates the pressure to read on a dedicated scale. The inconvenience of this system is that with time the shape of the tube slightly changes and it must be recalibrated or replaced.



- Digital pressure gauges are devices that convert applied pressure into signals which are displayed numerically. These gauges are based on various technologies that react to changes in pressure such as the mechanical deflection of a specific flexible element or a diaphragm, or strain-sensitive variable resistors that are used as elements in resistance bridge circuits that perform measurements. Also, pistons, vibrating components, micro-electromechanical systems, or thin-film can be used to sense changes in pressure.

Also, IMCA divides the gauges into two categories according to their function: Depth monitoring and and gas supplies monitoring.

- Depth monitoring gauges are used for operational and decompression control. IMCA says that the scale of analogical gauges must be appropriate to their usage and large enough to be read efficiently and accurately. They should operate in the range of 25 to 75% of their full-scale deflection *(see below)*. IMCA also says that they must work in the 0 to 25% range if used for decompression and must have scale divisions of no more than 0.5 msw / 2 fsw if used for the final stages of decompression. However, the bell is not the place where decompression is usually undertaken.
  If digital gauges are used, their display must be large and clear enough to be read in all conditions and the unit used must also be marked, they must display at least one decimal point *(see below)*.

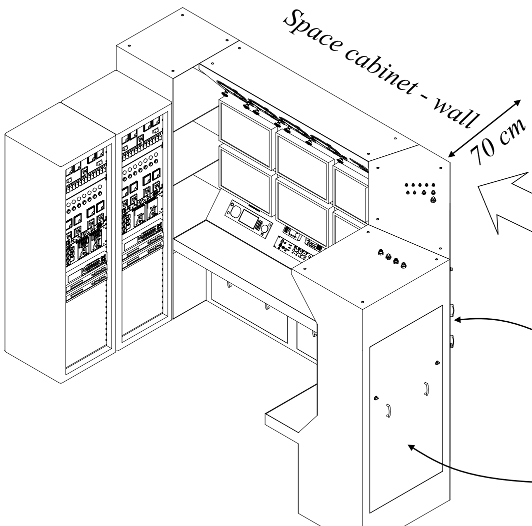
- Gas supply gauges are used for life support or as indicating gauges. IMCA says that they are not calibrated as depth gauges and must be positioned to show the line pressure of sources coming into the panel and also of any supplies leaving the panel. In addition, a system must be in place to ensure that incorrect readings cannot happen in certain valve positions. Their scale divisions must be as for depth gauges above except that they may be much smaller and with larger scale divisions. All gas supply gauges should be marked in the same unit system (imperial or metric) and dual scale marking is accepted.
  Supply gauges are usually provided with a flow restrictor that reduces the gas flow into a tiny gas trickle, so the gas leak does not affect the diving operation in case a gauge is dislodged or damaged. This item must be indicated on the panel schematic. Another system is to fit the gauges with an isolation valve providing that:
  - closing the valve does not interfere with the diver's supply.
  - the handle on the valve clearly indicates whether it is open or closed.
  - the handle is secured in the open position using light wire, tape or similar such that it cannot be inadvertently closed.

IMCA recommendations regarding valves are the same as those explained with the bell:

- The valves must be easy to operate, not be corroded, and their function must be clearly marked.

Also, when used with gas mixes containing more than 25% oxygen (NORSOK says 22%) valves and pipework Should be cleaned for oxygen service. IMCA says that "oxygen cleaning" should be demonstrated using a suitable procedure to ensure cleanliness, which is applied when any components are new or after there has been any significant alteration. Not indicated by IMCA, but very important, the materials used with these supplies must be oxygen compatible. This important requirement is explained at the beginning of this document. Also, NORSOK and classification bodies recommend to minimize to use of flexible hoses.
IMCA says that due to the depths involved in saturation diving, the pressure of such gases will often require to be above 15 bar, and that valves carrying oxygen and mixes containing more than 25% oxygen (22% with NORSOK) at a pressure higher than 15 bar must not be quarter turn. The reasons of this rule are linked to the possible ignition of oxygen that may destructs the gas circuit and injury or kill the divers. These effects are already explained in point 2.3.2.6 and at the beginning of this document. Note that the American Society for Testing and Materials (ASTM) recommends needle valves with a non-rotating stem.

- Exhaust pipework must not vent into an enclosed space. For this reason, they are generally directed to safe areas on deck *(see the general scheme)*. IMCA says that panel pressure relief valves and sampling for analysis do not constitute exhaust pipework. However, they are usually directed outside the room as well to avoid any unexpected oxygen concentration in the room.
- IMCA says that gas pipework, particularly in panels and at connection points, must be easily accessible for maintenance and repair. It is the reason that most dive controls are designed with access to the back of panels. It is the case of the systems used as support for this presentation which cabinets where the panels are housed can be opened from the back. Also, note that these cabinets are separated from the wall of the room by a space of approximately 70 centimetres that allows the technician to intervene comfortably.



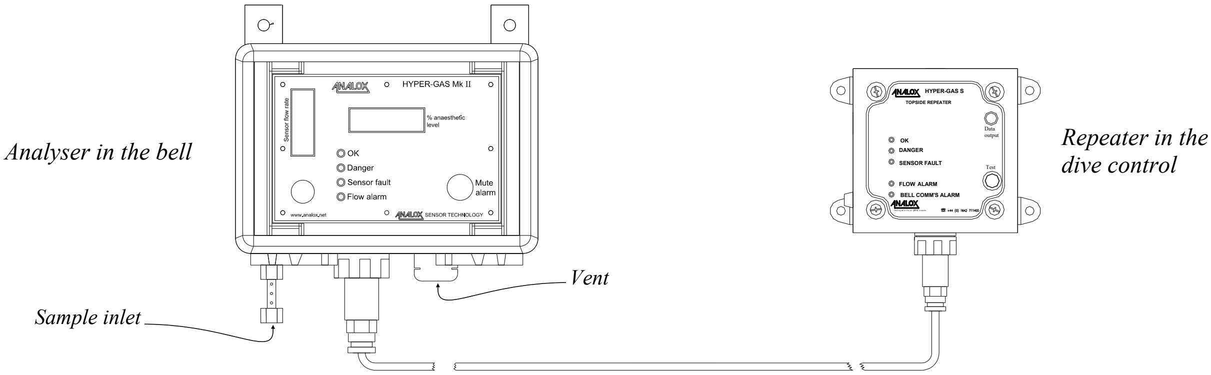
- Cross over valves are often installed on gas panels of saturation systems. IMCA says that cross-over valves should either be fixed in one position (the handles may be removed to avoid accidental changes) or should indicate very clearly which source they are connected to. In any event any gauge fitted with a cross-over valve must indicate very clearly at all times exactly what it is reading. This is particularly important if one gauge can show the depth of more than one diver.

Analysers used to control the gasses supplied to the bell and the panel in which they are grouped are already described in point 2.3.12.4 "Control console unit". Please, remember that regarding this point IMCA says the following:

- *There must be an oxygen analyser with an audible and visible high and low alarm fitted in line on the downstream gas supply to the divers*
- *If diver gas reclaim is being used, there must be a carbon dioxide analyser with audible and visible high level alarm fitted to the down-stream side of the diver gas supply. The adjustment of gas sample flow rate must not affect any other analyser fitted*
- *There must be a means by which the diving supervisor can monitor the bell atmosphere for oxygen and carbon dioxide levels. This may be by a manual procedure carried out by the bellman or by a remote reading in dive control*

Note that a hydrocarbon analyser is often installed in the dive control. This item is optional with IMCA, which considers that it should be installed following a risk assessment. However, it is mandatory with IOGP *(international association of oil & gas producers)*. As a result, contractors working for IOGP members must have this device permanently in place. The reason for this stringent rule from IOGP is that the majority of hydrocarbons are found in crude oil and natural gas, where decomposed organic matter provides an abundance of carbon and hydrogen. Hydrocarbons can be found near the installation where the diving operations are organized and can enter the bell during the dive or soil the diving suits of the divers and then be released in the bell atmosphere. Hydrocarbons can cause pneumonitis and systemic effects such as central nervous system depression with respiratory and cardiac failure. Some other potential damages can be done to the liver, kidneys, or bone marrow. The onset of these effects is usually rapid. Note that hydrocarbons and their effects are described in the document "Diving accidents" of this manual.

In appendix 8 “saturation diving“ of IOGP 411 “Diving recommended practices” it is indicated that the bell must be equipped with a hydrocarbon analyzer similar to the “hypergas MK2” proposed by the company Analox. This analyzer has a bell monitor which will detect the presence of vapoured hydrocarbons, and the topside repeater installed on the diving panel. Both items have audible and visual alarms running before the anesthetic threshold is reached.



In addition to the analysis of the gasses of the bell, the atmosphere of the dive control must be monitored for oxygen content. The reason is that undetected leaks may happen and build a flammable atmosphere.
Note that this requirement, which is indicated in the latest version of IMCA D 024, was not in force when some old generation systems had been built. As a result, ambiance oxygen analysers must be added in the dive control to comply with this rule if they are not already installed. Such analysers are specifically designed for this purpose and must not be confused with those used to monitor the bell atmosphere. Their concept may be based on those previously described in point 2.3.12.4 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 need a very reduced gas flow.
Manufacturers recommend installing the air intake of such 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.

2.3.14.3 - Communications, surveillance, recording, alarms, and electrical supplies

Communications, surveillance, and recording are of utmost importance during the diving operations. These elements can be divided into two segments: Communication and supervision of the bell and communications with the bridge and other vital parts of the vessel involved in the diving operation. Note that some elements are mandatory and some other are optional with IMCA. However, these optional elements may be required by clients or other safety organizations. For this reason, new saturation systems and Diving Support Vessels (DSV) are often fitted with them to avoid last-minute installation and improve their efficiency and safety. They can be classified into the two tables below:

Communications and monitoring bell

No	*Description*	*Requirements IMCA*	*Requirements from clients and other organizations*	*Additional information*
1	Two way voice communications divers (working divers & rescue diver)	Mandatory	Mandatory	There should be four wires into the communication cable to allow the installation of duplex communications. A duplex communication system enables all parties connected to the system to talk and listen at the same time.
2	Two way voice communications to the bellman	Mandatory	Mandatory	
3	Sound powered phone	Mandatory	Mandatory	
3	Through water communications (wireless comms)	Mandatory	Mandatory	
5	Video cameras outside and inside the bell	Not indicated	Mandatory (NORSOK and most clients)	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. Cameras are usually installed at the top, bottom and inside the bell.
6	Video cameras divers	Not indicated	Mandatory (NORSOK and most clients)	According to NORSOK U100, a diver must be monitored by an ROV or a 2^{nd} diver camera.

Communications and monitoring bell (continuation)

No	Description	Requirements IMCA	Requirements from clients and other organizations	Additional information
7	Diver Monitoring System	Not indicated	Not mandatory outside Norwegian waters / Mandatory with NORSOK and some clients	NORSOK says: *"A diver monitoring system shall be provided for each diver"*
8	Communications divers - supervisor recording	Mandatory	Mandatory	Retention of records is 24 hours with IMCA and 48 hours with NORSOK
9	Divers' video camera recording	Not indicated	Mandatory with NORSOK and most clients	Retention of records should be 48 hours
10	Divers' exposure data recording	Not indicated	Mandatory with NORSOK and some clients	NORSOK says that the diving contractor must have a system for recording the divers exposure data

Communications, monitoring and alarms vessel

No	Description	Requirements IMCA	Requirements from clients and other organizations	Additional information
1	Hard wired communications to and from the bridge (Intercom)	Mandatory	Mandatory	The primary link must be hard wire, immediately available and unable to be interrupted.
2	Wired secondary communications to and from the bridge	Optional	Optional	The secondary link can be hard wired, or a dedicated radio channel.
3	Hard wired communications to and from the launch and recovery console (winch operator)	Mandatory	Mandatory	These communications can be verbal if the console is in the same room as the supervisor.
4	Hard wired communications to and from the crane (Intercom)	Mandatory	Mandatory	Radio is no more accepted as main communication with the crane
5	Hard wired communications to bell trunk LARS deck (trunk connection)	Mandatory	Mandatory with most clients and contractors	There should be a clear connection between the competent person who monitors the bell on deck and the LARS operator and the diving supervisor. Hard wired communications have the advantage to be dedicated and not interrupted.
6	Hard wired communications to and from the ROVs (Intercom)	Mandatory	Mandatory	
7	Hard wired communications to and from the saturation 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.
8	Secondary hard wired communications to and from the saturation control room (Intercom)	Nothing indicated (It can be the phone)	Mandatory with most clients and contractors	Saturation control rooms are often in places where radio communications cannot work. For this reason, secondary communications should be hardwired
9	Hard wired communications to and from the surface orientated dive control room (if the dive controls are separate)	Mandatory	Mandatory with most clients and contractors	Surface orientated divers may be involved to rescue the bell. Hard wired communications have the advantage to be dedicated and not interrupted.
10	Hard wired communications to and from the survey control room (Intercom)	Mandatory	Mandatory with most clients and contractors	See above
11	Hard wired communications (Intercom) to and from Offshore Installation Manager (OIM) office	Nothing indicated (It can be the phone)	Mandatory with most clients and contractors	See above

Communications, monitoring and alarms vessel (continuation)

No	***Description***	***Requirements IMCA***	***Requirements from clients and other organizations***	***Additional information***
12	Hard wired communications (Intercom) to and from the conference room	Optional (It can be the phone)	Optional (It can be the phone)	Onboard new vessels, this office is generally connected to the dive control by hard wired communications
13	Hard wired communications (Intercom) to and from the inspection office	Optional (It can be the phone)	Optional (It can be the phone)	See above
14	Radio communications to boats cruising within the vicinity of the vessel	Mandatory	Mandatory	
15	Radio communications to key people or used as 2nd means of communication	Mandatory	Mandatory	Can be used as a 2nd means of communication with areas that have primary hard-wired communications
16	Phone (wired) communications to the areas indicated before and other parts of the vessel	Optional (It can be the intercom)	Mandatory with most clients	Onboard new vessels, office and cabins are generally connected to the dive control by phone communications
17	Video signal from ROV	Mandatory	Mandatory	The picture is the same as the pilot
18	Video signal from the launching and recovery areas and appropriate working areas	Mandatory	Mandatory	Cameras are not mandatory for the areas the supervisor has a direct view
19	Video signal from surface orientated dive control (if the dive controls are separate)	Not indicated	Mandatory with most clients	Surface orientated divers may be involved to rescue the bell. For this reason, the saturation supervisor must have a visual of what is carried on
20	Data from survey control to combo screen.	Not clearly indicated	Mandatory with most clients	A data screen indicating the position of the vessel and the divers is common today and often mandatory.
21	Video signals to bridge	Not indicated	Mandatory with most clients	A video screen showing the ongoing work of the diver to the bridge is mandatory with most clients. A similar screen from the ROV and the surface orientated dive-control is also compulsory.
22	Video signals to client office	Not indicated	Mandatory with most clients	A video screen showing the ongoing work of the diver to the client office is mandatory with most clients. A similar screen from the ROV and the surface orientated dive-control is also compulsory.
23	DP alarms	Mandatory	Mandatory	The diving supervisor must be able to mute the alarm if it is disturbing the communications.
24	Vessel emergency alarms	Mandatory	Mandatory	Fire alarm, abandon ship, personnel falling to the sea, gas release, etc. This alarm can also be muted.

Electrical supplies to and from the dive control

No	***Description***	***Requirements IMCA***	***Requirements from clients and other organizations***	***Additional information***
1	Main electrical supply 220 volts AC from generators	Mandatory (but voltage not indicated)	Mandatory (but voltage not indicated)	Dive controls are generally supplied with 220 volts AC, which is converted from the main generator(s) that provide current of higher voltages for the needs of the vessel. Note that some variations of voltages may be found such as 230 volts AC.
2	Backup electrical supply 220 volts AC from generators	Mandatory (but voltage not indicated)	Mandatory (but voltage not indicated)	See above

Electrical supplies to and from the dive control (continuation)

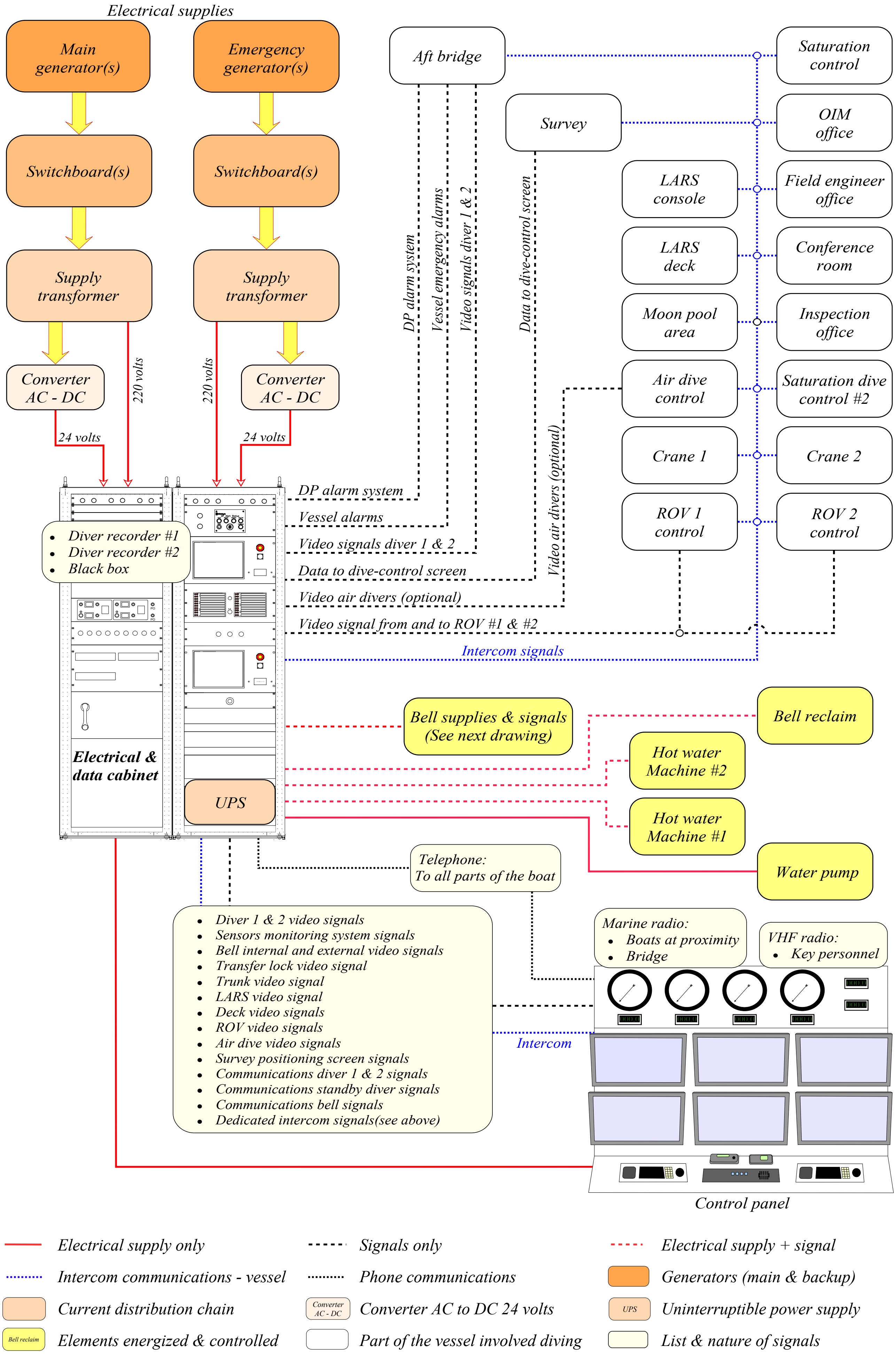
No	Description	Requirements IMCA	Requirements from clients and other organizations	Additional information
3	Main electrical supply 24 volts DC from generators	Mandatory (but voltage not indicated)	Mandatory (but voltage not indicated)	24 volts DC is generally converted from the 220 volts AC, which is converted from the main generator(s) that provide current of higher voltages for the needs of the vessel. This current is sent to the bell (24 Volts DC is not dangerous) and used to supply elements working with this type of electrical supplies. Note that some variations of voltages may be found such as 36 & 26 volts DC.
4	Backup electrical supply 24 volts DC from generators	Mandatory (but voltage not indicated)	Mandatory (but voltage not indicated)	See above
5	220 volts AC and 24 volts DC (or relevant voltage) from Uninterruptible Power Supply (UPS)	Mandatory	Mandatory	An UPS is a device that allows essential devices to keep running for at least 30 minutes (IMCA) when the primary power source is lost and the secondary supply is not yet engaged. Systems commonly supplied: - Communications systems not fitted with batteries - Recording - Emergency lights allowing to continue to manage the dive . - Video systems (optional with IMCA)
6	Current 24 volts DC to diving bell	Electrical supply of the bell is mandatory (voltage not specified)	Electrical supply of the bell is mandatory (voltage not specified)	This current is used to supply the elements of the bell for the reasons indicated in point 3. The switches of of helmet lights are in the electrical cabinet The elements usually supplied are: - Bell external cameras - Bell internal camera - Bell lights - Divers lights - Divers cameras - Scrubbers - Onboard batteries (charging) - Through water communication batteries - Sensors monitoring system - Hydrocarbon analyser (mandatory IOGP)
7	Current 220 or 110 volts AC to diving bell	Noting specified	Nothing specified	This current usually supplies the external lights only. The switches of these lights are in the electrical cabinet

Machineries controlled from the dive control

No	Description	Requirements IMCA	Requirements from clients and other organizations	Additional information
1	Bell reclaim system	Mandatory	Mandatory	Refer to the full description in point 2..3.12 An emergency stop allow to stop the unit from the dive control.
2	Hot water machine divers #1	Mandatory	Mandatory	Refer to the full description in point 2..3.13 An emergency stop allow to stop the unit from the dive control.
3	Hot water machine divers #2	Mandatory	Mandatory	See above
4	Water pump	Nothing specified	Nothing specified	This pump supplies the water to the hot water machines.

Hyperlink Tables of contents

The scheme below, which is based on drawings of UDS Lichtenstein, represents the main electrical supplies and wired communications of the dive control. Note that the communications and supplies to and from the bell and the client representatives office are not in this scheme and are explained on the next pages.



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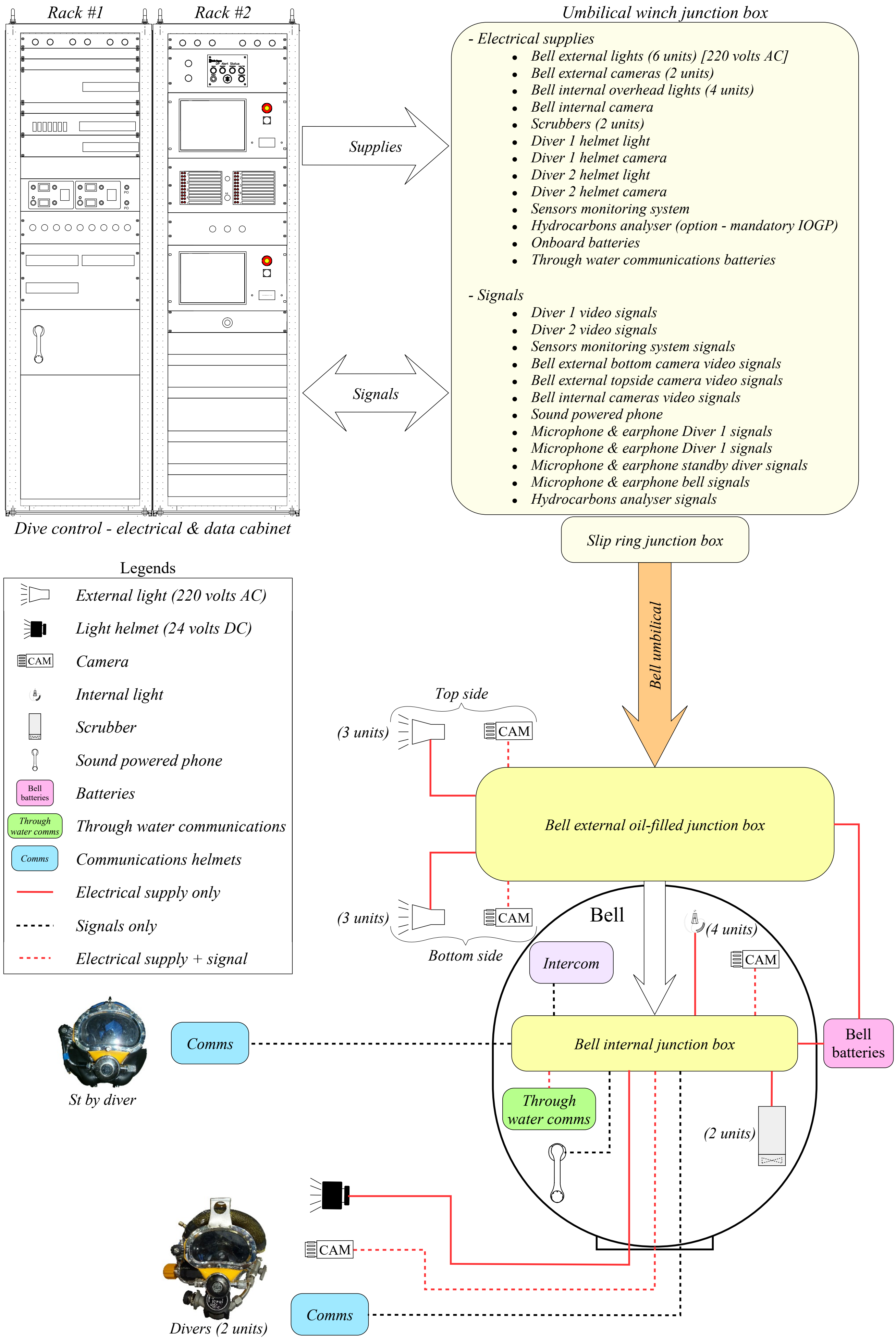
The scheme below represents the main electrical supplies and wired communications to and from the bell.



Client representatives office:
Client representatives are in charge of monitoring the performance of the contractor, report the progress of the operations and any incident, and help the contractor to achieve the planned task. However, they are not the persons the supervisor refers to directly as their action should be done through the chain of command. So, in the case of diving operations, and depending on the situation, through the Offshore Construction Manager (OIM), the diving superintendent, and the master of the vessel.
Their office is usually fitted with:

- Video screens from the dive and ROV controls showing the ongoing work of the divers and the ROV. They are mandatory with most clients.
- Positioning screen from the survey system that provides the position of the vessel, ROV, and divers.
- Dynamic Positioning (DP) alarms. They are not always in place but usually required by the clients.
- Phone communications with external and internal access. It is the minimum wired means of communication asked. However, a lot of oil and gas producers request an additional intercom that allows contacting the critical areas of the boat directly.
- A marine radio. It is in place in the client office of a lot of Diving Support Vessels (DSV), but not in all of them.
- UHF/VHF deck radios. They are commonly used. Sometimes the client provides his systems.

The diving monitoring panel allows the supervisor to monitor other parameters than the quality of the gas supplied to the bell and is already described in point 2.3.14.1 "General design". It groups the following elements:

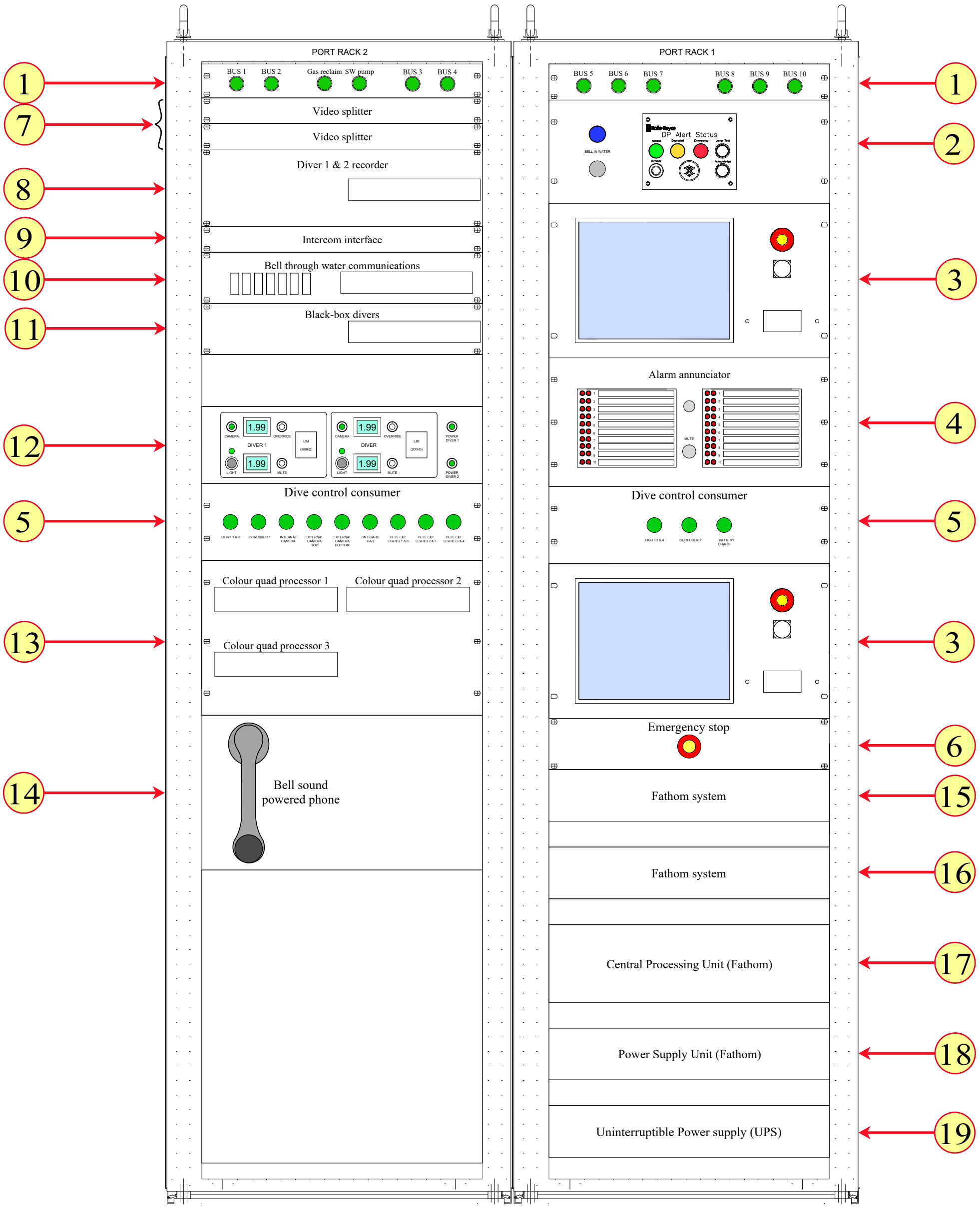
1 - Depth bell trunk
2 - Depth transfer lock
3 - Internal depth bell
4 - External bell / diver 3 depth
5 - Depth diver 2
6 - Depth diver 1
7 - Camera Diver 1
8 - Camera diver 2
9 - Screen survey
10 - Divers monitoring system screen
11 - Screen bell trunk & transfer lock
12 - Screen bell (external & Internal)
13 - Communications bell / divers
14 - Communications bell / divers
15 - Marine radio
16 - VHF radio
17 - Intercom system
18 - Phone
19 - Master base-stations of wireless communications to divers *(See more details in the next descriptions)*

Hyperlink Tables of contents

Notes:

- Divers monitoring system *(see #10 on the previous page)* is a specific electronic system which is optional with IMCA, but mandatory inside some national waters. It is explained on the next pages.
- The communications bell/divers *(see #13 & 14 on the previous page)* are digital systems of the latest generation. They are also explained on the following pages with more classical systems.
- Screens to monitor the transfer of the divers to and from the bell and the entry lock and the screen to monitor the external and internal of the bell *(see #11 & 12 on the previous page)* are divided in four. Other screens are above the gas panels and are used to control what happen on deck.

The electrical and data transfer cabinet groups some elements that cannot be integrated into the diving monitoring panel and is also the interface of the electrical supplies and the various video and data signals. Depending on the complexity of the system, it can be limited to one rack or be composed of several units where the following items can be found:



1 - Electrical inlets
2 - Dynamic Positioning (DP) alarms
3 - Hot water machines interfaces
4 - Alarm annunciator
5 - Dive control consumer
6 - Emergency stop gas reclaim
7 - Video splitter
8 - Video recorder divers
9 - Intercom interface
10 - Through water communications
11 - Black-box comms divers
12 - Cameras and lights divers
13 - Colour quad processors
14 - Bell sound powered phone
15 - Intelligent acquisition unit *
16 - Intelligent Network Logger *
17 - Central Processing Unit *
18 - Power supply Unit Computer *
19 - Uninterruptible Power Supply

* = Elements of the Divers Monitoring System *(See the notes above)*

Notes:

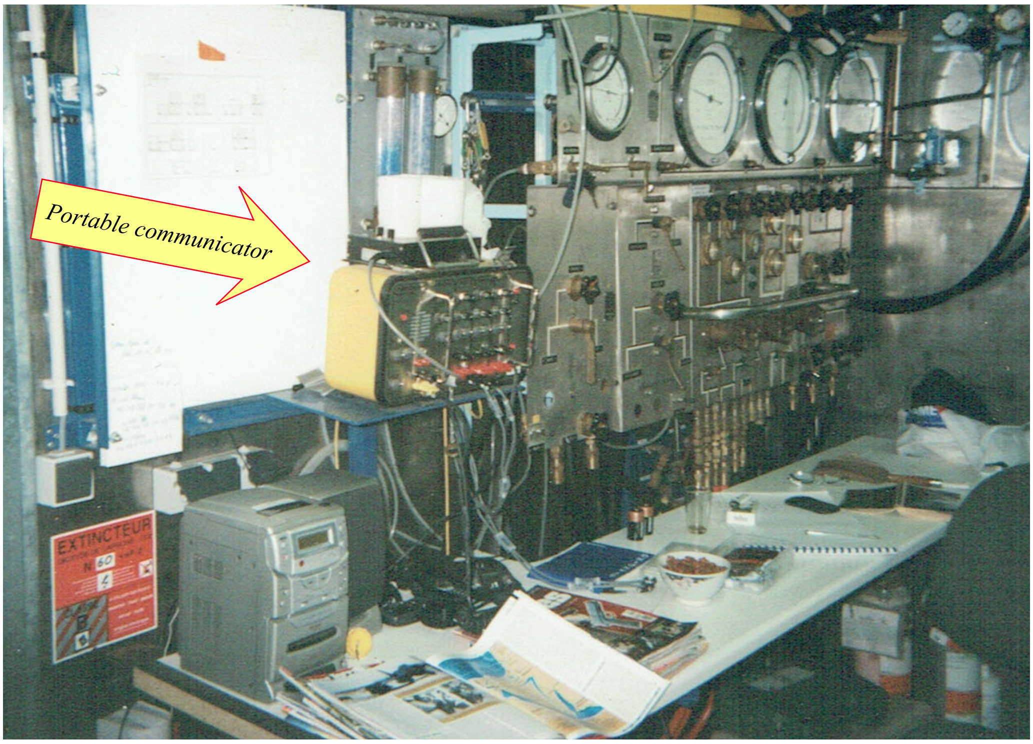
- The definition of an interface is a connection between two pieces of electrical or electronic equipment, or between a person and a computer.
- The dive control panel incoming power supply arrangement groups several "BUS" at the top of the cabinet *(see #1)*. In a power system, a "BUS" is defined as the vertical line at which the several components of the power system (generators, switchboards, transformers, etc.) are connected.
- DP alert status panel *(see #2)* is mandatory and provides visual and audio alarms. Note that last generation systems are provided with a "blue status" when the bell is in the water
- Interfaces with hot water machines *(see #3)* are described in the relevant topic on the previous pages
- Alarm Annunciator Panel *(see # 4)* displays the status of alarm signals using lights and sound features.
- The dive control consumer *(see #5)* groups the several switches of the bell that are illuminated when activated.
- A video splitter *(see #7)* is a device that takes one signal from a video source and replicates it over multiple monitors.
- Intercom interface *(see #9)* is a device in which all intercoms are connected and from which the signal emitted from one unit is routed to the selected intercom.
- The cameras and lights of the divers are switched on and off from the dive control *(see #12)*. A resistor allows dimming the lights of the divers when needed.
- A "colour quad processor" *(see #13)* turns any monitor into a quad monitor with security features and allows to connect up to four cameras and view all four locations simultaneously in real-time.
- An Intelligent Acquisition Unit *(see # 15)* is a system that acquires and processes measurement signals and convert them for the control of the applications of the system. In the Divers Monitoring system, it collects data from the various sensors and provides precise system diagnostics through the use of multiple status Light-Emitting Diodes (LED) which indicate the condition of input signals from sensors and the state of power supplies and telemetry links.
- An intelligent network logger *(see #16)* is a device that collects the "messages" emitted by network devices, operating systems, applications, and all manner of intelligent or programmable devices, and classify them in such a way that they can be accurately stored and interpreted.
- The Central Processing Unit (CPU) of a computer is a piece of hardware that carries out the instructions of a computer program *(see #17)*. It performs the basic arithmetical, logical, and input/output operations of a computer system.
- A Power Supply Unit (PSU) converts mains AC to low-voltage regulated DC power for the internal components of a computer *(see #18)*.
- Uninterruptible Power Supply (UPS) is described previously in the list of power supplies to the dive control. Note that in addition to the devices described in the list, this model is also designed to supply the Divers Monitoring System, which is mandatory in some national waters. Also, note that the batteries are housed in an open-air area outside the room.

2.3.14.4 - Communications with divers breathing heliox

Heliox mixtures are used in saturation as they alleviate the effects of narcosis and dyspnea (respiratory difficulty) which otherwise occur at depths deeper than 30 m with air.
However, the main disadvantage of such mixtures is that they increase the velocity of sounds and generate acoustic impedances with are altering the speech emitted by the diver to such an extent that its intelligibility is heavily impaired. Also, it has been established that trying to change the voice characteristics and slowing down the speech to adapt to the new environment generally results in a less intelligible conversation. As a result, severe mistakes in comprehension may occur that can lead to fatal errors. For these reasons, corrective systems have been created and implemented.
The first speech unscramblers were based on studies related to the general structure of vocal tracts and assumed that the voice distortion depended mainly on the physical and chemical parameters of the breathing mixture. Thus, the distortion of the voice in a helium-based atmosphere was supposed to be a linear process. As a result, these systems were not perfect, and the supervisor needed to be familiar with deformed voices to understand the divers fully.
More detailed researches on the emitted frequencies and the structure of vocal tracts demonstrated that the intelligibility of a conversation varies from one person to another and that the distortion of the voice of a diver breathing a helium-based mix is a non-linear process. However, the first systems based on these studies were limited by the available technologies and were not capable of independent manipulation of frequency bandwidths and amplitudes, which resulted that the modification of one parameter impacted the others. These problems demonstrate that the comprehension of a conversation also depends on the restitution of the bandwidth emitted by the equipment used, and thus, is directly linked to the quality and the technical possibilities of the material used.
The latest generation of unscramblers makes a profit of the progress of the quality of the materials and of the computing technologies that allow treating any problem separately without affecting the other parameters. However, despite the tremendous improvement, the results are not yet 100% perfect and research to improve the next generations continue.

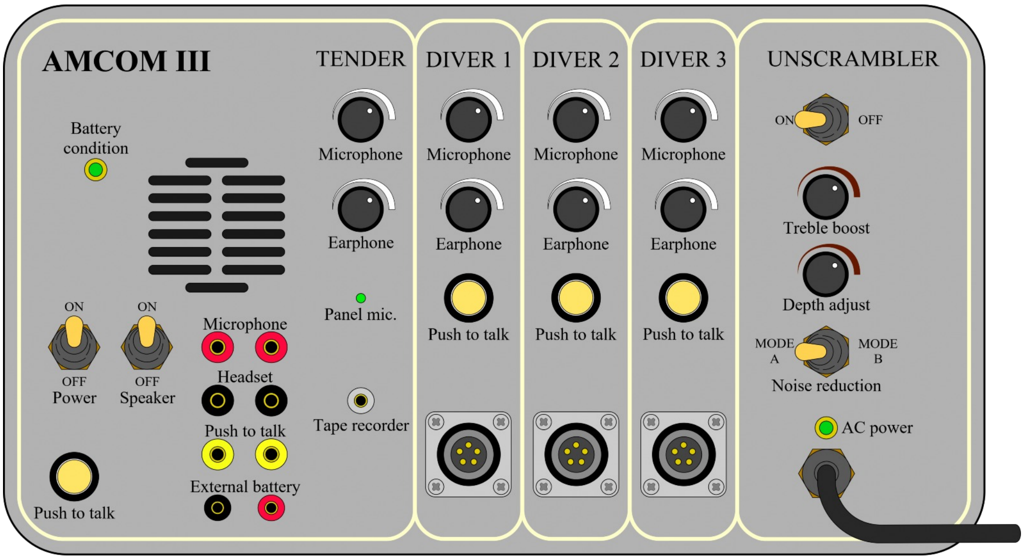
Helium speech unscramblers used in diving and saturation control rooms are generally designed to be inserted in the control panel *(see the previous point)* with their electrical and communication wires connected to their back, thus not visible and protected from shocks and inappropriate manipulation.
However, portable units are sometimes found with some small saturation systems. They are usually inserted in a

solid waterproof shell that is designed to protect their back from shocks and moistures. As a result, the communication wires that link the divers to the dive control must be connected to their front panel with the microphone and the headset. Also, the majority of portable models are based on systems designed for surface orientated air diving to which an unscrambling device is added. The advantages of mobile devices are their robustness and the possibility to replace them, in case of a breakdown, quickly. Also, most devices provide duplex communication allowing to speak and listen at the same time. However, their unscrambling performances are inferior than those of panel mounted models initially designed for heliox diving.



A lot of efficient portable communication systems designed for heliox are available on the market. However, it is impossible to describe all of them in detail. It is the reason the AMCOM III heliox communicator, which is often seen in dive controls (see above) and is a representative example of such equipment is described.
This model is a three diver communicator to which an optional unscrambler is fitted. It is designed with independent volume controls of the microphone, and earphone of the diving supervisor and each diver. Also, a connection to the tape/DVD/HDD recorder is available and can be connected to the video system. In addition, an external microphone with a push to talk command and a headset can be installed, so the supervisor can isolate from external noises when needed.
This diving communicator is usually powered with Alternative Current (AC) 220 volts, but it is also fitted with an internal battery and can also be supplied by an external 12 volts battery or transformer. The internal battery condition can be checked through a light that is green when the battery is full and red when it is empty or out of order.

Note that the optional unscrambling system converts the analog audio information to digital, store these digital data, and recombine them to reconstruct the audio without the frequency shift caused by the helium gas.
The model represented below has a “noise reduction” function which reduces background sounds such as hum and whistling which are increased by the concentration of helium. Mode A is usually for shallow depths and mode B for deeper depths. This function is completed by the “Depth adjustment” command which modifies the correction made by the algorithm according to the depth. “Treble boost” control enhances the frequency from the microphone of the diver.

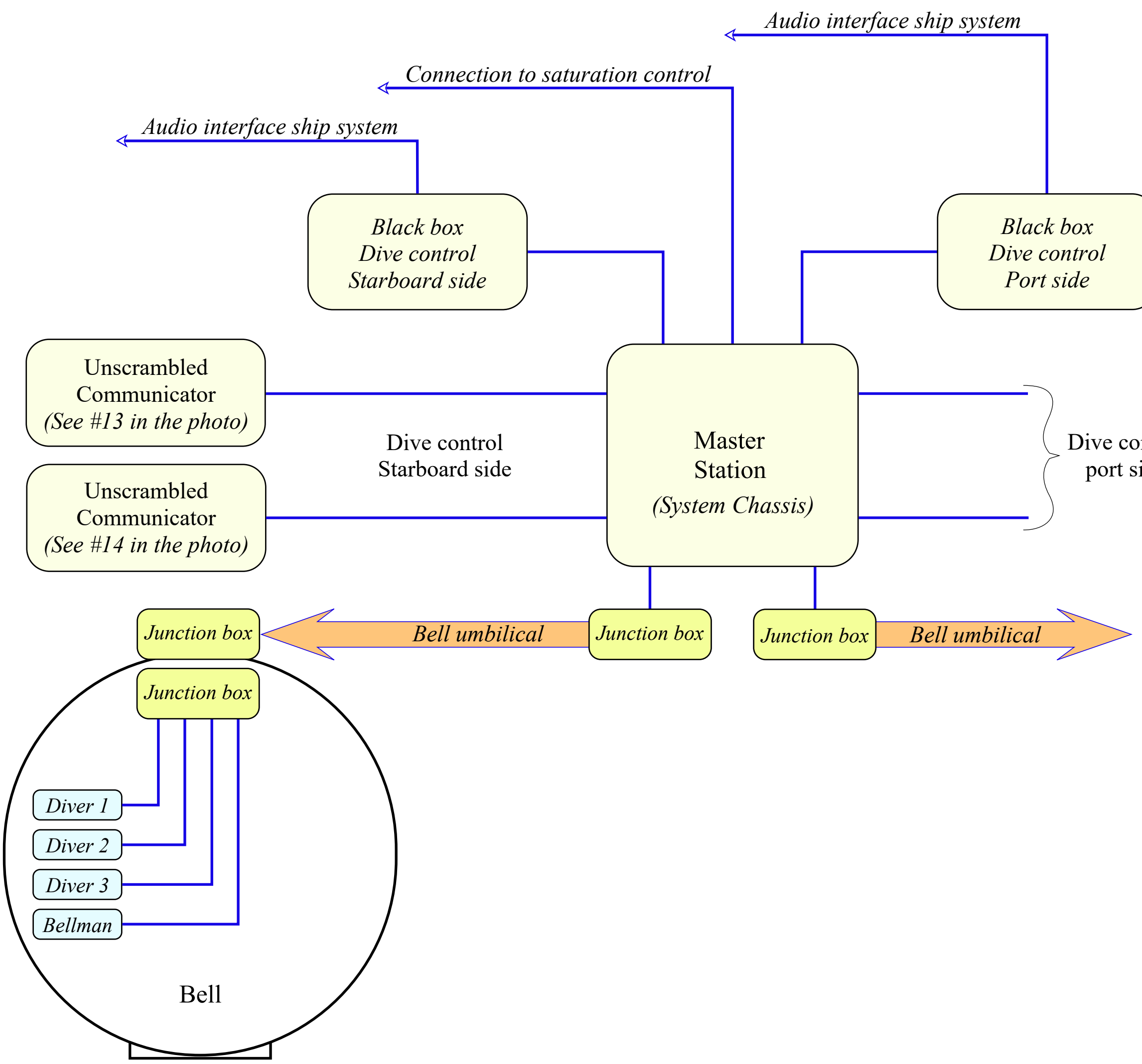


The portable communicator described above is based on reliable technologies that have evolved over the years and continue to be updated by small touches. Nevertheless, it is based on a concept from the nineties in which the quality of the sound is optimised using a series of potentiometers, and that limits the communications channels to those that are visible on the facade of the device. As a result, any new channel requires the installation of a corresponding module or the use of another unit.

Such inconvenience can be avoided with the latest generation of diver communications products that are based on a fully digital signal processing and routing. These systems that make a profit of the most recent progress of the computing industry can be configured for a wide range of applications ranging from a simple 3-channel stand-alone comms system up to a complex multi-channel system spread over a number of separate interconnected units. The advantages and possibilities provided by this new technology can be listed as follows:

- Improved audio performance which result from the fully digital audio processing (volume controls and channel mixing / routing) and the improved quality of the audio codecs and low-noise analogue signal paths;
- Fully isolated diver interfaces;
- As a result of the improved initial audio performance, the helium speech unscramblers allow for more intelligibility of conversations. Also, they are configurable on multiple channels.
- Their architecture provides more flexibility with the possibility to link multiple units together through a digital fibre-optic network, allowing any channel to be accessible from any communications unit. That avoids the installation of additional modules or units.
- Similarly to tablets and computers, there is the possibility for the supervisor to use a wireless communication system, allowing him to be always in communication with the divers when moving in the dive control and performing tasks such as adjusting the gas panels.
- Another advantage that is similar to those offered by last generation computers, tablets, and smartphones is that the supervisor can store his preferred system settings and organize for automatic standby redundant operation for mission-critical applications.
- Not normally used with bell management but in the saturation control room, a telephone interface allows the divers dialling internal or external numbers from within chambers and to speak to others in an unscrambled voice.

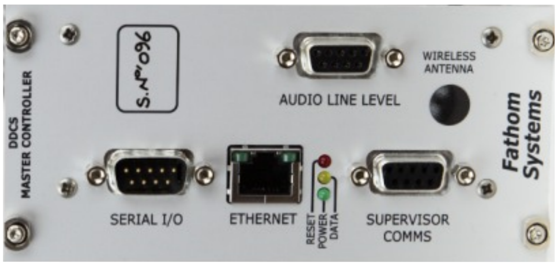
The drawing below, which shows the organization of the communications of the dive control that is taken as an example in this presentation *(refer to the photo of the monitoring panel)*, illustrates some of the possibilities offered by such new systems. Note that in this example, the interconnections have been limited to the dive and saturation controls.



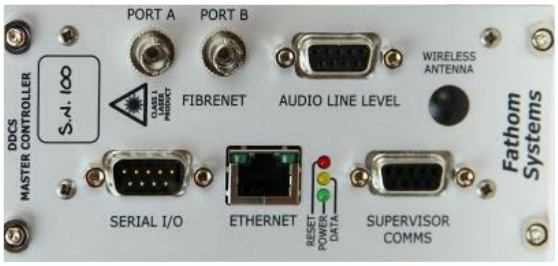
In addition to the extensive possibilities of interconnections, one crucial element to take into account with this new generation of communicators is that their control is based on series of menus that are accessed from the touch screen of a terminal that is linked to a master station which is installed in the dive control. That is a significant change compared with the previous generation systems to which most supervisors are familiar. For this reason, a description of the devices that are installed in the dive control taken as a reference is necessary. Note that the manufacturer of this system is Fathom.

As it can be seen in the scheme on the previous page, operation of the communicator, which is called "Digital Diver Communication System (DDCS)" by the manufacturer, requires a "master user", who is usually the diving supervisor, who controls one or more comms units which link to the various "remote devices". The remote devices can be a diver's helmet, the intercom of the bell, the saturation control room, or an outstation in a chamber if the system is configured for this purpose.
The system is composed of a chassis that can be mounted in any suitable location and does not need to be installed in the control panel, as is the case with classical communicator systems. This chassis is equipped with modules designed to provide sufficient channels to perform the operational requirements expected such as:

- The power supply module that provides Alternative Current (AC) 90-265 volts to Direct Current (DC) 24 volts.
- The Master Controller module in with a Digital Signal Processor (DSP) performs all signal routing, switching, mixing, level adjustment, multi-channel parallel helium speech unscrambling, breathing rate extraction, and filtering to reduce breathing noise levels.
  This module can be equipped with an optional fibre optic interface module that allows the audio channels to be available on any connected unit.



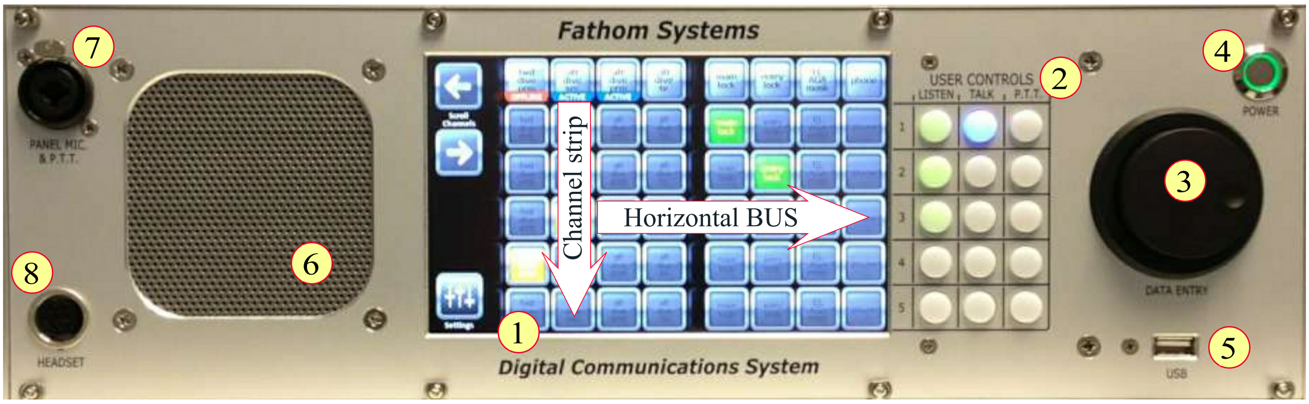
Master controller module (rear)



Master controller module with fibre optic interface (rear)

- A module provides galvanically isolated audio channels to the divers and the bellman in the bell, and if configured for, to chamber outstations or other remote stations. Note that "galvanic isolation" is a principle of isolating the functional sections of electrical systems to prevent current flow and provide safety from fault conditions in wired communication between devices that regulate their electrical supply. Each channel is designed with a configurable interface supporting various power and signalling technologies.
- A module provides input and output (I/O) channels that are used for connections of recording equipment, entertainment systems, and third-party equipment. When configured for, such module can also support a telephone interface that allows unscrambled telephone calls between the divers and any location in the vessel or onshore.

The modules described above are controlled from an "Operator Control Panel (OCP)" unit which can be installed in the chassis or remotely on a separate user's control stand. With the system taken as an example, the supervisor can use two "Operator Control Panels" *(see #13 & #14 in the photo of the control panel point 2.3.14.3)*.
Note that several versions of operator control panels are available and that the model in the dive control taken as an example is the "version 3" *(see the picture below)*.

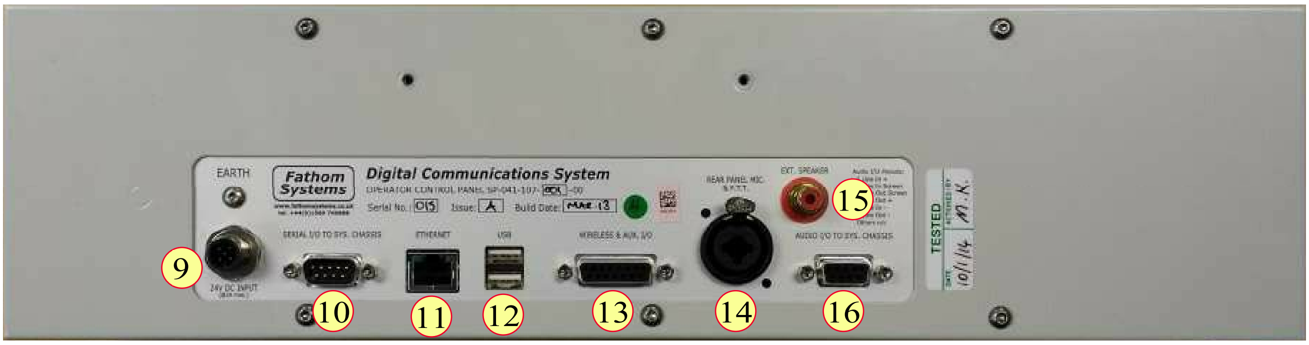


- This Operator Control Panel (OCP) is composed of a touch-screen display which is connected to an internal embedded computer card that manages its functions *(see #1 above)*. This touch-screen provides information about the connected channels and the settings of the system. Also, it allows the user to adjust the setup and navigate through several configuration pages.
  The main display is the "communications matrix" that represents various channels which are arranged in vertical columns that are identified by "tiles" and are divided into five horizontal rows or 'buses'. Each horizontal "bus" is a common connection that runs across all remote user channels in the vertical strips *(In computing, a "bus" is a communication system that transfers data between components inside a computer, or between computers)*. As a result, when touching the "channel tile" on the desired bus, the user can select any channel of this particular bus.

- Three “User controls” buttons are provided on the right side of each of the five horizontal buses *(see #2)*. These buttons provide the following functions:
  - “Listen”, which illuminates green when it is pressed on, allows the supervisor to listen to all the selected channels on the corresponding “bus”.
  - The “Talk buttons” allow the supervisor talking on a latching mode to remote users who are connected on the selected bus. These buttons illuminate blue when they are pressed on. Also, if the “listen” button is not already pressed on, this function is switched on automatically as it is assumed that the operator wants to receive an answer.
  - The “Press to Talk” buttons which are labeled “P.T.T.” are only functional when the Supervisor is not in latched talk mode *(the "talk button" is off, and the corresponding blue light is not illuminated)*. In this condition, the supervisor can use the "Press to Talk" button to call or answer to the user(s) connected through the corresponding bus.

- Situated further to the right of the touch-screen, the “data control wheel”, which is marked “Data Entry”, can be rotated either clockwise or counterclockwise *(see #3)*. It is a digital encoder knob that allows adjustments of parameters and the selection of controls on the particular touch-screen display page selected.
- The power button of the unit is installed in the corner above the “data control wheel” *(see #4)*. This button is illuminated in green when the power is on.
- A Universal Serial Bus (USB) socket is visible below the “data entry wheel” *(see #5)*. It allows connecting various devices such as a keyboard, a mouse, or a memory stick for software updating or other maintenance activities.
- A loudspeaker which is protected by a stainless steel grille is on the left of the touch-screen *(see #6)*. It can be used to listen to the person the user is talking with without a headset or headphones. It is switched on or off via the relevant configuration page in the software.
- A 3-pin XLR / ¼” mono jack combination socket is available at the top left of the panel and identified as “Pa Mic. P.T.T” *(see #7)*. This connector is used for either a panel microphone, such as a goose-neck microphone, or another type of wired microphone, or a “press-to-talk” wired switch.
- In the corner below the “PANEL MIC. & P.T.T.” connector described above, there is a screw-locking type 7-pin DIN socket that is labeled “Headset” *(see #8)*, which is designed for connecting a wired headset to allow for private communications. This connector also allows a remote “press to talk” switch to be used.

The rear of the “Operator Control Panel” allows noticing that this system is very different from the communicators of the previous generation and is, in fact, a network of computers.



- Similarly to the modules in the System Chassis the “Operator Control Panel” is supplied with Direct Current (DC) 24 volts, through a power connector (see #9) that is linked to an external power supply module.
- The “Operator Control Panel” communicates with the modules of the System Chassis via a dedicated RS232 serial link for its control functions *(see#10)*. In computing systems, 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 Ethernet connector is provided to link to other Digital Diver Communication System (DDCS) components and share information *(see #11)*. In computing technology, “Ethernet” refers to a system that connects computers together in a local area network or LAN. Dedicated cables connect to boxes called hubs or switches. Several standards exist that allow multiple computers to send data at any time. Such connection is commonly found on any desktop or laptop.

- In addition to the one provided on the facade, two utility Universal Serial Bus (USB) are provided on the rear panel *(see #12)*. USB is a standard that has been developed to simplify and improve the interface between personal computers and peripheral devices. It establishes specifications for cables and connectors and protocols for connection, communication and power supply between computers, peripheral devices and other computers.
- A D-sub (also called D-subminiature) connector is in place to provide power, audio interfaces and telemetry signals to the wireless master station *(see #13)*. Such connectors ensure correct orientation and screen against electromagnetic interference.

- An XLR connector is in place to install an external microphone *(see#14)*. XLR connectors are circular electrical connectors primarily found on professional audio, video, and lighting equipment. They are most commonly associated with balanced audio interconnection, including digital audio, but are also used for lighting control, low-voltage power supplies, and other applications.

- There is also a connection for an external speaker *(see#15)*. Note that this connection is similar to those used with communicators of the previous generation.
- Another D-sub connector is in place to provide additional power, audio interfaces and telemetry signals to the wireless master station *(see #16)*.

As indicated before, a 2.4 GHz wireless communication system that provides an audio link in both directions can be used by the supervisor. Note that for several years, wireless systems at a frequency of 5 GHz are available. The differences between the two frequencies are that 5 GHz band transmits data at a faster speed but provides less coverage. The more reduced coverage is due that the fact that high frequencies cannot penetrate solid objects, such as walls and floors. That explains the choice of many manufacturers of Wi-Fi controlled equipment not to use this frequency for their applications.

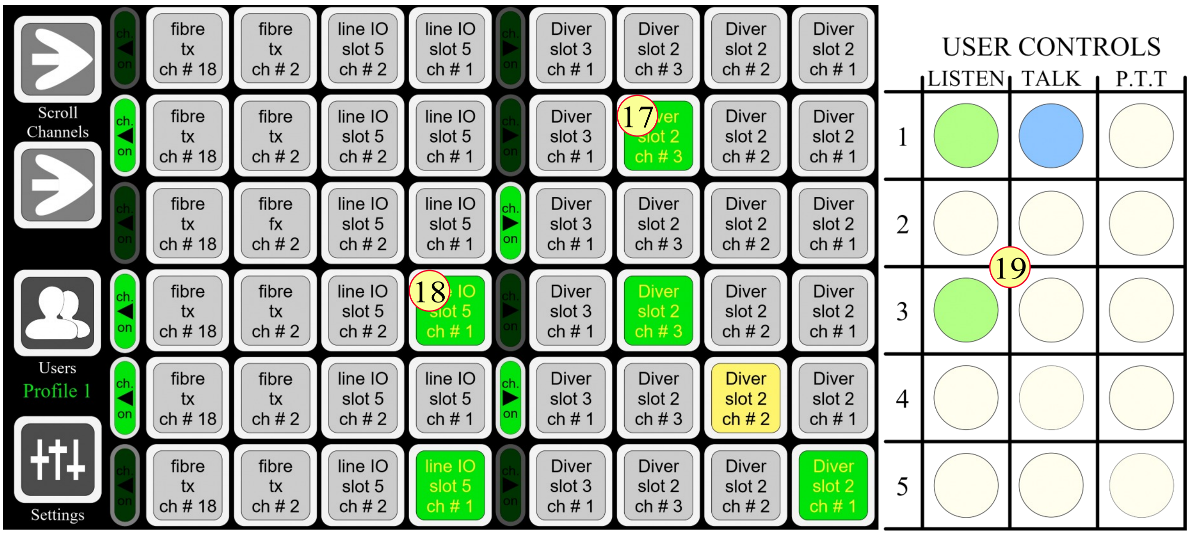
The supervisor connects to the system through a battery supplied hand-held or belt-worn unit which contains the wireless interface in addition to a headphone and a microphone interface. The battery that powers the device can be refilled with a phone USB charger. A keypad allows selecting one of three of the buses, and a press-to-talk button is used to communicate with the selected Bus. A failsafe system informs the user in the event of a link failure. Additional wireless units can be configured in the system for other users such as an example the person responsible for checking the bell on deck.

The wireless pack communicates with an interface module in the Operator Control Panel. It must, therefore, be paired with it to operate correctly. Note that in the networking process, “pairing” is the procedure to set up a dedicated linkage between devices, allowing them communicating together and not being affected by other communications. This process allows multiple wireless packs to operate in the same area.
Note that the latest Operator Control Panel version of the system described can be fitted with an external base station which is wired to it to improve the connection. These base stations are visible on the photo of the diving monitoring panel of the dive control taken as an example in point 2.3.14.3 (see #19).

Hand-held unit

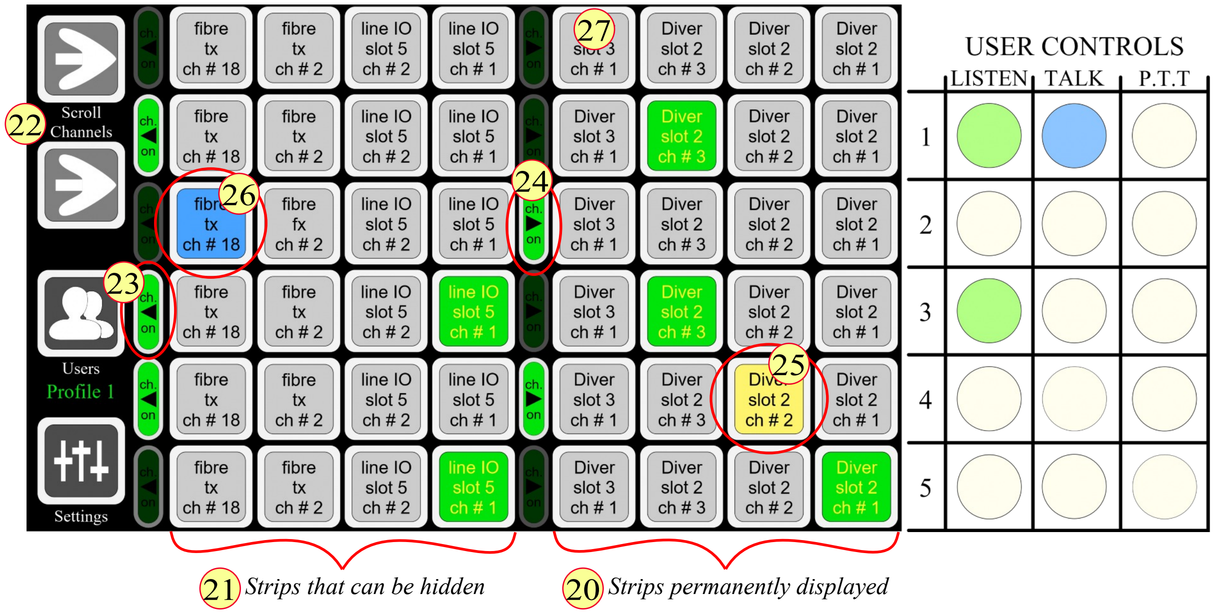
belt-worn unit

The presentation above shows that the setting up and control of this new generation of communicators are very different from those of more classical systems where the adjustment is made through a series of switches and potentiometers. However, People familiar with computers and tablets will not be disturbed with such a new design.
As explained previously, this concept considers that the horizontal buses displayed on the touch screen are a common connection that runs across all remote user channels in the vertical strips.
The user can select any channel of a particular bus to be connected through it. To do it, he touches the channel “tile” on the desired bus. As a result, the channel’s tile on the bus is illuminated *(see #17 &18 below)*, and the channel is connected to the desired bus. To disconnect the channel from the bus, the user touches the illuminated tile again, and the tile returns to the dark grey colour. There are 5 Buses on the model presented that are numbered from top to bottom on the “User Controls” keypad which is directly on the right-hand side of the touchscreen *(see #19)*. This keypad, which has been previously described *(see #2)* allows to listen or listen and talk, depending on the button selected.



If the user wishes to talk to a location, he places the location's channel on a bus (any bus will do), and then selects the corresponding button(s) on the keypad at the right of the touch-screen to be connected on that bus.

The space on the matrix screen is limited to eight (8) strips at one time. Also, it is organized with four static strips that are dedicated to the communications with the divers and are always visible. These essential strips are grouped to the right-hand side of the screen *(See #20 below)*.
To accommodate additional channels, the left-hand side section of the matrix screen is configured so that some channels are not always visible *(see #21 below)*. They can be accessed using two tiles in the topside left-hand side corner that allow scrolling to the left and the right *(see #22)*. To inform the user that there are active channels on a particular bus which are hidden due to the scrolling function, a small "activity indicator" is displayed for the involved bus pointing in the direction where an active channel is located *(see #23 & 24)*.



Fifteen "local channels" are available on the "System chassis" that can be connected to the "Operator Control Panel" and be visible on the matrix display if the corresponding modules are installed. Local channels are those limited to the modules in the "System chassis". They are connected through connectors which are specific to link several printed circuit boards together within the computer system.
Also, if the hardware configuration of the system includes the fibre-optic interface modules described previously, there is the possibility of communicating with remote stations in the ship through eight additional channels. In this case, a total of twenty-three (23) channels strips that can be visualized on the matrix display. Note that the remote fibre channels assigned to an "Operator Control Panel" have an indication on their tile that shows their status and whether the station is active or offline.

As a result of the numerous possibilities of channels, the supervisor may request that the function or the location of each channel is precisely indicated for a more suitable display and a better ergonomic. For this reason, the channel strips are configurable and can be named by the technician.

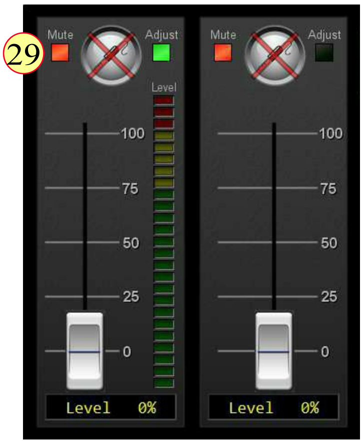
Diving communicators must be fitted with a connection to the safety recording system (Black box). Several channels can be configured for this purpose so that they are included in the "black-box" recording output group. This function is used to collect a number of audio comms channels and send them on a particular channel so that the audio can be recorded on a separate digital audio/video recorder. The selection of which channels are recorded is set up by the technicians, and all channels that are being recorded have a small red Light Emitting Diode (LED) on their title tile.

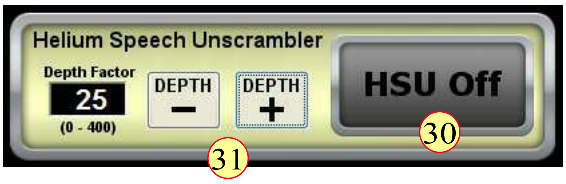
When the supervisor calls another station, both users can talk and listen at the same time without the need to press any buttons. It is the default setting for conversation, which is based on an algorithm called "Round-Robin Mode" that uses scheduling techniques to assign processing time slices, and transfer queued data packets. However, the supervisor can modify this setting using the functions of the "user controls" keypad.

"Cross-talk mode" which is commonly used with classical communicators to allow the divers in the water to talk to each other can be implemented. To do it, the channel strip tiles are merely selected onto the same bus.
Also, the supervisor can reduce the connection of one or several remote users to listen only. As an example, he wants the bellman hearing to the divers in the water but does not want him intervening in their conversations. In this case, the tile corresponding to the station is held pressed for a couple of seconds. As a result, it becomes yellow (amber) which indicate the new status of the station *(see # 25 in the drawing above)*. Also, the supervisor can talk to this station using the "press to talk mode. In this case, the yellow tile becomes light blue when the supervisor is talking *(see #26 in the drawing above)*.
Note that there are theoretically no limits to the number of remote users connected on the same bus. However, the manufacturer recommends limiting to two or three connection on a single bus as it can get quite confusing trying to understand who is talking if there are too many stations connecting at once.

Adjusting the volume of the channels is performed through the touchscreen: The user press first the 'title tile' at the top of the vertical channel strip he wants to adjust *(see #27 in the drawing on the previous page)*. As a result, the display changes to the channel adjustment page where two linear adjustment controls, also called “sliders”, for the volume of the microphone and the speaker/headset are displayed with the name of the channel and the commands of the unscrambler.

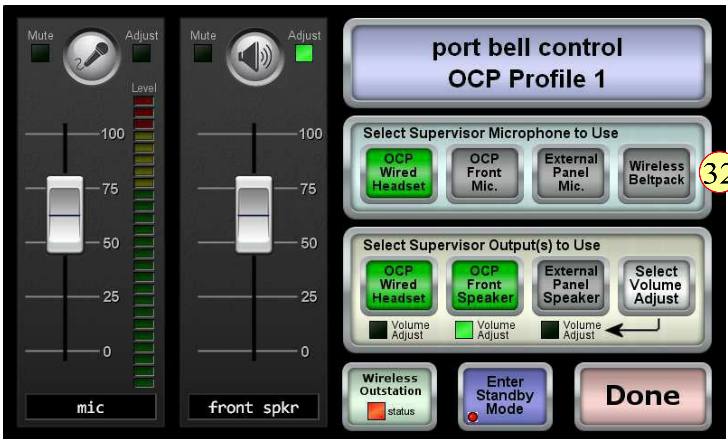
The volume of each device can be adjusted using a finger on the touchscreen or using the data wheel *(see #3 in the photo of the OCP’s facade)*. In this case, the operator must touch the adjustment control of the device to be adjusted on the touchscreen to select it. When an adjustment control is selected, a green light labeled “adjust” is illuminated *(see #28 above)*. If the volume of the device is set to 0%, the symbol above the slider shows a red X, and a red indicator below the label “mute” lights to note that the function is turned off *(see #29 below)*.





The helium speech unscrambler (HSU) can also be turned on or off from this page *(see #30 above)* and the depth of the diver adjusted to provide the best intelligibility *(see #31 above)*. To do it, the operator presses the corresponding tiles on the touchscreen.
When the adjustments are completed, the operator presses the tile “done” to close the page.

In addition to the settings of the several remote stations, the supervisor must adjust his microphone and speaker/headset settings. To do it, he presses the “Settings” button on the matrix display to obtain the adjustment page. The page displayed is similar but provides more options than the one described above.

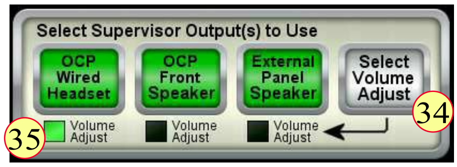


The sliders for the adjustment of the microphone and the earphone are similar to the one of the user channel described previously. For this reason, they are adjusted using the same procedure.
However, four possible microphone inputs can be used *(see #32 above)*:

- Wired headset
- Front panel microphone
- External panel microphone

- Wireless belt-pack

They are selected by touching the relevant button on the touchscreen to provide the supervisor with the desired functionality. Nevertheless, only one microphone input can be selected at a time. As a result, choosing a new microphone via the touch-screen turns off the previously selected input *(see #33 below)*.
Note that each selected microphone input has its volume/gain setting that is displayed on the adjustment control of the slider. Choosing a different microphone input causes the adjustment control to show the volume setting for the selected microphone automatically. Thus, if these adjustments were previously satisfactory, the supervisor does not need to touch them again.



Three possible speaker/ears outputs can be selected for use with the Operator Control Panel.
Wired headset
Front speaker
External panel speaker
They are selected to provide the desired functionality of the "Operator Control Panel". The system allows multiple outputs to be active together, and therefore the three buttons are used to toggle the particular output on and off. As there are three possible speaker/ears outputs, a "Select volume adjust" button allows the user to select which of the outputs is being adjusted *(see #34 above)*. In this case, the chosen output "Volume Adjust" indicator is illuminated in green *(see #35 above)*.

Note that if the wireless belt-pack system is in use, the headphone output on the wireless belt-pack is automatically enabled. However, such a device must be "paired" to the "Operator Control Panel" the 1st time it is connected. To do it, the operator presses the button "wireless outstation". When the device is successfully paired, the red status indicator becomes green.

The supervisor can place the "Operator Control Panel" into standby mode by pressing the relevant button. In this case the station is powered down and disconnected as it is the case with every computer. When the button is pressed, a confirmation pop-up asks the user for confirmation of this request.
As with the menu for external users, pressing the button "done" returns the display to the main matrix view.

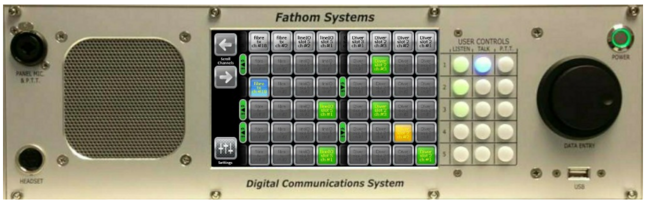
Phone communications:
The "Digital Diver Communication System (DDCS)" can be configured to provide one or more telephone interface channels through a module that connects to the host vessel phone system.
The purpose of the telephone system is to allow the supervisors or chamber occupants in saturation to talk to people such as doctors, family members, company managers, and others. That can be done with the benefit of the helium speech unscrambler if needed. Note that satellite phone communications in the dive and saturation controls are mandatory with the majority of the IOGP members and other clients.
The telephone page is displayed when the title tile for the phone channel at the top of the vertical channel strip is pressed. This page provides a dial pad that is used to compose the number to call and the sliders to adjust the volume of the microphone and the speaker that are similar to those used with the other setting up pages.

Operating the telephone is similar to using any smartphone. The supervisor dials the number to call or selects it from the list, and then presses the button labeled "call" to make the call. If the vessel telephone exchange requires an outside line, the relevant digit is to be dialed first.
Depending on the reason for the call, the supervisor places the telephone channel on a bus in round-robin mode and selects talk & listen to that bus. He can then talk to the party being called and handle the transfer to the diver in the chamber if needed. In the case of a private conversation, the supervisor then deselects his channel from the bus once the call is underway. The call can be ended by pressing the red button as with a smartphone.
The system also allows incoming calls to be handled. In this case, the system rings and flashes the channel title tile on the matrix view. The supervisor can choose to answer or reject the call.

When there are two identical “Digital Diver Communication Systems (DDCS)” operating side by side and interfacing to the same group of users, but with only one system being used at a time, they can be configured to operate in dual redundant mode. This function provides a backup system that can be used immediately in the event of a failure or problem with the primary system.
In this case, the primary “Digital Diver Communication Systems (DDCS)” must be powered up and the backup DDCS in standby mode. As a result, the unit standing by displays a “splash screen” that indicates its condition *(see below)*.

If the Operator Control Panel (OCP) is a member of a redundant pair, this status is shown for both Operator Control Panels in the redundant pair, allowing the user to check that the two units are operating correctly.
Note that when a redundant pair of Operator Control Panels is first powered up, the two units are into standby mode. For this reason, the operator must press the button “Switch to duty mode” of only the OCP that is going to be used. When the selected Operator Control Panel is placed into duty mode, the button “Switch to duty mode” is disabled on the screen of the second unit as long as the selected Operator Control Panel is on duty *(see the photos below)*. We can see that it is the case with the photo of the control panel taken as an example in point 2.3.14.3.

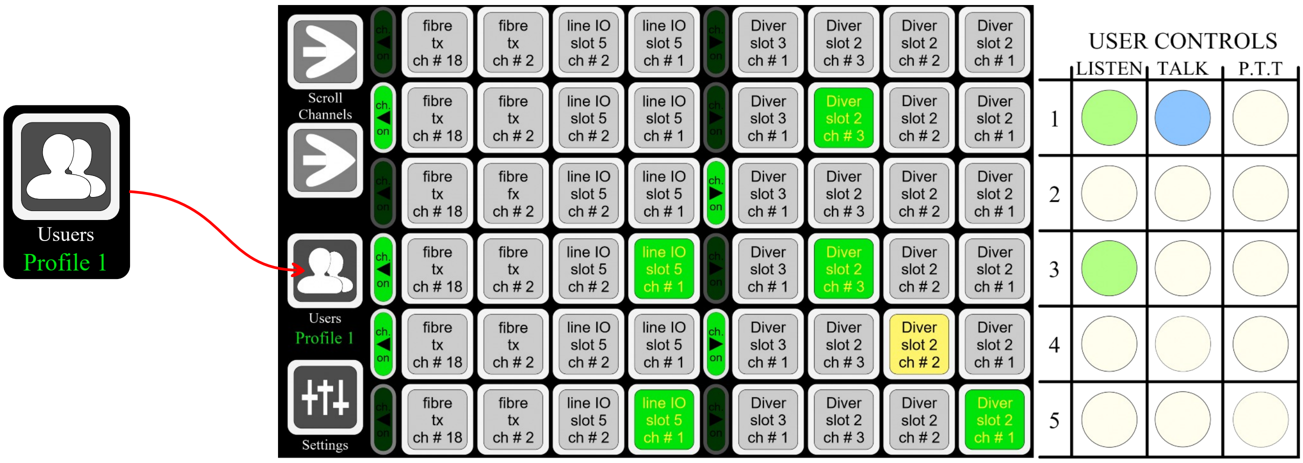
Operator Control Panel standing by



Operator Control Panel on duty

The manufacturer recommends that the duty and standby “Digital Diver Communication Systems’ are alternated on successive dives / bell-runs to ensure that both systems are maintained fully functional and tested regularly.
To swap the Operator Control Panel on duty, the unit in service must first be placed into standby mode. Then the unit to be used can be implemented. In the event of a fault or critical problem, it can be done by switching off the power to the defective unit.
Note that the systems described above can also be configured to operate in concurrent mode. As a result, the two master users can communicate with the same group of remote users at the same time (as an example, divers). In this case the stations used are on “duty mode”
This configuration is commonly used when inspection activities are carried out by one diver who needs to be in close communication with the inspection coordinator at the same time as the other diver continues to focus on other tasks under the diving supervisor’s instructions. In this case, it is vital that the diving supervisor can monitor all the diving activities he is responsible for, and this mode allows him doing it.

When the system is adjusted according to his preferences, the supervisor can save hi settings. The system provides twelve profiles that can be stored in the machine or the possibility to save profiles on memory sticks that can be connected to the USB port of the facade. To do it, the supervisor touches the button labeled “Profiles” on the matrix screen *(see below)*



The selection page that opens displays the twelve buttons of the profiles that can be saved *(see below)*.

To save his profile, the supervisor presses the button he selects to store it and then presses the button labeled "Done" *(see above)*. Note that the stored profile should be recorded on a document that is easily visible to avoid another supervisor from erasing it by accidentally.
If the supervisor prefers saving his profile on a memory stick, he inserts it into the USB slot of the active OCP and presses the tile labeled "Save". Then he follows the instruction provided by the machine. Note that the manufacturer says that memory stick provided must be compatible, not contain other files, and be certified virus-free.
To load a profile, the supervisor inserts a relevant memory stick into the USB slot and presses the button labeled "Load" *(see above)*. As a result, the machine prompts him to confirm the operation. When the procedure is confirmed, the profile settings saved on the USB stick replaces the settings for the currently active profile.

To conclude on diver communication systems:
The presentation above shows two types of communicators that are based on technologies that are not from the same generation and coexist with their advantage and inconvenience. Both systems provide a Modified Rhyme Test (MRT) score above 0.91 *(see below)*, and so, can be used to manage a conversation in a pressurized heliox atmosphere.

Communication requirement	***MRT score***
Exceptionally high intelligibility; separate syllables understood	0.97
Normally acceptable intelligibility; about 98 % of sentences correctly heard; single digits understood	0.91
Minimally acceptable intelligibility; limited standardized phrases understood; about 90% sentences correctly heard (not acceptable for operational equipment).	0.75

It must be noticed that the fully digital system presented is one of the most advanced that can be found on the market, and its MRT test scores 0.97 and above. Such last generation computing technology systems can replace all the communication systems present in the dive control, as in addition to the communications from and to the divers, the system is designed to replace the intercom and the phone and interact with them if necessary. Also, the latest developments of the computing industry allow navigating through the menus as easily as with a smartphone. That enables the supervisor to refine and save his selected settings, which is not possible with devices from the previous generation.
Nevertheless, we can see that this system is not exploited in full in the dive control taken as a reference in which a separate intercom and a phone are provided for the communications outside the diving area *(see #17 & #18 in the photo of the control panel point 2.3.14.3)*. As a result, we can say that the choice of the features offered by communicator systems depends not only on the design of the system but also on the working and safety philosophy of the diving system owner.
Note that most manufacturers propose fully digital systems that give good results but often have less advanced functions as those described here.

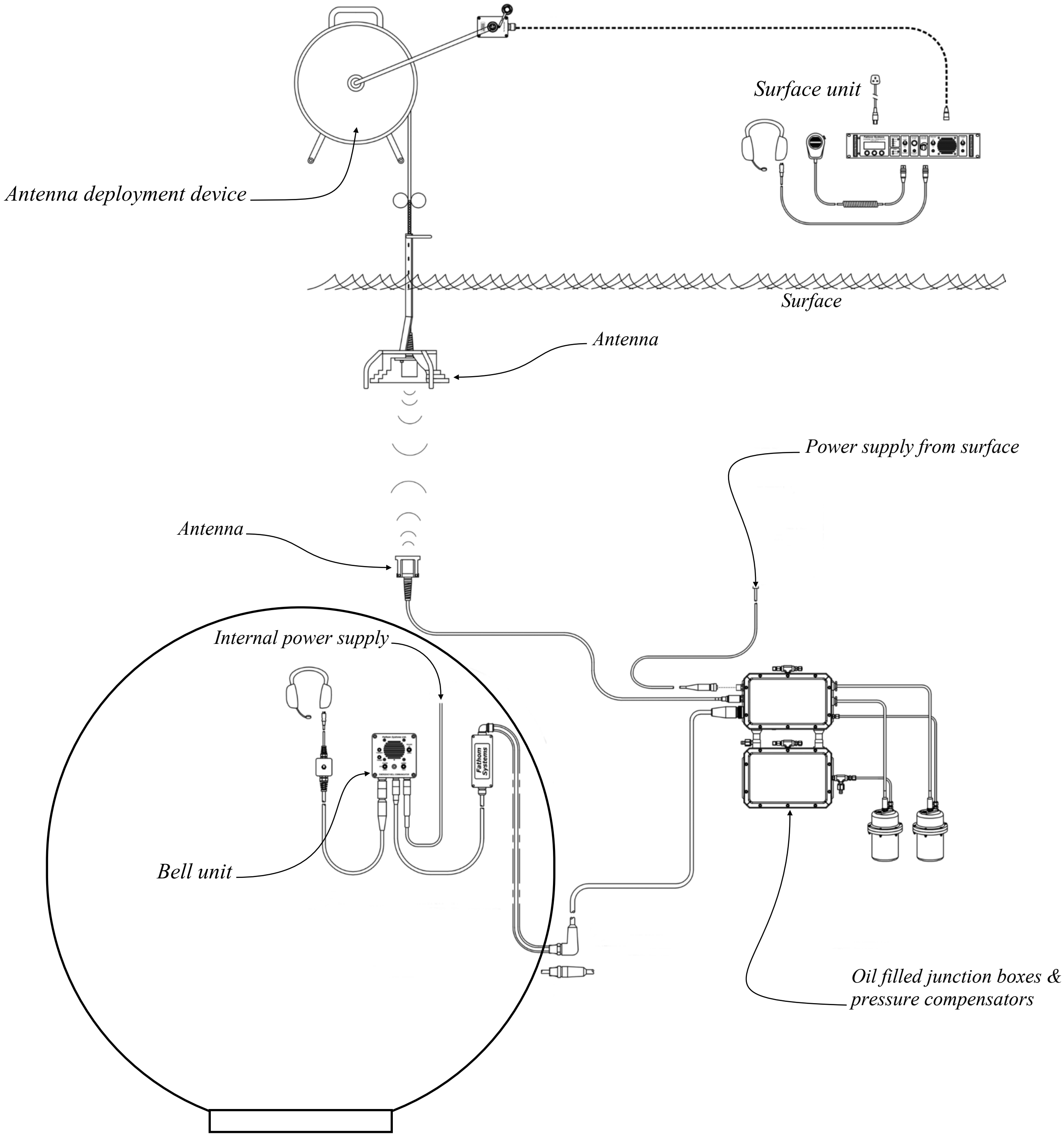
2.3.14.5 - Particularities of emergency communications to the bell

In point 2.3.14.3 it is indicated that A "sound powered phone" and "through water communications (wireless comms)" are mandatory in the dive control. It is also indicated in point 2.3.2.7 "Bell internal equipment". Both systems are located in the "Electrical & data cabinet".

- A sound-powered telephone is a communication device powered by the sound pressure of the voice of the user rather than batteries or an electrical power source.
  When the user speaks into the mouthpiece, the sound waves of his voice cause a diaphragm to vibrate. The vibrations are transferred from the diaphragm through a drive rod to an armature centered in a wire coil that generates an electrical current. The current then is transmitted to the earpiece of the receiver, where the process is reversed. As a result, the person at the other end of the circuit hears the sounds transmitted. Note that the earpiece and the mouthpiece can be used interchangeably. As a result, the user can talk into the earpiece or hear through the mouthpiece, which allows continuing a conversation if one of these two elements fails. Ringing is accomplished by a manually activated magneto producing sufficient electrical power to operate a howler at the called station. This system is

robust and was already used during the 2nd war. However, the communications performed with this device are not unscrambled. Thus, a conversation with divers in a pressurized heliox atmosphere will be difficult to understand. Nevertheless, it can be used to transmit a message from the surface and verify that the divers are well.

- "Through water communications", also called "Emergency bell communicator", are wireless communications that must be available to allow the supervisor to talk to the divers inside the bell when it is in the water and communications through wired systems are no more possible.
  The system operates by using high-frequency ultrasonic sound waves that are passed through the water between the bell and the surface vessel. As an example, the set installed in the dive control taken as a reference, which is built by Fathom, uses a frequency of 25kHz. This frequency is also used by other manufacturers. However, 30 to 35 kHz are also very common frequencies.
  The set installed in the bell is powered by the onboard electrical supply of the bell and a dedicated battery pack allowing a conversation during approximately 5 hours. The set installed in the dive control is supplied through the Uninterruptible Power Supply (UPS). There is an output from the topside transceiver for a black-box recorder and also for the helium speech unscrambler. Also, the unit that is in the bell of the system taken as an example has a pinger function that repeatedly sends an "S.O.S." morse code.
  The emitter/receptor (antenna) is usually deployed in the water when the bell left the surface and is recovered when it is close to the surface. The manufacturer says that the transmission range is about 3 Km, depending upon the underwater conditions. It is true that previously reported experiences have shown that sometimes teams were obliged to deploy the emitter very close of the bell.



Note that the wireless communication systems used with scuba divers are based on the same principle.

2.3.14.6 - Diver monitoring system

This system, which is also designed by Fathom in this example, is integrated into the dive control taken as a reference. It is a computing tool that provides accurate information from the dive system through a dedicated monitor to the diving supervisor *(see #10 in the photo of the diving monitoring panel point 2.3.14.3)*. A similar display is available for the Life Support Supervisor (LSS) . It is also designed to be easy to operate and maintain for both operations and maintenance personnel. Such systems are gradually adopted in the diving industry as they allow for better controls of the operations ongoing. Another reason for the implementation of these systems is that they are mandatory with NORSOK standard U100 which says in point 7.11.3.3 that a diver monitoring system must be provided for each diver. As these standards are to be applied in Norway, the company working in this country are mandatory to use such equipment.

The system is designed to display, record, and provide alarms for at least the following parameters:

- Divers depth (Diver 1 & 2 and standby Diver 3 in the bell).
- Bell internal depth.
- Bell external depth.
- Bell internal temperature.
- Divers' breathing gas PO_2 and ppm CO_2.
- Sampled bell internal gas PO_2 and ppm CO_2.
- Hot water temperature supply to the bell measured at the surface
- Hot water supply flow rate supply to the bell measured at the surface
- Hot water temperature supply to each diver measured at the bell
- Duration of each bell-run.
- Duration of the "in-water time" of each diver.
- Depth of each chamber lock in the saturation system.
- For each chamber lock in the system:
  - PO_2
  - ppm CO_2
  - Temperature
  - humidity

NORSOK standards also request to display the temperature at the divers' suit, and the hot water flows of the divers measured at the bell in case of dives deeper than 200 m.

The manufacturer can also provide additional optional features such as:

- Personnel management features (tracking Divers, Dive supervisors, and LSSs/LSTs)
- Remote access for maintenance
- Secondary / system status alarms and alerts
- Provision of Diver's Gas temperature, measured at the Diver.
- Scheduled data archiving and management

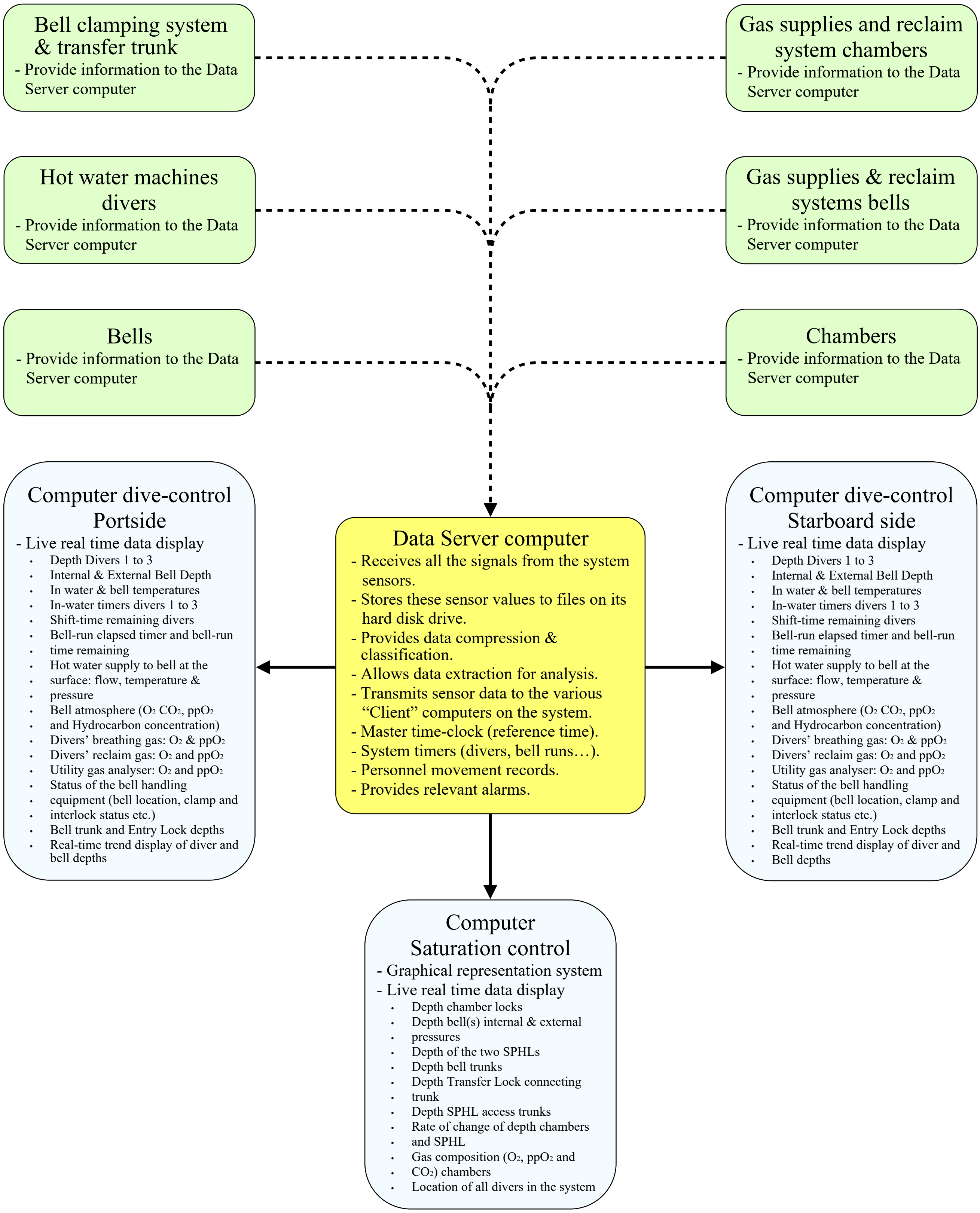
The Diver Monitoring System (DMS) is composed of networked computers which communicate with bespoke hardware devices that acquire data from sensors fitted to various parts of the dive system. These sensors measure parameters such as depths, temperatures, gas compositions, hot water flow, humidity, etc. 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.

- The "Data Server computer" is the "Master device" of the Diver Monitoring System. It receives signals from various sensors over a dedicated Ethernet network via multiple interfaces, and stores these values to files on its hard disk drive. One data file being created every hour. There are therefore 24 separate files recorded to disk every day, with their filename identifying the start and end times. These saved files can be copied to CD/DVD ROM for off-line examination and analysis, and long-term archival.
  This computer is also fitted with the "master time-clock", which is used to provide a universal system time for all computers on the network. As a result, the various system timers that are used to measure the in water durations and bell-run times, and provide relevant clock alarms thresholds are provided by this unit and synchronized with this clock.
  The server also displays the data stored in real-time to the computers in the dive and saturation control rooms, and even various utility or maintenance computers. That allows the supervisors and technicians managing the dives and the maintenance of the saturation system to react proactively.
  Also, the server records personnel movements such as the status and identity of the supervisors on duty and the identity and location of the divers in the dive system.
- There is one Diver Monitoring System "Client computer" for each diving bell. It is situated in the control panel with a display located in front of the supervisor. As the saturation system taken as a reference has two bells, two units are installed in the dive control. These displays have been designed to be ergonomically correct and straightforward to read. They provide a full range of relevant information, so the supervisor has an accurate view of the condition of the divers and the dive system during the operations.
- Another Diver Monitoring System "Client computer" is located in the saturation control room. This computer runs an application that displays a graphical representation of the chamber complex, which is overlaid with live real-time data values for the Life Support Supervisor (LSS) and Technicians (LST). In addition to sensor parameters, the names of the

divers in each chamber lock or at work in the bell are indicated. For convenience, because the saturation control panel is extensive, this computer is fitted with two monitors that provide the same information at opposite ends of the saturation control panel. Note that the procedure for managing the information provided by this computer is not described here, but in the chapter that explains the saturation control.

- The manufacturer also says that other “Client computers” *(not indicated in the scheme below)* can be used for maintenance purposes.

The scheme below summarizes the computer network of the Diver Monitoring System.



The data from the bell that are collected are sent to the Master Unit through an “intelligent Acquisition Unit (iAU)” that acts as the local interface. This unit, which is visible on the side of the bells of the system taken as a reference is a stainless steel oil-filled enclosure that is pressure compensated to the ambient depth. An acrylic window on the front of the unit allows technicians to diagnostic the status of each interface channel. This intelligent Acquisition Unit communicates through a communication protocol that is designed to transmit signals over long distances to the intelligent comms router (iCR) in the dive control, where the data from the bell sensors are converted and transferred to the server across the network. Note that similar "intelligent Acquisition Units" are provided for the other components of the dive system. However, as they are located at the surface, they do not require a pressure compensated oil-filled enclosure.

Pressure compensator

intelligent Acquisition Unit

A lot of sensors are permanently installed on the dive system to provide various signals to the central computer of the Diver Monitoring System, giving immediate information on the physical parameters and conditions of interest.
Also, specific sensors, such as those designed for measuring the depth of the divers, give a substantial advantage. These depth sensors that are installed at the far end of the excursion umbilicals are of similar technology as those used with ROVs. They measure the divers' depths at regular intervals and are as small as possible so as not to disturb the divers. Their signals are sent to the local "intelligent Acquisition Unit' and then to the central computer that interprets and records the data coming from them and draws diving excursion curves in nearly real-time.
As a conclusion, this system offers significant advantages over the conventional pneumo gauges. It is also a helpful tool to progress in the comprehension of saturation procedures when coupled with other information such as the temperature at the diving suit, the composition of the gas breathed and its consumption. We can imagine that in the near future other sensors, which technologies already exist for surface activities, may be adapted to inform the supervisor of the heart rate, blood pressure, and other parameters in real-time.
Another specific sensor fitted to the bell that provides significant progress is the "intelligent Contents Gauge (iCG)". This unit contains four specially designed pressure transducers and a custom interface circuit that monitor the pressure of the three HeO2 banks and the O2 in real-time and displays them on the monitor of the diving supervisor. With systems where this device is not installed, such information can be provided by the bellman only.

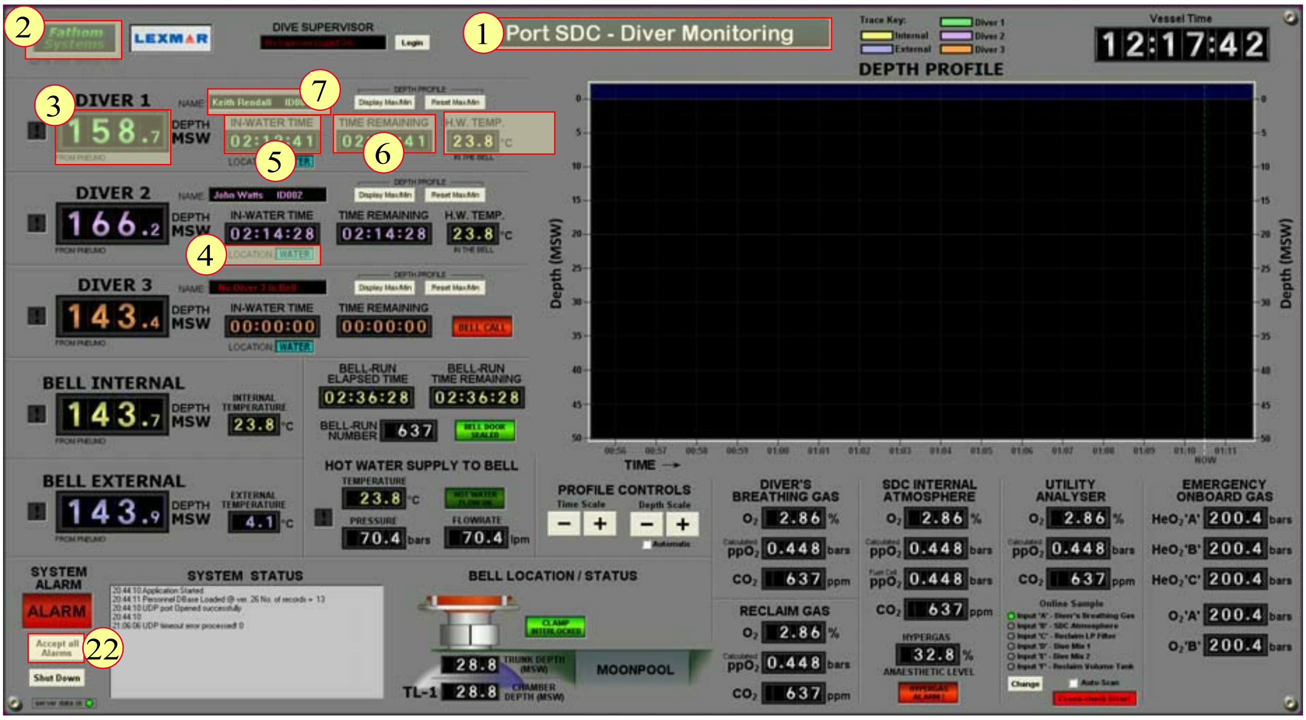
Ø = 99 mm

intelligent Contents Gauge (iCG)

Ø = 26 mm

Depth sensor

The "real-time data" of the dive system are displayed as in the drawing underneath on a monitor that is on the control panel. Their description allows a better understanding of the possibilities of the Diver Monitoring System.

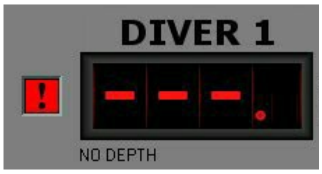


Note that the reference numbers of the elements described are those in the drawing on the previous page.

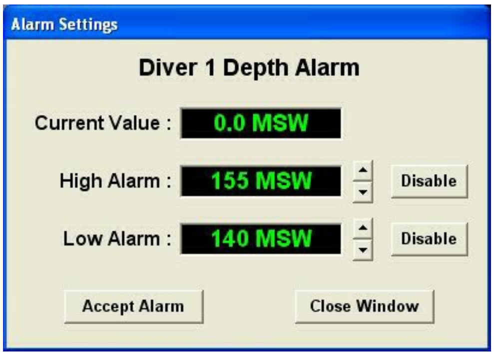
1) - Display screen title:
This title shows which bell, also called Submersible Decompression Chamber (SDC) is being viewed *(see #1)*.

2) - Software revision *(see #2 in the drawing on the previous page)*:
Details of the software revision status of the Dive Control display client. Clicking on the Fathom logo provides more details.

3) - Diver depth displays *(see #3 in the drawing on the previous page)*:
Three colour-coded digital display readouts show the current divers' depth in metres of seawater (MSW), with an accuracy of 0.1 MSW. The colour coding is green for Diver 1, purple for Diver 2 and orange for Diver 3. When the diver's depth signal is either unavailable, in a fault condition or out with the preset alarm limits, the digital display changes from its standard colour to red. A signal fault is represented as a row of red dashes *(see on the side)*.



Normally, the signals for these readouts come from the divers' depth transducers attached to the end of the excursion umbilical (at the D-ring) and connected back to the "intelligent Acquisition Unit (IAU)" mounted on the outside of the Bell. In this case, a small label under the depth reading shows "FROM iAU". If for some reason the intelligent Acquisition Unit depth signal is unavailable, the system automatically reverts to the surface Pneumo depth transducer reading. In this case, the depth value is displayed in red and the label beneath shows "FROM PNEUMO". When no valid depth signal is available, the label shows "NO DEPTH".
Clicking on the depth display readout for a particular diver opens up the window of the depth alarm settings:



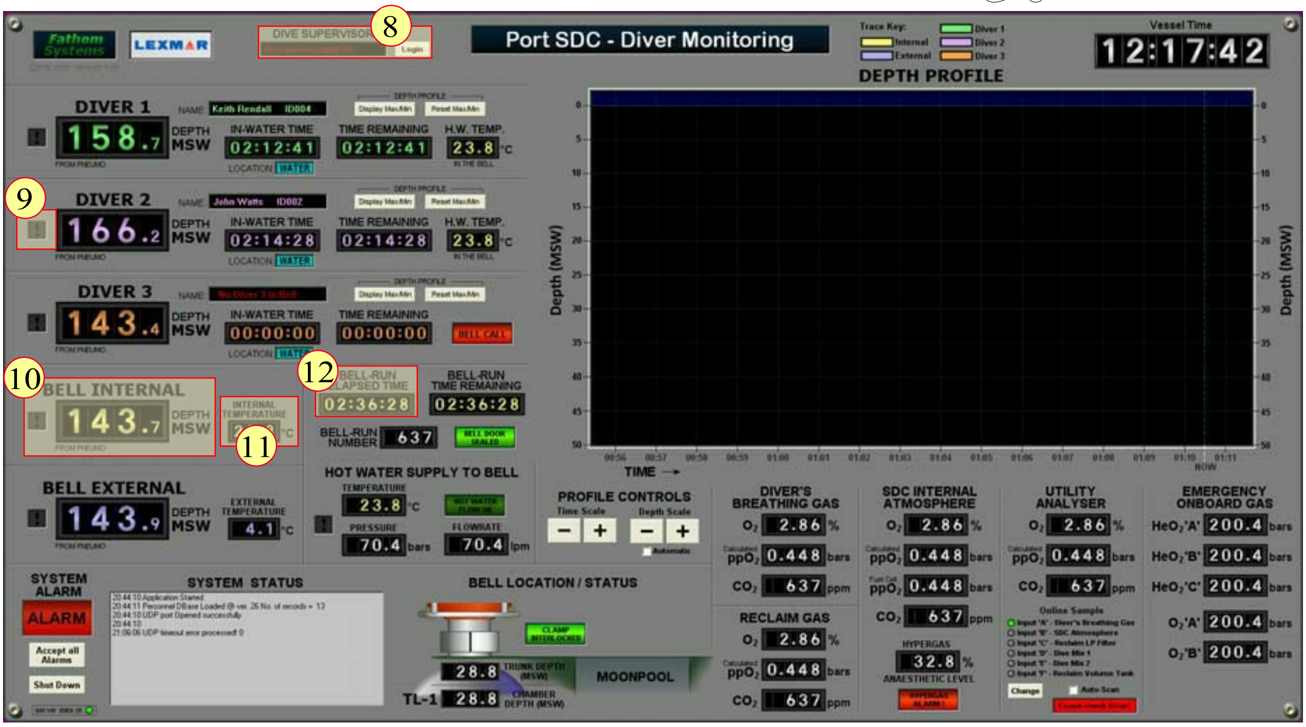
Using the up and down arrows and the buttons on this window allows the diving supervisor adjusting the diver's minimum and maximum depth alarm set-points.
When a Diver's depth signal is in an alarm condition, this is initially presented as an 'Active' alarm, where the depth value flashes red, and the audible alarm sounds every 10 seconds. The Supervisor can click the button "Accept Alarm" on the alarm setting window to accept this alarm or click on the global "Accept Alarms" button *(see #22 in the drawing on the previous page)*.

4) - Diver location indicator *(see #4 in the drawing on the previous page)*:
This status display panel shows the current location of the diver, either in the bell or in the Water. The information displayed here comes from the pushbutton switches operated by the dive supervisor. This information is also stored in the master data file on the server to allow dive profiles to be recorded for each dive.

5) - Diver in water timer display *(see #5 in the drawing on the previous page)*:
A digital display is provided for each diver to show the duration that he has spent in the water (his in-water time). This display is colour-coded the same as the depth displays and automatically increments every second so long as the supervisor has pressed the pushbutton on the panel to indicate that the diver is actually in the water. When the pushbutton is returned to the off state, the timer stops but continues to display the last total time figure.
This display indicates hours, minutes and seconds as follows: HH:MM:SS
The dive supervisor can reset the in-water accumulated time to zero via the timer configuration window (accessed by clicking on the "in-water" or "time remaining" time displays).
The in-water timers have an alarm system which results in a red alarm indicated on the screen when the elapsed in-water time exceeds the alarm threshold. Configuration of the alarm thresholds is made via the timer configuration window.

6) - Diver shift-time remaining display *(see #6 in the drawing on the previous page)*:
A digital display is provided for each diver to show the time remaining for his current operational shift. This display is documented every second so long as the supervisor has pressed the pushbutton on the panel to indicate that the diver is actually in the water. When the pushbutton is returned to the off (in Bell) state, the timer stops but continues to display the last total time figure. This display also indicates hours, minutes and seconds (HH:MM:SS).
As with the in-water timer, the shift timers have an alarm system which results in a red alarm on the screen when the shift time remaining is less than the alarm threshold. The alarm thresholds are configured though the timer configuration window.

7) - Diver Identification (name and ID number) *(see #7 in the drawing on the previous page)*:
Before starting the bell run, the Life Support Supervisor (LSS) logs the names, identification numbers(ID), and the function (Diver 1, 2 or bell-man) of the divers transferred to the bell. As a result, their names and ID numbers automatically appear in this display window.



8) - Dive supervisor name, identification (ID) number, and login/log off button *(see #8 above)*:
This display window shows the name and ID number of the dive supervisor currently on shift. The supervisor logs on or off using the pushbutton

9) - Alarm indicator *(see #9 above)*:
The alarm indicator is grey when all alarm conditions for a particular diver depth or bell depth are within limits and healthy. The alarm indicator is illuminated red when a depth alarm condition for a diver or the Bell are outside the boundaries, or the signal is faulty. The alarm indicator flashes until the supervisor accepts the alarm through the Alarm Settings window.

10) - Bell Internal depth display *(see #10 above)*:
This colour-coded digital display provides the bell internal depth in metres of seawater (MSW) with an accuracy of 10 centimetres. If this signal is faulty or unavailable, or the bell is outside the preset alarm limits, the digital display changes from its standard yellow colour to red.
The signal for this readout comes from a depth transducer mounted external on the bell and connected to the bell internal depth sample pipework. The signal from this transducer is connected back to the “intelligent Acquisition Unit (IAU)” mounted on the outside of the Bell. In this case, a small label under the depth reading shows "FROM iAU". If for some reasons the iAU depth signal is unavailable, the system automatically reverts to the surface Pneumo depth transducer reading. In this case, the depth value is displayed in red and the label beneath shows "FROM PNEUMO". When no valid depth signal is available, the label shows "NO DEPTH".
When the supervisor clicks on the display readout for the bell internal depth, he opens up the alarm settings adjustment window (similar to the Diver depth alarm settings window described above)

11) - Bell internal temperature display *(see #11 above)*:
This display indicates the current ambient temperature inside the diving dell in degrees Celsius. The sensor for this display is mounted on the bell internal Diver Monitoring System junction box. Its signal is converted to run over long distances with minimal signal losses (4 to 20 mA type) and connects through the penetrator to the “intelligent Acquisition Unit (IAU)” on the outside of the Bell.

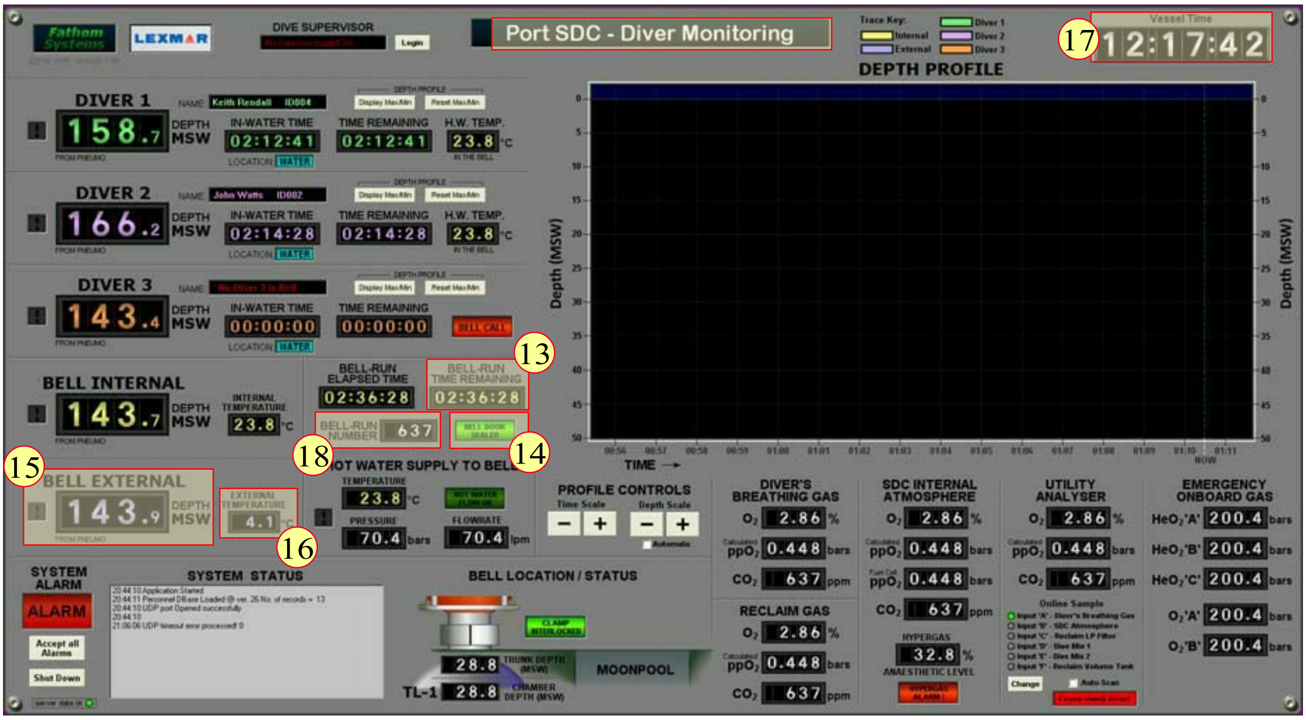
12) - Bell-run timer display *(see #12 above)*:
Bell-run timers are started and stopped automatically from the status of the bell transfer trunk pressure sensor (a difference in pressure between the trunk and the bell internal implies that the bell is locked off and bell-run timer running). Three modes for the bell-run timer are available:

- Normal mode – where the timer is started and stopped automatically based on the “bell seal” status from the trunk pressure sensor. This mode requires a manual reset of the timer at the start of each bell-run.
- Automatic reset mode – where the system works the same as in Normal Mode, except the bell-run timer is reset to 0 when the bell locks back on to the trunk.
- Don’t Stop mode – where the bell-run timer continues to run even if the bell is locked back on to the trunk. This mode is used where the bell is required to be returned to the system and then launched again all within a single bell-run.

Bell door seal status is implied automatically from a pressure (depth) difference between bell internal and bell external depth readings.
A digital display shows the total elapsed duration of the bell-run. This display is yellow colour-coded and automatically increments every second whenever the bell-run timer is running. The bell-run timer is running when one of the following sets of conditions are satisfied:

- The bell is located on its mating trunk, and the bell internal depth is more than 5 metres sea water (MSW) deeper than the trunk and there are one or more divers in the bell;
- The bell is not above the bell trunk and there are one or more divers in the bell;
- The Dive Supervisor has selected the “Don’t Stop” bell-run timer mode;
- There is a fault / logic error with any of the signals that are used to control the bell-run timer.

The dive supervisor can reset the accumulated bell-run time to zero at any time via the bell-run timer configuration window (accessed by clicking on either the bell-run timer display or the bell-run time remaining display). This reset function is provided automatically by the trunk pressure signal when the "Automatic Reset/ timer mode" is selected.
The Bell-run timer is fitted with an alarm, which triggers a red signal on the screen when the elapsed bell run time exceeds the alarm threshold. The setup of the alarm thresholds is made via the bell run timer configuration window.



13) - Bell-run time remaining display *(see #13 above)*:
This function displays the time remaining for the bell run ongoing to ensure that the maximum legal duration of the bell run is not exceeded (strictly 8 hours seal to seal). This display is documented every second as long as the bell-run timer is running. The target time and the alarm threshold are set using the relevant configuration window.

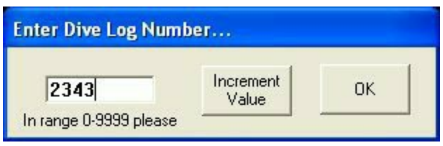
14) - Bell door seal status display *(see #14 above)*:
This display indicates whether the Bell door is sealed. This tool compares the bell internal depth with the Bell external depth to provide a status. When the difference of two depths is 3 metres of Seawater (MSW) and above, the system assumes that the door of the bell is sealed. As a result, the indicator is illuminated in green.

15) - Bell External depth display *(see #15 above)*:
This colour-coded digital display provides the bell external depth in metres of seawater (MSW) with an accuracy of 10 centimetres. If this signal is faulty or unavailable, or the bell is outside the preset alarm limits, the digital display changes from its standard blue colour to red.
The signal for this readout comes from a depth transducer mounted inside the “intelligent Acquisition Unit (IAU)” on the outside of the bell. In this case, a small label under the depth reading shows "FROM iAU". If for some reasons the iAU depth signal is unavailable, the label shows “NO DEPTH” (there is no bell external Pneumo signal to use).
When the supervisor clicks on the display readout for the bell external depth, he opens up the settings adjustment window (similar to the Diver depth alarm settings window described above).

16) - Bell external temperature display *(see #16 above)*:
This display indicates the ambient temperature outside the diving bell in degrees Celsius. The sensor for this display is mounted on the bell “intelligent Acquisition Unit”.

17) - Vessel time display *(see #17 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.

18) - Bell run ID display *(see #17 above)*:
This window shows the dive log reference number that should match the one used for the dive records hand-filled by the supervisor. This tool allows correlating the recorded data against the manual dive logs. Clicking on this display opens a small pop-up window that is used to set the dive log number.



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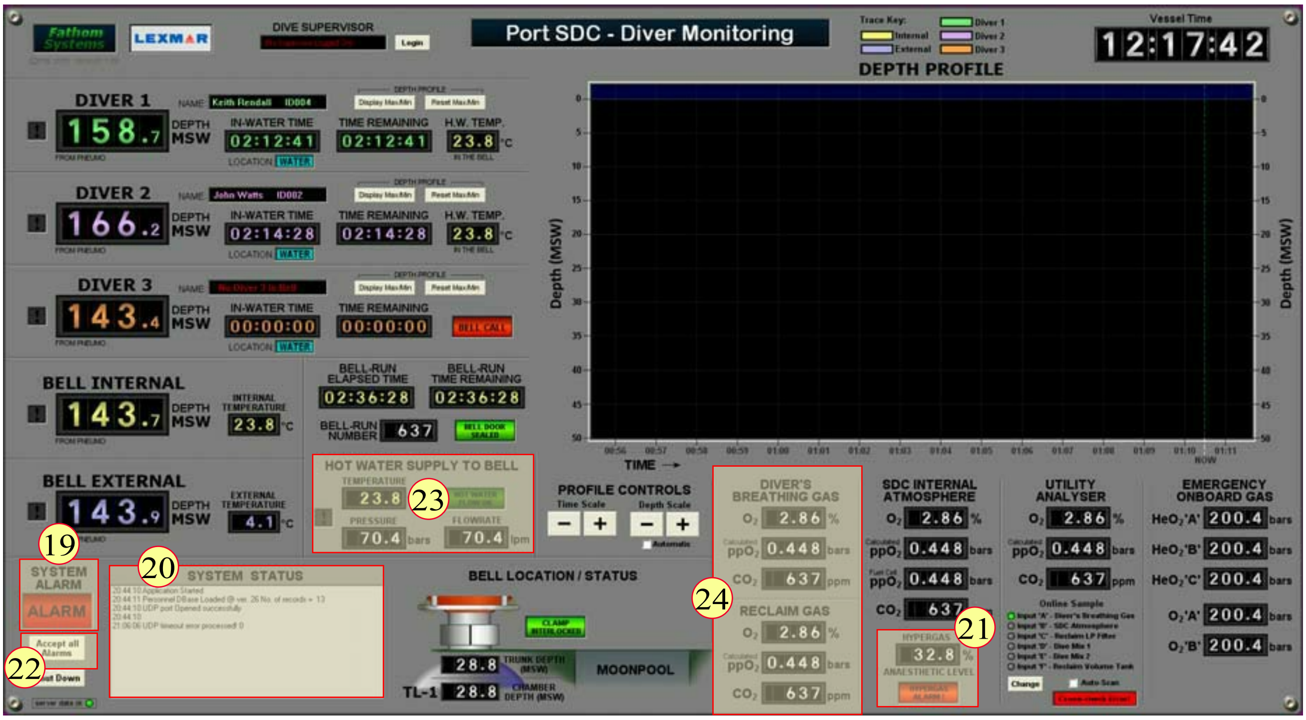
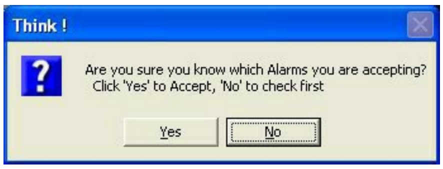


19) - System Alarm Indicator *(see #19 above)*:
This indicator panel is illuminated in red and flashes whenever there are one or more active alarms on the system, or is illuminated steady red when there are one or more accepted alarms (and no active alarms).

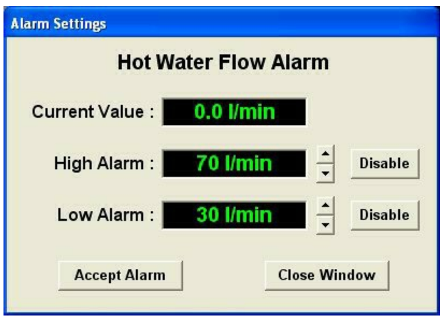
20) - Status display *(see #20 above)*:
This window provides diagnostic information and status of the Diver Monitoring System. As a result, the alarms are also documented in this window. Over time, this list of status messages increases and the oldest logs will not be visible in the window. For this reason, the previous messages can be accessed using the vertical scroll bar at the right-hand side of the window.

21) - Bell "Hydrocarbon analyser" display *(see #21 above)*:
This alarm status panel indicates the hydrocarbon concentration inside the bell and illuminates red when the alarm is active. This function uses the data from the "Analox hypergas MK2" analyzer which are updated every 10 seconds. It is merely a repeat of the sensor values displayed on the relevant display inside the bell.
Note that the alarm threshold is adjustable which allows setting a low alarm limit for an early warning in case of hydrocarbons building up in the bell.

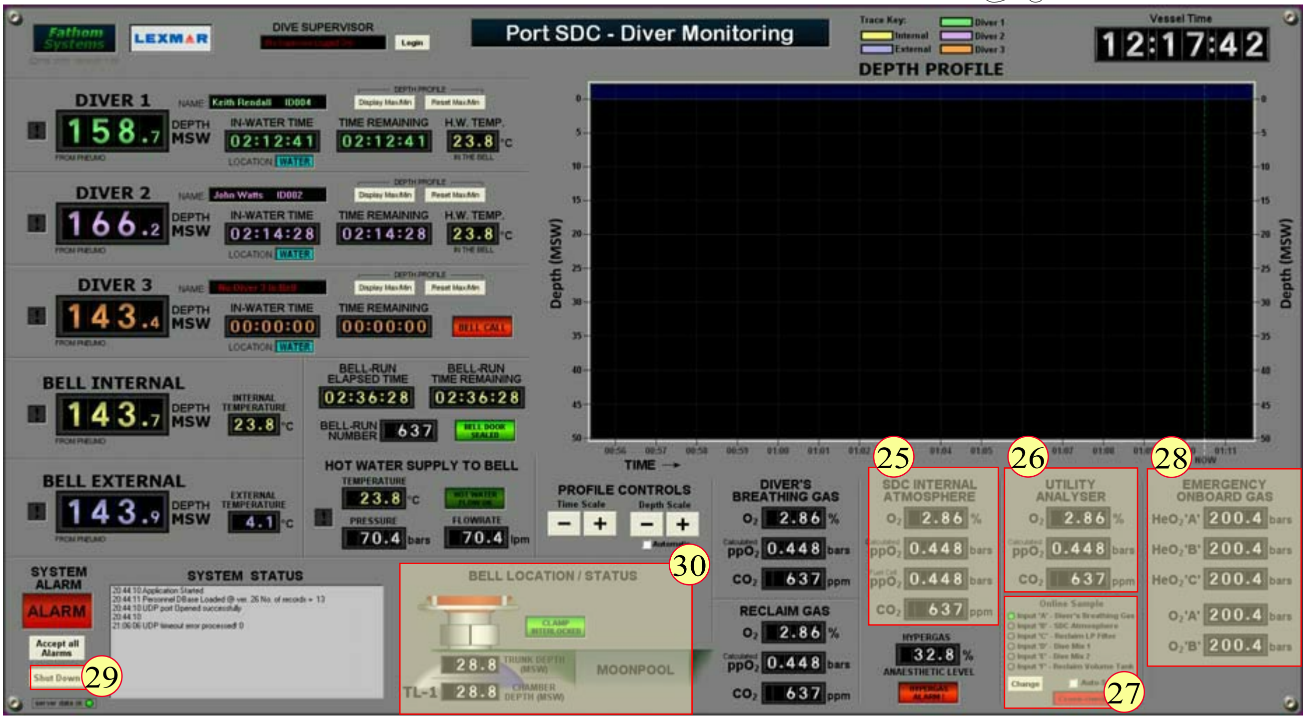
22) - Accept all Alarms Button *(see #22 above)*:
This button allows the Supervisor to accept all active alarms at once. Of course, he must be sure that he understands them, as this button does not require that each alarm condition be viewed prior to accepting. The System status window *(see #20 above)* does, however, provide a list of active alarms to assist in this operation. The system requests confirmation from the supervisor that he acknowledges his responsibility for accepting all alerts at once with a relevant dialog box.



23) - Hot-water supply to the Bell displays *(see #23 above)*:
Three digital readouts provide details of the hot water supply to the bell (temperature, flowrate and pressure), measured at the surface. The relevant sensors are located at the hot-water machines and interfaced via the "intelligent Network Logger (INL)". The hot-water flow is measured by an ultrasonic non-invasive flowmeter attached to the outside of the supply pipework of each bell. These sensors connect to the "Intelligent Network Logger" in the dive control using a signal that is designed to run over long distances with minimal losses (4 to 20 mA type).
The supervisor can adjust the alarm of each hot-water sensor. That is performed by clicking on the particular digital display. As with other warnings, the test in the window flashes red when an alarm is activated or is steady red when it is accepted.



24) - Diver Breathing Gas composition displays *(see #23 above)*:
This window shows the composition of the breathing and reclaimed gasses before they enter the gas hoses of the main umbilical of the bell. The PO2 and ppm CO2 values are generated by the gas analysers in the dive control that are connected to the "intelligent Network Logger (INL)". These values are measured at surface-equivalent pressure and therefore are based on 1-atmosphere concentrations.
Note that the system displays the values of the deepest Diver. The reason for using the most profound depth is to indicate the most critical condition.



25) - Bell atmosphere composition display *(see #25 above)*:
These displays provide details of the composition of the atmosphere of the Bell (internal). The partial pressure O2 and parts per million CO2 values are those from the gas analysers in the dive control that are transmitted to and read by the “intelligent Network Logger (INL)”. These values are measured at surface-equivalent pressure and therefore, are based on 1-atmosphere concentrations.
The ppO2 is calculated from the surface-referenced partial pressure O_2 sample reading and the bell internal depth (pressure) reading from the “intelligent Acquisition Unit (IAU)” sensor.

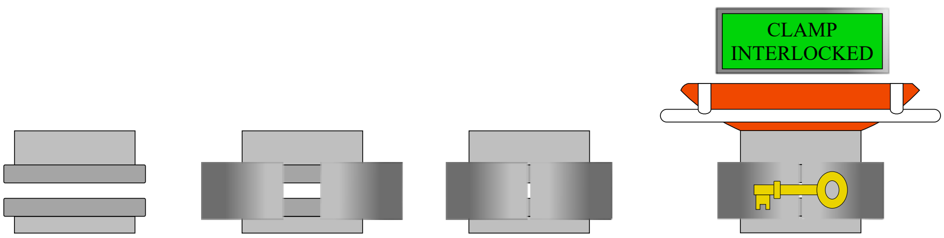
26) - Utility analyser display *(see #26 above)*:
This window provides the PO_2 and ppm CO_2 values that are generated by the utility gas analyser in the dive control whose Ethernet data is transmitted to the server of the Diver Monitoring System. These values are measured at surface-equivalent pressure, and therefore are based on 1-atmosphere concentrations.
The ppO2 is calculated from the surface-referenced partial pressure O_2 sample reading and the bell internal depth (pressure) reading from the “intelligent Acquisition Unit (IAU)” sensor.

27) - Utility analyser sample selection display *(see #27 above)*:
The online sample to the Utility Analyser (one from six possible inputs) is shown, and the supervisor can select this online sample. An auto-scan function is provided that cross-checks the primary gas analyzer readings against the Utility analyzer automatically and is enabled with the check-box.

28) - Bell Onboard Gas displays *(see #28 above)*:
These displays show the pressure in the bell onboard gas banks (HeO_2 and O_2). The signals for these displays come from the “Intelligent Content Gauges (ICG)”, that has been previously described, and is mounted on the outside of the bell and send the data from the sensors to the “intelligent Acquisition Unit”.

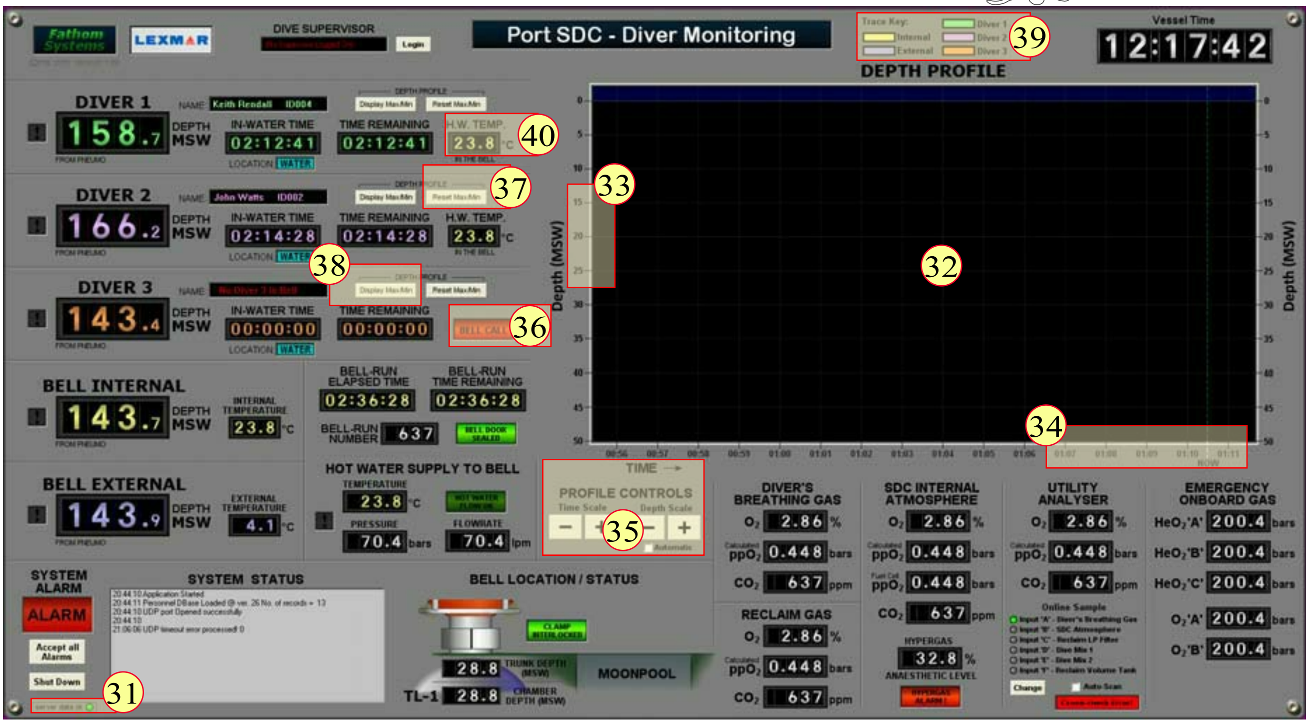
29) - Shut Down pushbutton *(see #29 above)*:
This button is used to shut down the dive control client display screen. A prompt dialog appears to check that this action is required before the application is shut down.

30) - Bell position, clamp and trunk status displays *(see #30 above)*:
This area of the display screen shows the status of the clamp that secures the bell to the trunk when it is under the control of the diving supervisor. This is done using several mimic drawings. Note that when the bell is not above the trunk, there is no mimic picture of the bell shown. The display indicates the four possible states below:



Clamp fully open | *Clamp between Open & closed* | *Clamp fully closed* | *Clamp fully closed & interlocked*

A digital indicator for the depth (pressure) of the bell mating trunk is visible below the drawing of the clamp. This value comes from the pressure transducer located in the dive control.
In addition, there is another digital indicator for the depth of transfer lock below the the trunk depth display. This value comes from the pressure transducer located in the saturation control.



31) - Server status indicator *(see #31 above)*:
This indicator is illuminated green when the data server computer runs correctly and provides the dive control client display with correct information. If the server is down or unavailable, this indicator illuminates red.

32) - Depth profile display *(see #32 above)*:
This large display shows a real-time plot of the five key depth signals against time. It is updated automatically and provides a graph of depth (on the Y-axis) against time (on the X-axis), and uses colour-coded traces to represent each of the following depth sensor signals:
- Diver 1 Depth (Green)
- Diver 2 Depth (Purple)
- Diver 3 Depth (Orange)
- Bell Internal Depth (Yellow)
- Bell External Depth (Blue)

A graticule allows reading the scales easily. Clicking on the main graph area selects various (alternate) display scaling modes. The depth range of the display area automatically re-scales to suit the desired display settings
The data visible on this display are held locally in the dive control display application and is retained in the client computer memory for 12 hours. Data older than 12 hours are discarded, so if a review of older data is required, the “Report Generator application” should be used.

33) - Profile depth scale *(see #33 above)*:
The depth profile is scaled vertically in metres of seawater (MSW).

34) - Profile time scale *(see #34 above)*:
The depth profile is scaled horizontally in time. The timescale for the data is either 1, 4, or 12 hours, and the actual time of day (Vessel time) is shown on the horizontal display.

35) - Profile time and depth scale selector buttons *(see #35 above)*:
These buttons allow selecting the different profile time scales and adjusting the depth range shown on the graph. Checking the “automatic” check-box scales the depth to the most suitable range automatically.

36) - Bell call indicator *(see #36 above)*:
This display indicates that there is a pending call from the bell to the supervisor (taken from the bell call system status signal). This indicator illuminates red and reads “BELL CALL” when a call is pending. This condition is cleared by the Supervisor

37) - Profile maximum and minimum depth cursor reset buttons *(see #37 above)*:
The horizontal colour coded dashed lines show the limits of excursion of Divers 1 to 3 within the previous 12 hours. These cursors can be reset with the three buttons, one for each diver. That would typically be done before starting a bell run.
Note that when reinitialised, these cursors only track depth changes from this time onwards and not historically over the past 12-hours.

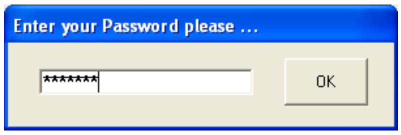
38) - Profile maximum and minimum depth cursor enable buttons *(see #38 above)*:
These horizontal colour coded dashed lines show the limits of excursion of Divers 1 to 3 within the previous 12 hours. These cursors can be turned on or off using the dedicated buttons (one for each Diver).

39) - Profile trend key *(see #39 above)*:
This key shows the colour coding used for the profile display traces.

40) - Diver's hot water temperature at bell level *(see #40 above)*.

Diver monitoring system preparation:

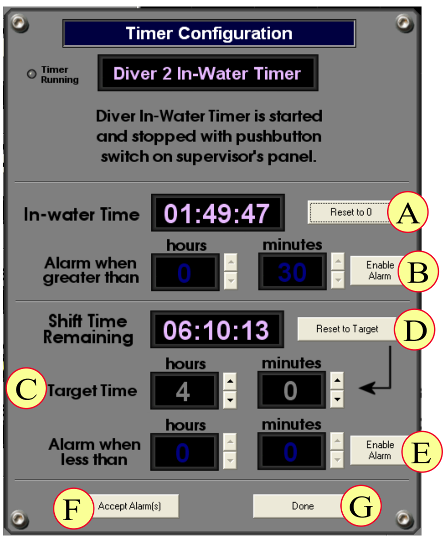
The diving supervisor is required to log onto the system at the start of his shift. To do it, he clicks the "Dive supervisor Login" button on the Main screen display *(See #8 in the drawings on the previous pages)*, and then selects his name from the list provided. A prompt is then presented to the supervisor to enter his password before login is permitted.



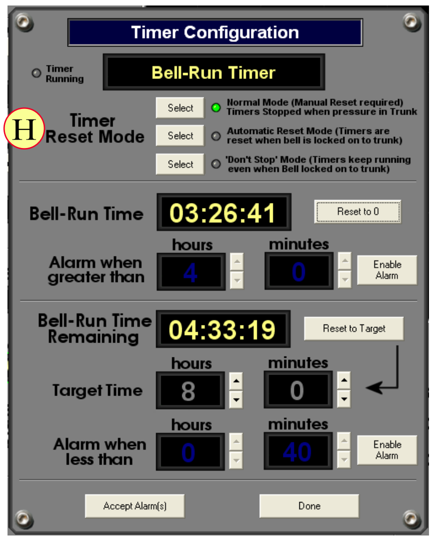
If the Supervisor has never worked on the vessel where the Diver Monitoring System is installed, he must enter his details at first into the Monitoring System database. It is usually performed from the client computer of the saturation control. It can also be done by the dive technician using a remote saturation control client session.
Note that when the supervisor is logged on, the text displayed on the button changes from "Dive supervisor Login" to "Dive supervisor Log off". At the end of his shift, the supervisor must log off the system. To do it, he clicks the "Dive supervisor Log off" button on the Main screen display and follows the menu.

When the supervisor is logged in the system, he must reset the timers before starting the bell run.

- To access the menu of the "Diver in-water timer", the supervisor clicks on the particular diver's timer display *(see #5 in the description of the monitoring screen)* to open the configuration window. Then he clicks on the button "reset to 0" *(see #A below)*. Also, he configures the alarm time using the scrolling arrows to adjust the time as required *(see #B below)*.
  The Supervisor should adjusts the duration of the shift of the diver by clicking the up and down the scrolling arrows of the boxes "target time" *(see #C below)*. When the desired target time for the shift has been entered, the supervisor clicks the tile "Reset to Target" *(see #D below)* to transfer the values entered to the "live timer". The alarm is configured as for the in-water time *(see #E below)*. When both alarms have been setup their displays flash in with red digits until the setup is accepted through the dedicated button *(see #F below)*. The widow is then closed by clicking the button "Done"*(see #G below)*.
- The "bell run timer" must be also configured. To access the menu, the supervisor clicks on the bell internal or external depth readings *(see #10 & 15 in the description of the monitoring screen)*. He can also open this window by clicking on the bell-run timer displays *(see #12 in the drawing of the monitoring screen)*. The configuration of the bell run timer is similar as the divers in-water timers, but there are three additional buttons which relate to the operating modes*(see #H below)*.
  - "Normal mode" : Based on the "bell seal" status from the trunk pressure sensor, the timer is started and stopped automatically. This mode requires a manual reset of the timer at the start of each bell-run.
  - "Automatic Reset mode" : The system works the same as in Normal Mode, except the bell-run timer is reset to 0 when the bell locks back on to the trunk.
  - "Don't Stop' mode" : The bell run timer continues to run even though the bell is locked back onto the trunk. This mode is used where the bell is required to be returned to the system and then launched again all within a single bell-run.



Diver in-water timer



The bell run timer

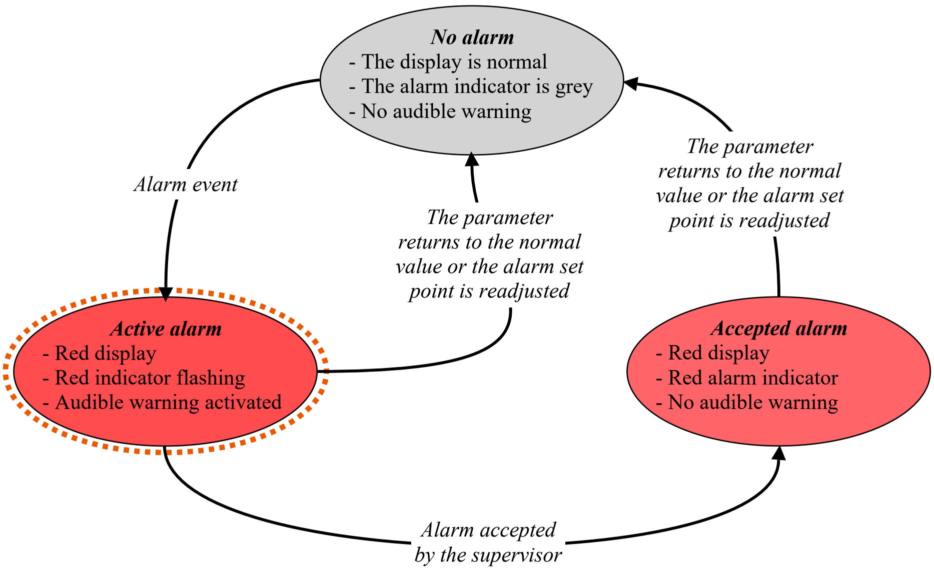
- Prior to transfer the divers to the bell, the supervisor ensures that their names are those indicated in the relevant displays and that their function during the planned bell run is correctly logged (Diver 1, Diver 2, and bellman).

If the diver's names are incorrectly logged, the diving supervisor informs the life support supervisor (LSS) who rearranges the assignment of the divers in the Bell.

- During pre-dive checks, the diving supervisor must ensure that the values on the Diver Monitoring System display conform with the primary instrumentation. If a displayed parameter disagrees with a primary instrument reading, the reason for the discrepancy should be investigated and the problem solved before commencing the dive.
- The diving supervisor does not need to interact frequently with the software, except for adjusting the alarm settings, selecting alternative display modes, or logging on or off the system. However, he must enter the names of the divers moving from the bell to the water and vice versa. To do it he presses the pushbutton switches on the control panel of the Diver Monitoring System computer monitor *(see #4 in the drawing of the monitoring screen)*. As a result, the indicator lamp is illuminated, which signifies that the diver is in the water. When the switch is in "out" position, the light is not activated, which means that the diver is in the Bell.
- During the operations, the Diver Monitoring System may raise an alarm that can be a repeated display of a diving system alarm, or an alert relating directly to one of its features. As a reminder, the warning generated by the system can be one of those listed below:
    - Diver in-water timer alarm for each diver (target duration has been exceeded)
    - Diver shift remaining timer alarm for each diver (time remaining is less than the alarm set point)
    - Bell-run timer alarm (target Bell-run duration has been exceeded)
    - Bell-run time remaining timer alarm (Bell-run time remaining is less than the alarm set point)
    - Diver depth alarm for each diver (maximum or minimum depth alarm set point has been exceeded)
    - Bell internal or external depth alarm (maximum or minimum depth alarm set point has been exceeded)
    - Hot water supply to the Bell flow alarm (water flow is below low flow alarm set point)
    - Hot water supply to the Bell temperature alarm (water temperature is above or below alarm set point)
    - Hot water supply to the Bell pressure alarm (water delivery pressure is below or above the alarm set points)
    - Hypergas anaesthetic level percentage (high alarm).
    - Onboard gas bank pressures (high and low alarms).

  This alarm status results in:
    - The digits of the element affected turning red
    - The alarm indicators are illuminated red and flashing *(see #9 & #19 in the drawing of the monitoring screen)*.
    - An audible warning generated every 10 seconds
    - A description of the problem published in the status box *(see #20 in the illustration of the monitoring screen)*.
    - In case of a system error or fault alarm is generated, the display changes to a row of red dashes.

  Remember that the active alarm must be accepted by the supervisor to stop the indicator from flashing and the audible warning from being repeated.
  Clicking on the red numeric display of the parameter in the alarm state opens the "alarm settings window" for the particular sensor *(see #9 in the drawing of the monitoring screen)*.
  Once accepted, the alarm indicator remains illuminated red and the digital parameter display remains red also.
  When the alarm returns within the setpoint(s), the display returns to its normal display colour and the alarm indicator returns to grey.
  Also, the Supervisor can accept all the active alarms at once through the button "Accept all alarms" *(see #20 in the illustration of the monitoring screen)*. As already said, he must be sure that he understands them, as this button does not require that each alarm condition be viewed prior to accepting it.



In case of a system error alarm or a warning from a part of the diving system, the manufacturer recommends informing the technician who is the competent person to investigate the error remotely and effect a repair as necessary.

2.3.14.7 - Fire fighting

IMCA D 024 says: *"Suitable firefighting arrangements must be made for dive control. 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

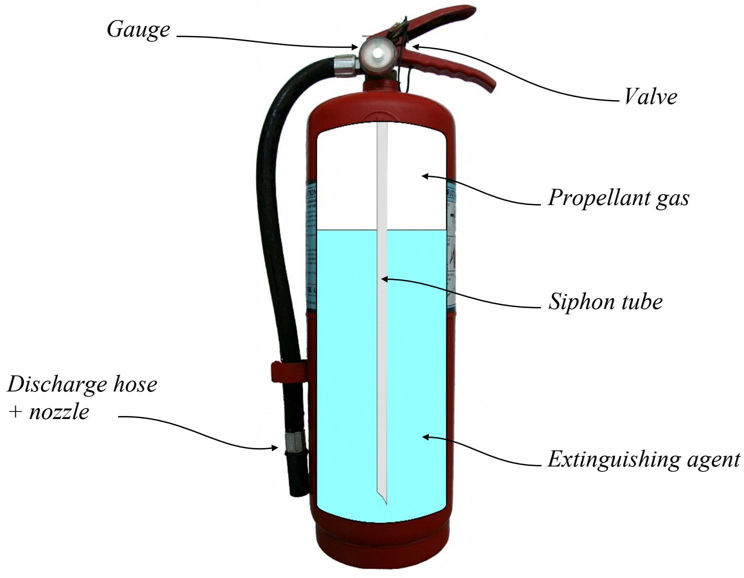
  Foam is not generally used in the dive control room as items filled with oil are usually not present in it. However, depending on the design of the saturation system, such extinguishing agents may be present outside the room and at its direct vicinity.
- Carbon dioxide (CO_2):
  Carbon dioxide dilutes 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

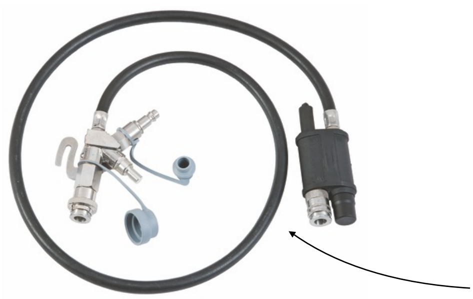


- “Cartridge-operated extinguishers” have the fire extinguishing agent not stored under pressure and the propellant gas that is in a separate small sealed cartridge. Depending on the design, this cartridge is operated by a specific mechanism triggered by the valve that pushes a plunger or by pressing 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

2.3.14.8 - Emergency breathing apparatus

IMCA D 024 says: *“Emergency breathing apparatus fitted with communications must be available for the supervisor (and winch operator if relevant) 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.

2.3.14.9 - Documents to be provided in the dive control

IMCA Says that the following documents must be present in the dive control:

- Copies of the diving contractor's manuals and diving rules.
- Emergency procedures (Generic procedures supplemented by project-specific addendums).
- Diving logs or pre-printed sheets and other relevant documentation.
- Copies of the diving bell internal and external pre-dive checklists.
- A photographic record that clearly identifies the bell valves, internal and external, should be available to allow the supervisor to guide the divers in an emergency.
- Plan to deploy a surface standby diver in emergency, unless a robust alternative plan (proven through exercises) has been developed to ensure assistance can be rapidly given to a stricken or fouled bell at all depths within the working range of a surface diver, including the period while the bell is close to or in a moonpool.
- A layout of the vessel thrusters and other obstructions must be displayed if the ship operates on Dynamic Positioning mode, with also a diagram of the maximum permitted lengths of the umbilicals of the working and standby divers for each depth at the specific dive location(s). This should include the umbilical ranges for the emergency surface standby diver.

Not indicated by IMCA, but very important, the following documents should also be available:

- The list of the divers in saturation, their function, and working periods.
- The list of the personnel on deck, their function, and working periods.
- The phone numbers of the key persons.
- Emergency communication channels and the emergency response plan chart should be displayed at the direct vicinity of the supervisor.
- The task plans and risk assessments for the project.
- Tool box talk forms.
- Safety observation cards & stop cards.
- Incident report forms.
- Equipment manuals and implementation procedures.
- A plan of the diving system where the important elements linked to the management of the dive are highlighted must be displayed.
- The list of the gasses in line with their % oxygen.

2.3.14.10 - Summary of the maintenance of the elements in the dive control room

There is no change of the rules of certification of the mechanical and electrical components present in the dive control compared with those of other parts of the diving system.

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			Manufacturer specifications
Alarm testing	6 months			Manufacturer specifications
Analysers	6 months			Manufacturer specifications

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*
Gauges	6 months			
Valves and pipework	6 months	2 years		
Relief valves	6 months	2 ½ years		
Electrical	6 months			
Fire fighting portable system	6 months			Manufacturer specifications
Fire fighting fixed system	6 months	12 months		Manufacturer specifications
Automatic fire detection	12 months			Manufacturer specifications
Emergency breathing apparatus	6 months	2 ½ years	5 years	Manufacturer specifications
Remote bell contamination control *(hydrocarbons +H 2 S)*	6 months			Note: Mandatory with IOGP

The computing systems described in the previous points are perfect tools for the observation of the diving system during the operations. However, that does not replace the classical planned maintenance system promoted in IMCA D 024 and described in the previous texts and the table above. Also, these tools need particular maintenance that is not yet taken into full account by IMCA and other professional organizations.
Computing systems can be subject to errors, faults, or flaw in programs or hardware systems. Such problems that are commonly called "bugs" produce unexpected results or cause a system to behave unexpectedly.
A lot of bugs are due to errors made by developers designing the source code of a program, or within components and operating systems used by the program in question. Also, malicious users can exploit potential bugs or weaknesses of an application to bypass access controls to obtain unauthorized privileges. Nevertheless, note that it is well known that most viruses are implemented accidentally through access to corrupted programs.
For this reason, the updates published by the manufacturers that correct the errors and vulnerabilities of software or the exploitation system should be installed on time. Also, memory sticks are identified as a significant source of transmission of bugs and viruses. For this reason, the manufacturer of the systems described in this presentation recommends not connecting such devices that contain other files and programs than those from the system. Considering that the price of such an item is negligible, the best procedure is to provide a new one to each supervisor arriving on board and ensure that these devices are always stored in the control room.

2.3.14.11 - To conclude with the latest generation dive controls

The latest generation of dive controls have their ergonomics improved compared to systems of the previous generation. Also, they provide additional tools that can be used for the management of the gasses, the condition of the divers, and the tasks performed. Nevertheless, note that dive controls from the previous generation can be upgraded to this latest standard by the addition of these new tools.

The dive control of Seven Pelican that has been built 35 years ago is an example of an old system upgraded to the latest standards.

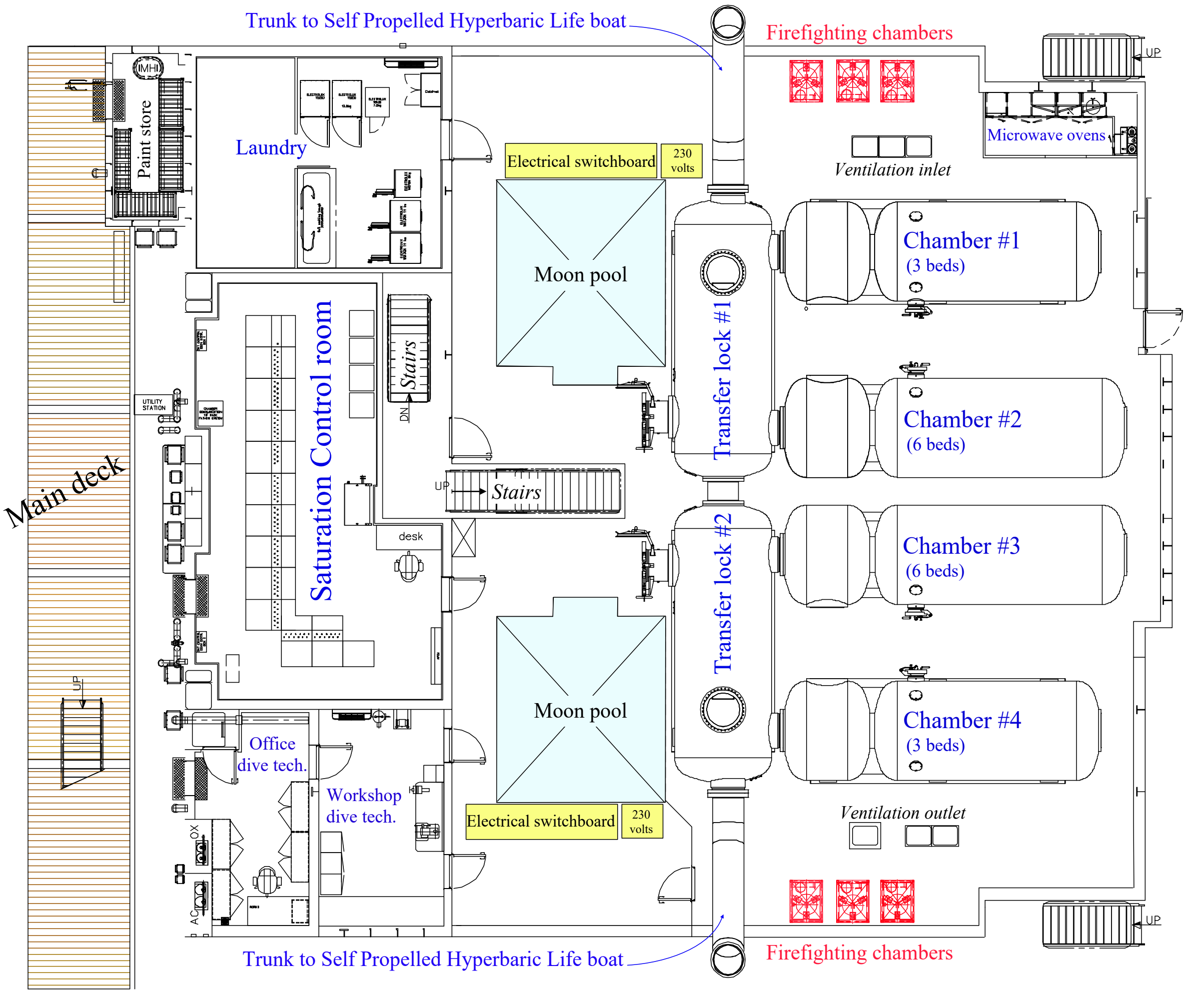
The implementation of technologies from the computing industry allows significant improvements in the communications and the management of the conditions of the diver health and of the system his life depends on during the bell run. As a result, and even though new technologies such as the Diver Monitoring System are not mandatory with IMCA *(International Marine Contractor Association)*, IMO *(International Maritime Organization)*, and ADCI *(Association of Diving Contractors International)*, we can say that such equipment should be used.

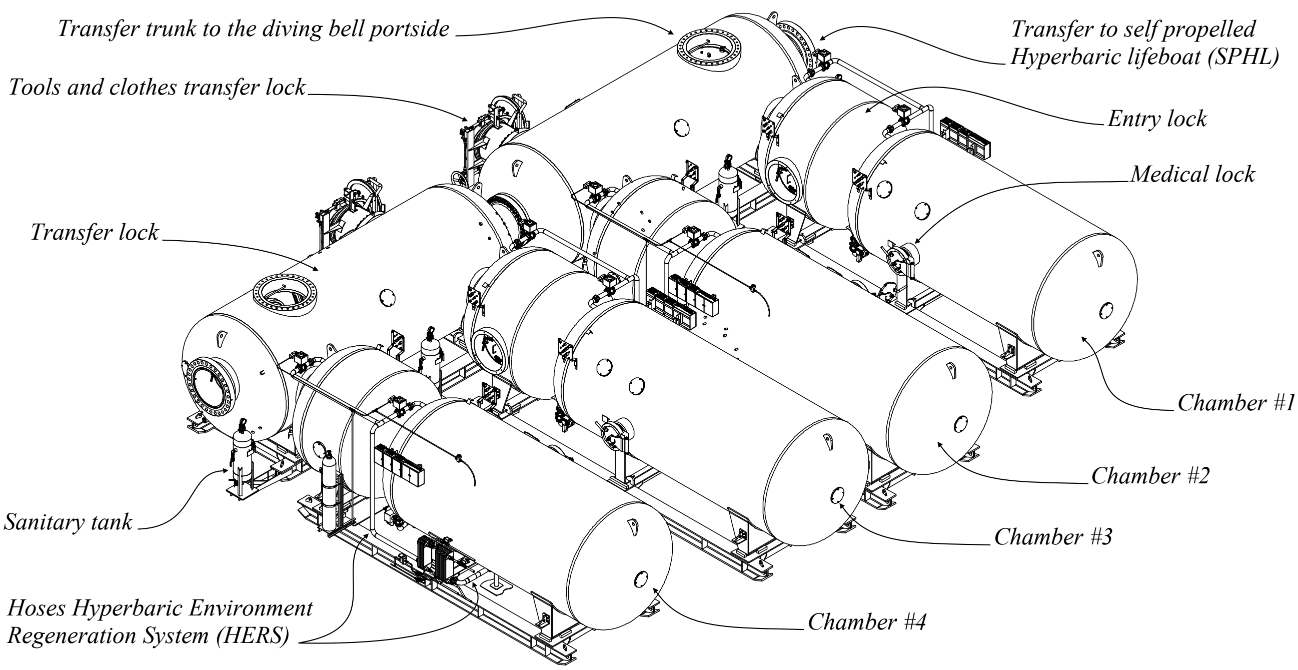
The implementation of such technologies with divers is merely the continuation of their use in many industries, and particularly the space, aviation, and maritime activities for more than 40 years.
However, we can see that the manufacturer of the system taken as an example acts prudently and that the classical control systems are still present and ready for immediate use. It is probably the best philosophy for systems that are designed to protect the life of people working in a dangerous surrounding, which is the case of saturation diving activities. Several accidents that have happened in the aviation industry prove that fully computerized systems may lead to catastrophic events. As a result, despite clear menus, the management of such new systems requires the supervisor to be familiar with them, and the owner of such a system should organize a specific formation before the beginning of the operation. This formation should be anyway mandatory with all saturation systems, even those that do not provide electronic tools as each system has its specifications and the supervisor must keep his knowledge regarding the use of the classical commands.

2.3.15 - Chambers

2.3.15.1 - 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.

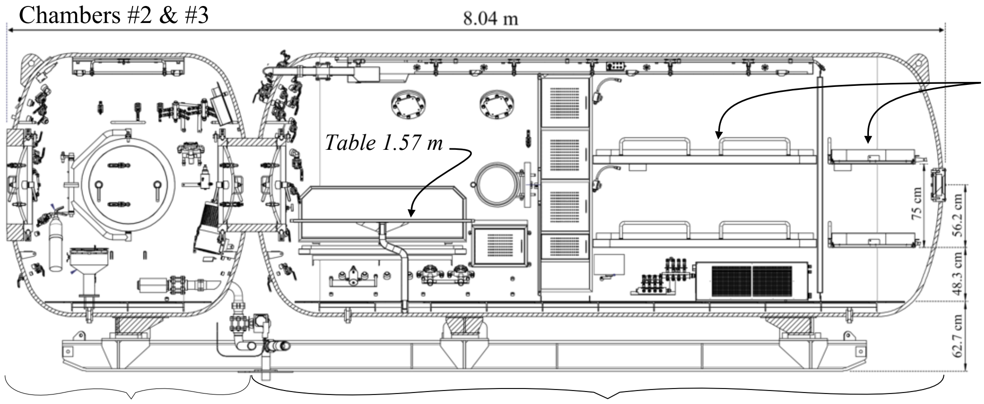


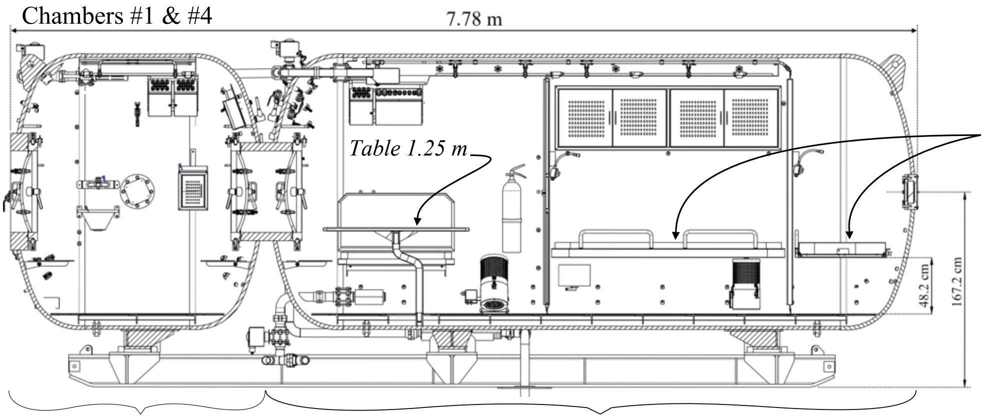


The system allows storing divers at several depths, depending on the way the project is organized. As an example, one team at 100 m and the others at 60 m. Also, that allows organizing crew changes with incoming divers compressing while out-going divers are decompressing. Also, a chamber can be used 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.

2.3.15.2 - 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:

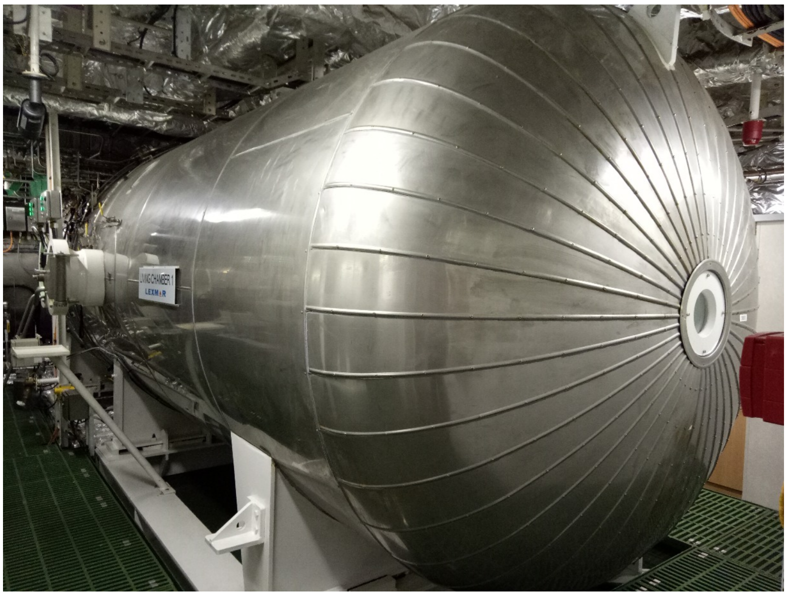
- Chambers used for saturation are usually fitted with insulation, which is protected from shocks and moisture by series of metal shaped sheets or composite materials *(see on the next page)*. This protection must be in perfect condition to ensure the absolute integrity of the isolating material, and 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%)*.

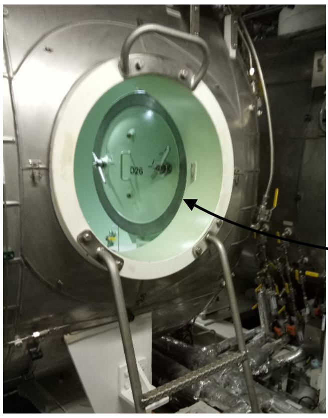
- IMCA says that all valves and penetrators must be marked with their function indicated. That can be seen in the photo below. Also, manufacturers generally provide additional penetrators by precaution *(see in red circles)*.

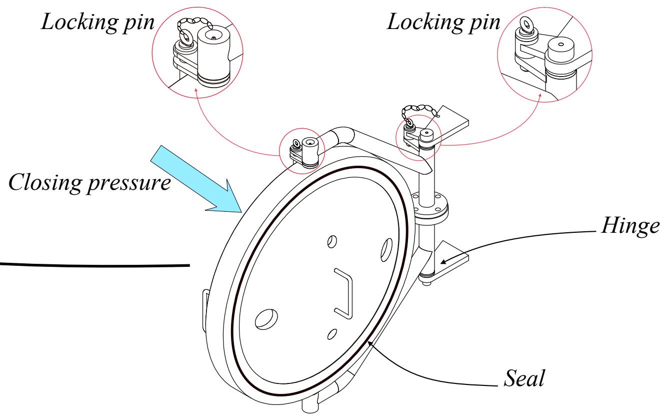
Marked hollow penetrators and their valves



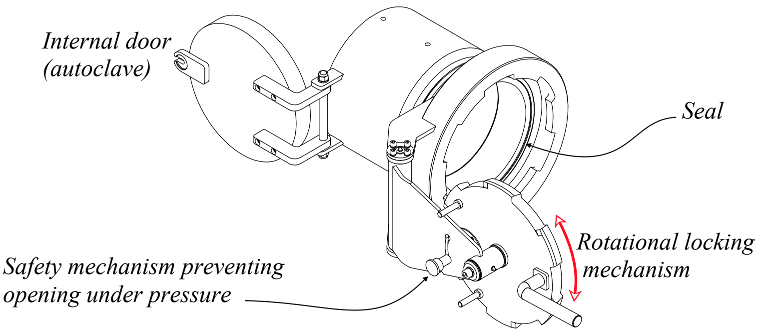
Protection of the isolation (made of stainless steel sheets)

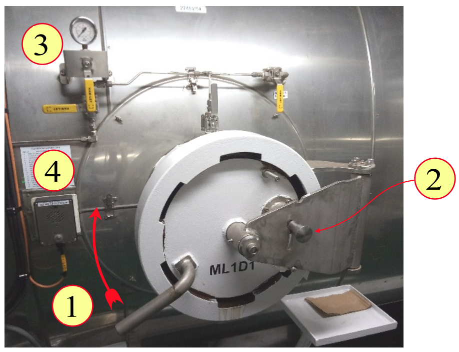
- A door on the side of the entry lock allows accessing the chamber when it is not under pressure *(see below)*. This door must be marked with a dedicated number as the other doors of the system for identification purpose.
  As with the bell, this door is autoclave, so the pressure inside the chamber 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.



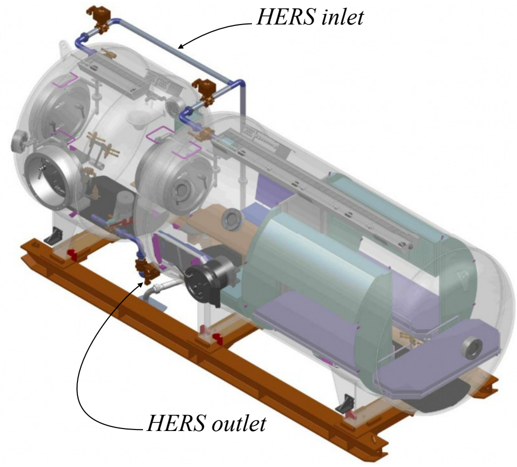


- A medical lock is fitted on the side of the main chamber to transfer the food and of course medicines if necessary. Opposite to the door above, this door works against the pressure, which means that it can be opened by the internal pressure if it is incorrectly closed or opened while the lock is under 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)*.

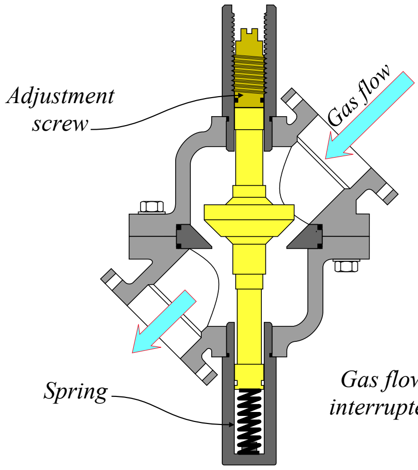




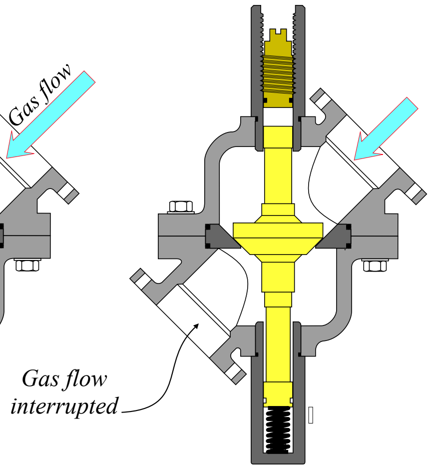
- The gas in the living chambers and their entry locks is regenerated by the Hyperbaric Environment Regeneration System (HERS), which removes the CO2 and moisture resulting from the respiration of the divers. This system uses pipes of approximately 6 cm diameter that are figured in the drawing below. 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

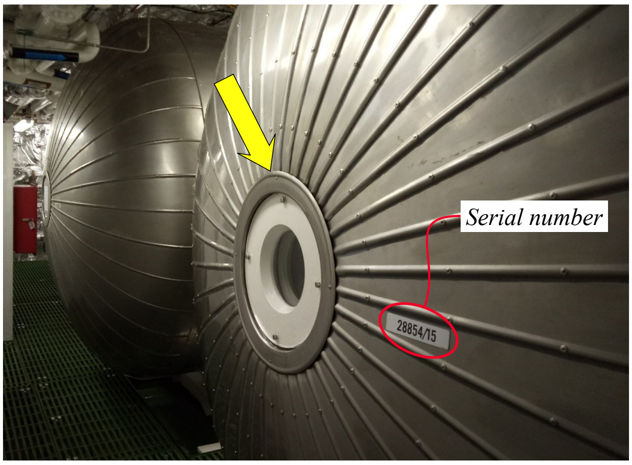


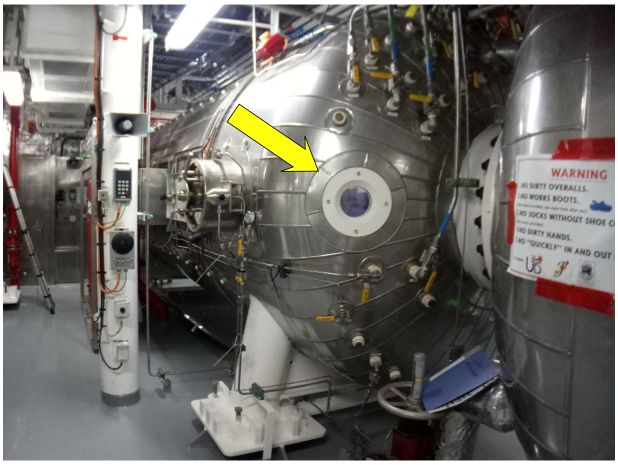
Flow fuse open



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"*.





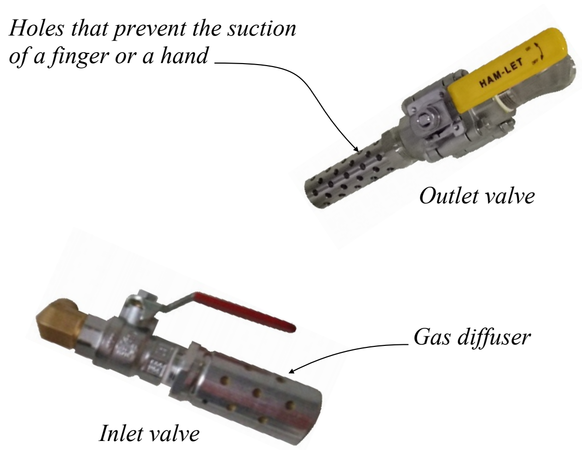
Viewports must be manufactured according to a recognized standard, and tested according to the “American Society of Mechanical Engineers” (ASME) Pressure Vessels for Human Occupancy (PVHO) procedures. The serial number or another identifying mark for each viewport fitted to the chamber must be visible. 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 systems must be provided to protect and cool the chambers. They are the same as those used with the dive control and that are described in point 2.3.14.7 “Fire fighting”. The models of extinguisher provided should be selected according to the categories of fires that should be identified through a risk assessment.

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



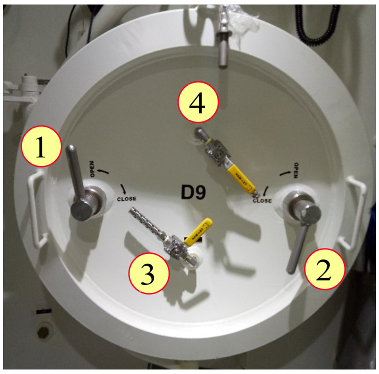
- NORSOK says that the chambers used as living and sleeping accommodation must be equipped with seats and individual bunks for the number of divers who use this part of the chamber complex. The beds must be designed to allow a minimum comfort and a minimum size of 200 X 70 cm is required *(see the photo 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

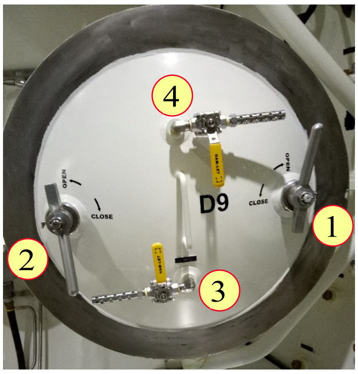
Bed light and communication box

- 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.

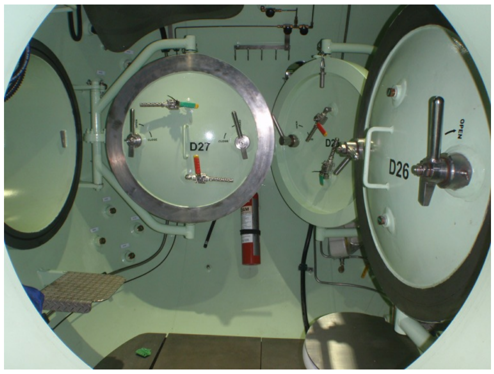
- The chambers are linked together by trunks that can be pressurized and deflated from the saturation control room. They are isolated by autoclave doors similar to the one used for the access from external already described at each end of the trunk. So the divers are protected in the case of depressurization 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, as indicated in point 2.3.14.4.
  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.

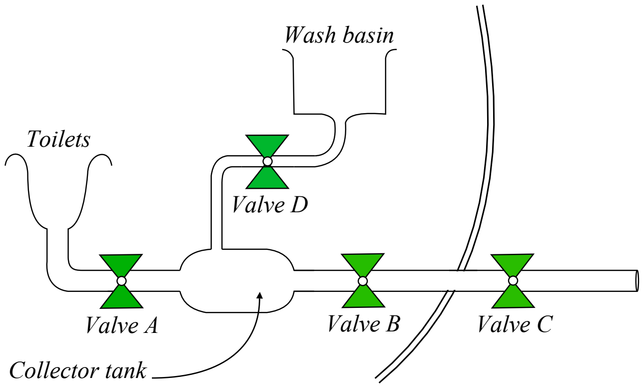
- Toilets used in chambers are of flush type installed in the entry lock. They are based on a series of receivers at normobaric pressure to which the faeces are pushed by the pressure inside the chamber. As a result, toilet flushing involve the operation of several valves inside and outside the chamber. 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.

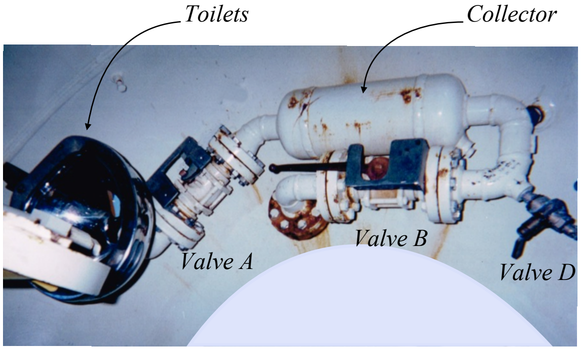
To address these potential accidents, the following elements must be implemented:

- 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:

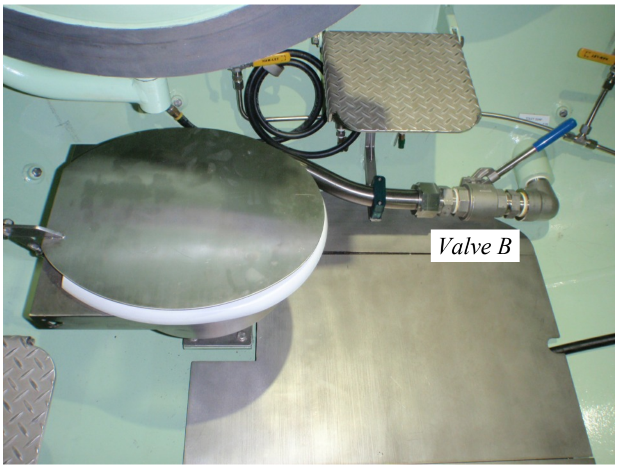
- While standing by, or during utilisation, the 3 valves A, B, and C are closed.
- After utilisation (valves A, B, C and D closed), the user stands by the system and calls for an assistant outside the chamber.



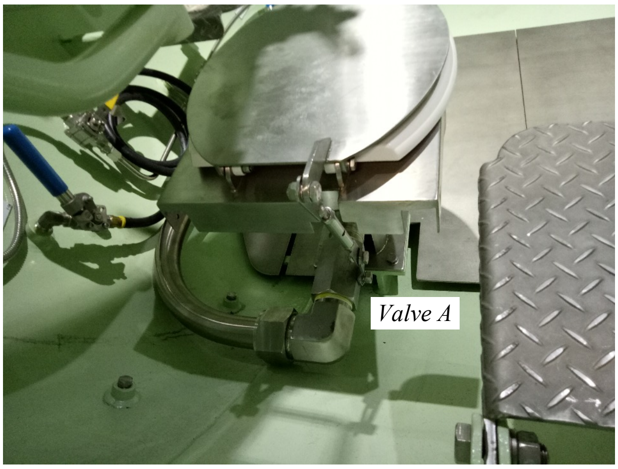


1. The Life Support Technician checks visually through the port that the bowl is clear, opens valve C and remains by the port for the duration of the procedure,
2. User opens valve B
3. User closes valve B
4. User opens valve A (or D)
5. User closes valve A (or D)
6. User opens valve B
7. User closes 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.

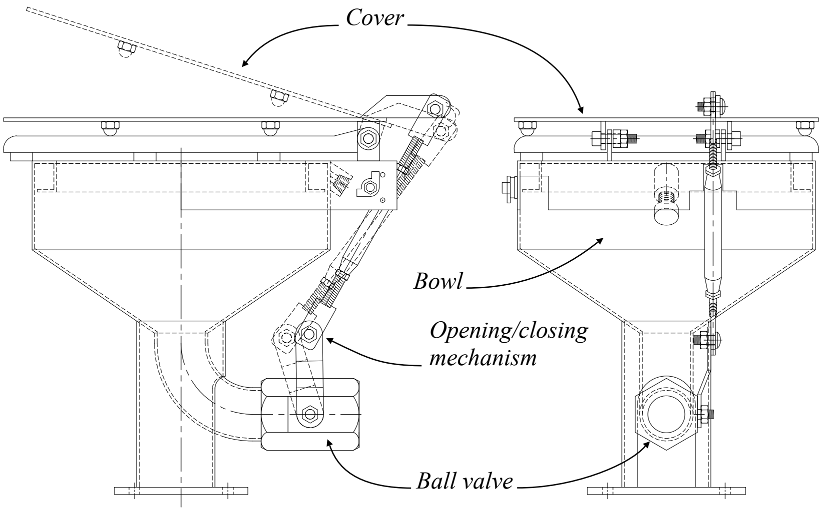


View from the top: Valve B is kept close by its spring



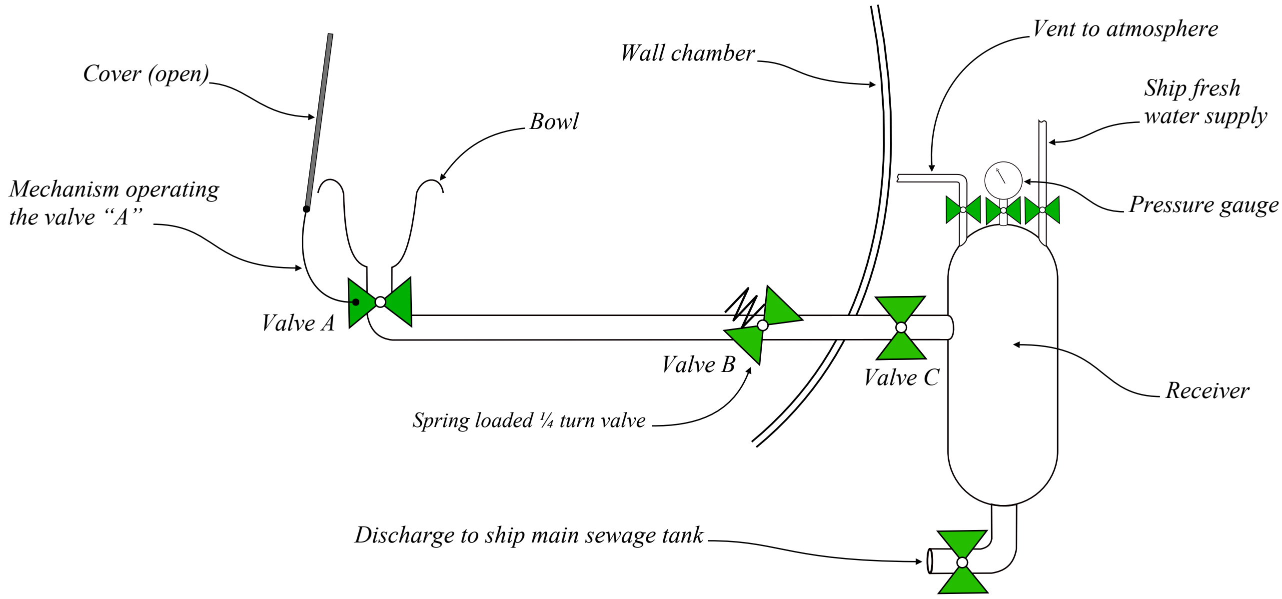
Valve A is operated by a lever connected to the cover

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.

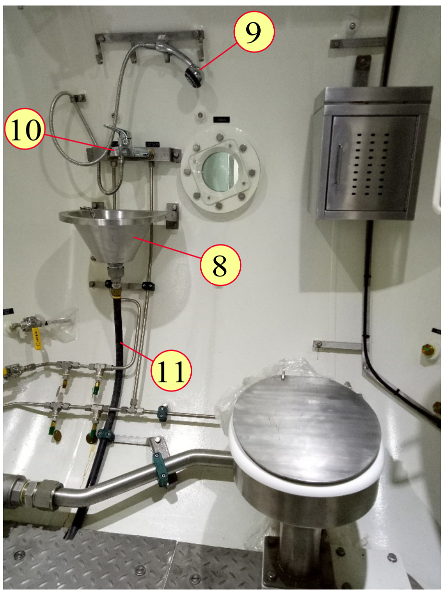


Opening/closing mechanism of the toilets

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.



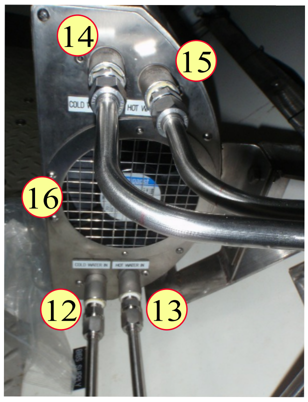
Note that DMAC 26 says that:

- 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

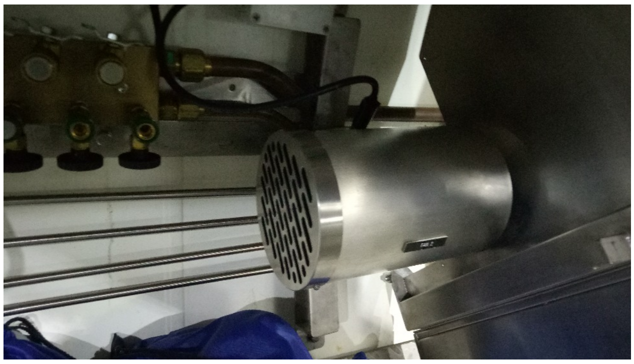
The atmosphere of the chamber must be adjusted at the ideal temperature and humidity levels. With the saturation systems taken as reference, it is done through devices that cool the gas to its dew point to remove the excess of moisture and then reheat it to the ideal temperature. These devices are fitted 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



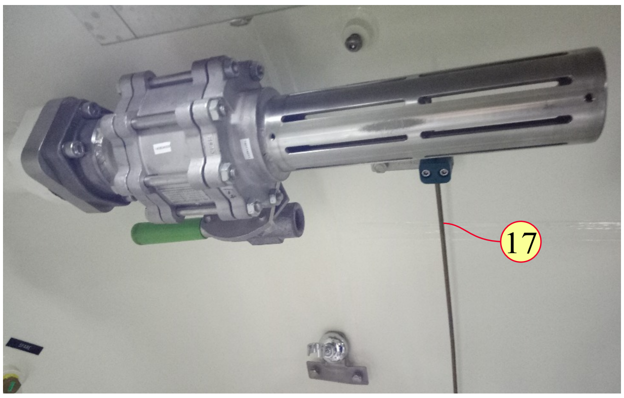
Additional fans are used to ventilate the chamber and increase the efficiency of the heating/cooling system. They are usually at floor level and at direct proximity of the heating/cooling element.

Fan #1 - Eating / recreational side

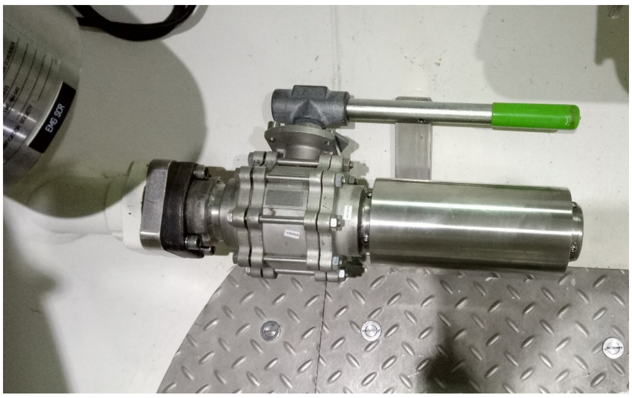


Fan #2 - Sleeping side

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.



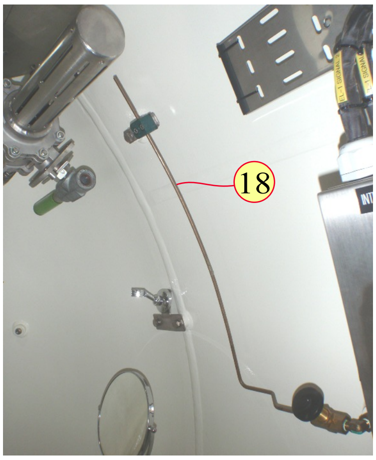
Gas inlet from HERS



Gas outlet to HERS

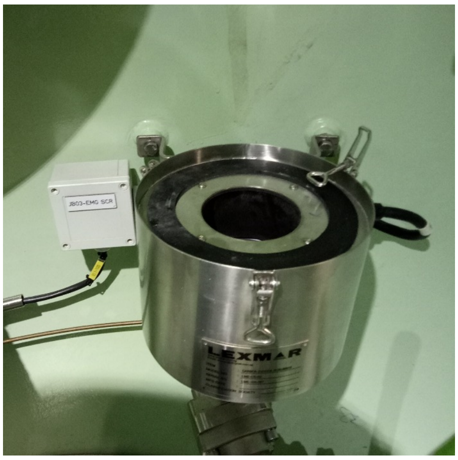
The oxygen consumed by the divers must be renewed. For this reason, a small hose 1/4” is installed with its opening at the direct proximity of the HERS inlet to obtain a proper mixing *(see #17 in the photo above and #18 in the picture on the next page)* Note that IMCA recommends this design.
Also, IMCA 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.



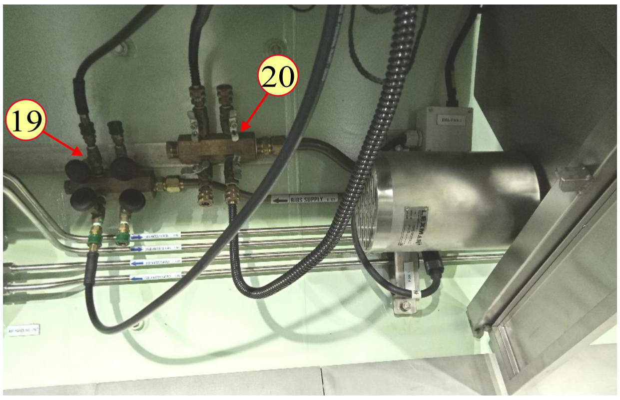
Oxygen supply hose

Scrubber

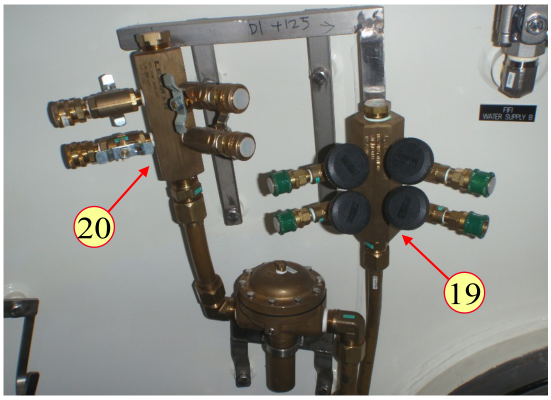


Fan block with the 3 clips

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 connectors and masks provided are the same as those used in the bell *(see point 2.3.2.7 - "Bell internal equipment")*.
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)*.



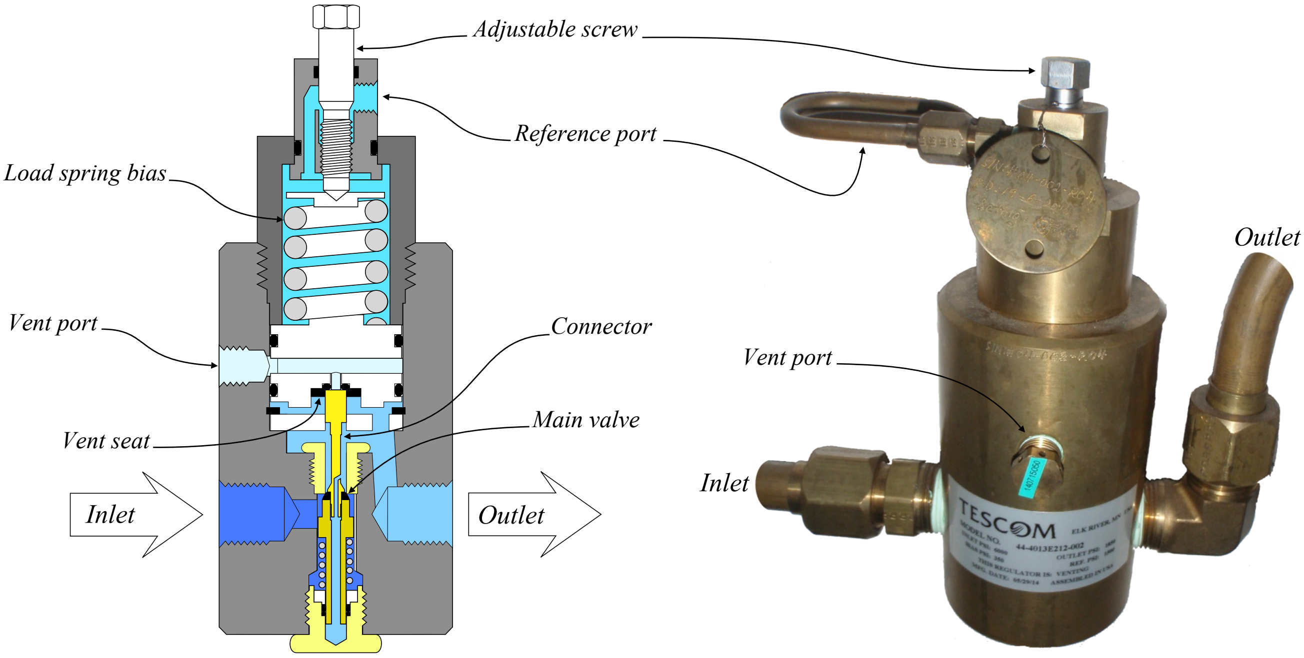
BIBS inlet and outlet manifolds under the bunks



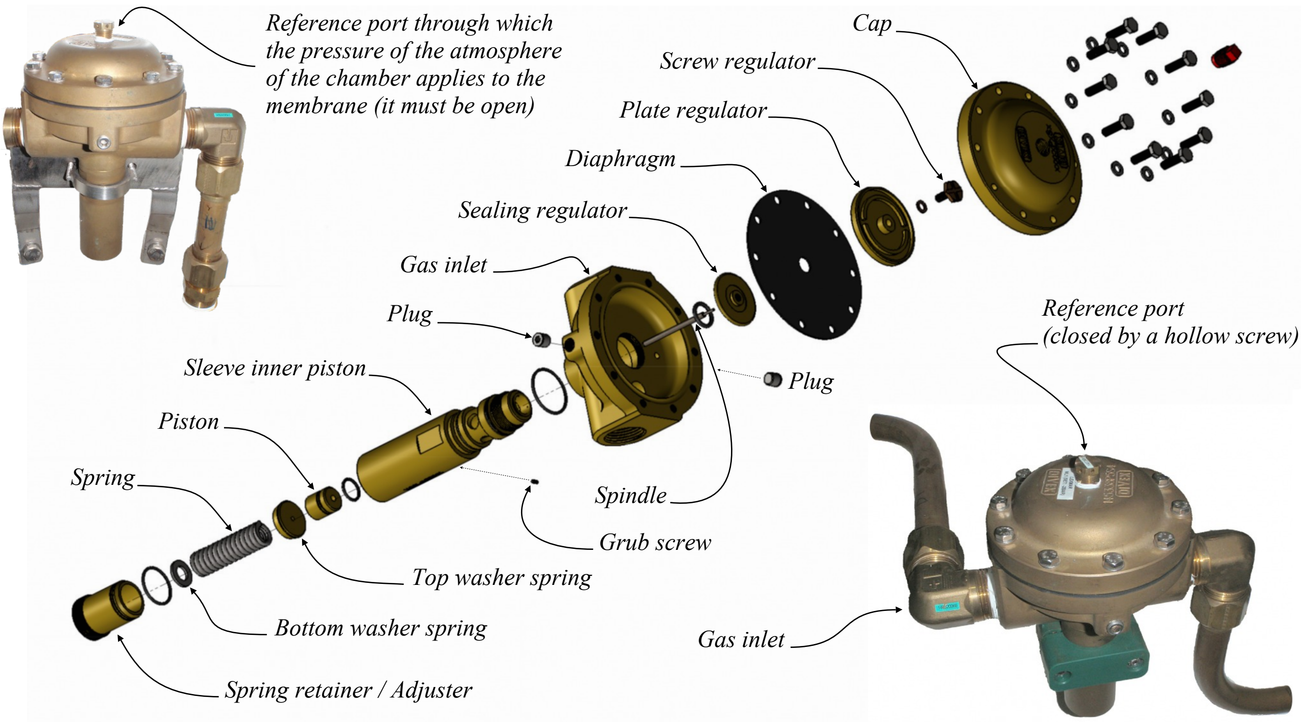
BIBS inlet and outlet manifolds in the entry lock

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.

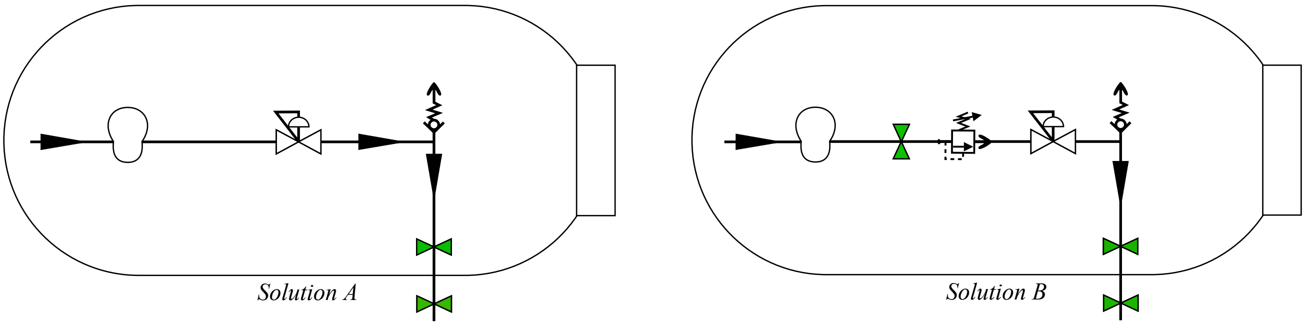


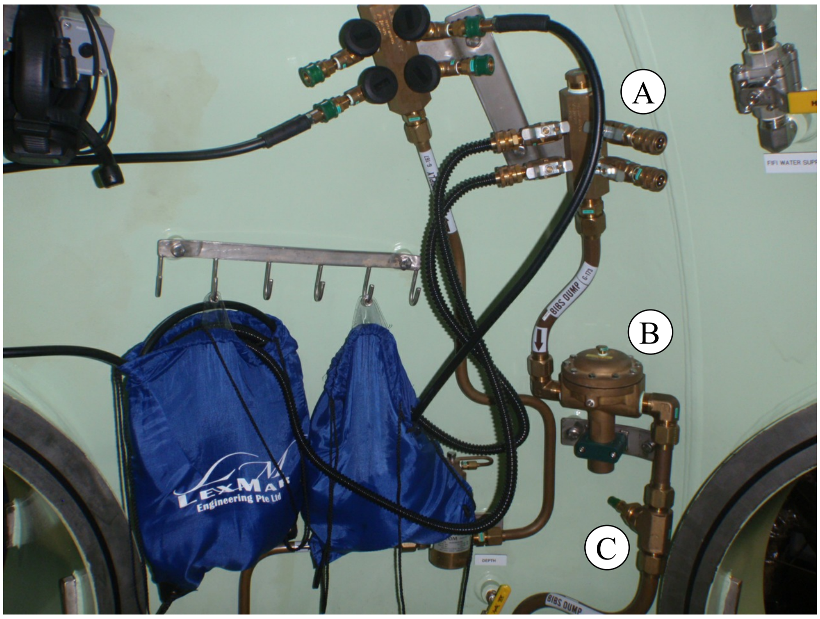
As already explained with the bell, the gas is recovered to the surface by the suction resulting from the differential pressure between the surface and the depth the chamber is stored. However, a too lofty aspiration may injure or kill the divers. For this reason, a back pressure regulator is used to 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)*.





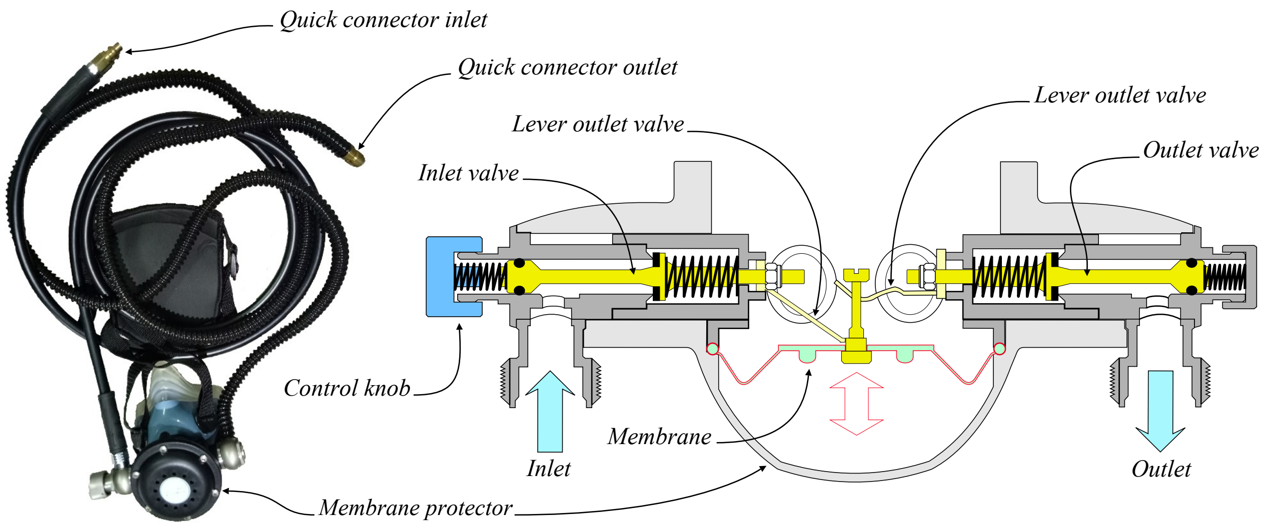
Legends

- *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*

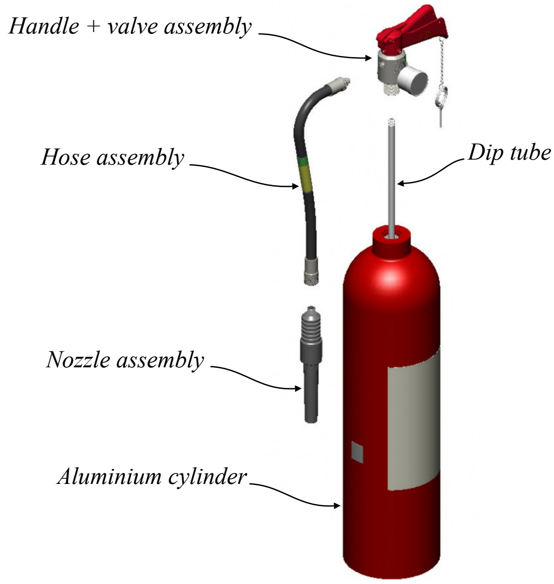
In the case that the back pressure regulator is installed outside the chamber, a tracking pressure (pilot) pipe that is connected to the inside of the chamber is fitted to reference port of the regulator *(see in the drawing in the previous page)*. Note that such tracking pressure connection hose *(see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

As a reminder of what is said in point 2.3.2.7 "Bell internal equipment", breathing masks are systems that consist of one membrane connected by two levers to an inlet valve and an outlet valve. When the diver inspires, the movement of the membrane opens the inlet valve and closes the outlet valve. When the diver expires, the movement of the diaphragm closes the inlet valve and opens the outlet valve.



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.



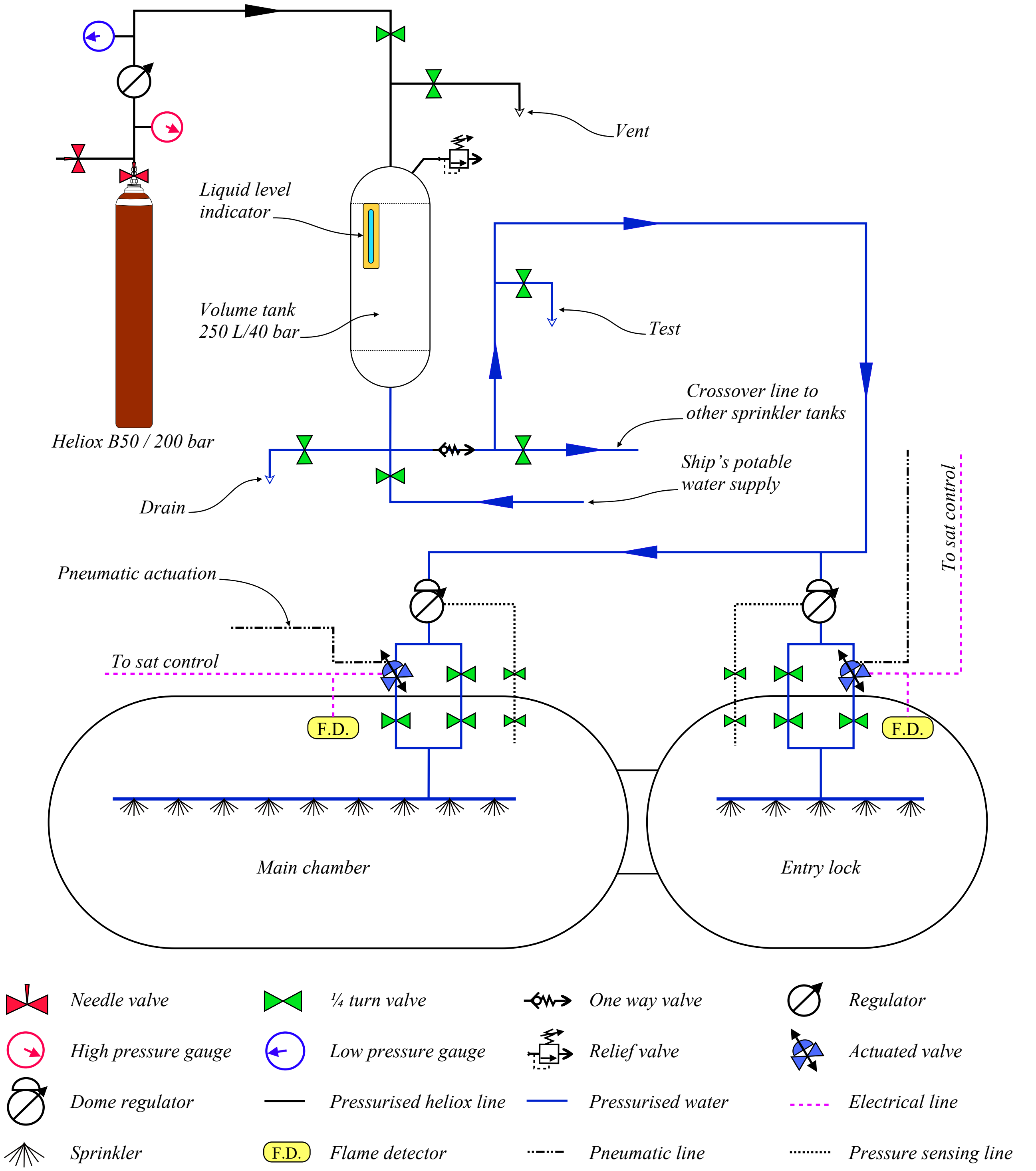
The extinguishing agent used in these extinguishers is an Aqueous Film Forming Foam (AFFF), which is suitable for fabrics, combustible solids, flammable liquids, and electrical fires up to 24 Volts. Note that its technical sheet indicates that this product is not considered harmful to aquatic organisms 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.

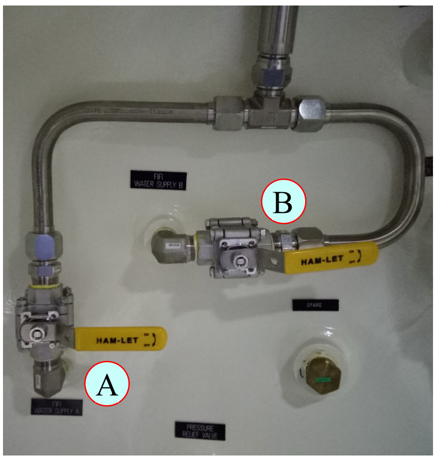
Three main systems can be used used to detect a fire: Flame detectors, heat detectors and smoke detectors.

- 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.

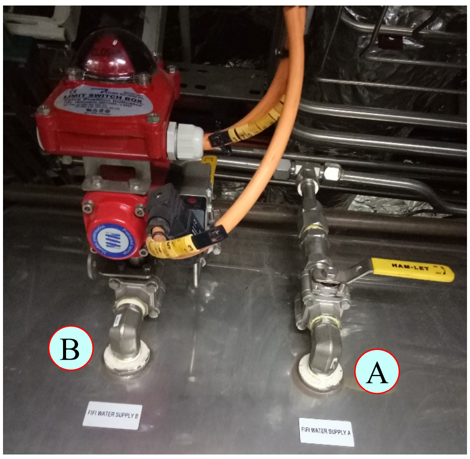
Fixed water deluge extinguishing system is highly recommended in chamber compartments that are designed for manned operations. Also, as indicated previously, these systems are mandatory in several countries.
The systems consist of water supplied to the chamber through a number of spray nozzles. In chambers 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.





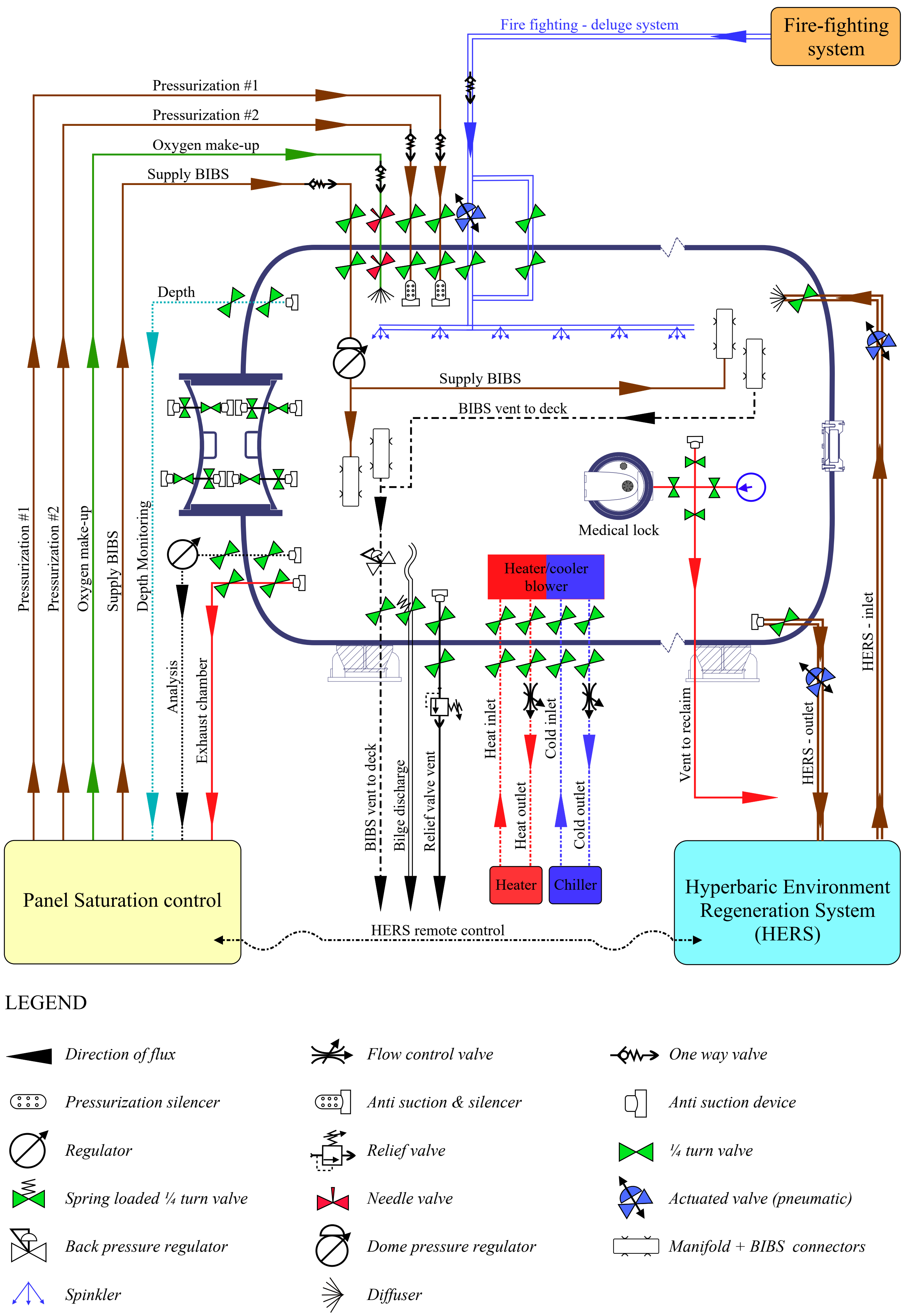
Internal manual (A) & actuated (B) valves



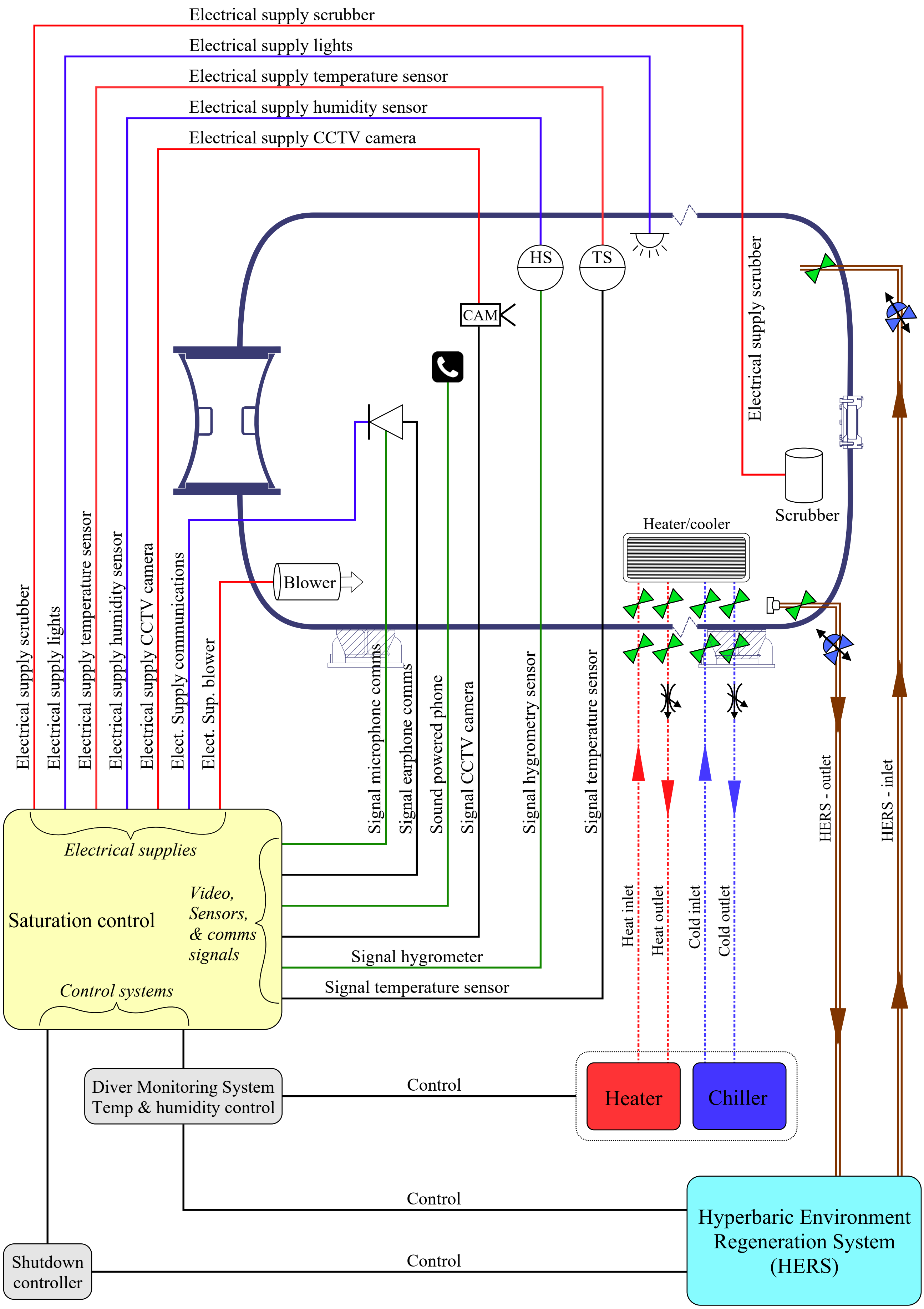
External manual (A) & actuated (B) valves

Volume tank & its pressurization sys.

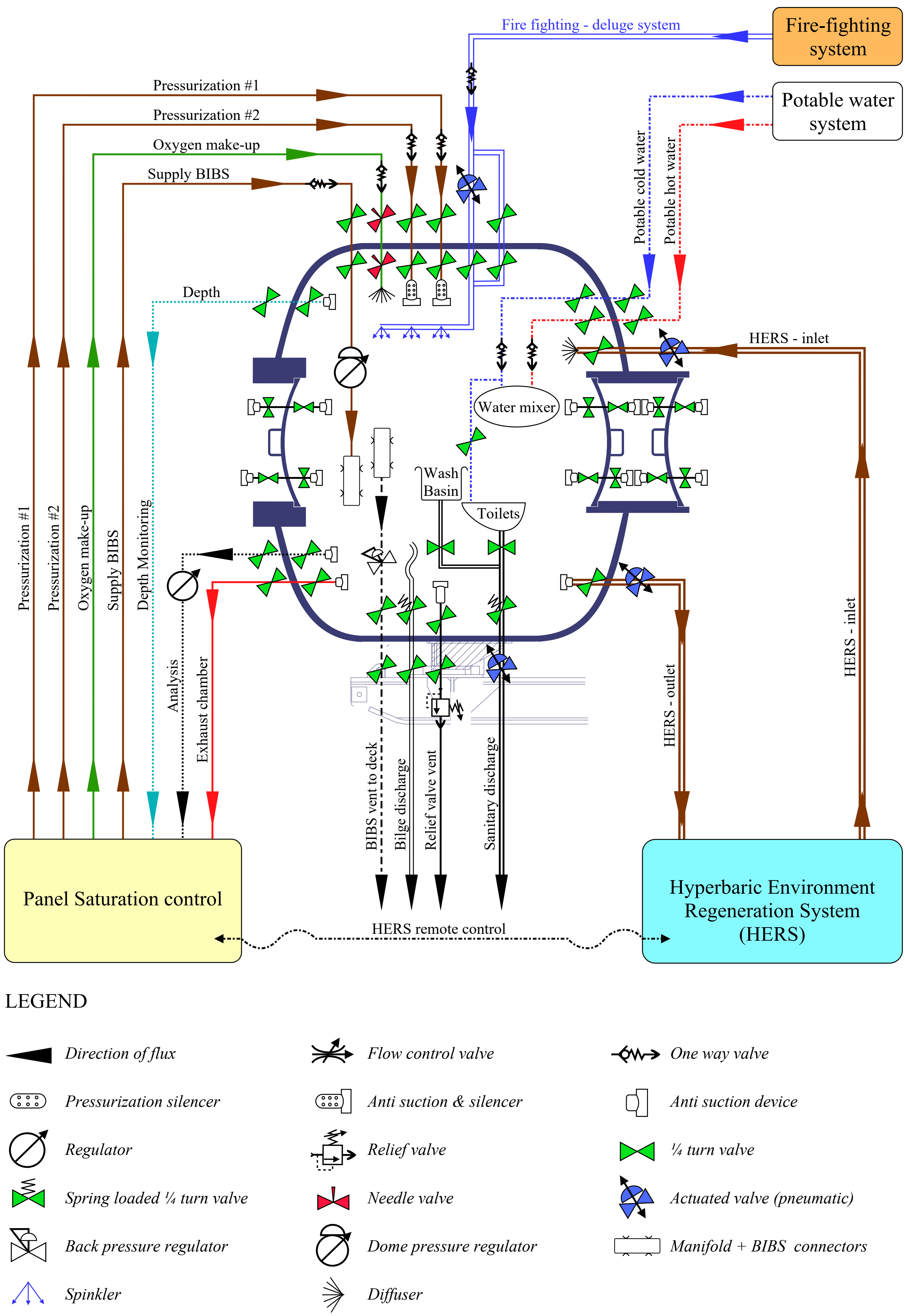
The scheme below summarizes the gas inlets and outlets and elements of the Environment Control Unit (ECU) of the main living chamber that are described on the previous pages.



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.

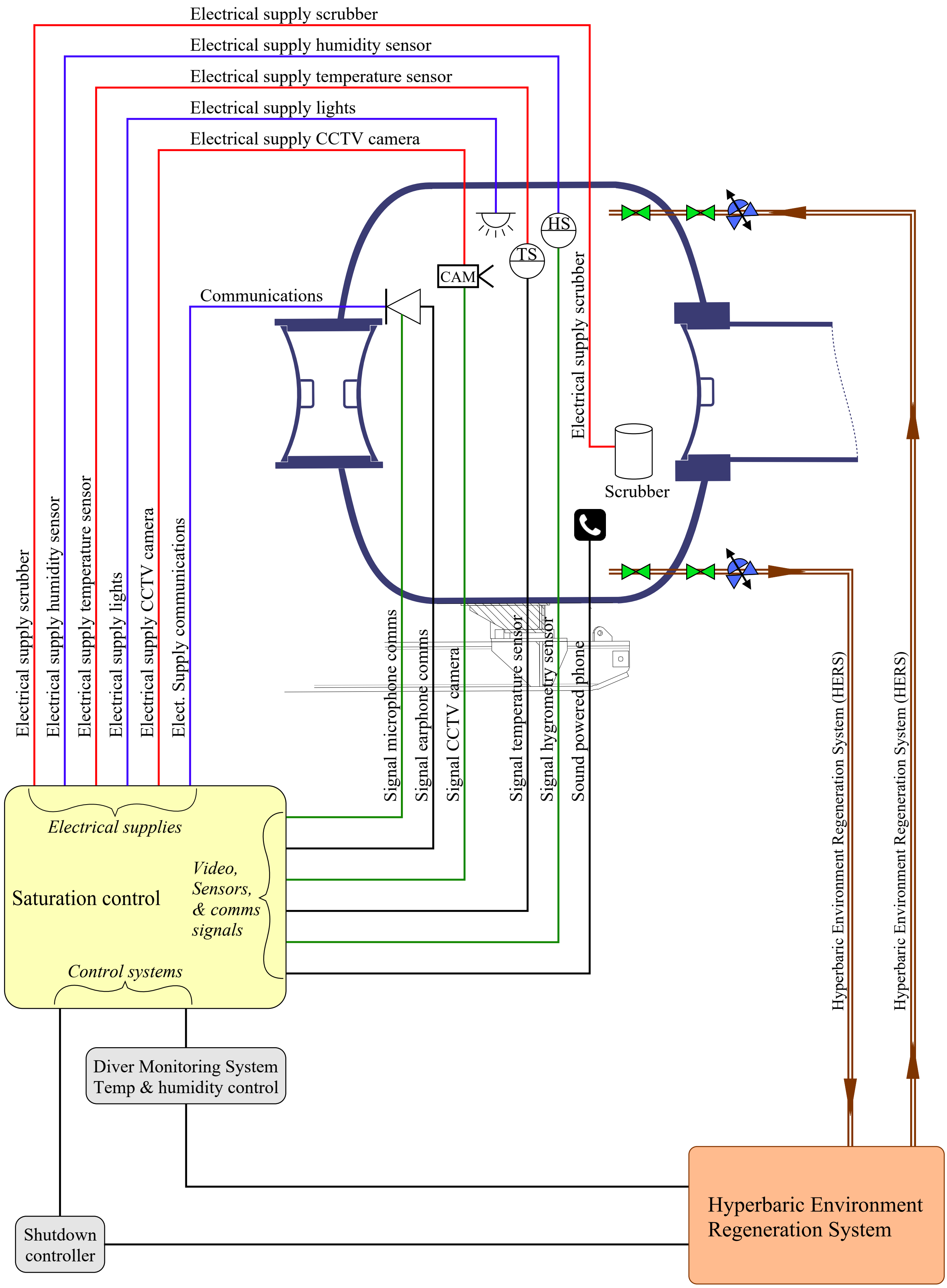


The scheme below summarizes the gas inlets and outlets and elements of the Environment Control Unit (ECU) of the entry lock that are described on the previous pages.

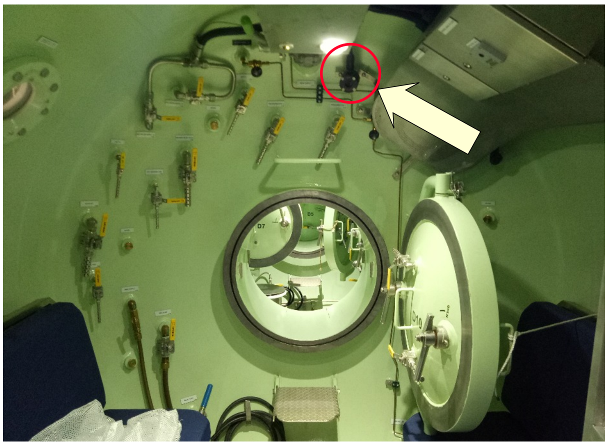


Hyperlink [Tables of contents](#)

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

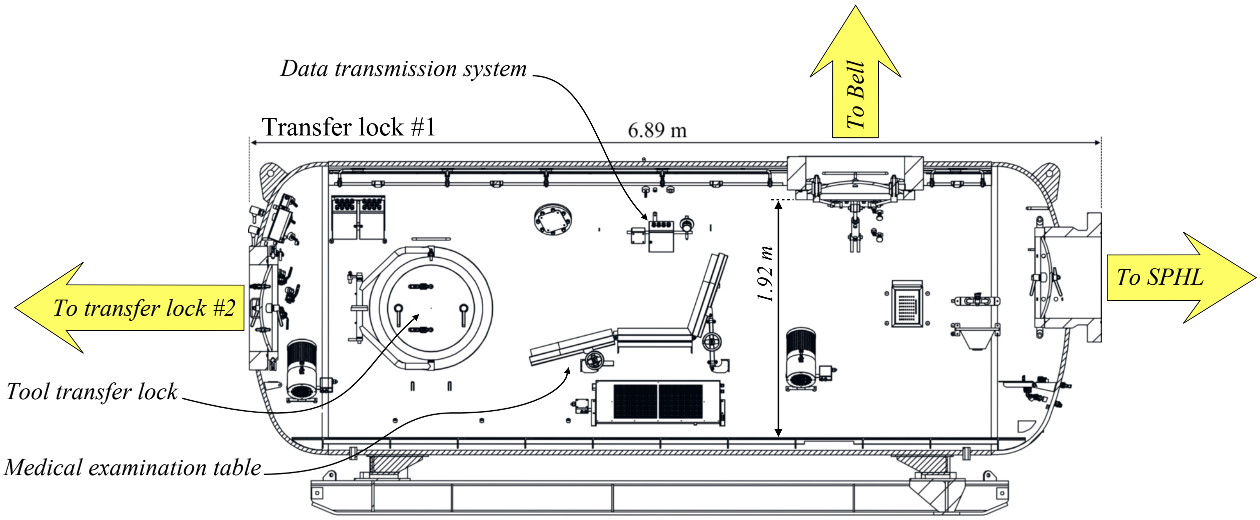
2.3.15.3 - Transfer lock

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:

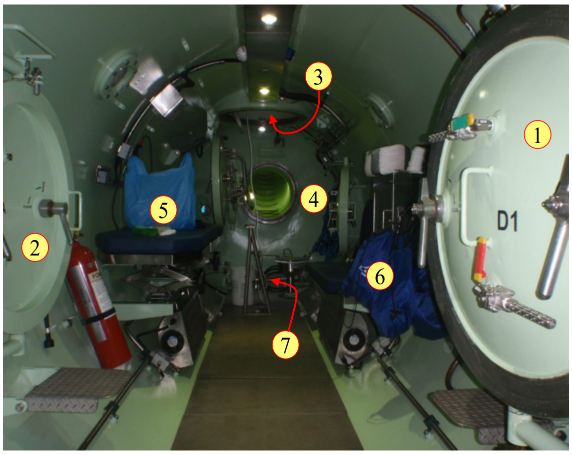
- A minimum internal diameter of 1.8 metres (6 feet) but preferably exceeding 2.15 metres (7 feet);
- The ability to remove, or move out of the way, bunks and other equipment normally fitted to the chamber but not needed directly for a medical emergency;
- A bunk for the patient which should:
- be waist 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.

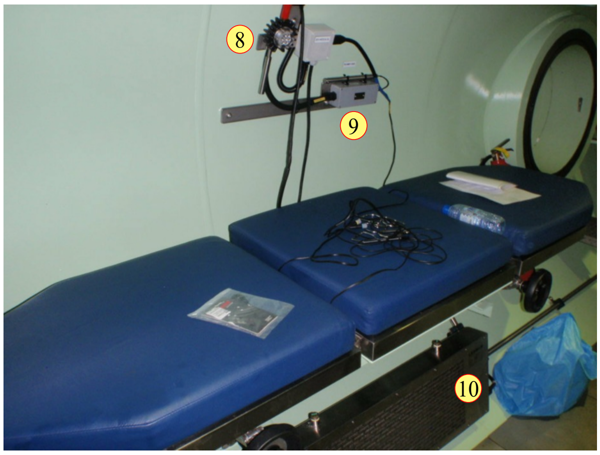
In addition to the above, and as it can be seen in point 2.3.15.1, the transfer locks are also the rooms through which the divers can transfer to another chamber and the SPHL. On large systems with two transfer locks, these chambers are linked together by a trunk allowing to move from a chamber to both bells, another chamber, or any self-propelled hyperbaric lifeboat (SPHL).



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

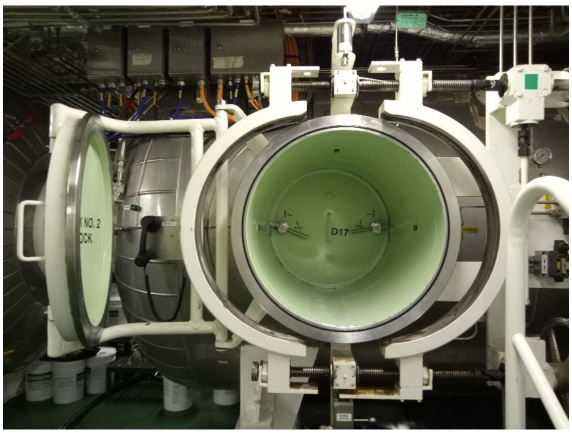


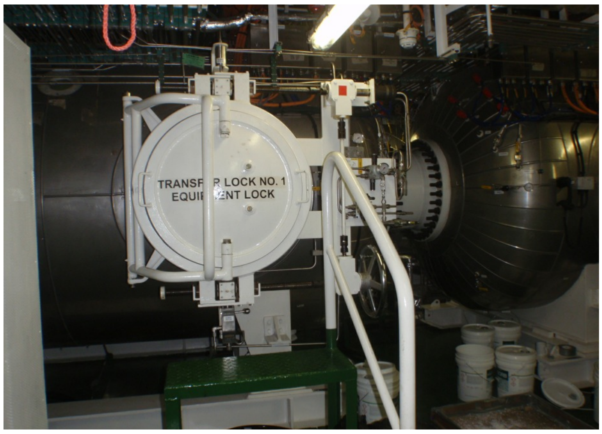
Transfer lock #1 from transfer lock #2 UDS Lichtenstein:
- *#1: Door trunk to transfer lock #2*
- *#2: Door tool transfer lock*
- *#3: Trunk to bell*
- *#4: Trunk to SPHL*
- *#5: Medical examination table*
- *#6: Breathing masks*
- *#7: Step to access to the bell trunk*



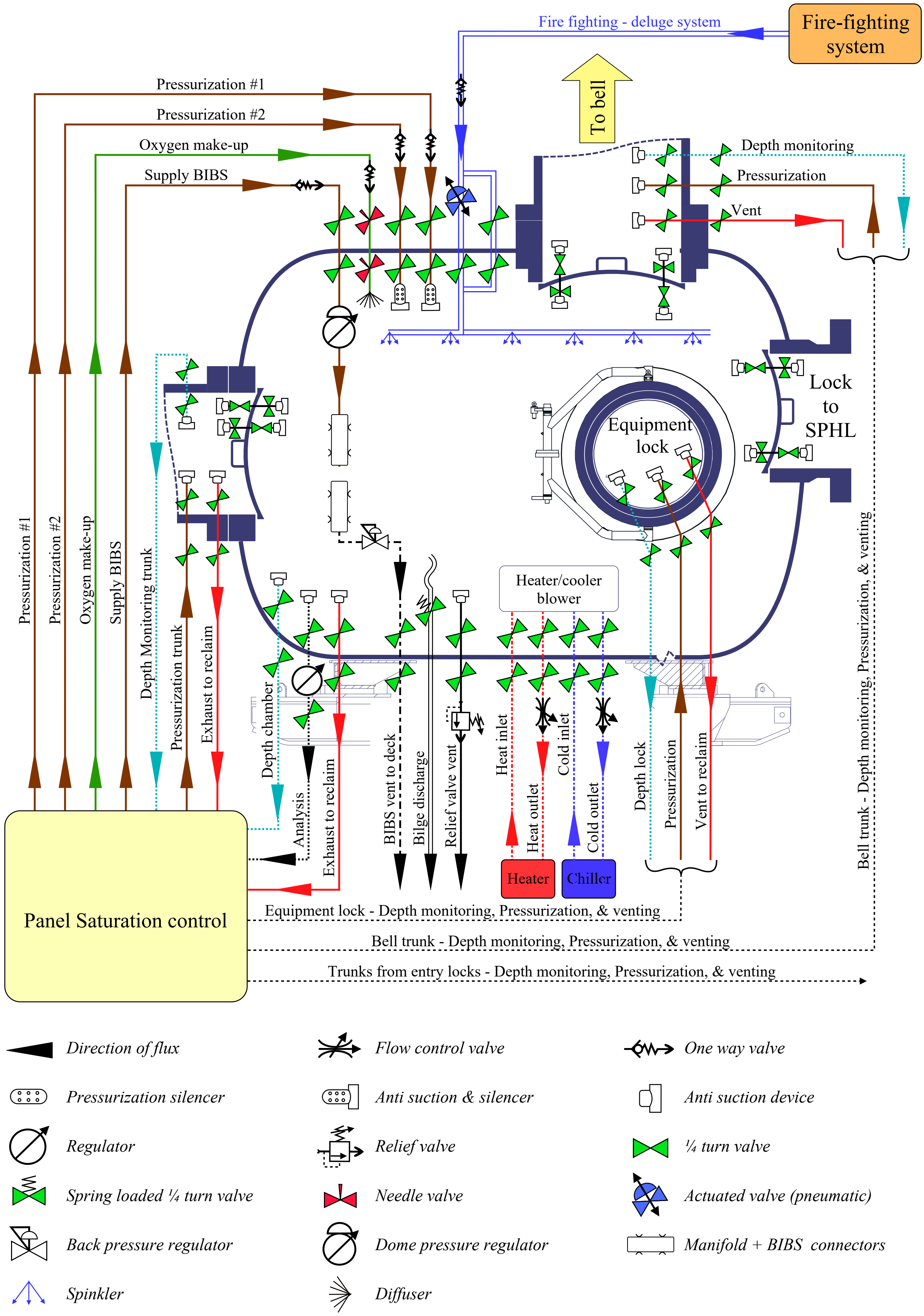
Medical examination table transfer lock #2 UDS lichtenstein
- *#8: Connectors of the system that allows a doctor who is remote visualizing the essential information of the patient*
- *#9: Communication block*
- *#10: heating / cooling element*

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 and described in point 2.3.11.4 “Connection to transfer lock” *(see below)*.

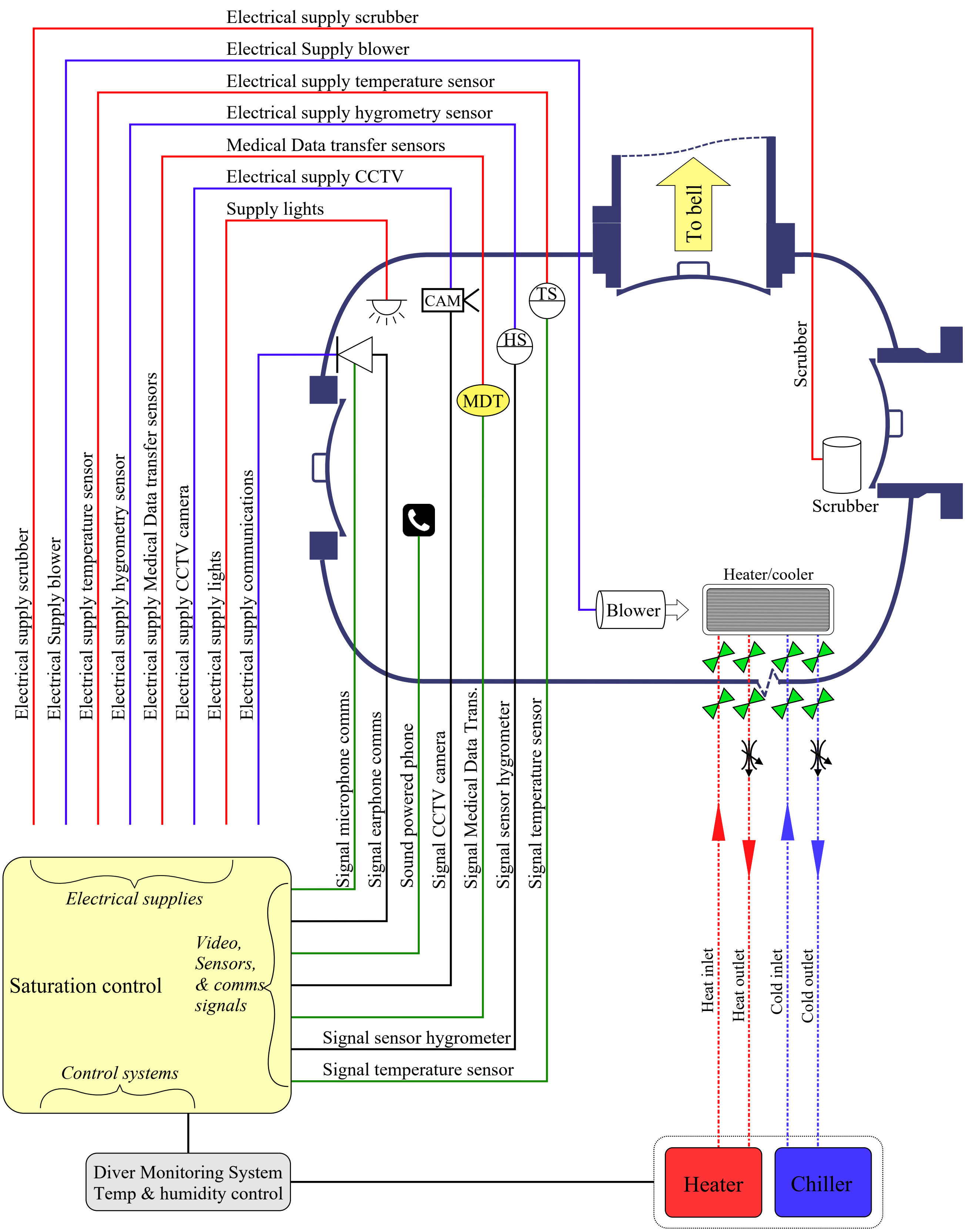




The gas supplies and exhaust are the same as those of the main living chamber. However, this chamber is not fitted to the Hyperbaric Environment Regeneration System (HERS). One of the reasons is that it is in direct communication with the bell and can be contaminated by pathogens and harmful chemical 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.

2.3.15.4 - 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.

2.3.16 - Water supply and waste removal

2.3.16.1 - Purpose

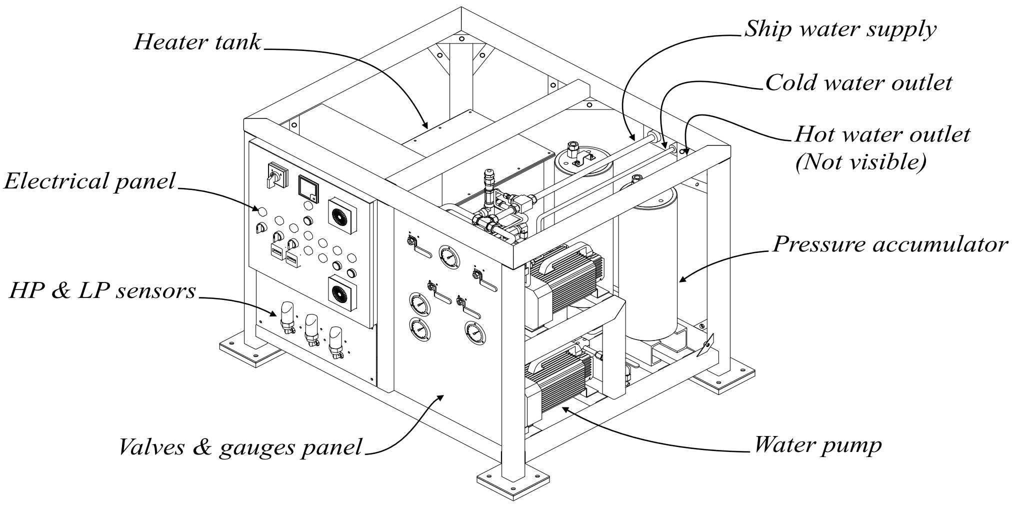
The bathroom of the chamber must be supplied with fresh water. However, this water must be pressurized above the ambient pressure to be able to enter it. Also, the chamber is designed to have an internal pressure that varies in function of the diving operation ongoing. For this reason, the system that 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.

2.3.16.2 - 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 *(see the description in point 2.3.13.2)*, pH neutralizers *(also called Acid Filters)*, and softeners that remove minerals such as calcium, and lime deposits, to improve the quality of the water.

2.3.16.3 - 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.



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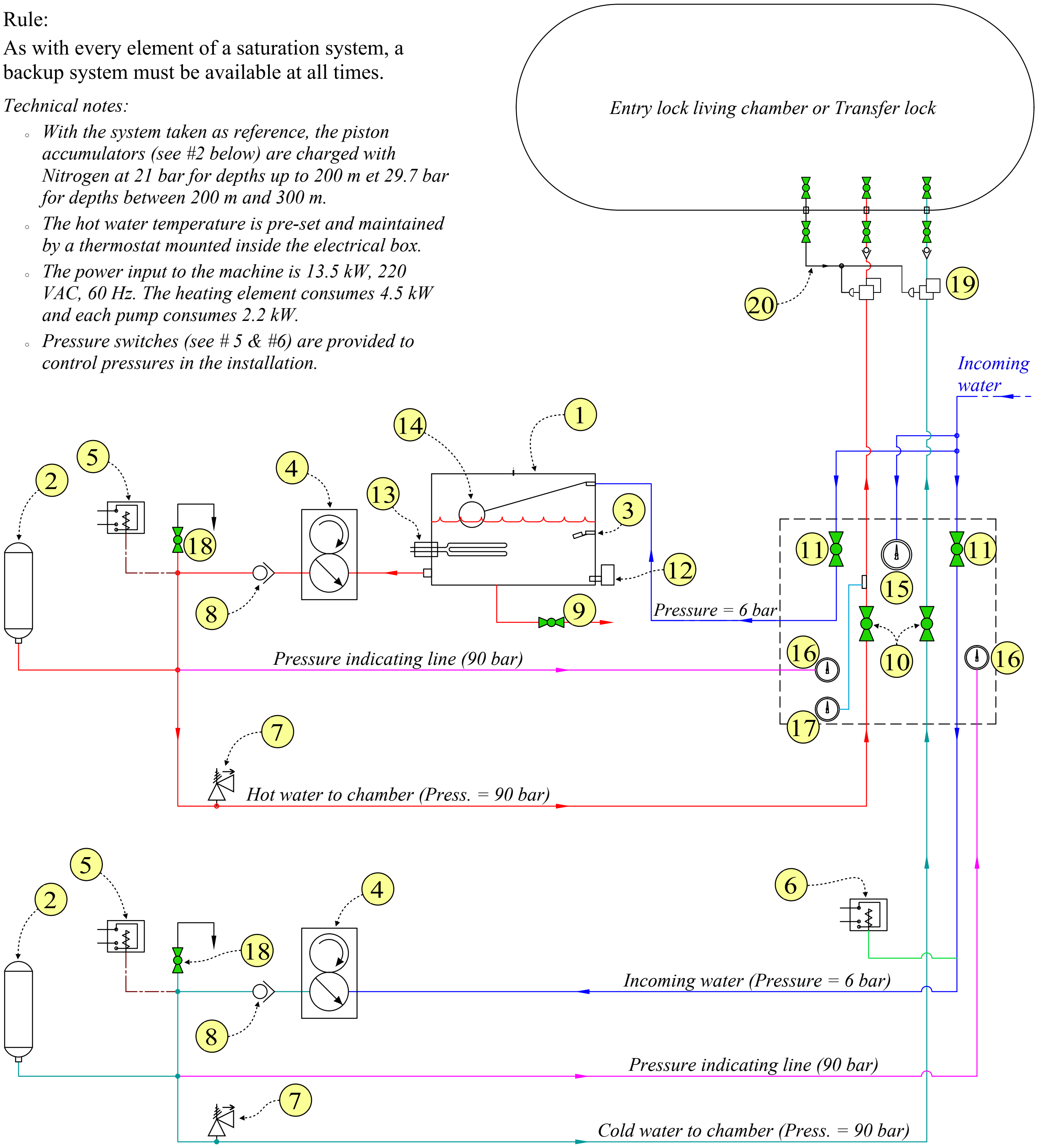
Dome-loaded regulators regulate the water supply to 5 bar above the chamber internal pressure through depth sensing lines. They are placed at the external of each entry lock or transfer lock to supply with water *(see #19 & #20 below and the photo on the next page)*. Pressure relief valves *(see #7 below)*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

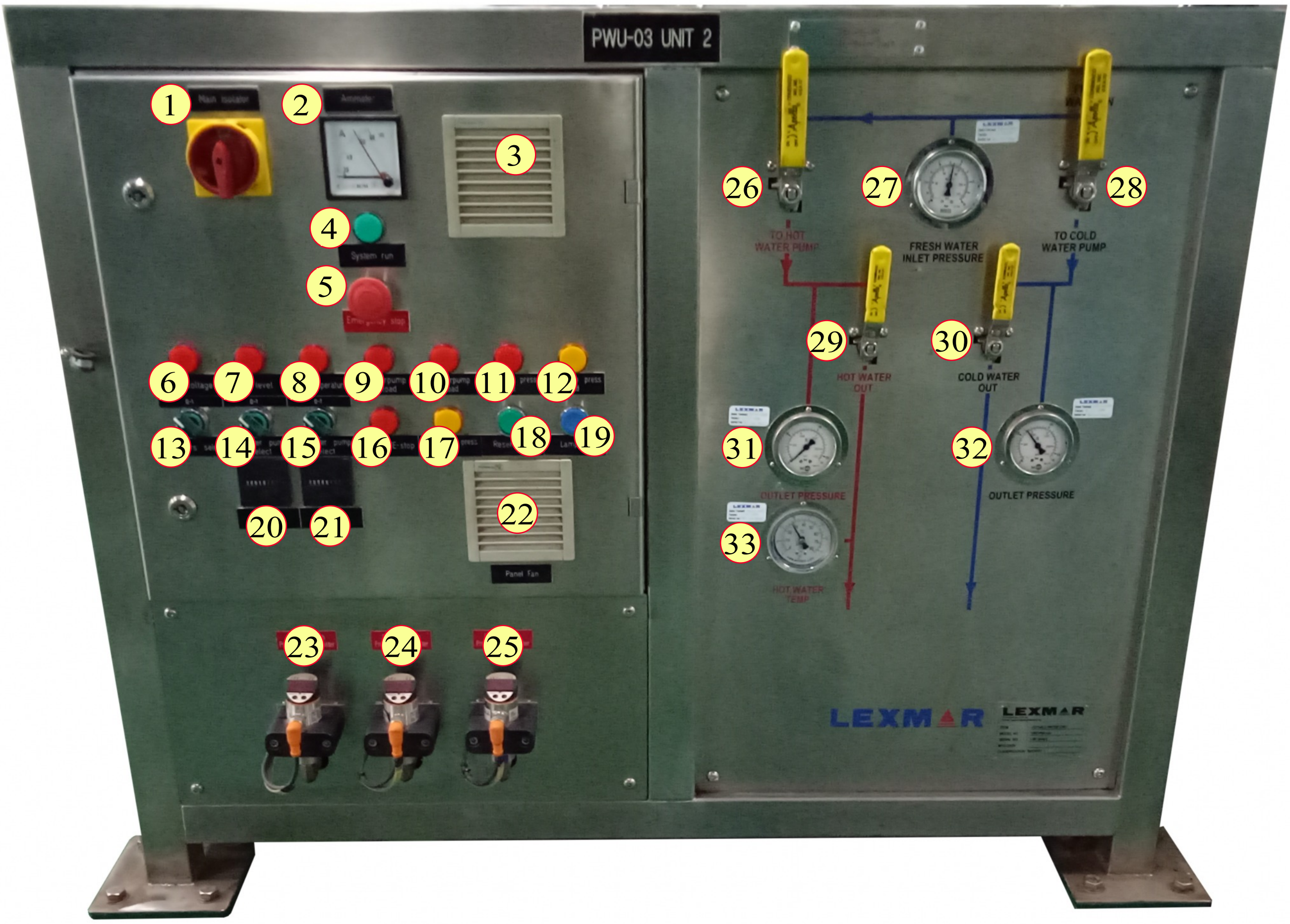
Technical notes:

- *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

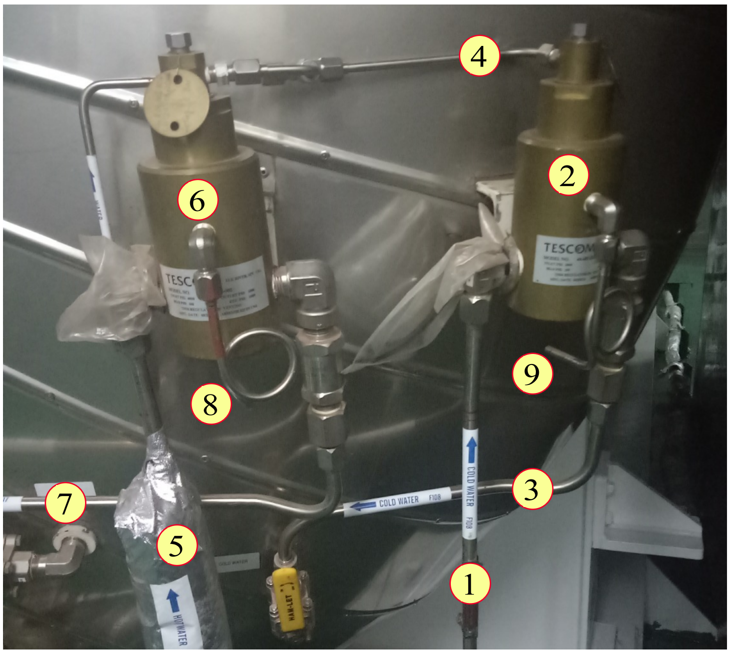
29 - Hot water outlet valve

30 - Cold water outlet valve

31 - Hot water outlet pressure gauge

32 - Cold water outlet pressure gauge

33 - Hot water temperature gauge

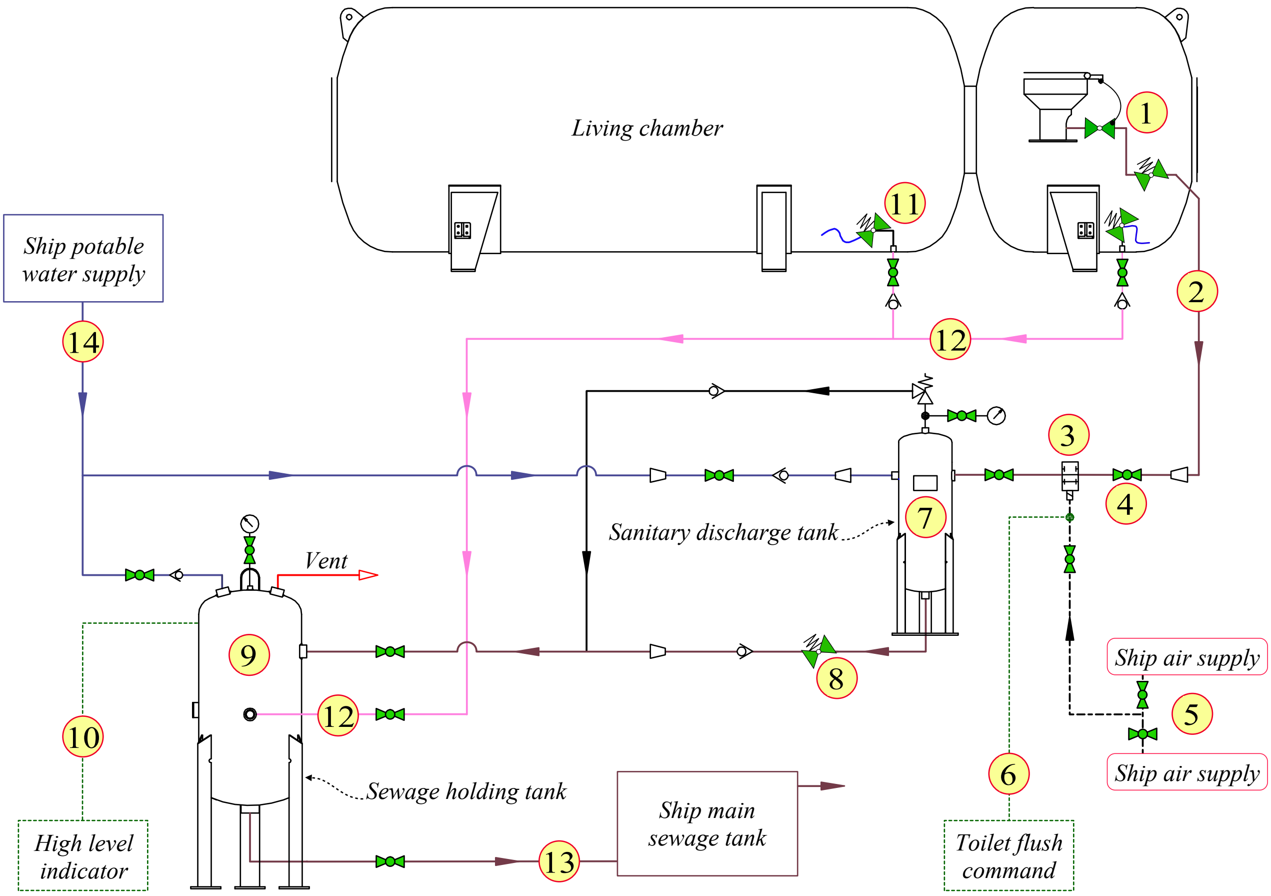


The photo on the side shows the regulators that stabilize the water supply to 5 bar above the chamber ambient pressure and their depth-sensing lines.
Note that the model of regulator used is the same as the one used with the Built-In Breathing Systems (BIBS) of the chambers.

- *#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*

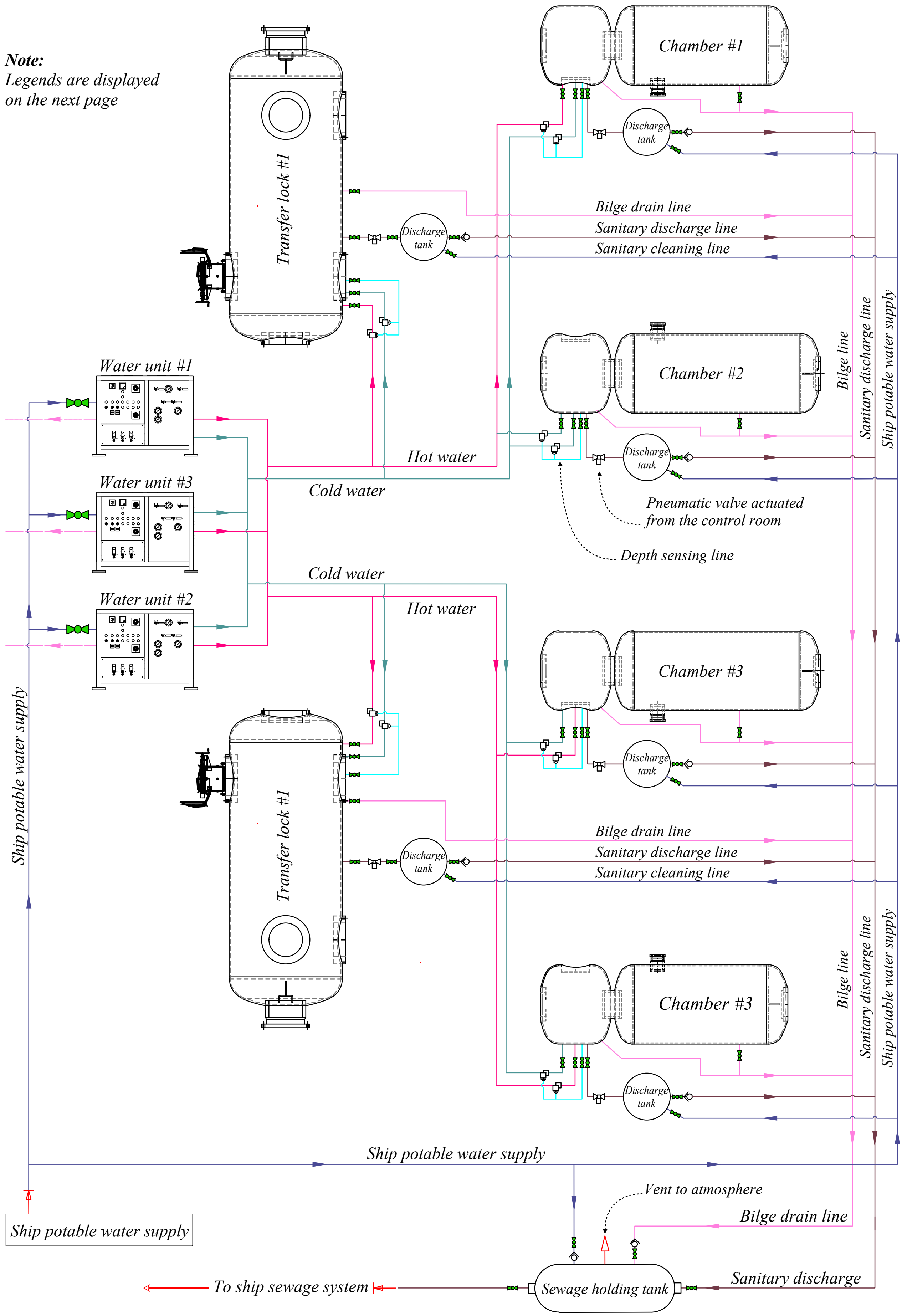
2.3.16.4 - Sewage system

The toilet and bilge drain systems already described in point 2.3.15.2 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 2.3.15.2 *(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)*.



2.3.16.5 - 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.



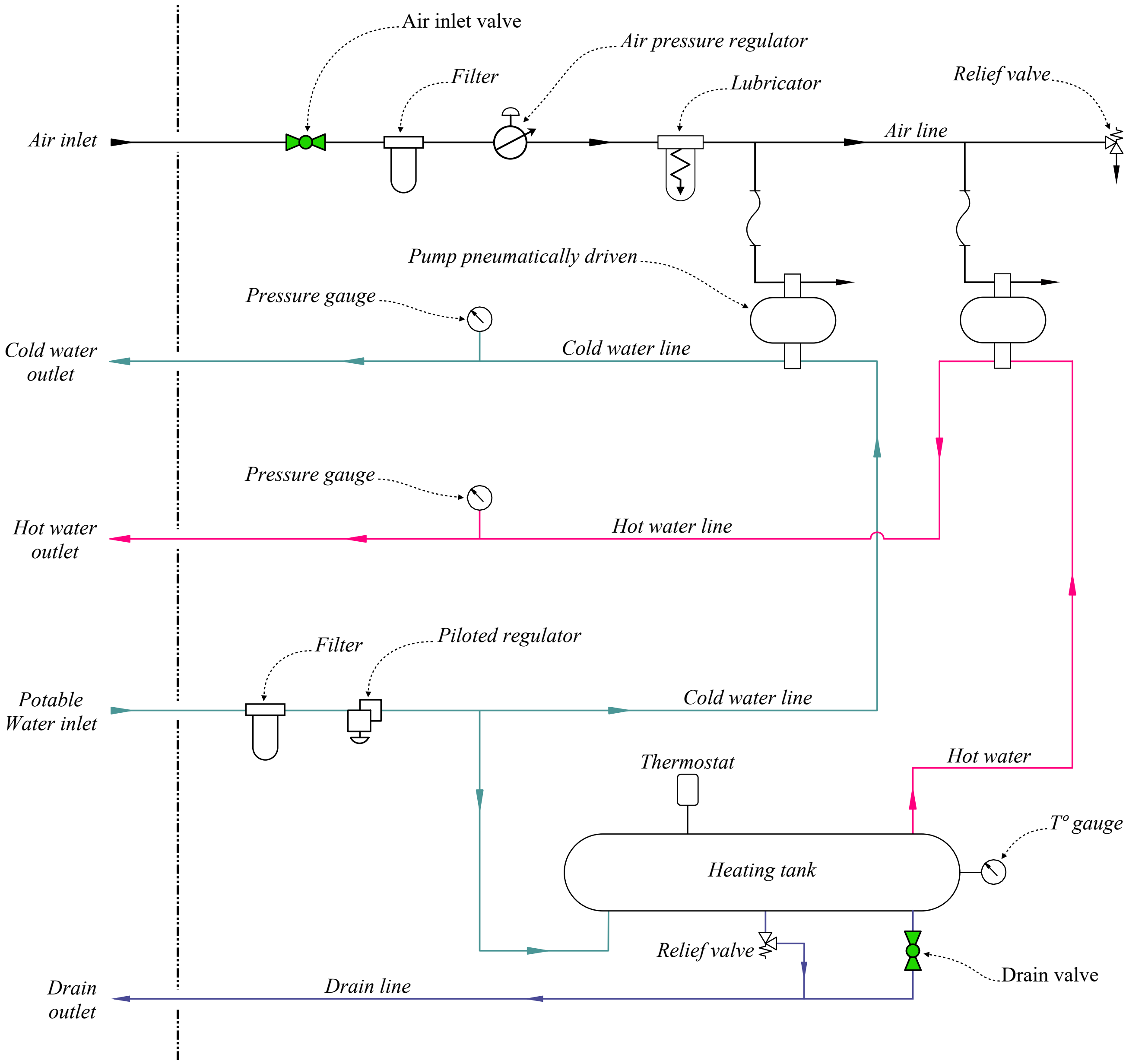
Legends of the scheme on the previous page

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

2.3.16.6 - Variations of the design of the systems

As explained in point 2.3.15 “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 Cº.



2.3.16.7 - 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 2.3.15.2. 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.

2.3.16.8 - 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.

2.3.16.9 - 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.

2.3.16.10 - 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.

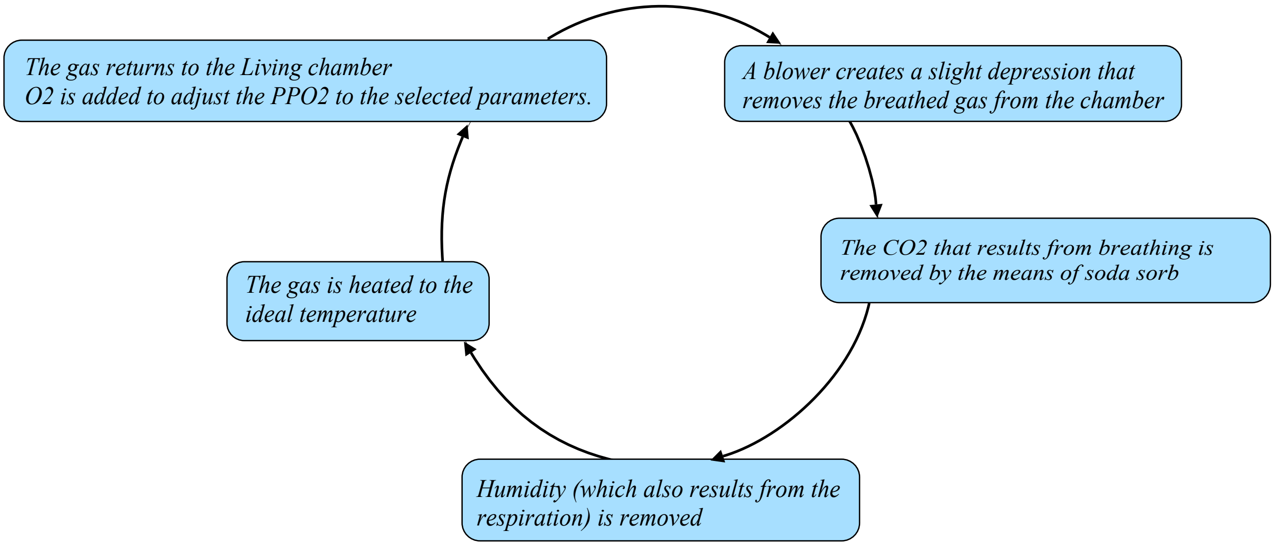
2.3.17 - Hyperbaric Environment Regeneration System (HERS)

2.3.17.1 - 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 2.3.15, 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

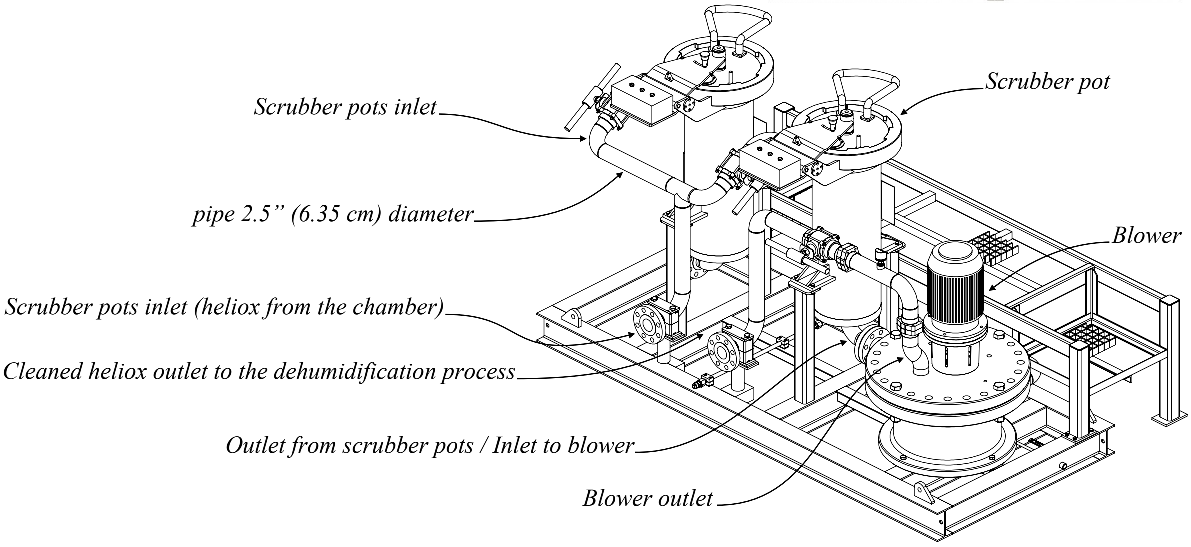
- Five Blower Pots complete with a regeneration blower
- Five CO2 Scrubber Pots
- Two Chiller Control Unit complete with Tank and Pumps (1 x main with 1 x back-up)
- Two Heater Control Unit complete with Tank and Pumps (1 x main with 1 x back-up)
- Gas conditioning heat exchangers

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:

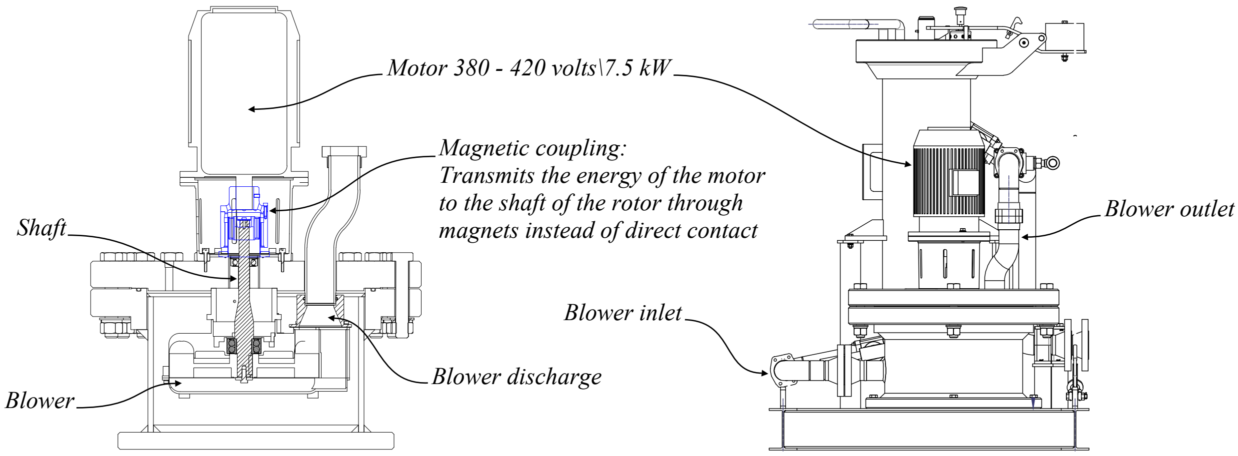


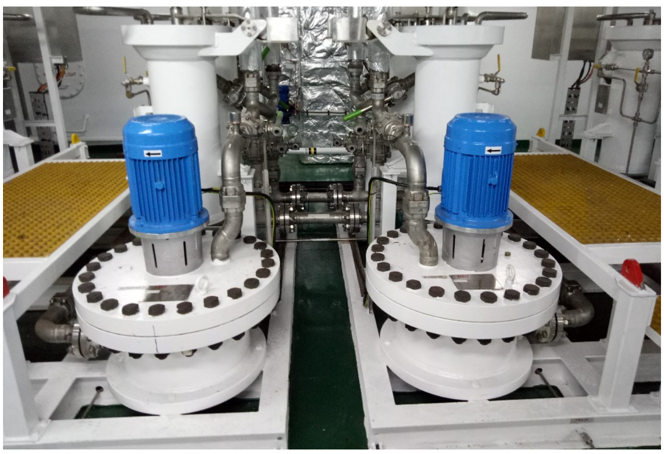
- 1 - The breathed gas is drawn out of the living chamber by the blower and enters the scrubber pot of the HERS through a pipe work 2.5” (6.35 cm) diameter.

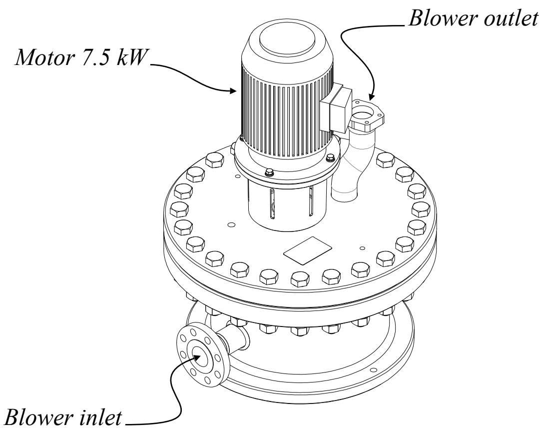
As already indicated in point 2.3.15, the chamber outlet is situated near the floor to collect the maximum CO2, which is a heavy gas. Opposite, the inlet is situated at the top of the chamber. This configuration allows good ventilation.



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.



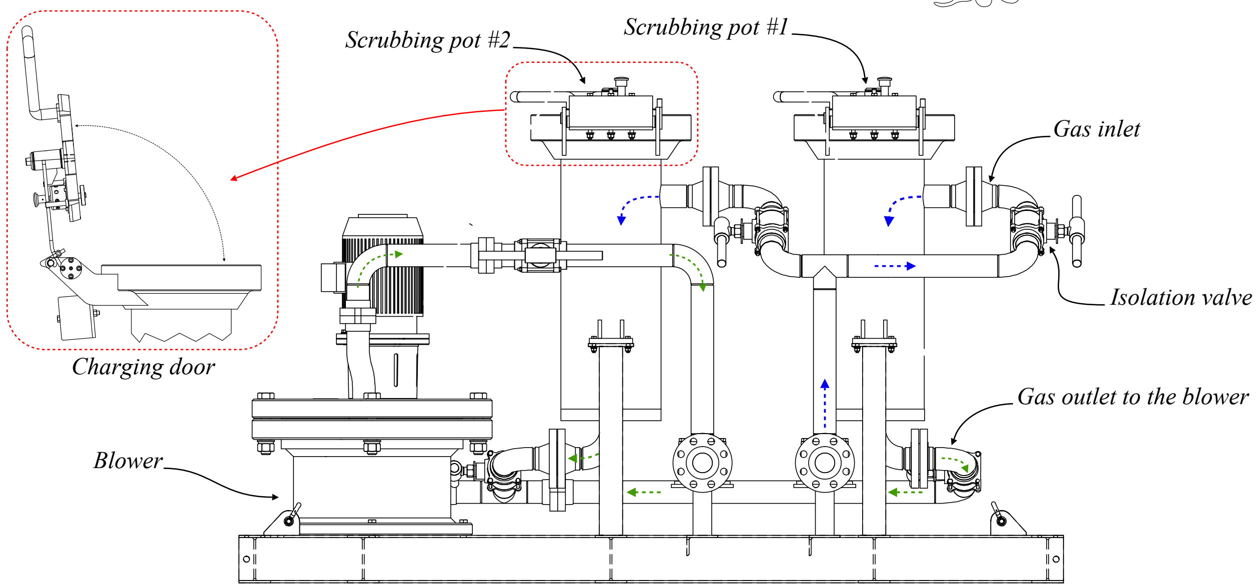


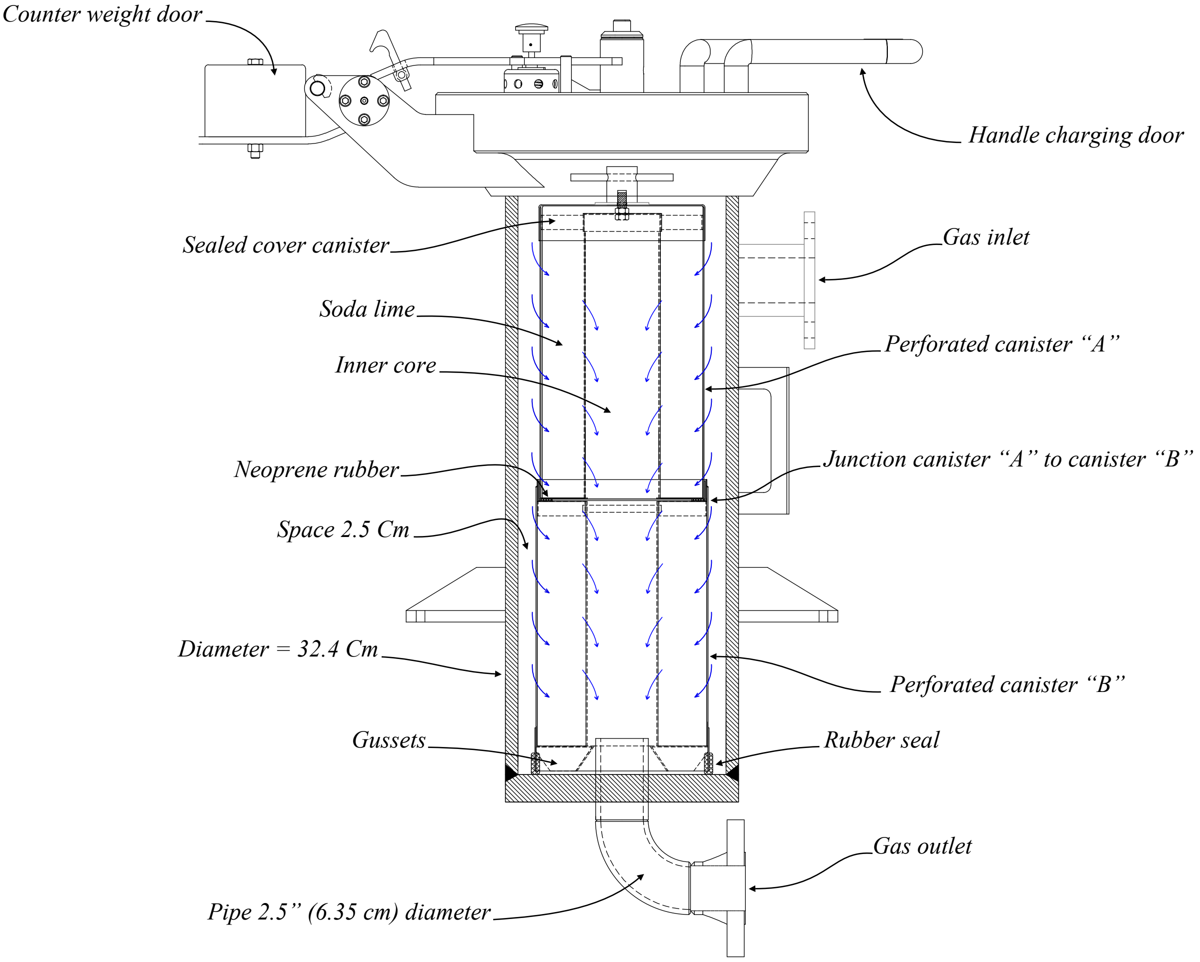


- 2 - The gas enters a scrubbing pot, consisting of two Sodasorb scrubbing canisters, that removes the CO2.

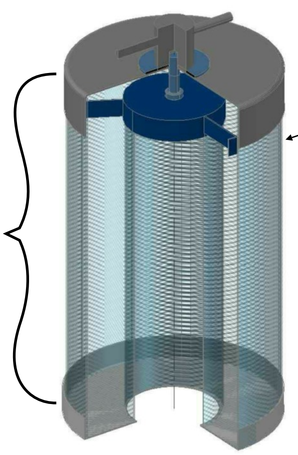
  Each blower has two associated scrubber pots mounted on the same skid. Interconnecting pipework and valves are arranged so that one scrubber pot is online whilst the other is on standby. As a result, the second scrubbing pot can be brought on-line while the first unit is isolated for change-out of the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

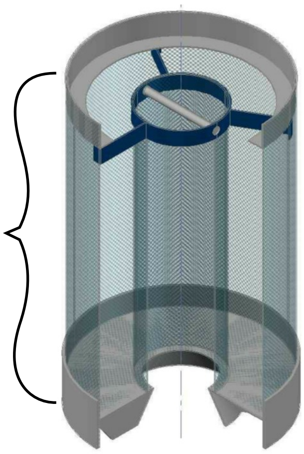


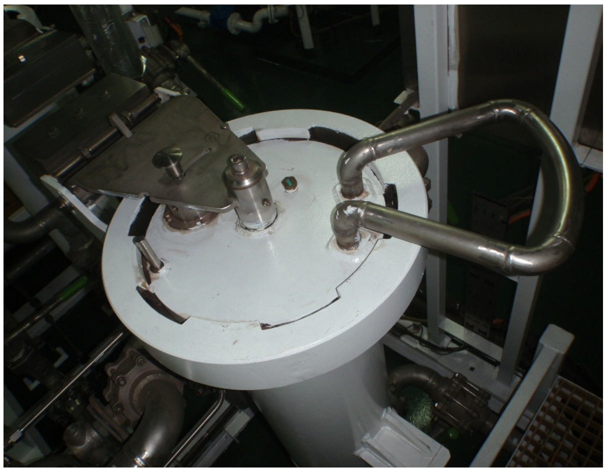


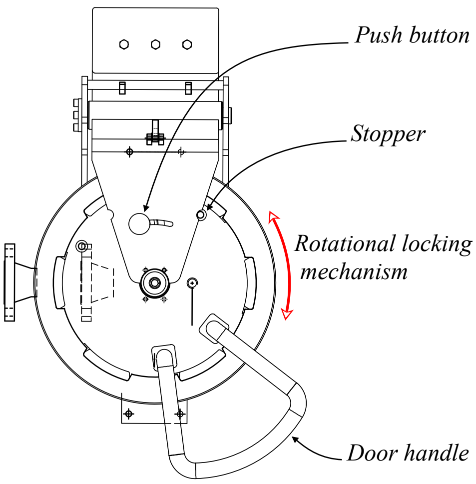
Canister "A"
- *Empty weight: 7.1 Kg*
- *Volume soda lime: 12.7 litres*
- *Weight soda lime: 10.34 kg*
- *External diameter: 22.8 cm*
- *Total weight:17.44 Kg*

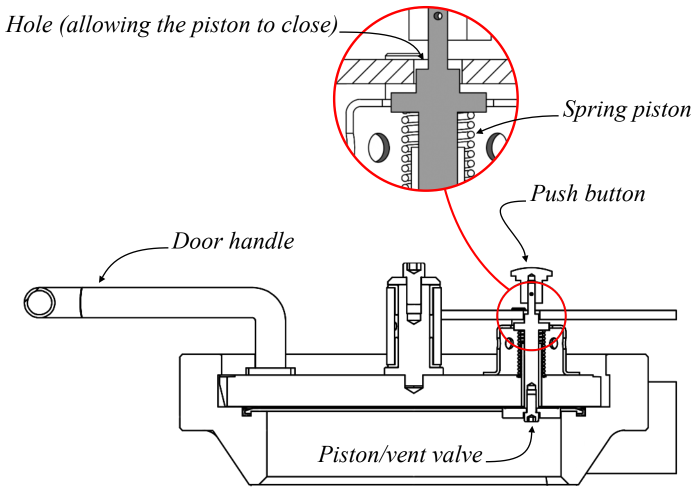


Canister "B"
- *Empty weight: 7.5 Kg*
- *Volume soda lime: 13.2 litres*
- *Weight soda lime: 10.79 kg*
- *External diameter: 23.9 cm*
- *Total weight:18.29 Kg*





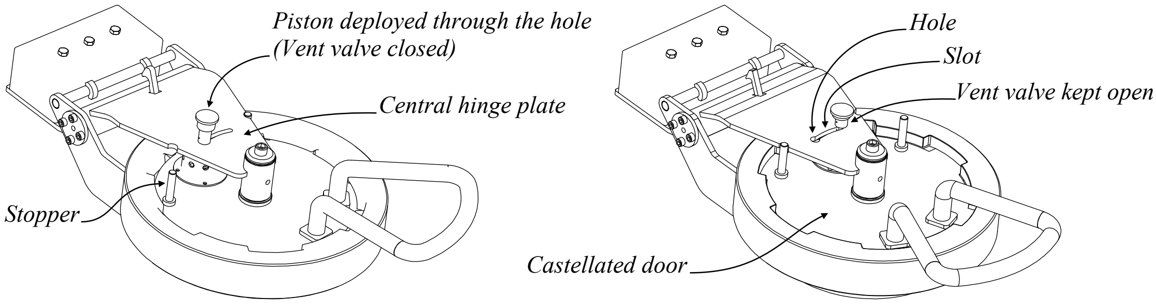




The charging door of the scrubbing pot works against the pressure.
For this reason, a safety interlock mechanism is in place to prevent this door from opening while the scrubbing pot is under pressure. It consists of a small locking piston/vent valve that is pushed out by the pressure inside the system 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.

- 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.

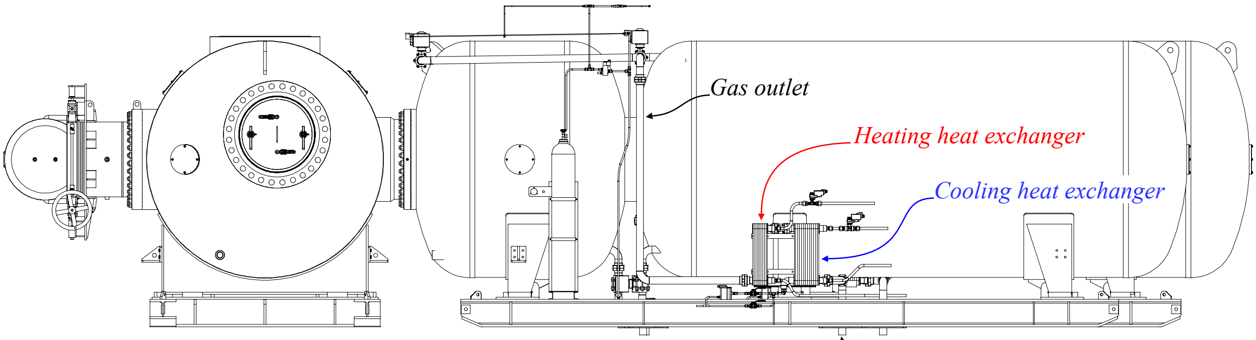
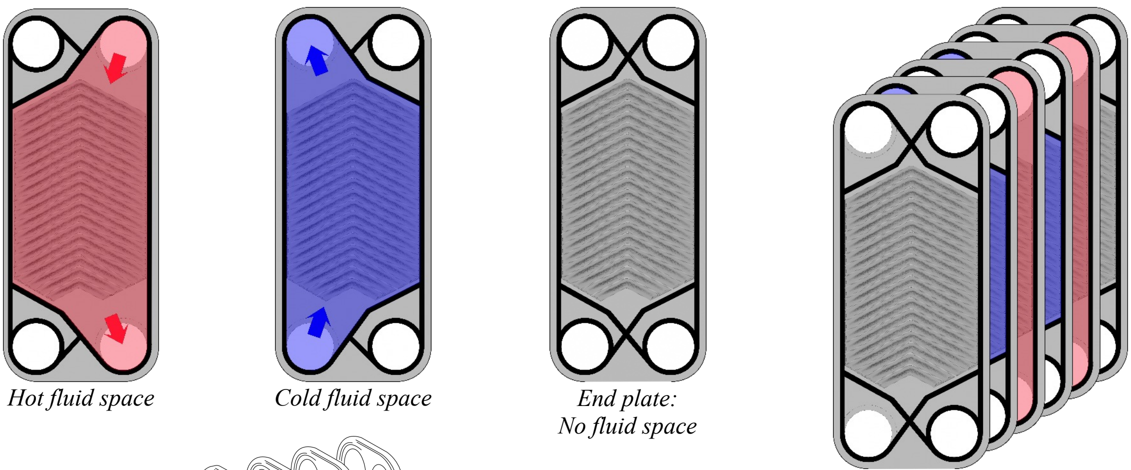
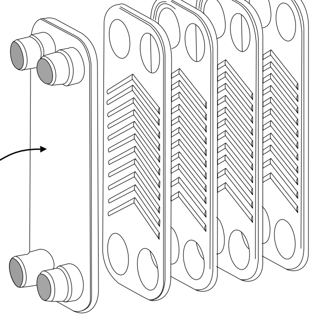


Plate heat exchangers are composed of thin nested metal plates that are assembled to create dedicated flow spaces of cold or hot fluid between them. These plates are arranged so that there are alternatively hot and cold spaces, so the exchange of heat and cold is performed by conduction through the metal 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".



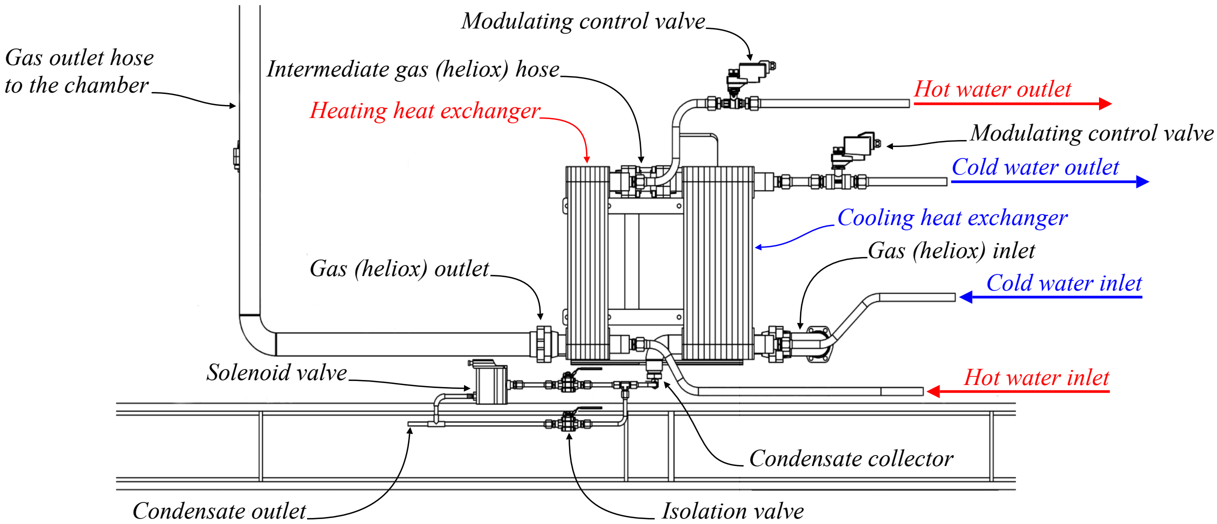
Hot fluid space *Cold fluid space* *End plate: No fluid space* *Fluid spaces arrangement*



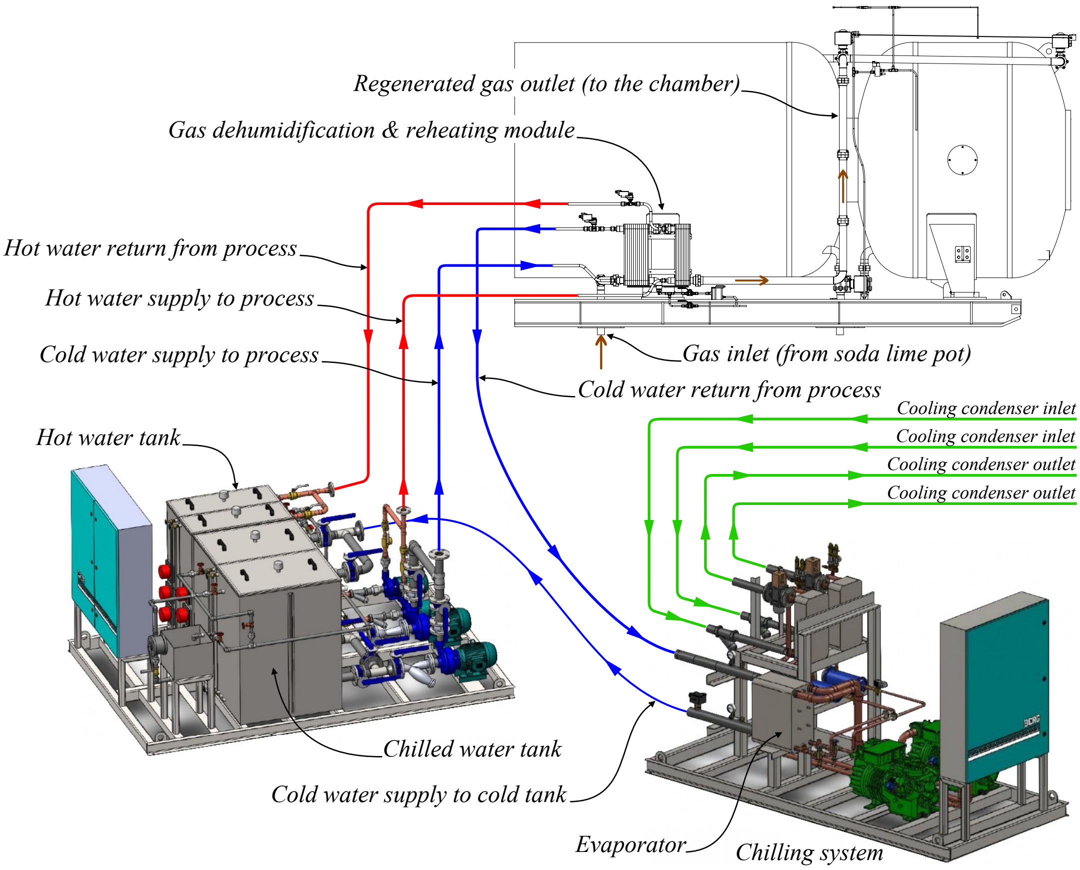
Note:
There is no fluid space between the cover and the 1st plate (end plate).
These heat exchangers offer high-efficiency with a compact size.
They are easy to install and maintain.

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

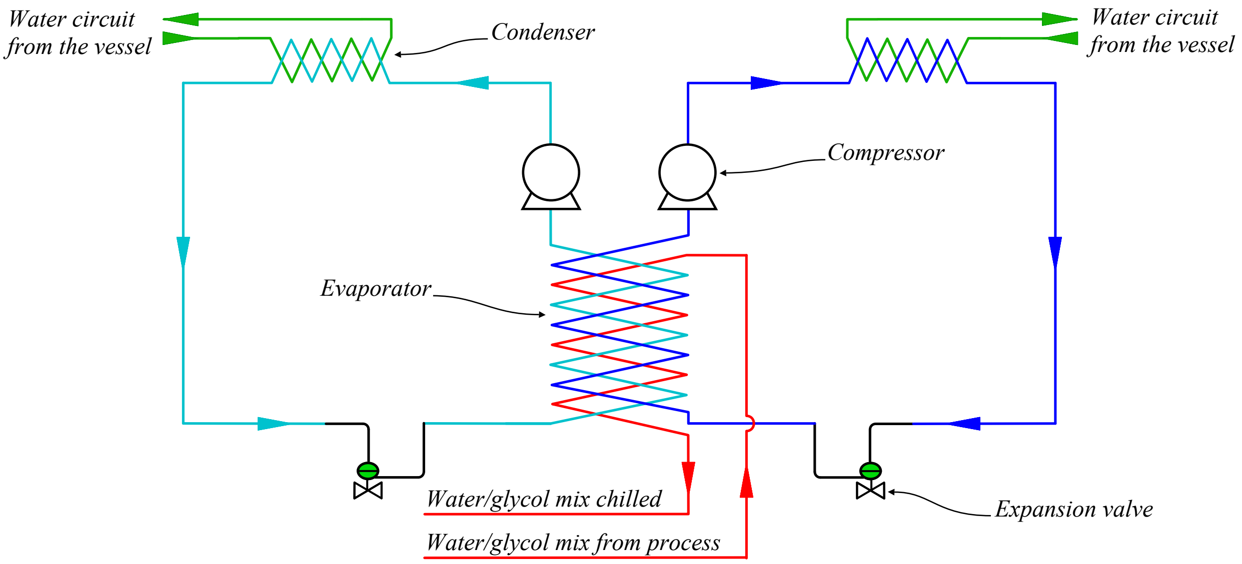
The cold fluid is a mix of water and 30% of propylene glycol. “Propylene glycol” is used by the chemical, food, and pharmaceutical industries as an antifreeze when leakage might lead to contact with food. This substance must not be confused with “Ethylene glycol,” which is also used for cooling circuits 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.

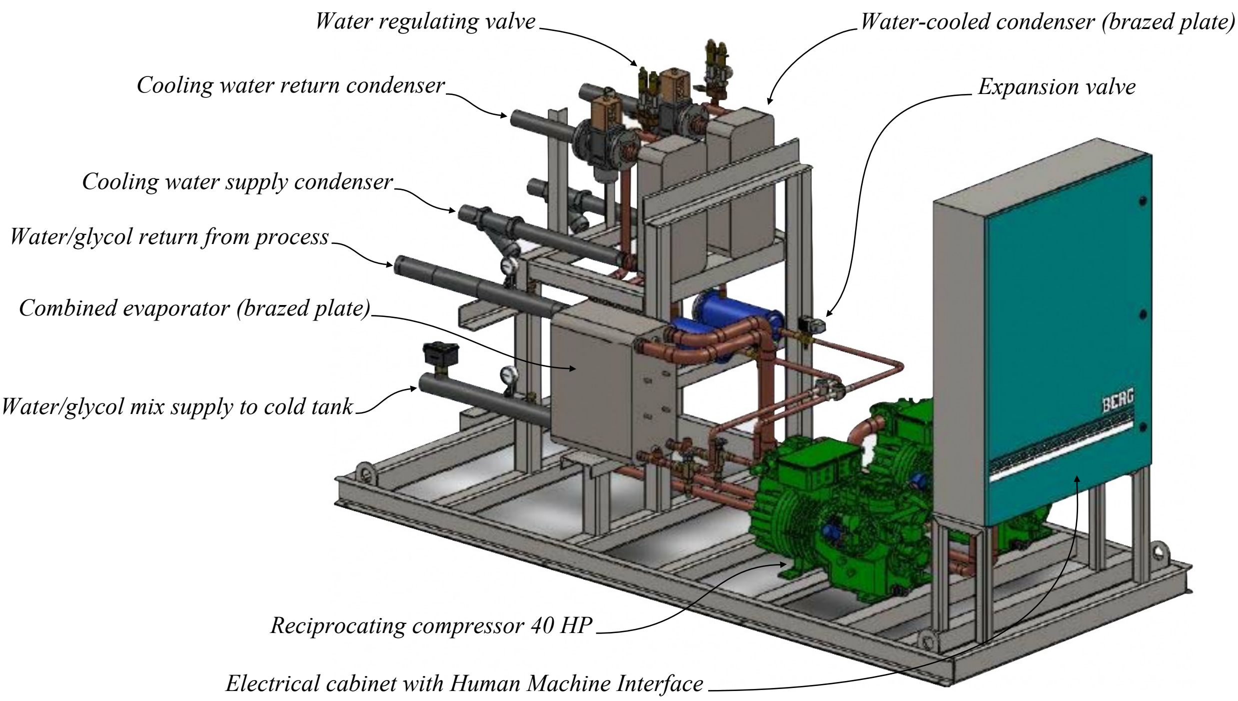


The environmental exchanger equipment is supplied by chillers that are composed of refrigeration compressors and water/glycol tank assemblies from which the cooled mix is sent to the cooling heat exchanger/moisture collector. Hot water tanks that are fitted with heating elements are used to produce and 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.

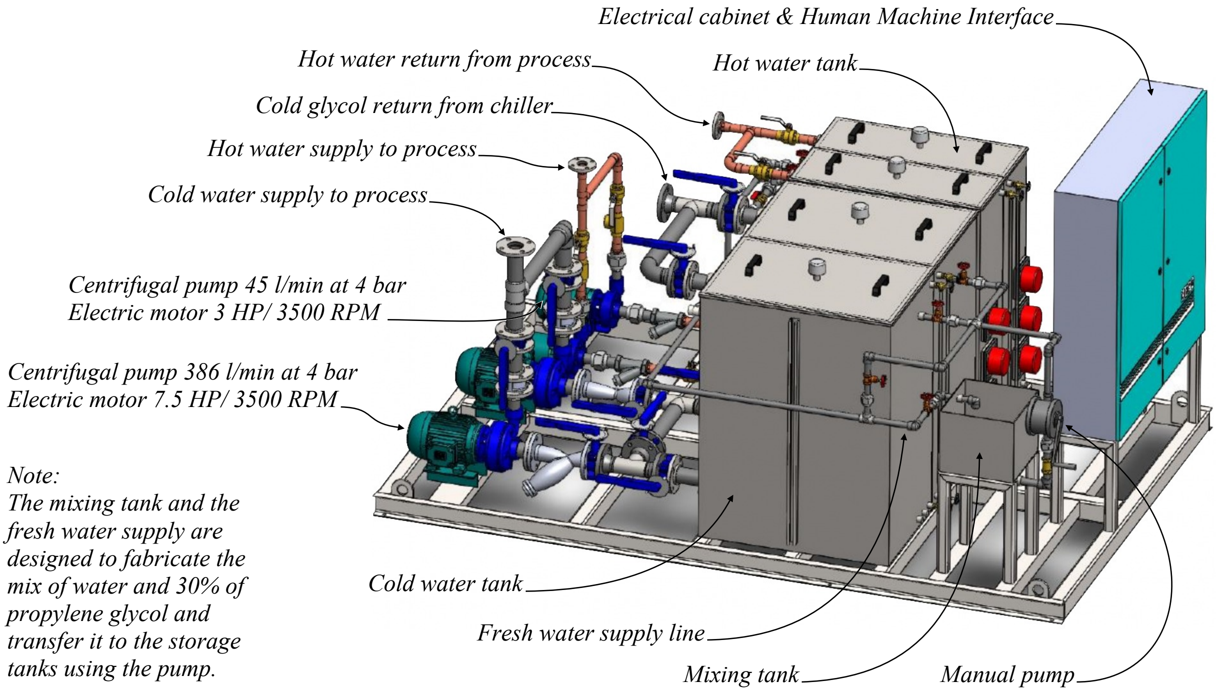




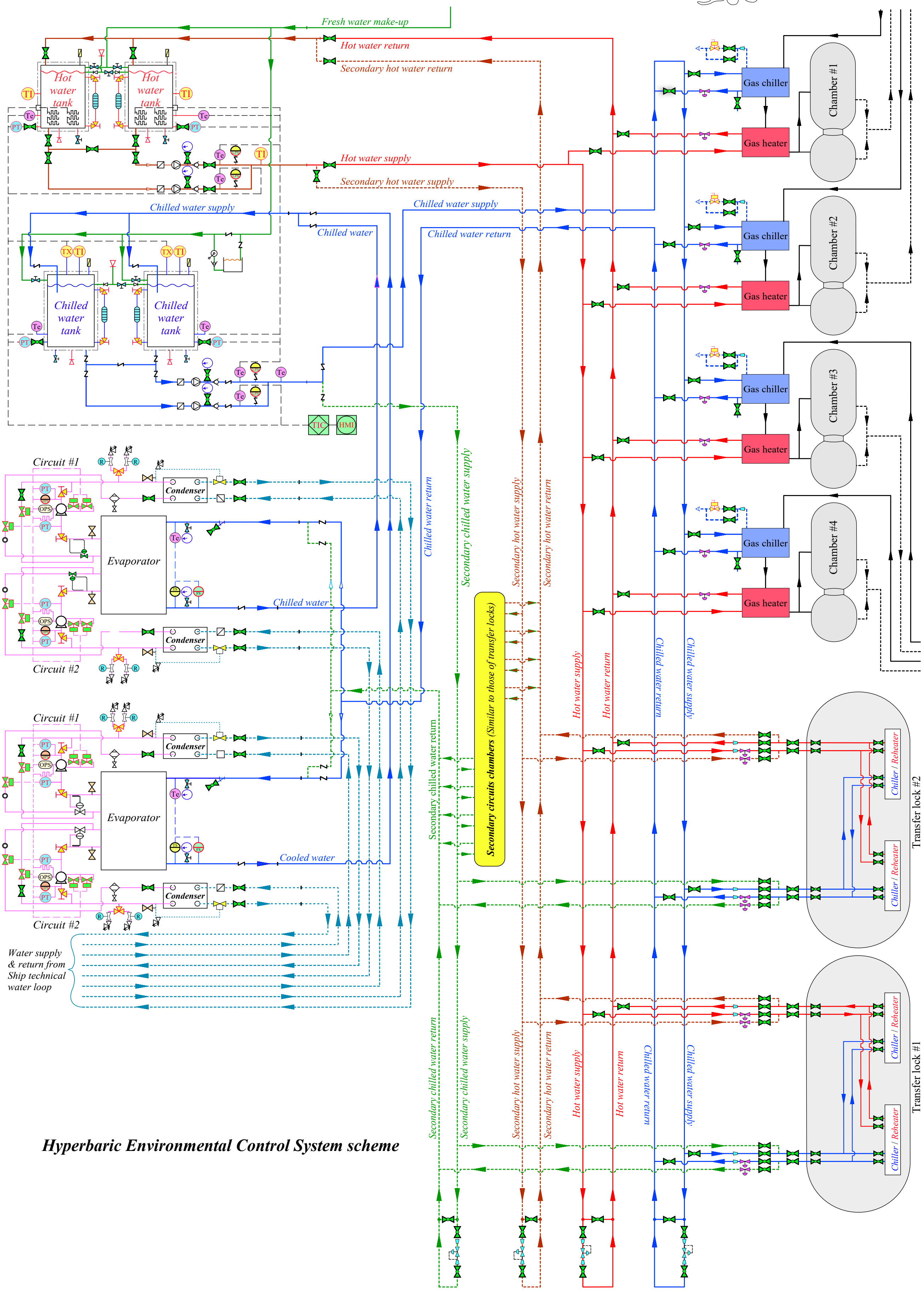
The standard of refrigerant used is R-134A, ASHRAE *(American Society of Heating, Refrigerating, and Air-Conditioning Engineers),* with toxicity class A1. This substance, which is named “1,1,1,2-tetrafluoroethane,” and which chemical formula is CH2FCF3, is part of the “Hydrofluorocarbons” (HFCs) family.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

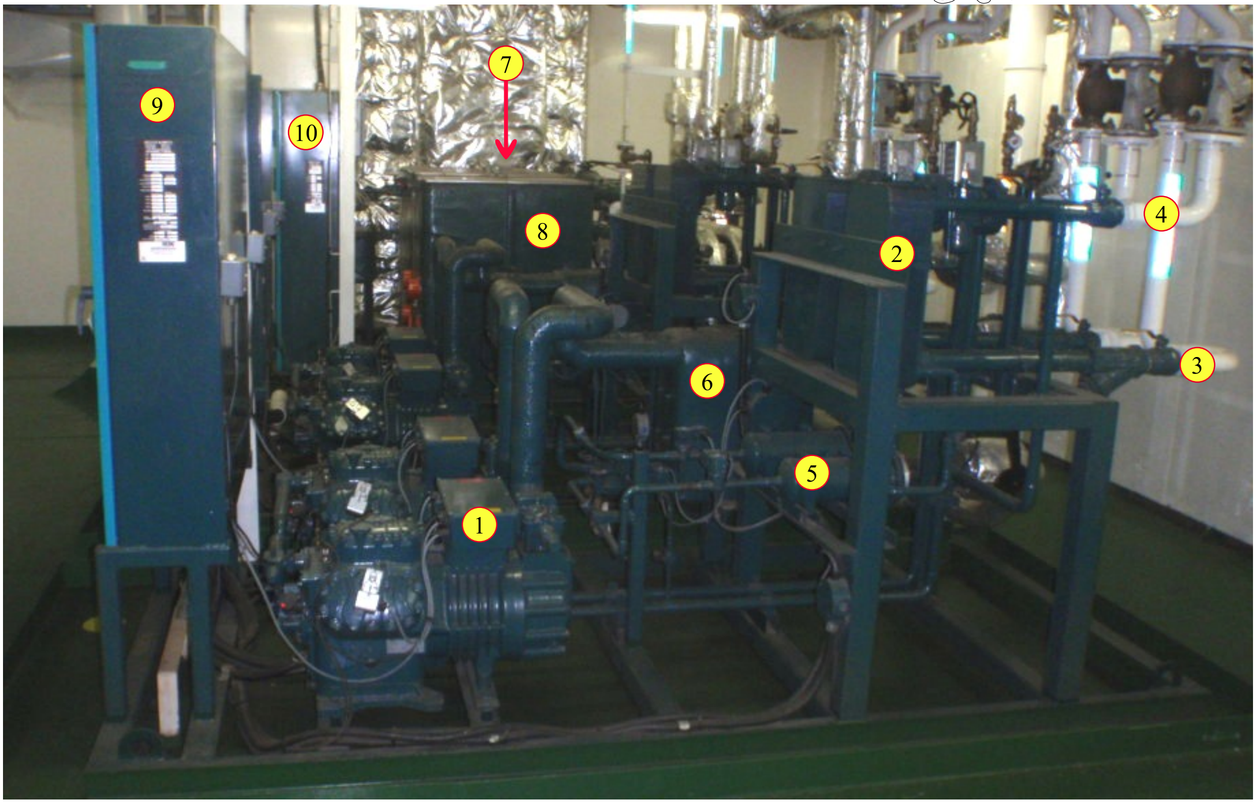


Hyperbaric Environmental Control System scheme

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 2.3.15.3.

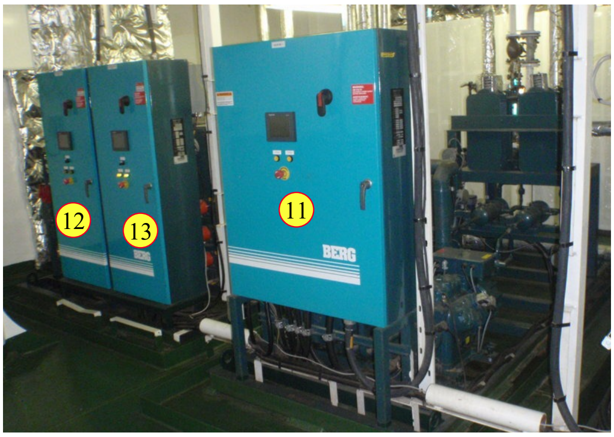
Also, this scheme shows that chillers and water heating machines are shared. However, the dehumidification and reheating of the gas of each chamber are adjusted independently by the action of the modulating control valves installed on their heat exchangers.



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

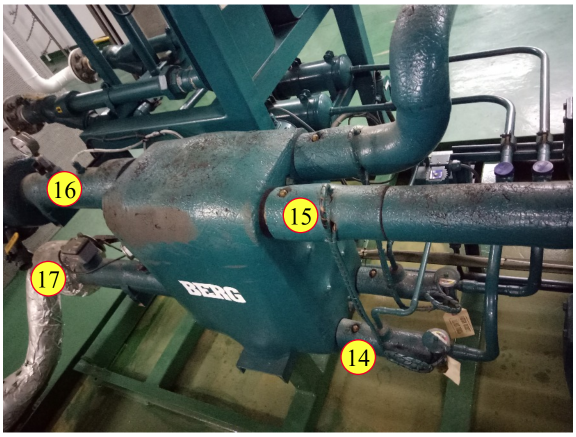
1 - Compressor | *3 - Cooling water inlet* | *5 - Expansion valve* | *7 - Chilled water tank* | *9 - Electrical cabinet*

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

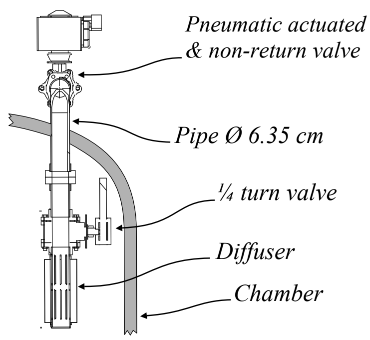


Evaporator:

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 2.3.15. 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 2.3.15. Note that with modern systems, the oxygen add is performed automatically.



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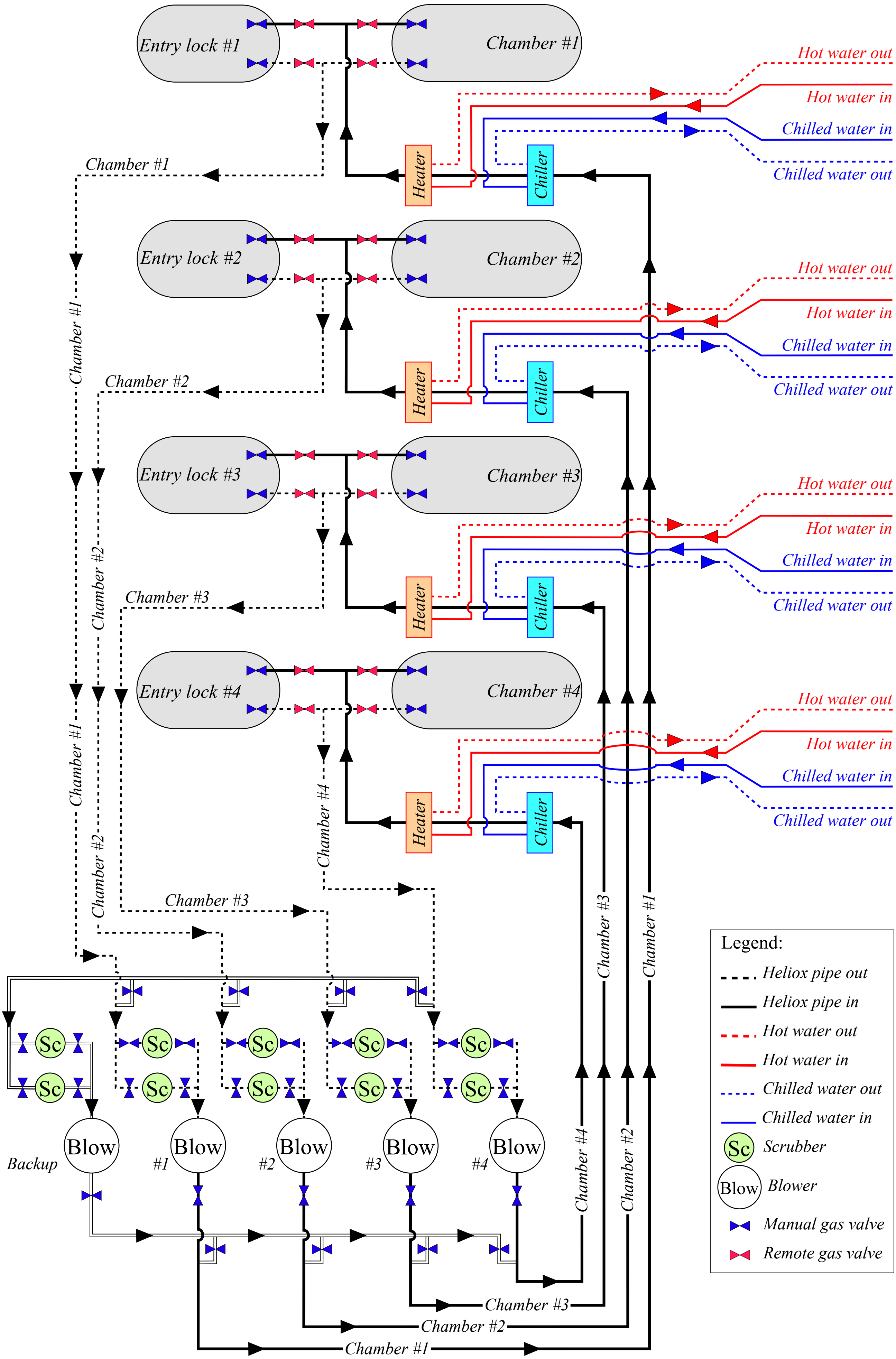
The drawing below summarizes the organization of the Hyperbaric Environment Regeneration System (HERS)



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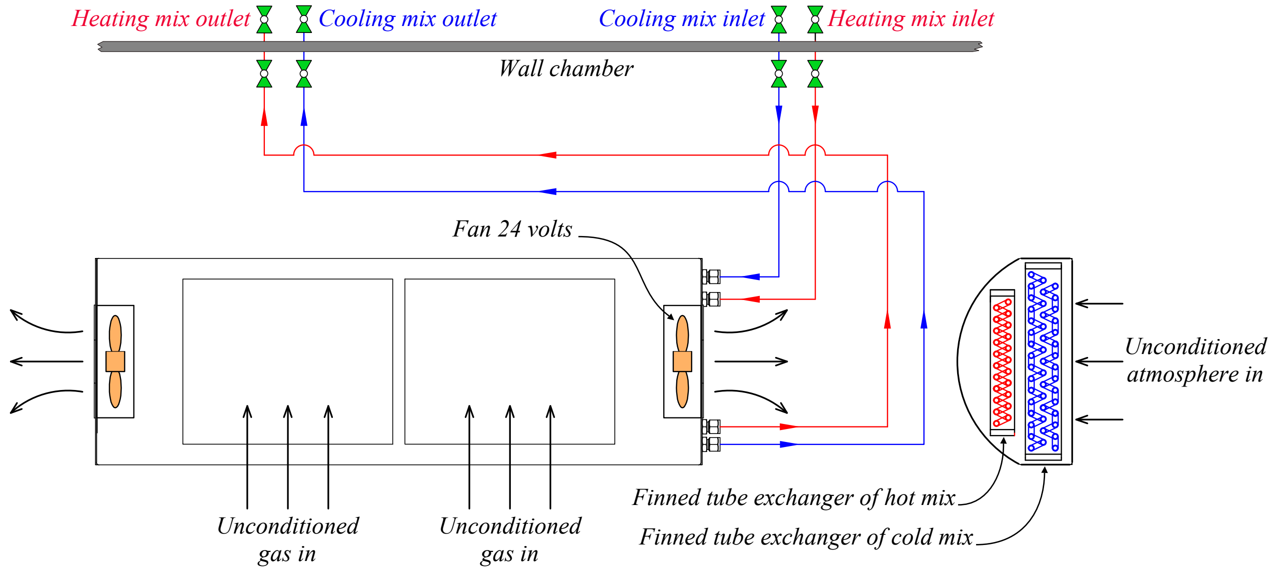
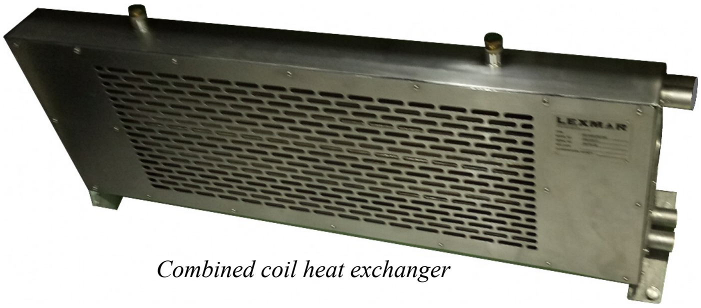
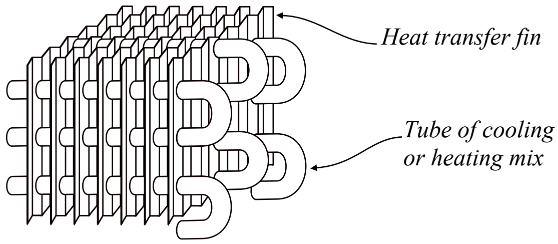
The secondary heat exchangers already described in point 2.3.15.2 and the scheme of the Hyperbaric Environmental Control System are composed of heating and chilling finned tube heat exchangers. Finned tube heat exchangers are composed of small tubes which surface of contact with the atmosphere of the 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.



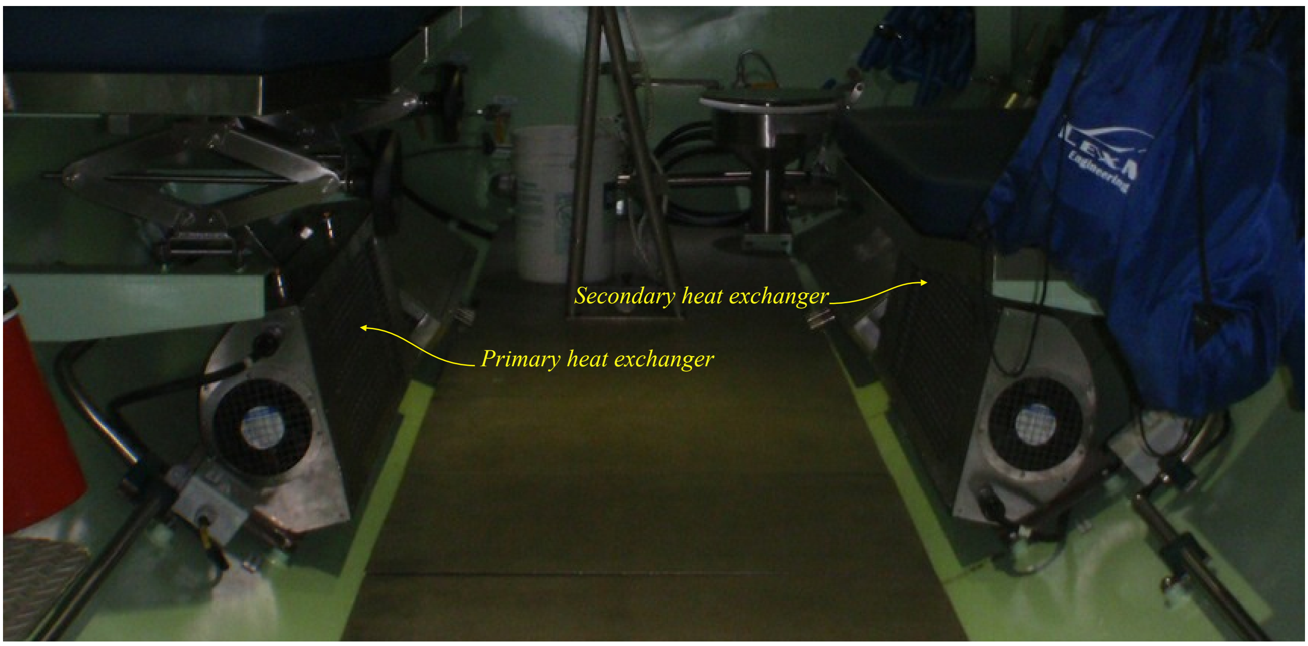


Combined coil heat exchanger



Detail of a coil heat exchanger

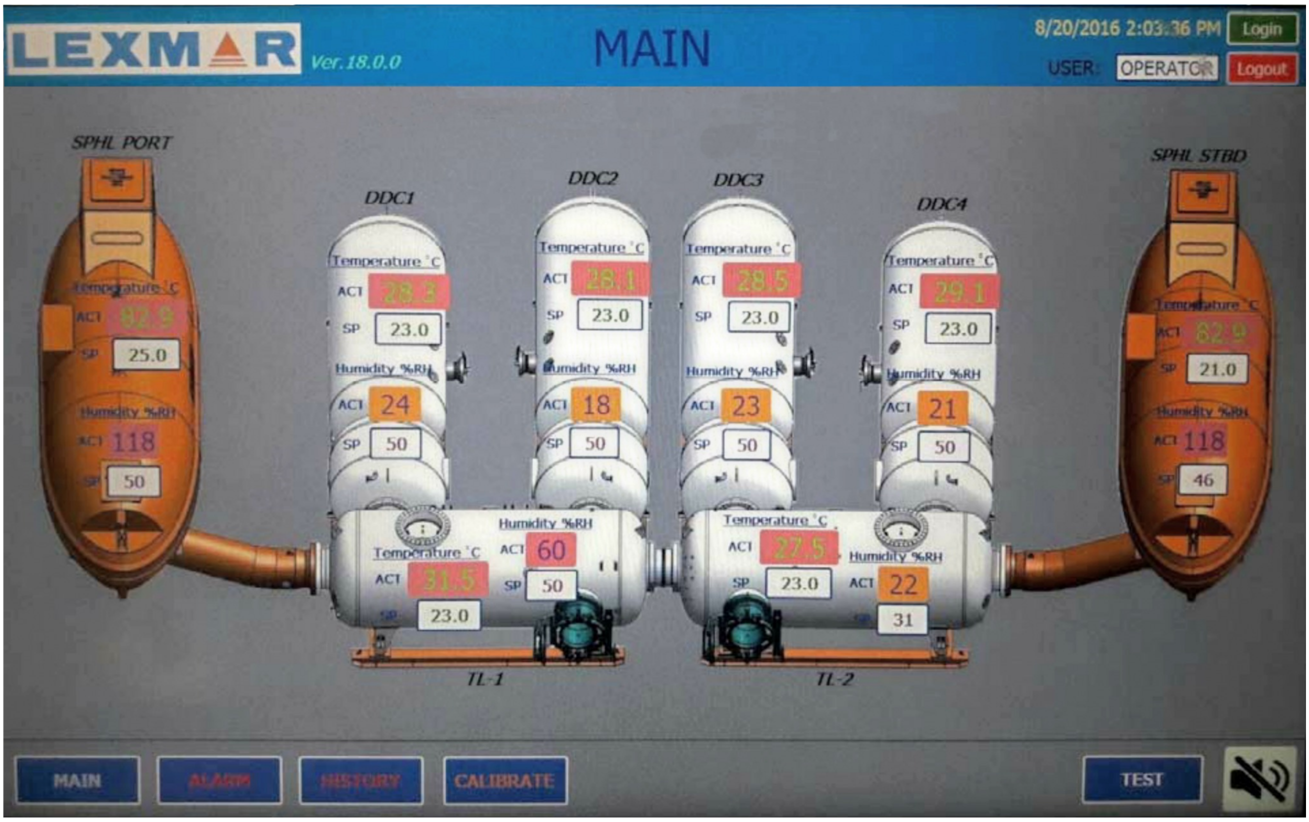
As already discussed, these heat exchangers are used as primary and secondary chilling and heating systems in the transfer locks of the systems taken as reference *(see the photo below)*.



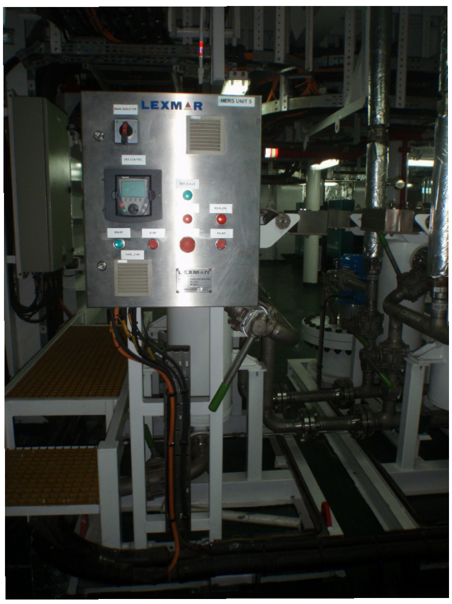
Note that some manufacturers install such devices in place of the primary external heat exchangers described with the saturation systems taken as references. As a result, the gas that returns to the chamber from the scrubber is still moistened, and its dehumidification is performed in the living chamber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

2.3.17.2 - 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

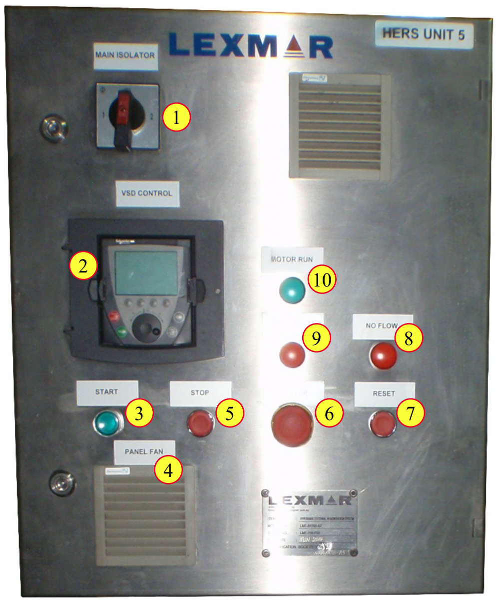
6 - Emergency stop button

7 - Reset button

8 - No flow warning light

9 - Run fault light

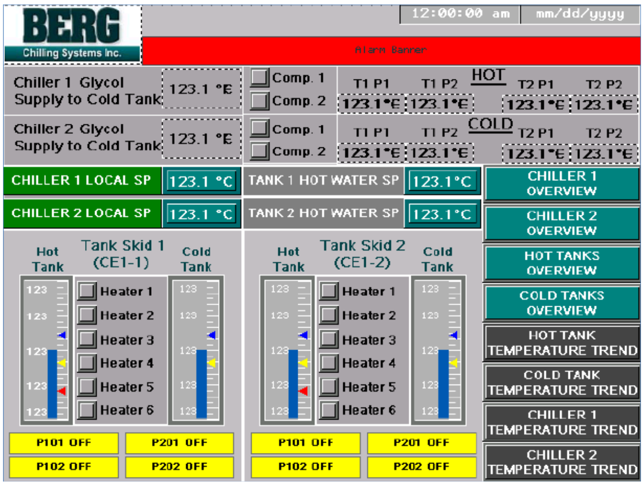
10 - Motor run light



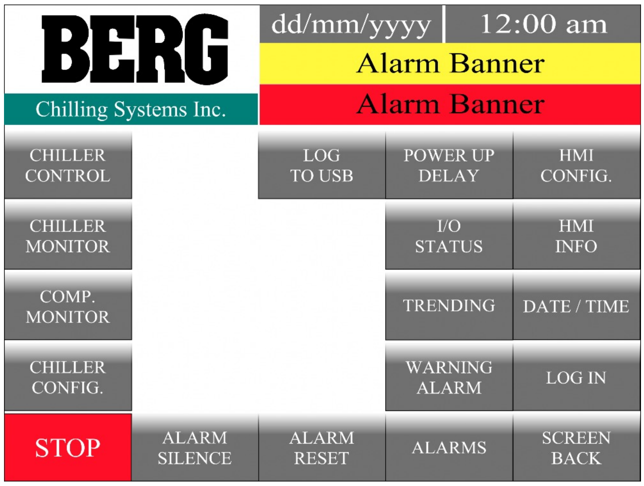
The chillers and the hot water production systems are controlled through the Human Machine Interfaces (HMI) installed in their electrical cabinet and the temperature sensors installed in each tank, as already indicated in the previous point. However, the operator screens can be viewed on any PC or wireless 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.

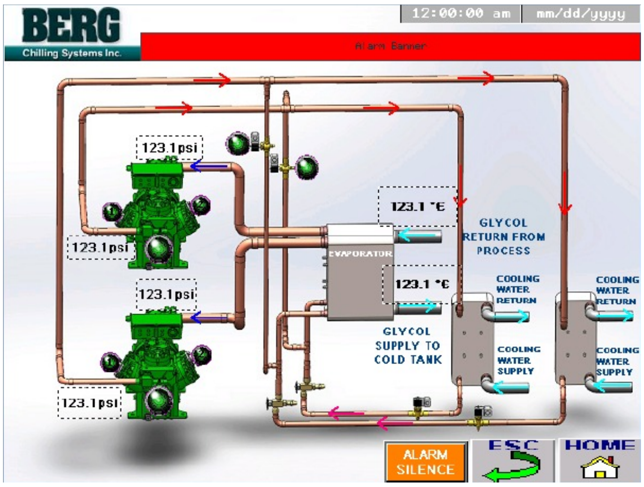
Relevant menus provide access to all areas within the Human Machine Interface program through the main screens of the chiller and the tanks *(See below)*. As a result, the parameters can be controlled from the saturation control room through a dedicated touch screen panel that can be used to set up the way the machines operate and display relevant information *(see below)*.



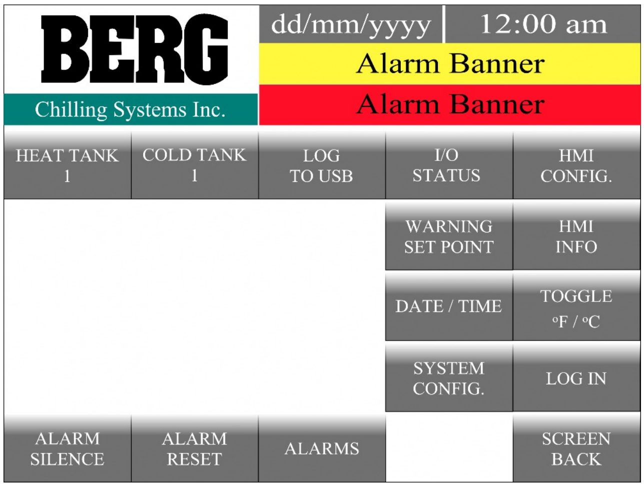
Alarm status display



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

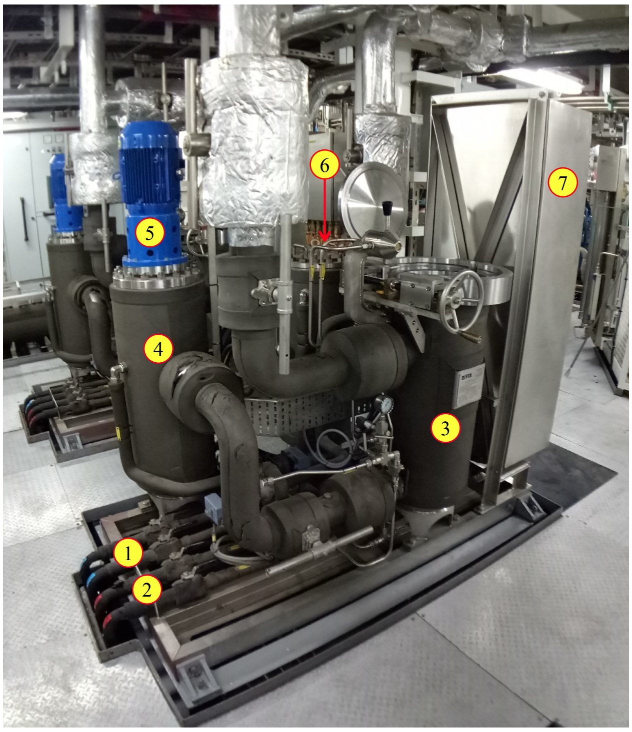
Note that the controllers used with the machines described above are Proportional Integral Derivative (PID) controllers. Such devices are used in industrial control applications to keep a constant temperature, flow, pressure, speed, and a variety of other applications requiring continuously modulated 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.

2.3.17.3 - 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.

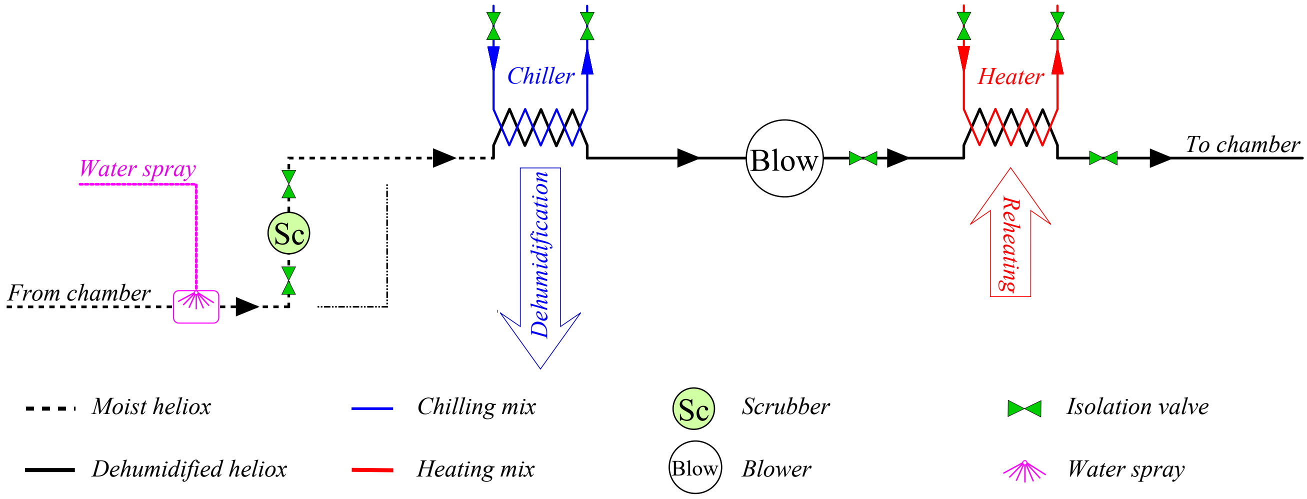
Of course, there are often some small variations of the design. As an example, the system in the photos below, which is designed by Divex, and installed in Ultra Deep Solution (UDS) Van Gogh, proposes the working steps described above with a slightly different configuration as the system Lexmar.



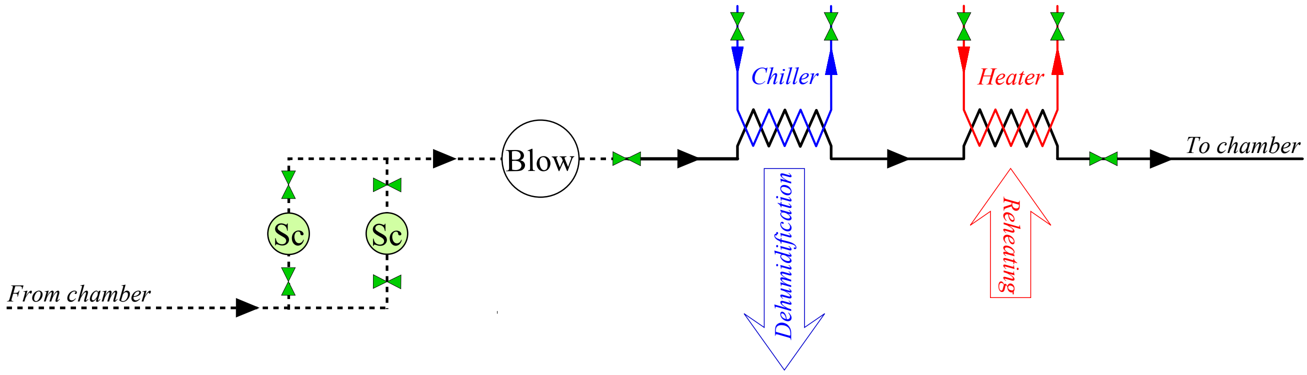
Description of the elements in the photos above:

- 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.

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

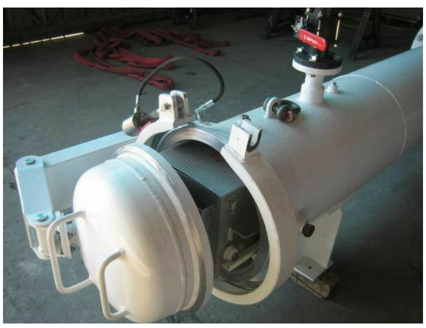


As a reminder, the organization of the system Lexmar is as follows:



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.

2.3.17.4 - 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.

2.3.17.5 - 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			

2.3.17.6 - 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.

2.3.18 - Chamber reclaim system

2.3.18.1 - 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.

2.3.18.2 - 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)*.

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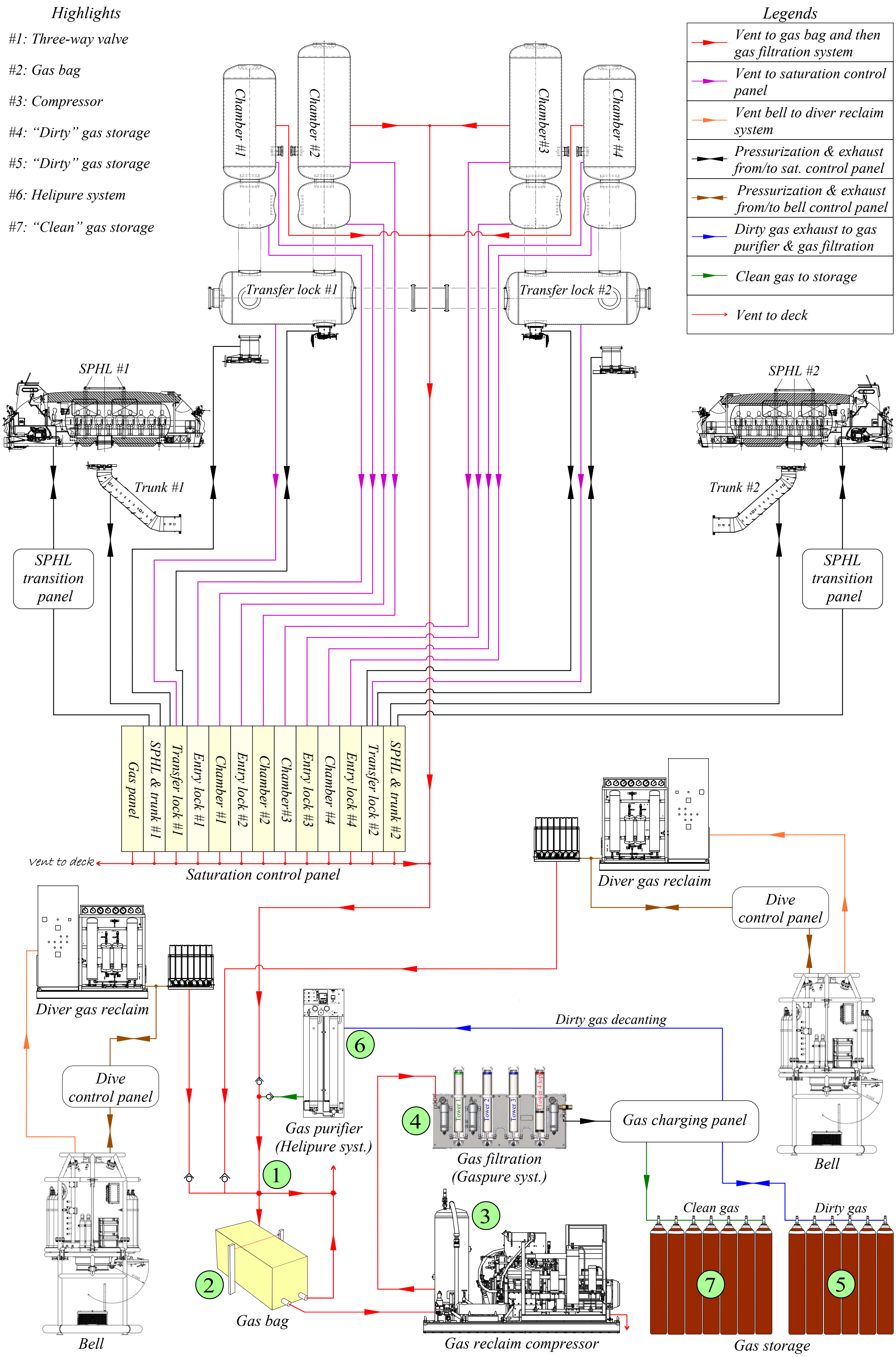
Scheme of the "chamber gas reclaim system" of UDS Lichtenstein and Picasso.



2.3.18.3 - Gas bag

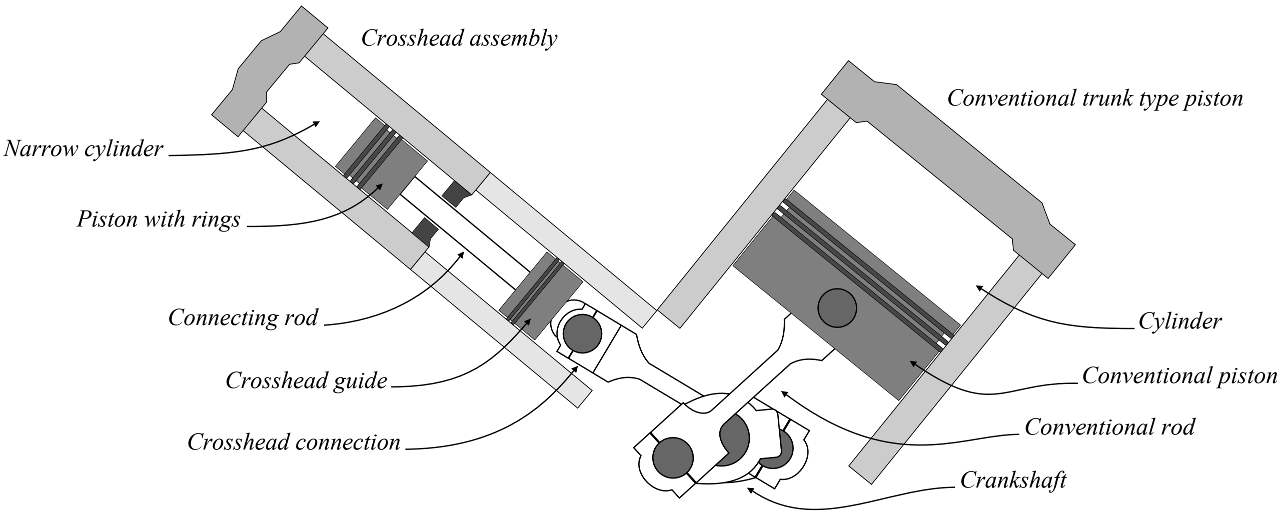
A Gas-bag is usually made of a vinyl cloth that is welded and to which the inlet and exhaust must be suitably sealed to be perfectly gas-proof. A relief valve protects this assembly from overpressure. It is fixed to the floor and installed in a dedicated cage that maintains it in shape and protects it 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

2.3.18.4 - 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.

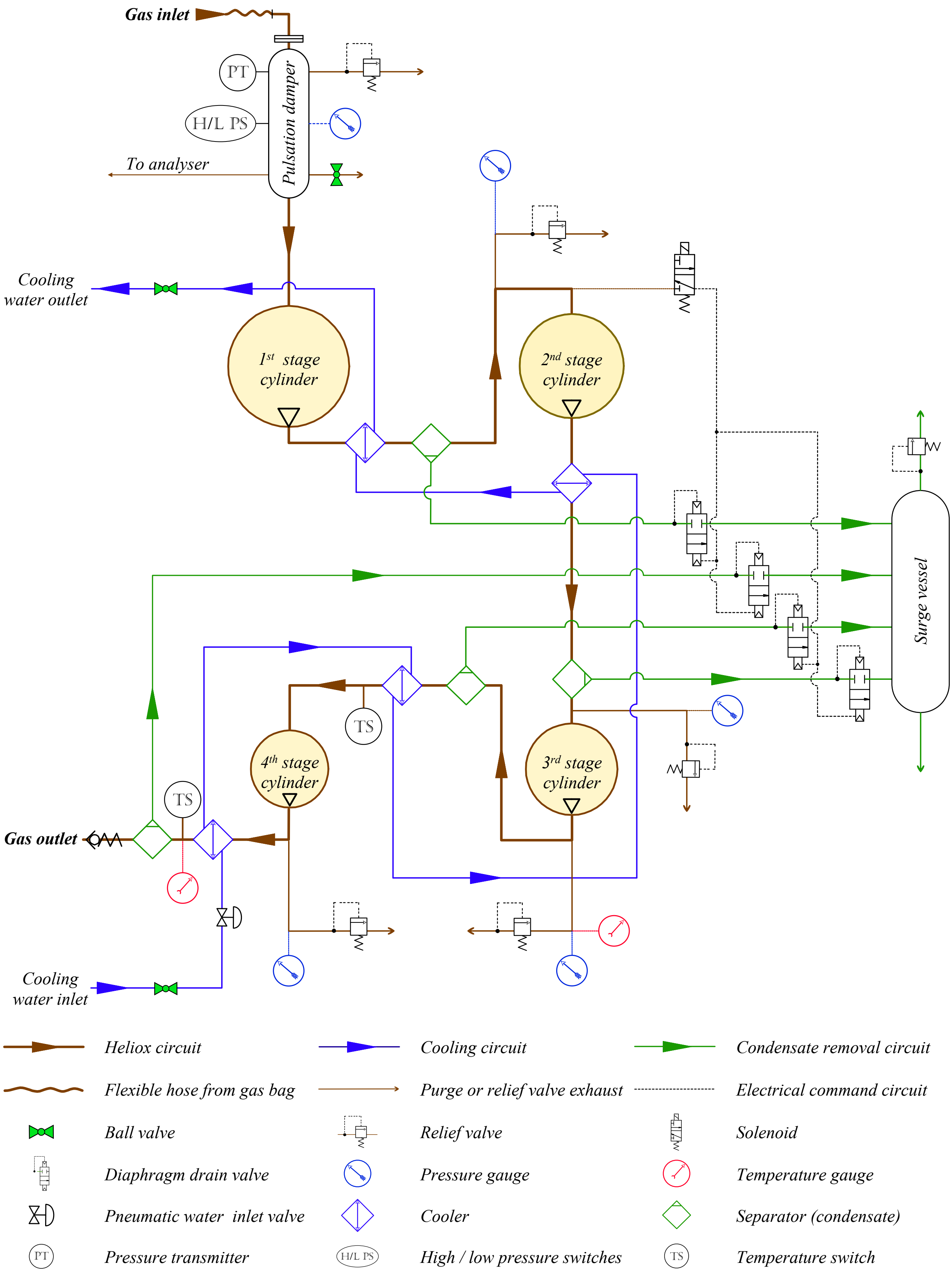


The cylinders, pistons, and valves are splash or spray lubricated through a forced feed system. The oil pump is driven from the crankshaft.
Inter-stage coolers are provided after each stage of compression and are designed for a water flow of 75 l/h/kW. They allow cooling the gas heated by the compression 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.



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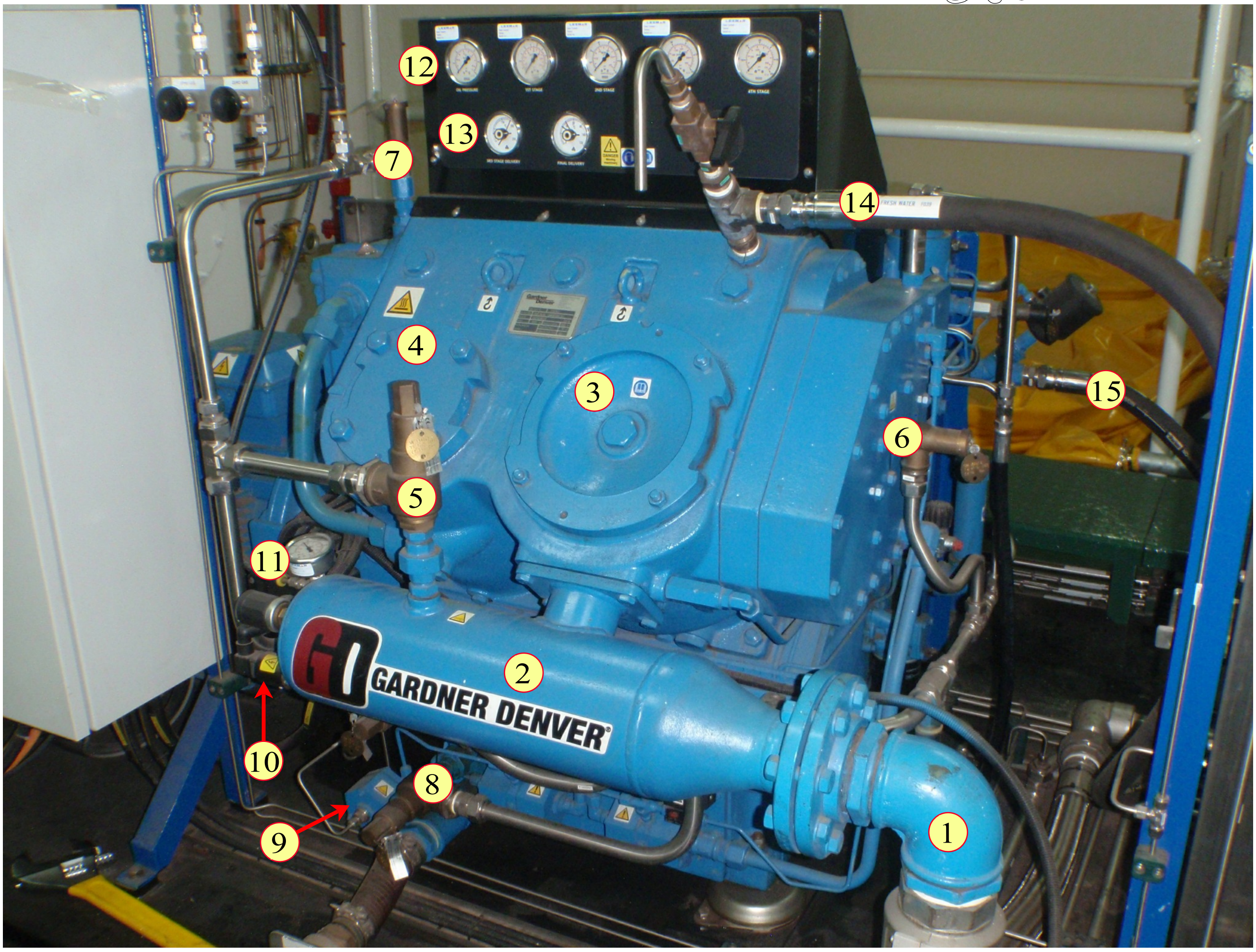
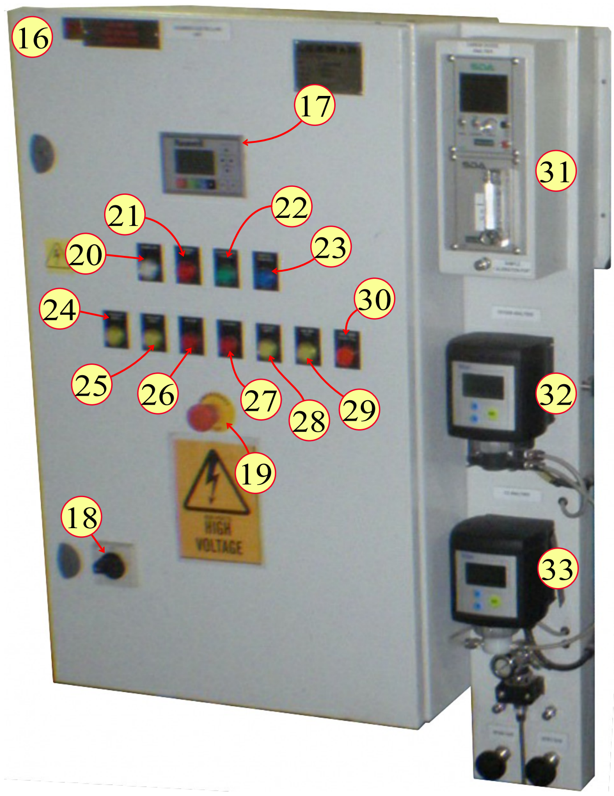


- 1 - Air inlet
- 2 - Damper
- 3 - First stage cylinder
- 4 - Second stage cylinder
- 5 - Relief valve inlet
- 6 - Relief valve 1st stage
- 7 - Relief valve 2nd stage
- 8 - Relief valve surge vessel
- 9 - Diaphragm drain valve
- 10 - Pressure transmitter
- 11 - Pressure gauge inlet
- 12 - Pressure gauges 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:

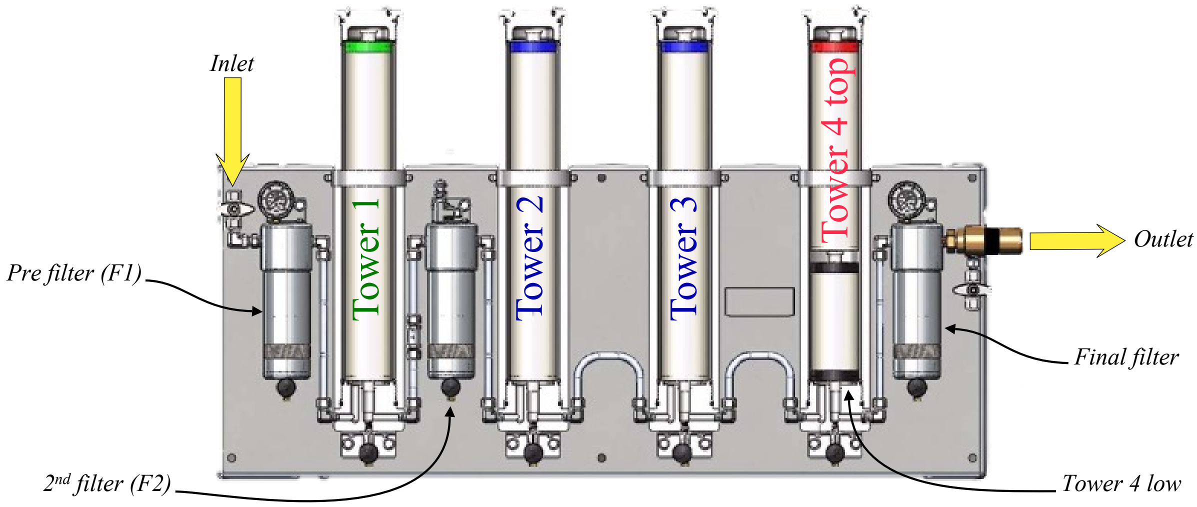
- 18 - Power switch
- 19 - Emergency stop switch
- 20 - Power on indicator
- 21 - Common trip indicator
- 22 - Compressor running
- 23 - Service required alarm
- 24 - Transfer mode indicator
- 25 - Reclaim mode indicator
- 26 - Alarm oxygen high
- 27 - Alarm carbon monoxide
- 28 - Gas bag empty alarm
- 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.

2.3.18.5 - 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.
As indicated in point 2.3.18.6, 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.

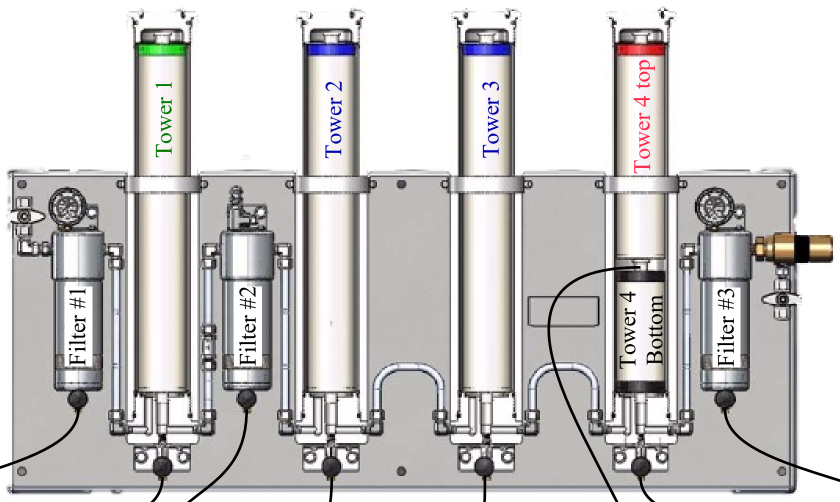
5. Tower #4 top cartridge (red)
The upper cartridge of tower #4 is composed of two sections:
   - The gas first passes through a broad band absorbent and oxidant, removing a wide range of impurities from the gas, in particular sulphur dioxide, ammonia, nitrous oxides, other light hydrocarbons and any 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 2.3.18.2, the reclaimed gas should be purified to be able to be reused safely. It is the function of the system described below.

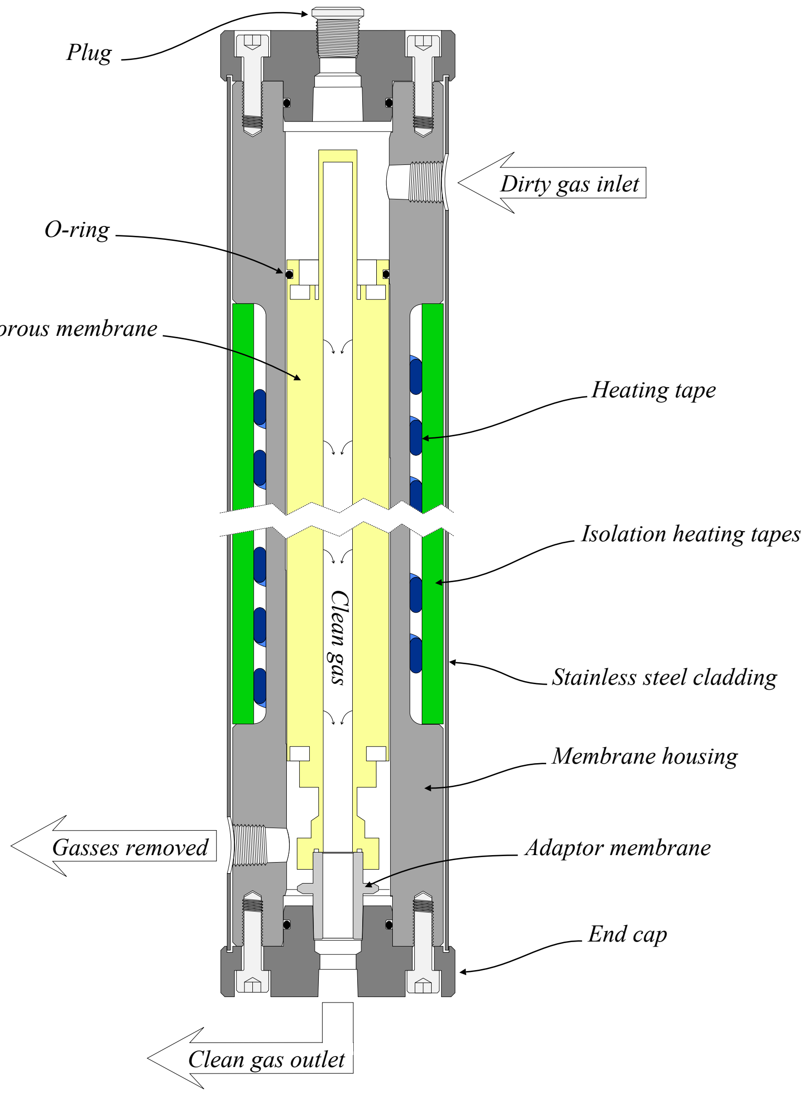
2.3.18.6 - Divex Helipure system

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

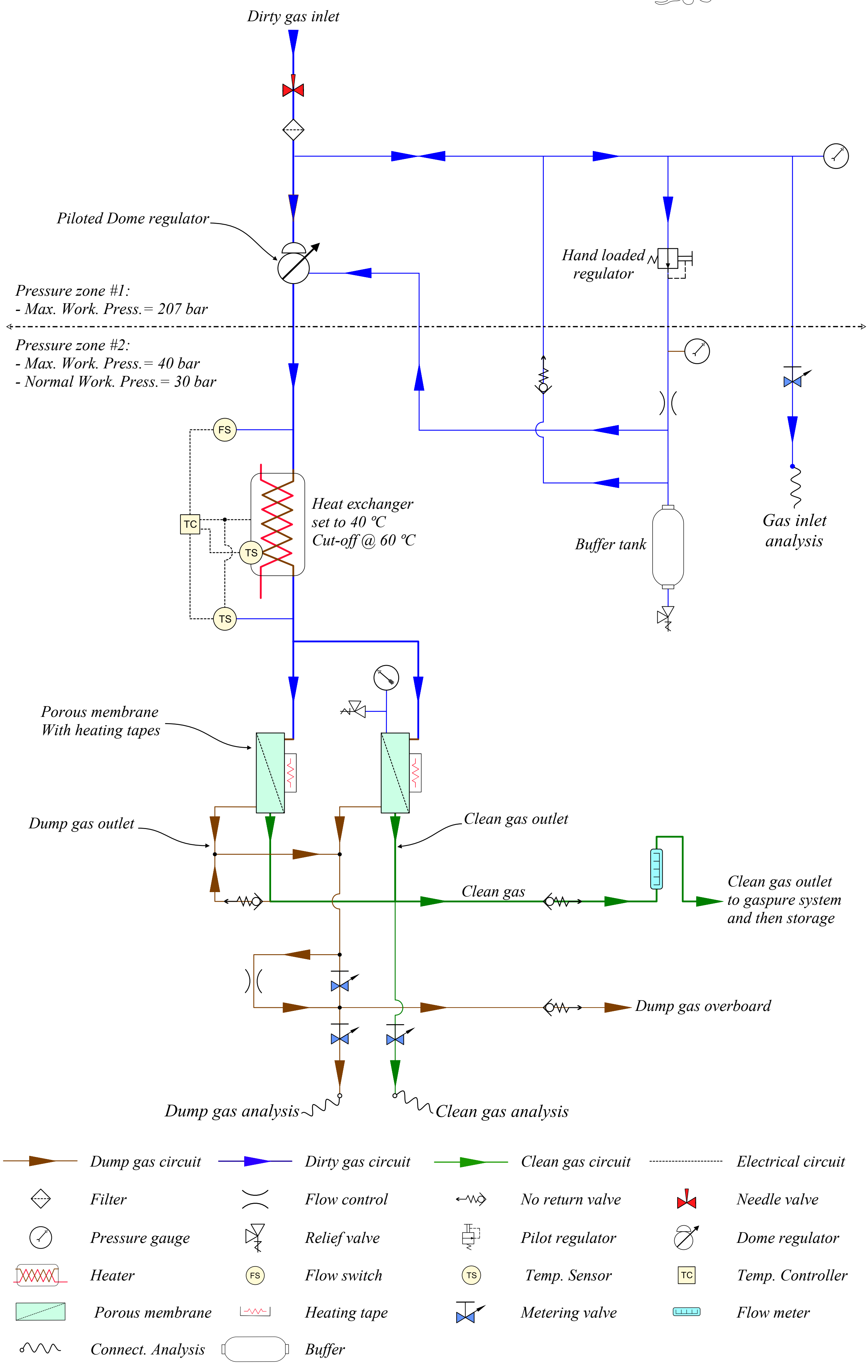
- 6 - Gas analyser

- 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

2.3.18.7 - 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 2.3.18.6)*.

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 2.3.18.2.
- 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.

2.3.18.8 - *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.

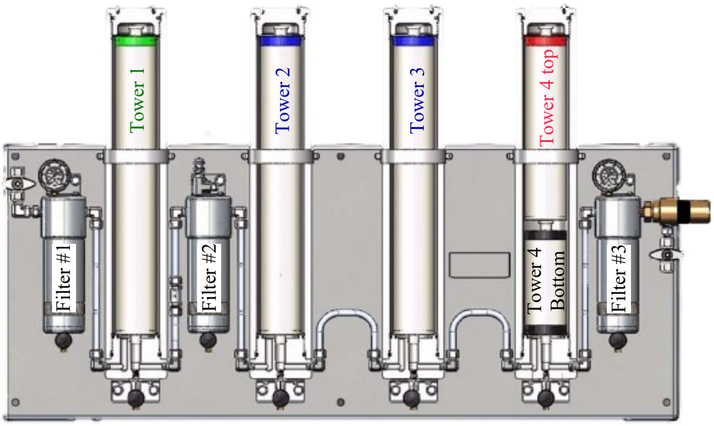
Also, IMCA D 024 recommends the following:

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 m^3 *(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 m^3 /hr (15 scfm)	*100*
50 m^3 /hr (30 scfm)	*50*
100 m^3 /hr (60 scfm)	*25*
125 m^3 /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.

2.3.19 - Gas storage and distribution

2.3.19.1 - 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 today the most used reference in force that is used by the manufacturers to design systems with sufficient operational capabilities, and that allows the Life Support Supervisors (LSS) to calculate the necessary gas to be provisioned for a project. It provides the following recommendations:

A) Surface orientated diving

I - Sufficient compressed gas always needs to be available for two emergency dives to the full intended diving depth and time. This gas is to be kept as a reserve. This gas should either be stored in containers or else supplied by two totally independent dedicated sources.

II - Sufficient compressed air needs to be available to pressurise both locks of the deck decompression chamber to the maximum possible treatment depth (normally 50 metres) plus sufficient air for three complete surface decompression cycles. This air should either be stored in containers or else supplied by two totally independent dedicated sources.

NB: Two totally independent sources could be two separate compressors, one of which is connected to the rig or vessel emergency electric power or separate power source (e.g. diesel) or one compressor plus compressed air storage containers.

Rig air should not be considered as a dedicated air supply for diving as it is principally provided for other purposes and may not be available to the quality, or in the quantity, or at the pressures required.

III - 90 m^3 (3200 cu ft) of breathing quality oxygen needs to be available for emergency treatment procedures.

B) Closed bell diving

B1 - General

I- Helium and helium gas mixtures, due to the extremely small size of the helium atom, leak from storage cylinders even when precautions are taken to tighten fittings.

II- Due allowance therefore always needs to be made for leakage when calculating minimum quantities of gas required at the start of a diving operation.

III - In mixed gas, bounce, or saturation diving, there is always the possibility of the deck chamber atmosphere becoming fouled, due to smoke or other contaminants. In such circumstances, the chamber occupants should use the built-in breathing system (BIBS), dumping the exhaust overboard while they transfer to another chamber or the main chamber atmosphere is cleansed or flushed out. 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.

IIII - The composition and use of therapeutic or treatment gases varies from company to company, dependent on their detailed operating procedures and treatment tables used. Sufficient quantities of treatment gas for the depths involved need to be available to carry out any foreseeable treatments as detailed in the company's rules. This applies to both bounce and saturation diving.

B2 - Bounce diving

Before commencing diving, certain quantities of gas and/or air should be available as follows:

I - Sufficient mixed gas should be available for the divers in the water or bell to carry out their planned work. Additional gas should be available to allow a complete dive to be made to the maximum depth in an emergency.

II - Sufficient mixed gas and/or air should be available to pressurise the deck chamber to the transfer depth, twice. If atmospheric control in the chamber is to be achieved by flushing, then sufficient gas or air should be available for the necessary flushing for two complete decompressions from the intended transfer depth. Should it be intended to use air for the deck chamber, then this air should be available from two independent sources (see note in A.1) or else be stored in containers.

III - In the event of emergency medical treatment being required, there should be sufficient helium or mixed gas available to pressurise the deck chamber to maximum diving depth and allow a full saturation decompression to be completed. In this case, sufficient oxygen should be available as identified in B3/III.

C) Saturation diving

Before commencing diving certain quantities of gas should be available as follows. If the gas supplies fall to a level such that the remaining gas only satisfies paragraphs B.1 iii) and B.3 ii) to iv), then decompression should be started immediately.

I - Sufficient mixed gas should always be available at the start of a bell run to carry out the intended bell run or for both intended bell runs if conducting bottom turn-rounds/continuous diving, plus the same quantity of gas should be held as a reserve. This gas will be in addition to the gas requirements in the following paragraphs. Gas carried onboard the bell or hyperbaric evacuation system (HES) in cylinders should not be included in these calculations.

II - Before the start of a saturation, there needs to be sufficient mixed gas available to be able to pressurise the system (all deck chambers/HES involved in the saturation) required for the envisaged operation, to the maximum intended storage depth, plus at least an equal amount as a reserve. During the operation, the reserve of mixed gas, sufficient to completely repressurise the system, should be maintained at all times.

III - There should be sufficient oxygen to allow for metabolic consumption by each diver, any oxygen make-up prior to decompression, plus that required to maintain the PPO2 during decompression. This quantity should be doubled for safety reasons and held in two separate banks.

IIII- Before a saturation dive there should be a minimum of three weeks' supply of calibration and zero gas for the analysers. This reserve needs to be maintained during the saturation.

D) Additional recommendation for saturation diving (IMCA D 022)

I - Back-up supplies must be immediately available. For chamber use this means that they must be at sufficient pressure to go directly into the chamber. Gas at a pressure of less than 20 or 30 bar cannot be considered as part of the reserve.

II - Minimum quantities of other consumables like soda lime and Purafil will normally be specified in company manuals. Typically, they will be sufficient to continue operations for about two weeks without further supplies being received.

IMCA says that in case that national regulations or standards are more stringent than this guidance, they must take precedence over it. Also, note that the volume of gas to provide depends on the number of divers to pressurize, the size of the system, and their working conditions. Taking into account what is said previously, prudent Life Support Supervisors (LSS) always plan for much more gas than what is found with the calculation. This gas must be safely stored and appropriately distributed. Depending on whether the system is built-in or a portable one and the nature of the gas, the reserves can be installed in the cargo, in a dedicated ventilated space, or on deck.

2.3.19.2 - Gas containers

The gasses 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 overwrap formed by layers of continuous fibres in a matrix, or a composite overwrap 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 11, 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:

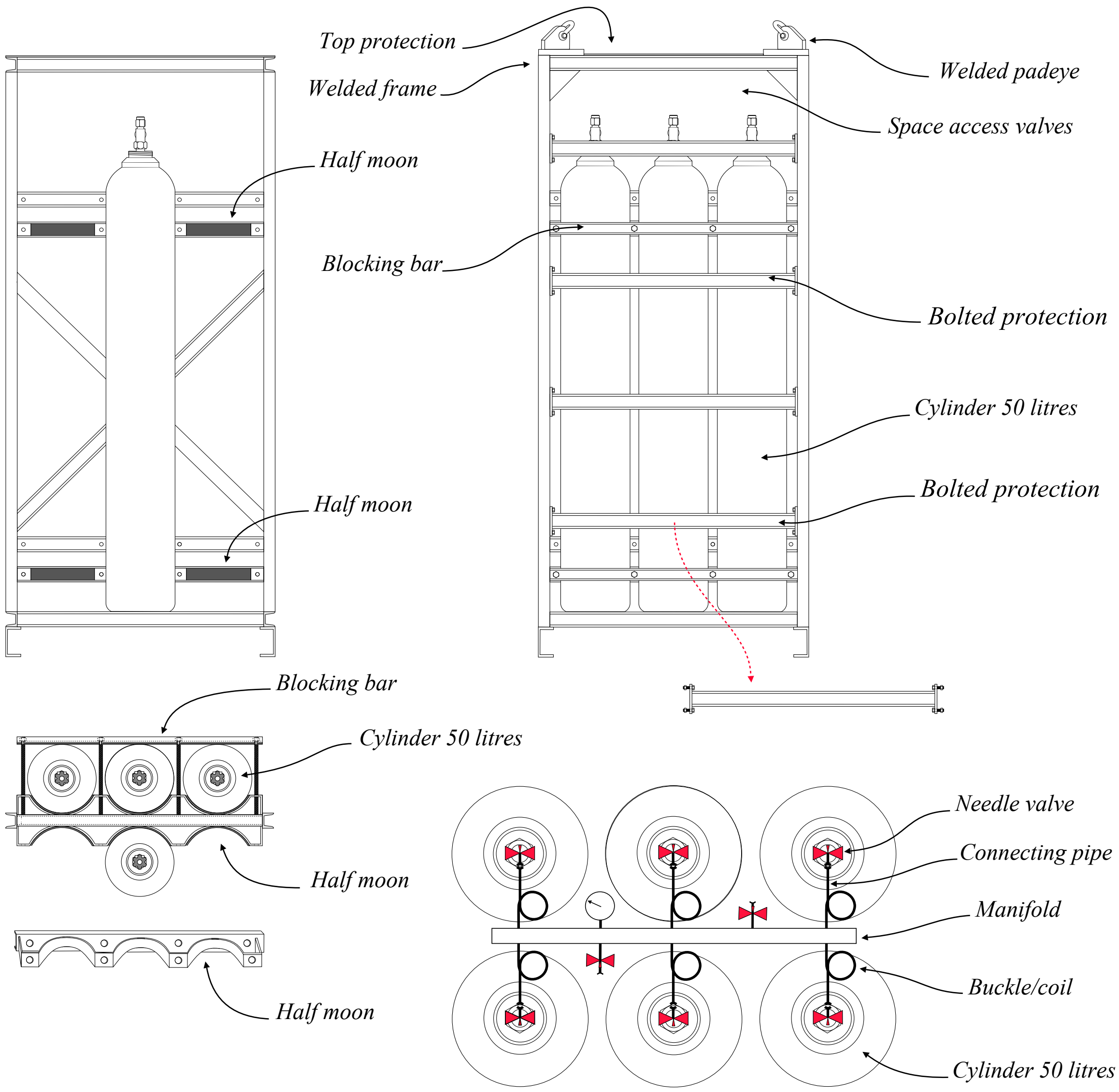
- Strength of structure, including design details
- Material specifications
- Welding and other joining methods
- Lifting set
- Supporting structures for other permanent equipment.

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

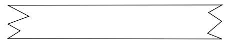
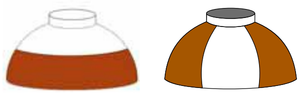
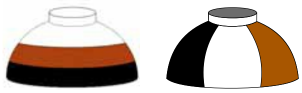
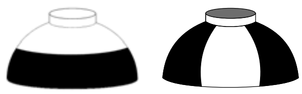
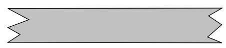
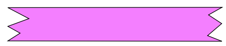
Note that these devices must be approved by relevant competent bodies such as governmental organizations and internationally recognized classification societies. Thus, homemade Multiple Elements Gas Containers cannot be used unless such organizations approve them.

***2.3.19.3 - 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:

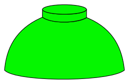
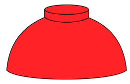
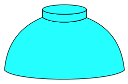
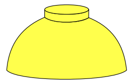
Gas	***Symbol***	***Cylinder shoulder***	***Quad upper frame / Frame valve end***
Helium	*He*	*Brawn* 	*Brown* 
Medical Oxygen	*O2*	*White* 	*White* 
Heliox	*HeO2*	*Brown & white bands or quarters* 	*Brown & white alternating bands 20 cm* 
Nitrogen		*Black* 	*Black* 
Trimix Helium + Nitrogen + Oxygen	*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*	

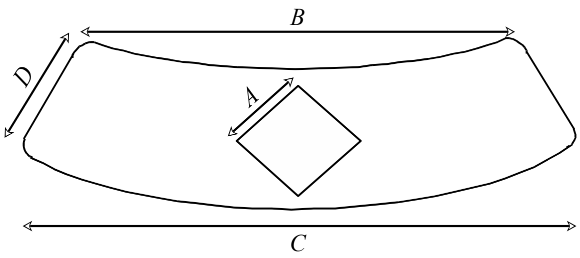
As a complement of the colour codes, precautionary labels should be attached and maintained so that they are clearly visible and legible for as long as the cylinders remain in the same gas service.
The purpose of precautionary labels on gas cylinders is to facilitate the identification of each cylinder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

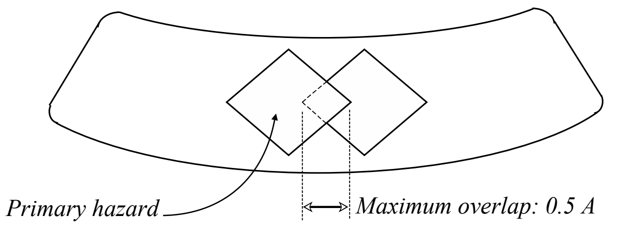
- Name of the gas or gas mixture
- Danger or Warning: International Maritime Dangerous Goods Code symbol and class for hazards *(see below)*
- Hazard statements
- Handling instructions
- Supplier identification and contact numbers

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

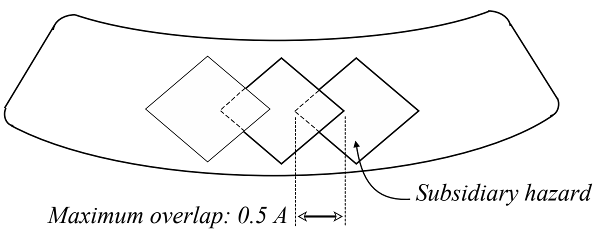
- UN number
- Chemical formula
- First aid advice
- Hazard chemical number
- Emergency respondent’s contact detail

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*



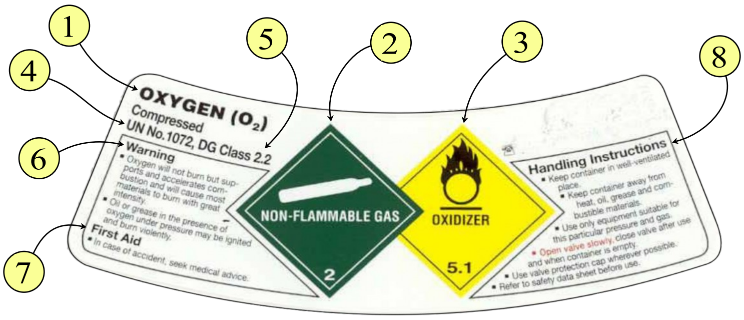
International Maritime Dangerous Goods Code classifies the hazards into the nine main classes displayed below that are also divided into sub-classes according to their characteristics - Note that gasses have three sub-classes:

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*

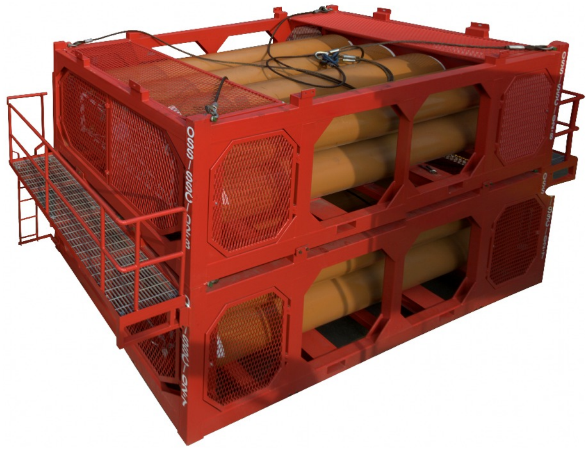
For cylinders and tubes that are grouped in Multiple Elements Gas Containers (MEGCs), either all-visible cylinders are labelled as suggested for single cylinders, or a label with a minimum size of 100 mm x 100 mm is visible on each side of the Multiple Elements Gas Container. A label as suggested for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

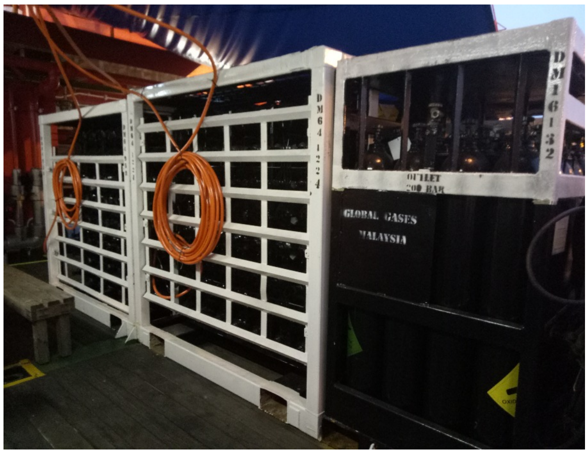
2.3.19.4 - Storage and distribution of the gasses

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.

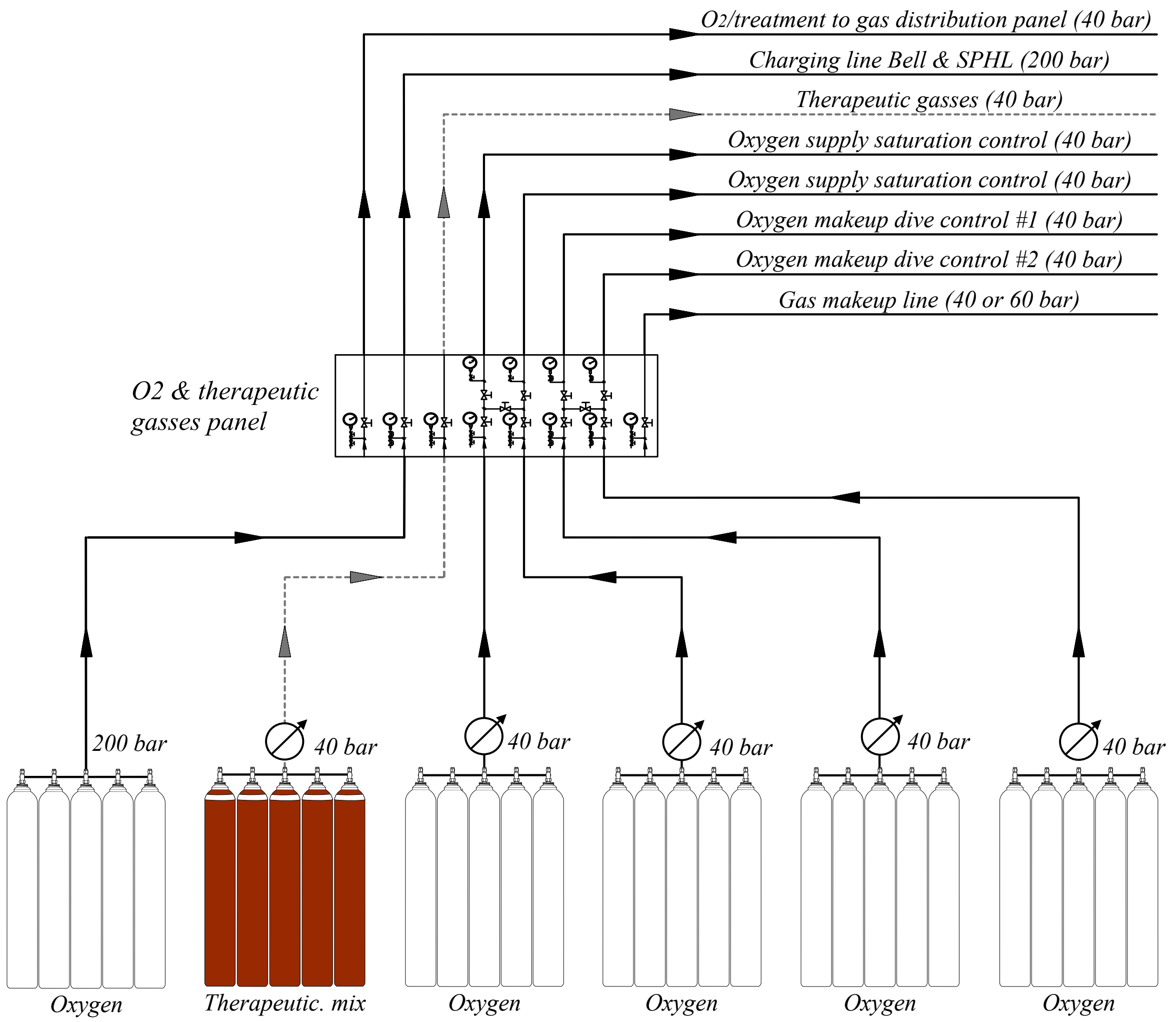


Heliox tubes containers designed by Lexmar (JFD group)

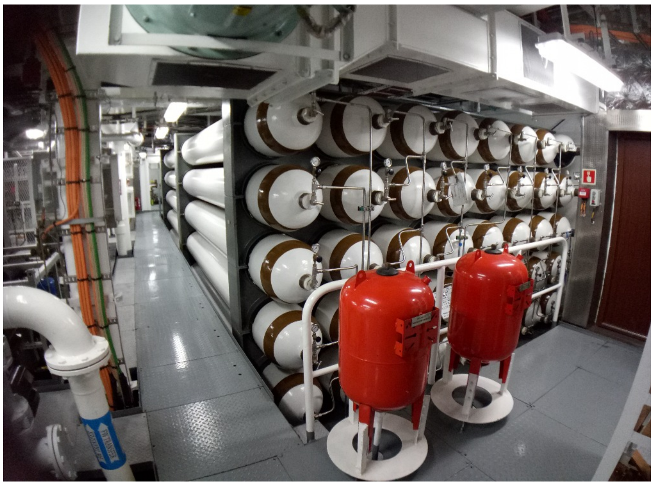


Oxygen super-quads on deck

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.

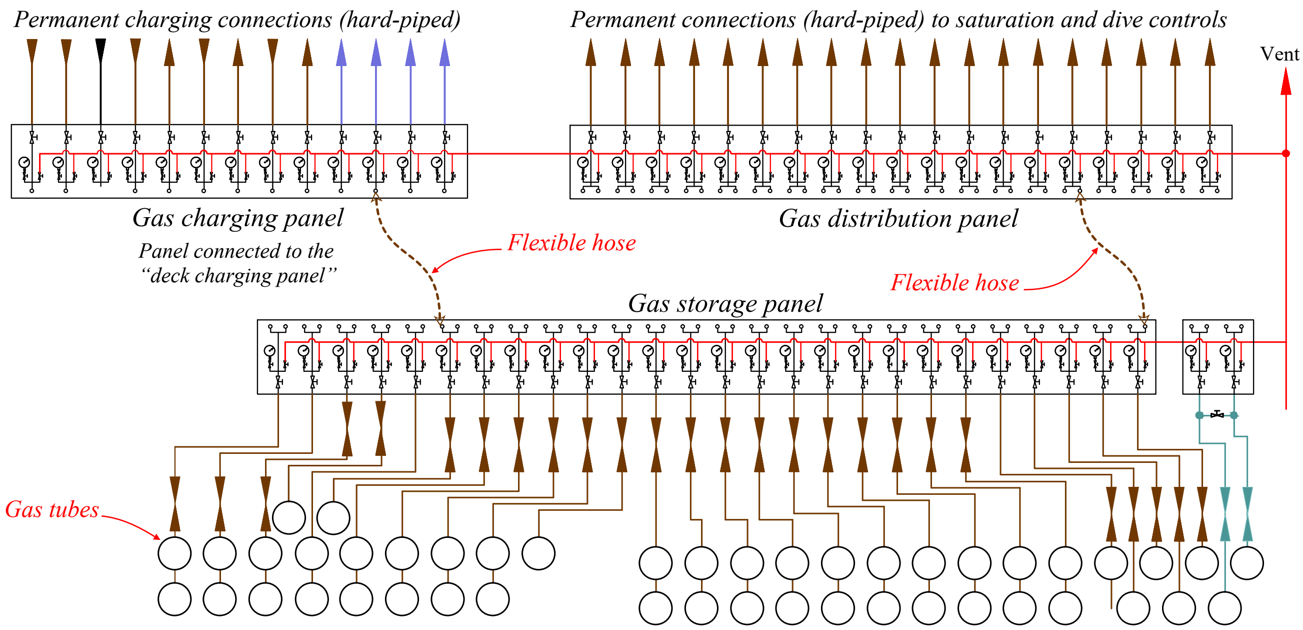


Built-in systems are provided with gas reserves that are usually made of banks of kelly tubes installed in dedicated rooms situated on one of the lower deck to which the gas delivered has to be transferred through connected panels that are accessible on deck. This gas reserve usually is sufficiently 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.

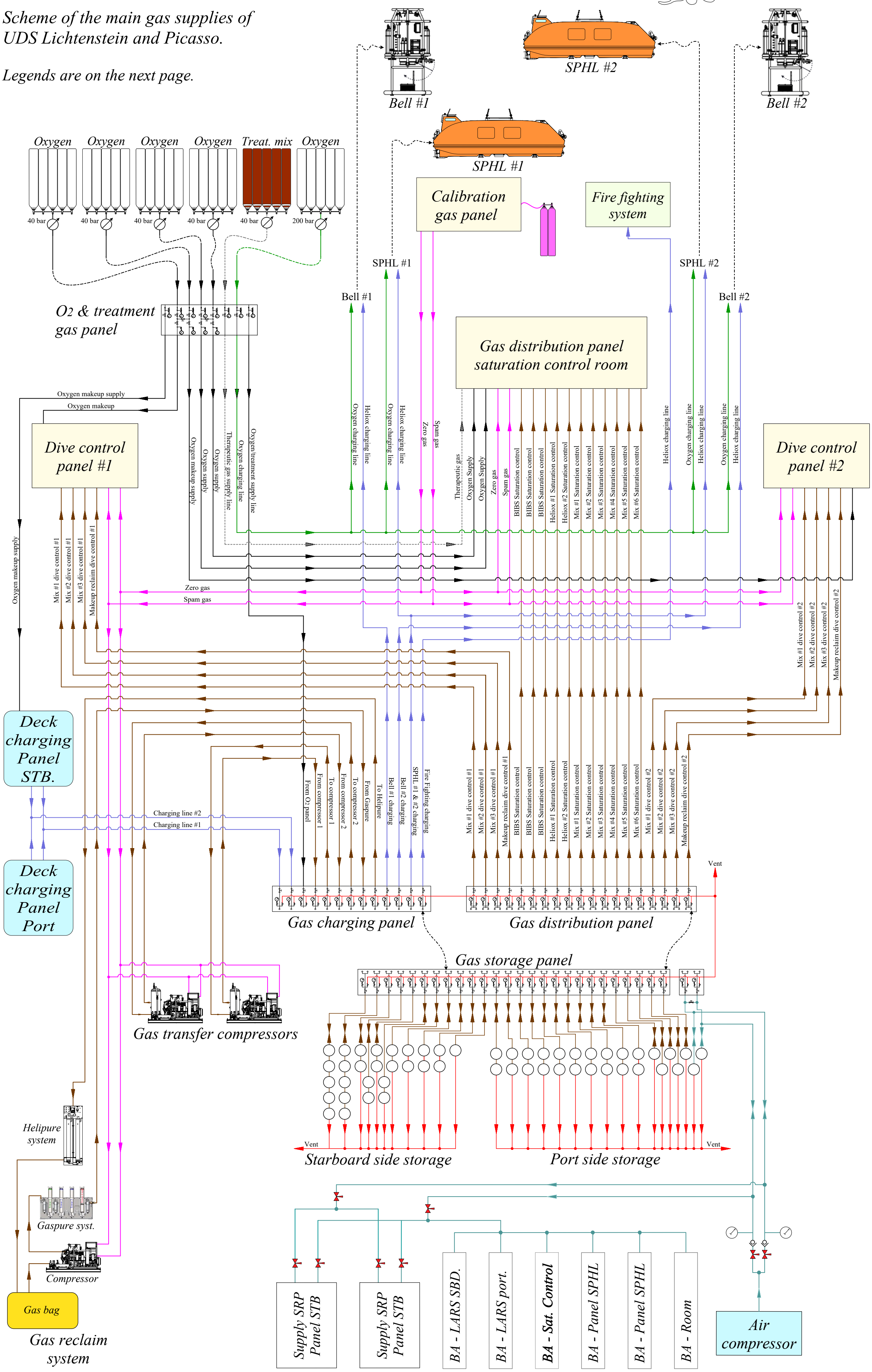
The gas transported through the the connecting panel situated on the main deck, which is often called “deck charging panel” is distributed to the storage tubes through the “Gas charging panel” that is installed at the direct proximity of the tubes and then through the “Gas storage panel” that is connected 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 Tables 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*

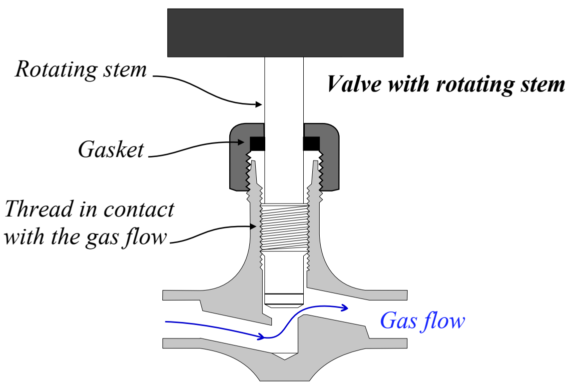
Vent lines stored gasses | *Connecting gas hoses*

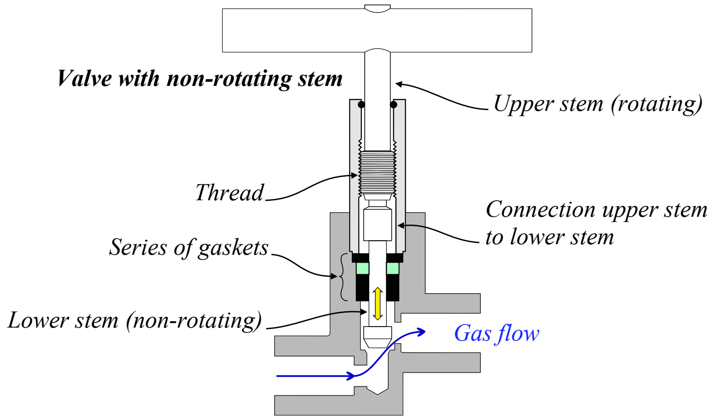
IMCA D 024 says that oxygen lines should be hard piped wherever possible. However, this requirement should apply to the entire pipework of the saturation system.
Heliox is commonly distributed through Stainless steel pipes of ¾ inch (19.05 mm) diameter. However, charging lines and transfer lines are 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)

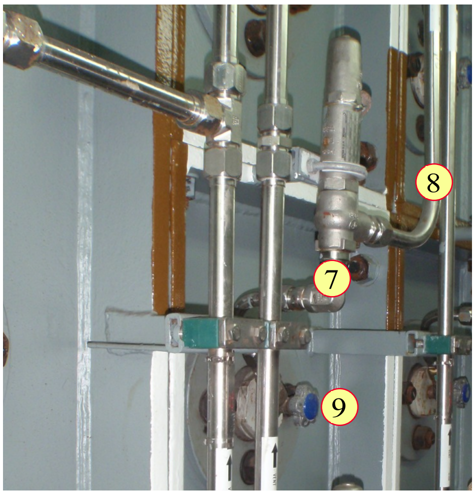
Needle valves are preferred to quarter-turn valves in the panels used for gas transfer and distribution, because they can be opened slowly, which avoids pneumatic impact and adiabatic compression.
For these reasons, and depending on the standard used, such valves are mandatory for pure oxygen and mixes 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")

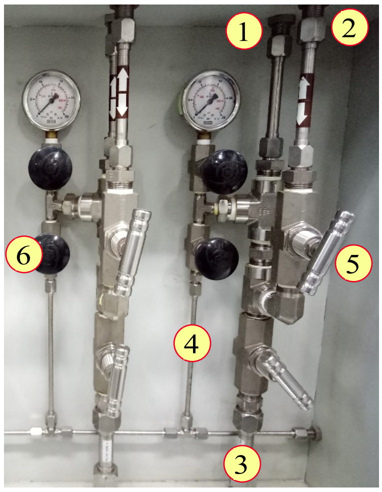
5 - Needle valves inlet & outlet

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:

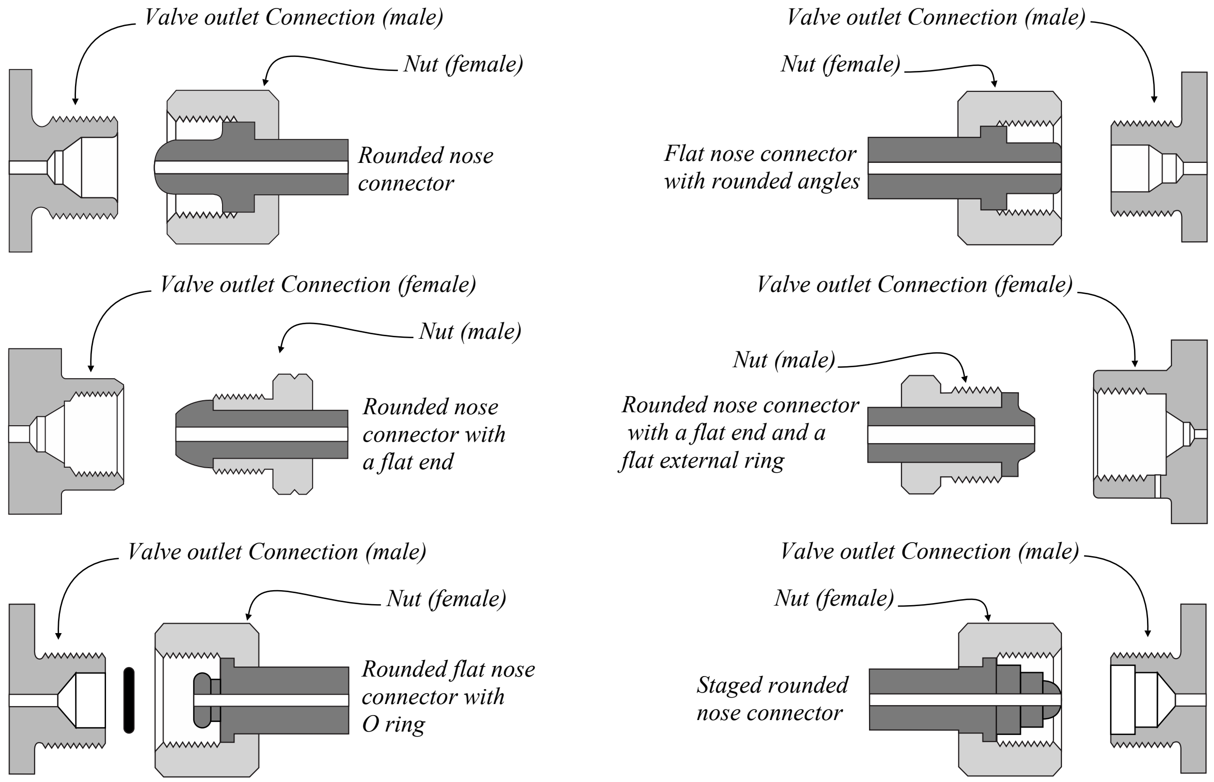
- ISO 15245-1 "*Parallel threads for connection of valves to gas cylinders*",
- ISO 11363 -1 *"17E and 25E taper threads for connection of valves to gas cylinders"*.

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 to 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.

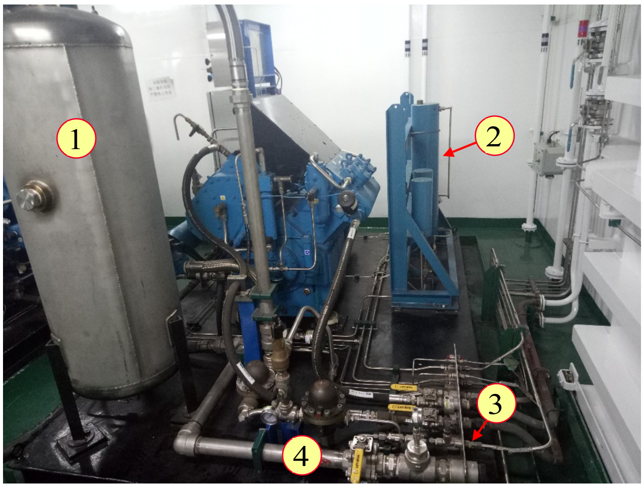


2.3.19.5 - Piston compressors

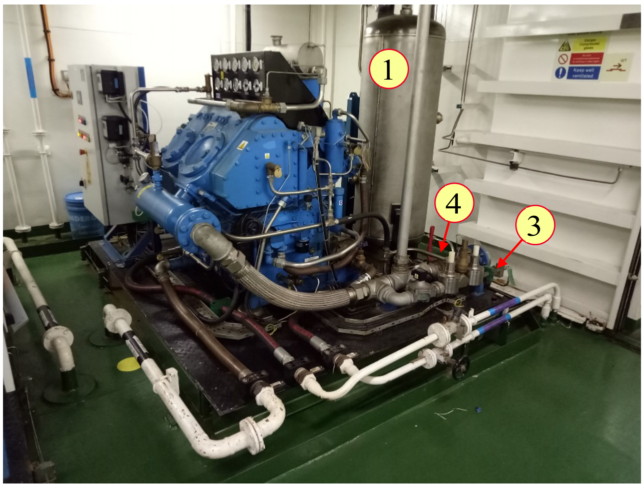
Gasses can be transferred by decantation. However, this procedure that is efficient when the reservoir to fill is empty, cannot be used in case the content of cylinders or tubes to transfer have less pressure than those to top up.
Piston and membrane compressors, also called diaphragm compressors, are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

Piston compressors of the same model of the one used with the gas reclaim system, and described in point 2.3.18.4 are used with the saturation systems taken as references. It is also the case with a lot of last generation installations.
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.

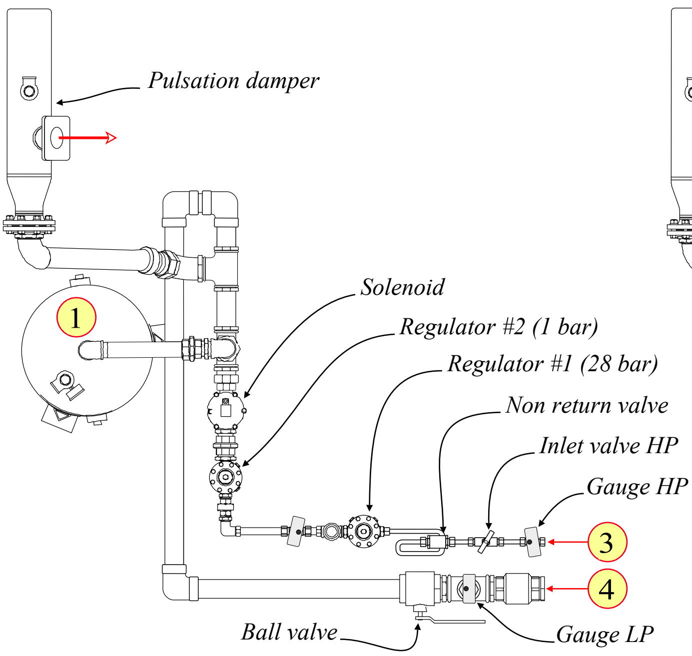


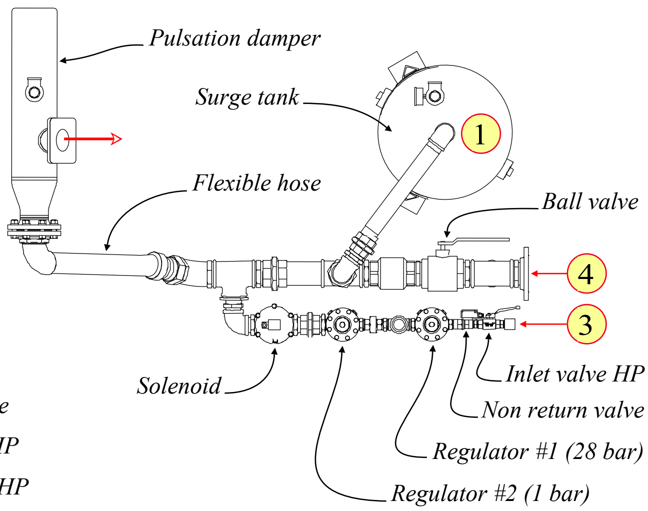
Gas transfer compressor UDS Picasso



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.

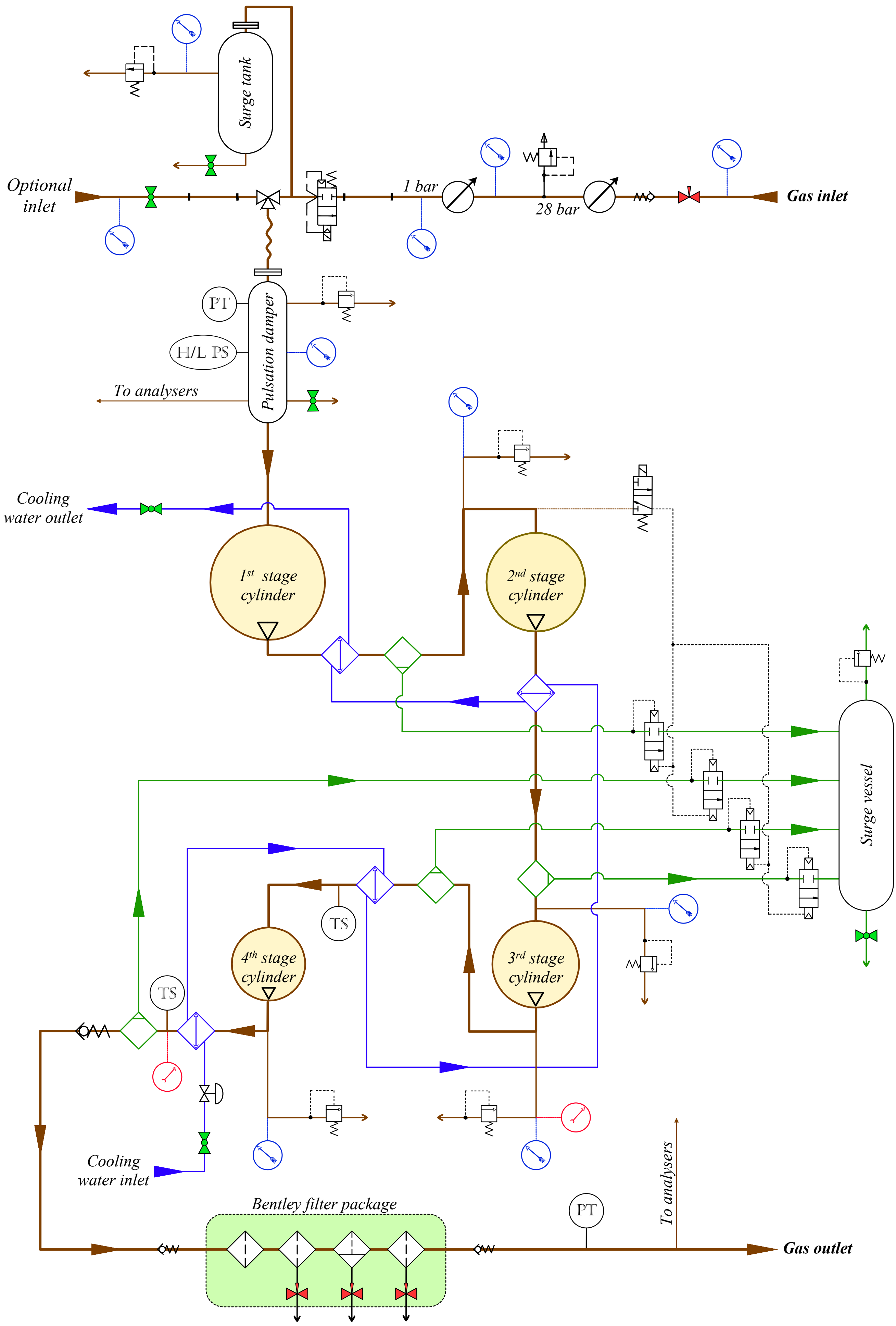


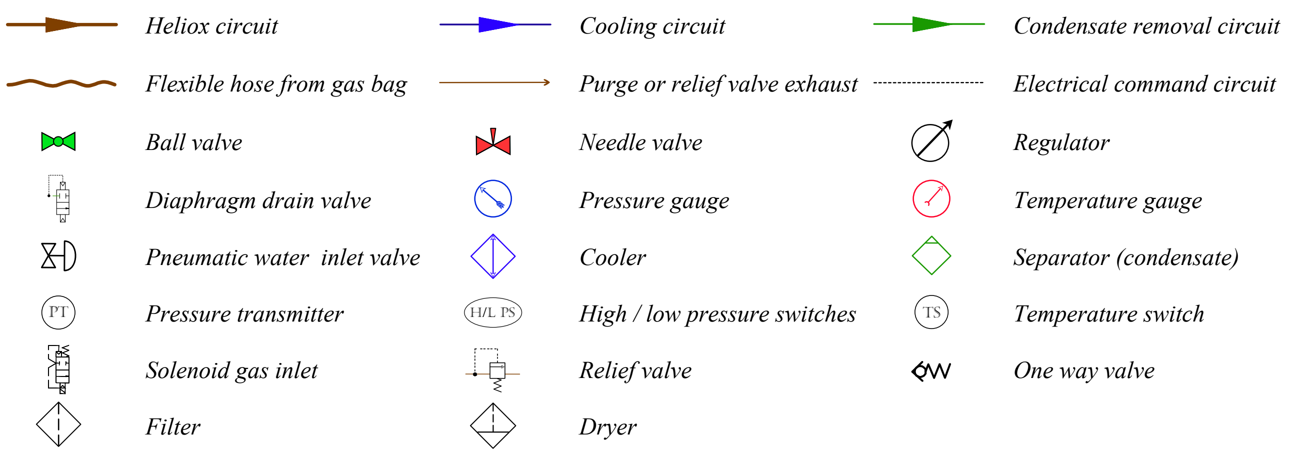


Legends:

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

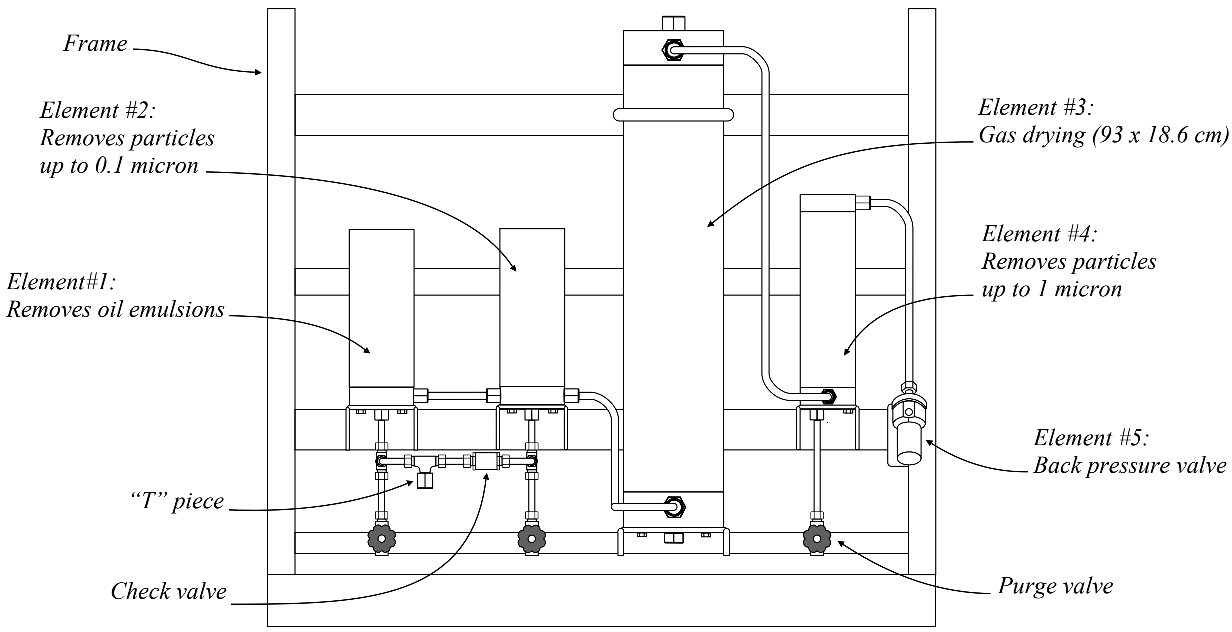
Scheme of the piston compressor described on the previous page. See the legends on the next page.





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.



2.3.19.6 - 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.

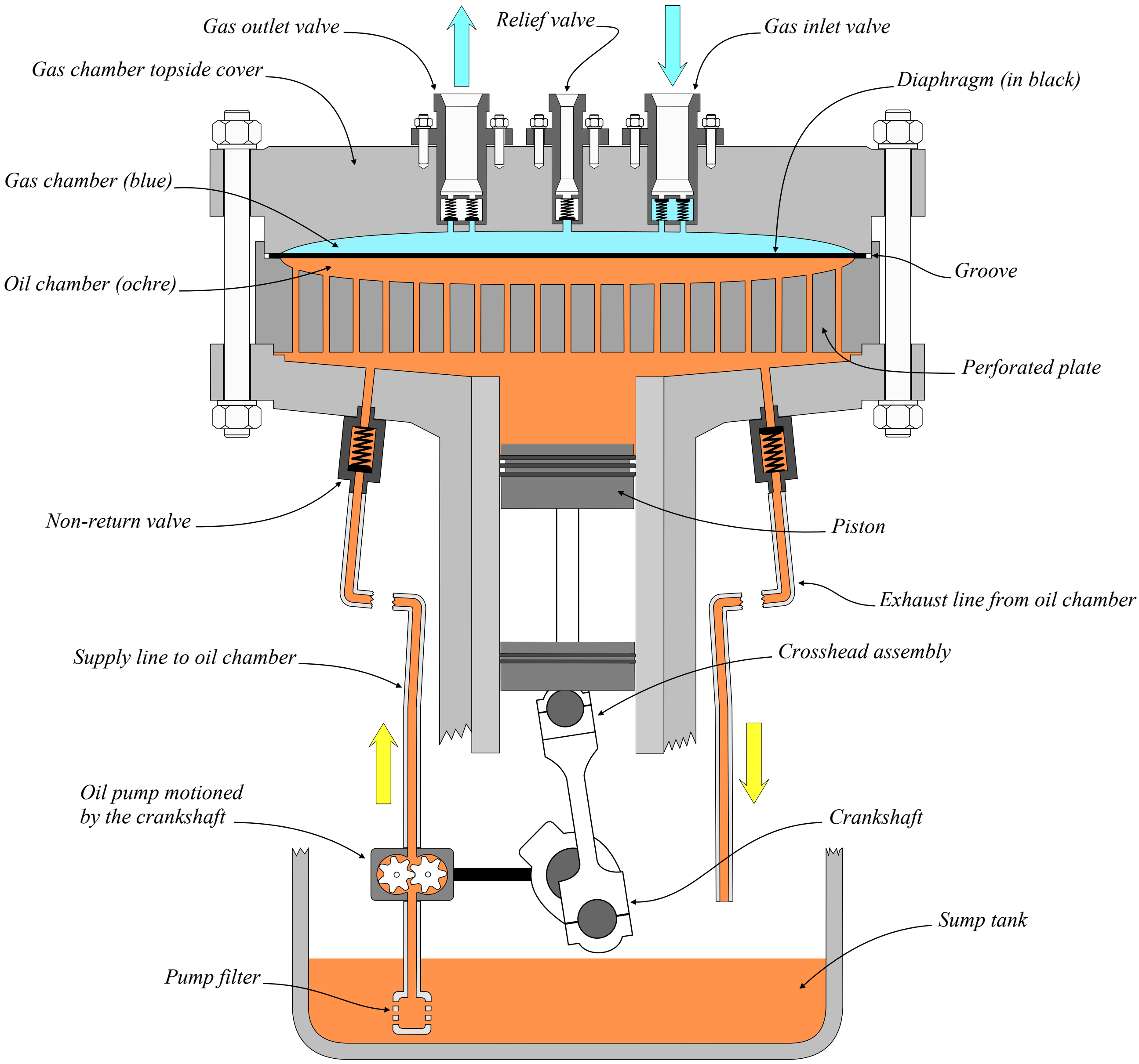
Membrane compressors were used for the gas transfer of all saturation systems in the past, as they were the only machines capable of heliox transfer. However, as a result of technical progress in sealing materials, piston compressors and transfer pumps are today able to transfer such mixes, and a lot 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.

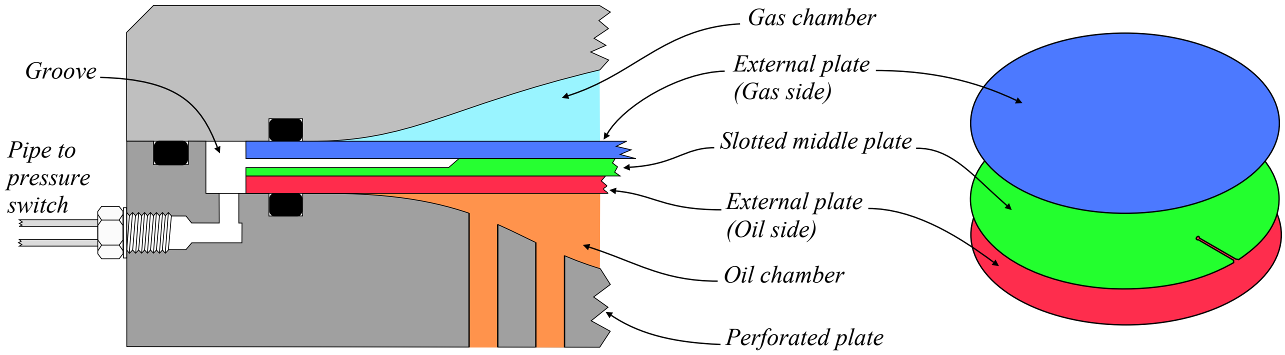


Manufacturers indicate that the life length of the plates that compose the diaphragm is approximately between 3000 and 5000 hours. However, they may fail before this time, which can result in gas contamination or the machine damaged. For this reason, *IMCA requires that a cracked plate detector which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

This detection system is the reason the diaphragm is composed of three superposed plates:

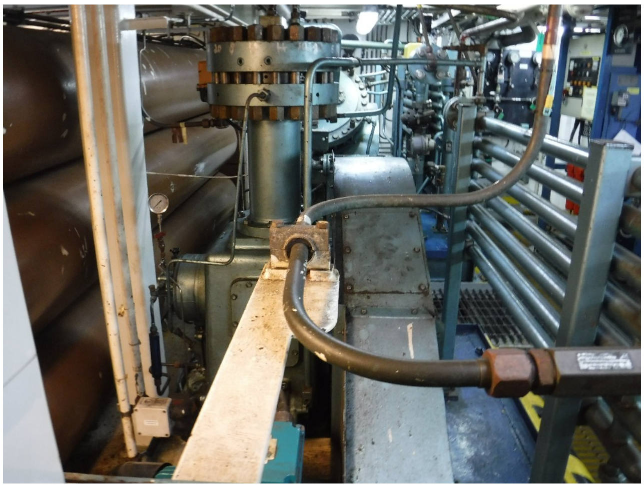
- One external plate is in contact with the gas *(see the blue plate below)*
- The other outer plate is in contact with the oil *(see the red plate below)*
- The middle plate is not in contact with the gas to compress or the oil and is slotted. This slot is positioned to guide any leakage to a groove to which a pressure switch is connected in addition to a pressure gauge and an alarm *(see the green plate below)*.

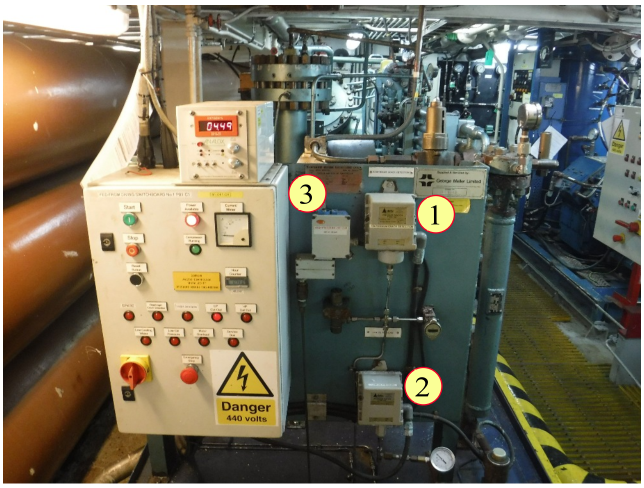
In the case of a diaphragm failure, the gas or oil penetrates the space between the external membranes and pressurizes it. As a result, the pressure switch is activated and shuts the machine down.



Depending on their function (compressor or gas booster), membrane compressors are usually composed of 1 to 3 stages that can be organized, vertically, horizontally, or in V. They are usually water cooled through exchangers similar to those used with the piston compressors.
In addition to the cracked plate detector and the relief valve, they are usually equipped with:

- Inlet and inter-stage gas pressure and temperature gauges and switches
- Delivery gas pressure and temperature gauge and switch
- Low cooling water and low oil pressure switches
- Gas analyser, and undesirable gasses switches





Electrical cabinet and safety switches and alarms of the gas booster above (one stage). Note the cracked plate detector(#1), oil pressure detector (#2), high pressure switch (#3). An emergency shut down switch is also provided.

Compressor two stages arranged in "V"

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

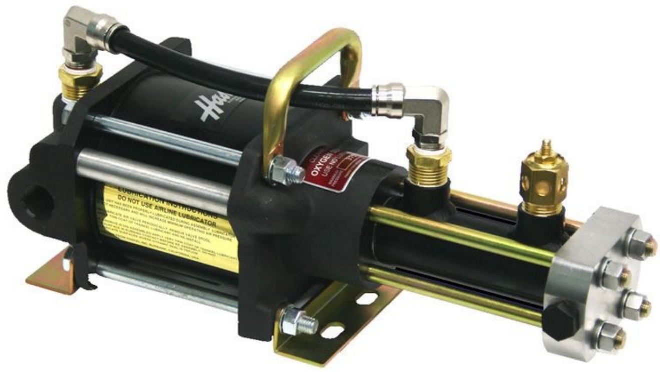
- Their gas chambers are fully sealed towards the outside, so the compressed gas is protected from contamination.
- Linked to above, there are no oil particles in the gas delivered, so the reinforced filtration of piston compressors is not necessary.
- These machines have a reputation of high yield: 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.

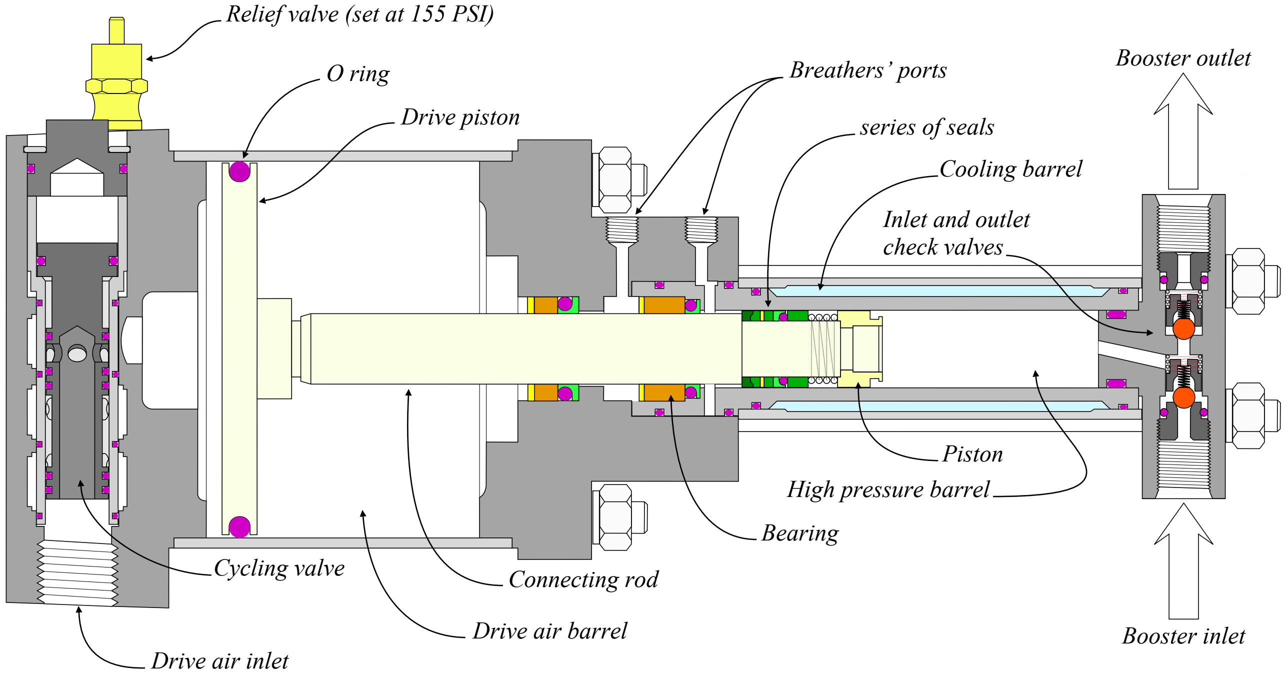
2.3.19.7 - Transfer pumps

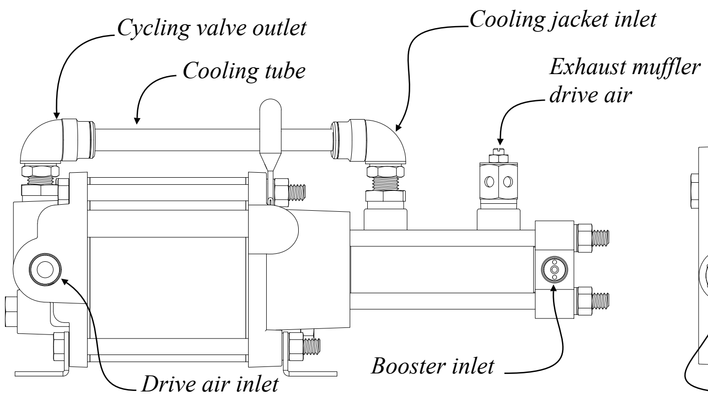
Transfer pumps are machines used in replacement or as a complement of membrane compressors for transferring pure oxygen and therapeutic gasses with an oxygen percentage above 21%.

"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.

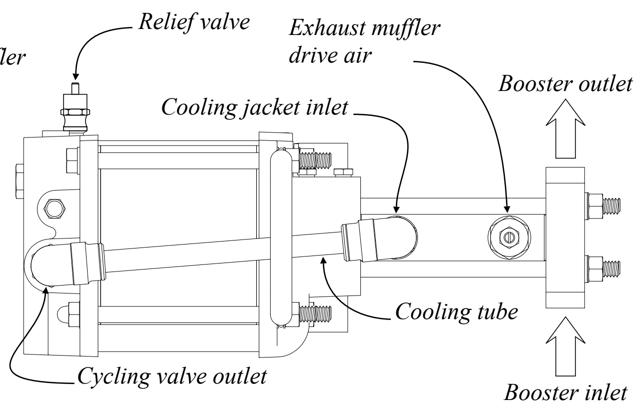


The operating principle of these machines that are powered by compressed air is that a large piston, which is driven by the air provided from a compressor, moves a smaller piston, that is in a separate cylinder, to compress the gas to transfer to the reception gas container.
The small piston that compresses 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.



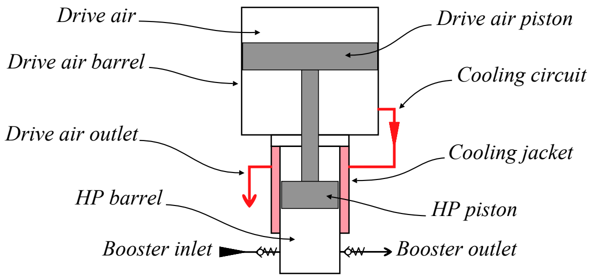


Side view

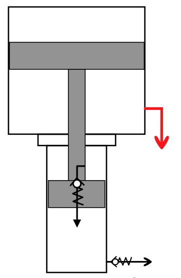


Plan view

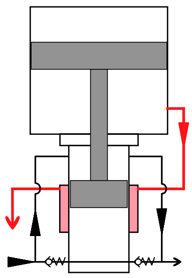
Haskel propose a wide range of machines which various configurations are summarized in the schemes below. Note that the models used in the diving industry are usually limited to 300 - 350 bar.
Also, more than one booster of the same ratio can be linked together to create a multi-stage gas booster, allowing 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.



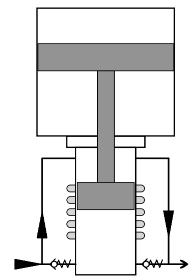
Single stage & single acting with cooling jacket



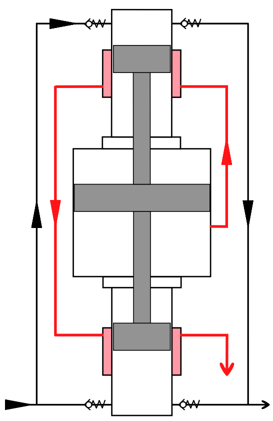
Single stage & single acting Flow through the piston



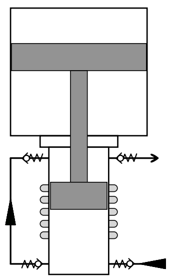
Single stage, double acting with cooling Jacket



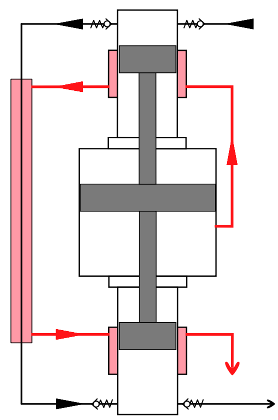
Single stage, double acting with cooling fins



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/m^3
2	≤ 400,000	≤ 6,000	≤ 100	≤ - 40 °C	0.1 mg/m^3
3	–	≤ 90,000	≤ 1000	≤ - 20 °C	1 mg/m^3
4	–	–	≤ 10,000	≤ +3°C	5 mg/m^3

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:

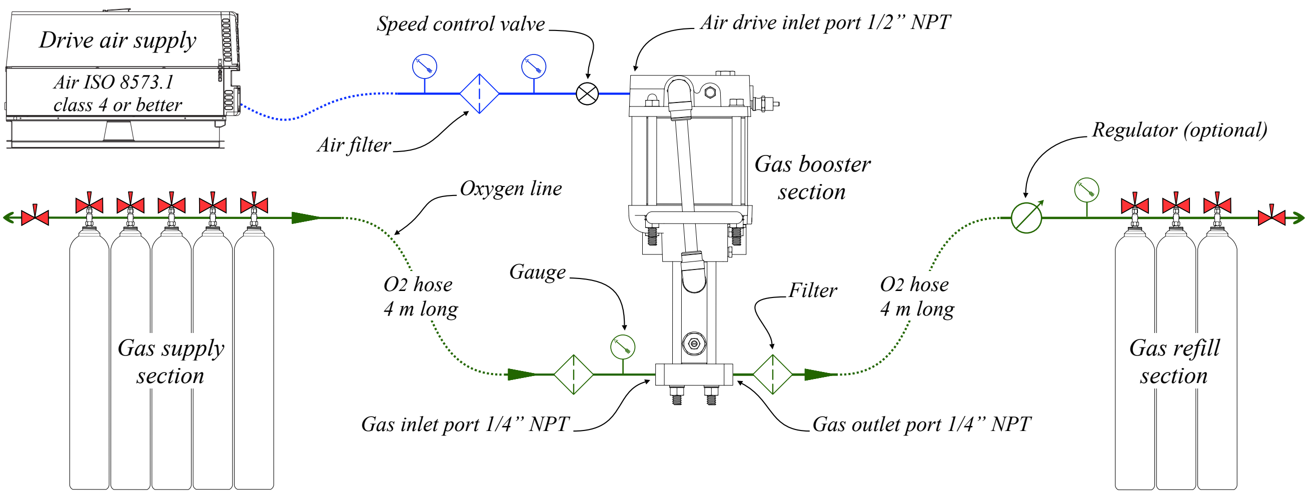
- The operator should ensure that a maximum of water and oil vapour condenses and can be efficiently removed. For this reason, the filters should be installed downstream of coolers and air receivers, and at the point where the temperature of the installation is the lowest. Such an arrangement also reduces 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)*

2.3.19.8 - 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 2.3.19.4. The compressors commonly used are piston compressors that are smaller than the model used for heliox transfer discussed in point 2.3.19.5.

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.

2.3.19.9 - 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.

2.3.19.10 - 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	6 months			
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			

The planned maintenance of piston compressors is as already explained in point 2.3.18.8.
Note that the maintenance of membrane compressors is similar, 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% O2

- 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 *(note that methods using solvents are not listed for safety reasons)*:
    - 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.
    - However, 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.
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 method to select cleaning agents is to select products that are indicated suitable by recognized diving organizations.

2.3.20 - Means for hyperbaric evacuation

2.3.20.1 - 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.

2.3.20.2 - 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".

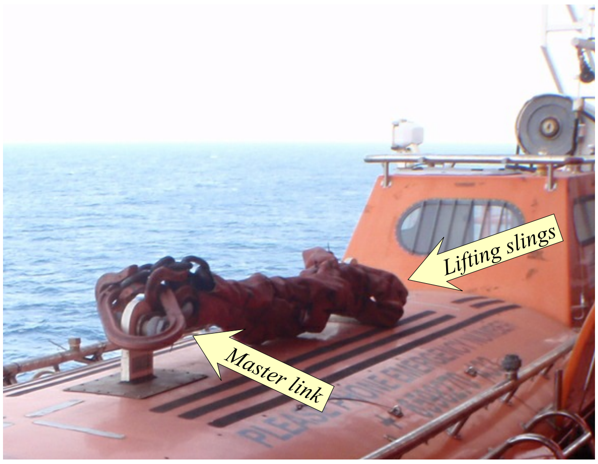
IMO says: The design and construction of the hyperbaric evacuation system should be such that it is suitable for the environmental conditions envisaged, taking into account the horizontal or vertical dynamic snatch load that may be imposed on the system and its lifting points, particularly during evacuation 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.

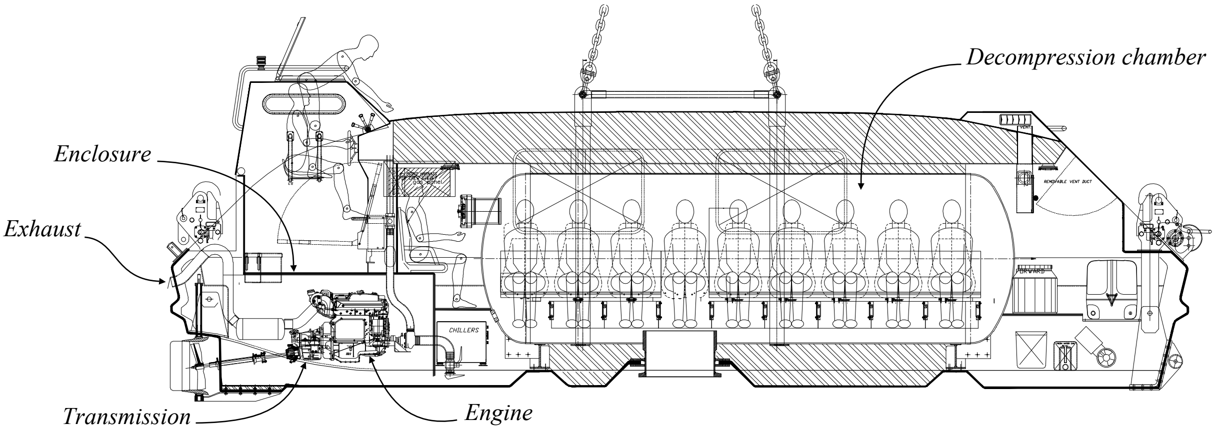
Towing point



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.

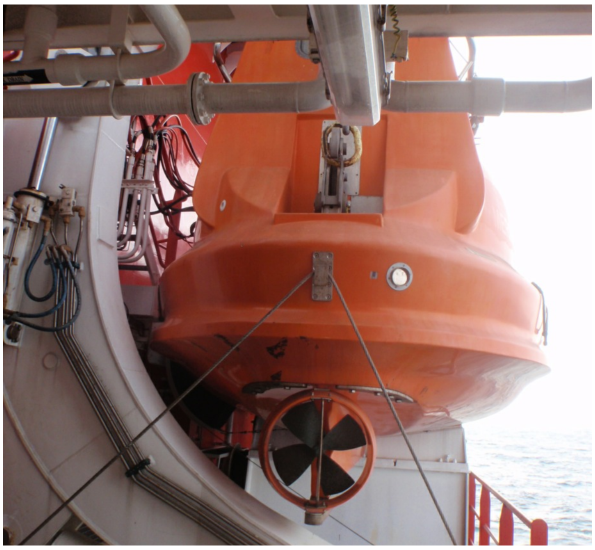
The engine and transmission must be controlled from the helmsman's position. Note that the propeller shafting must be designed so it can be disengaged from the engine.
The engine must be capable of running in any position during capsizing and continue to run after the lifeboat returns to the upright 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.



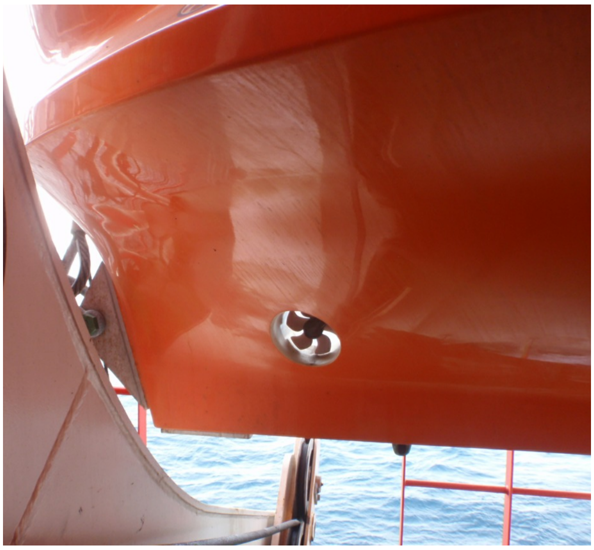
- The electrical systems must be designed to minimize the risk of electrical capacity depletion, fire or explosion, electric shock, the emission of toxic gases, and galvanic action.

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.



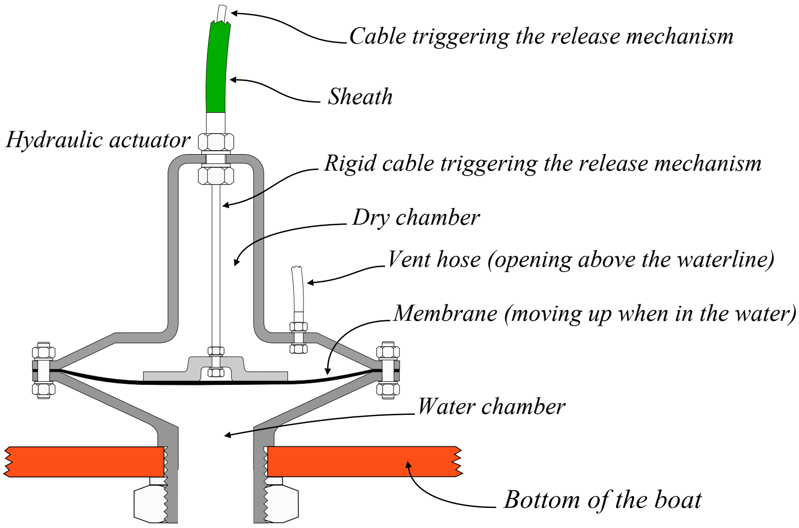
Propeller and rudder



Bow thruster

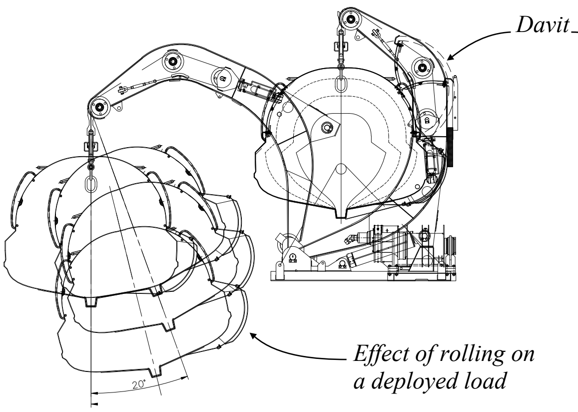
- Self Propelled Hyperbaric Lifeboats are launched using two davits. For this reason, they must be fitted with a mechanism that is designed so that the two cables used to deploy them are released simultaneously.
  IMO says that there should be a normal release capability that will release the lifeboat 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)*.

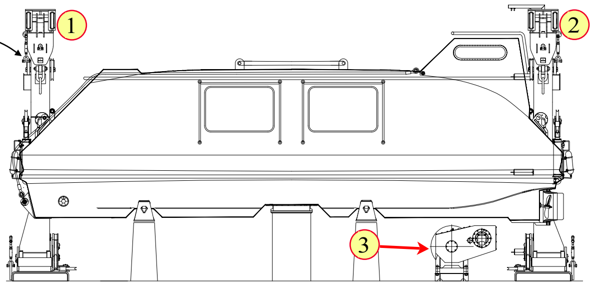
Release system bow (external)



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.

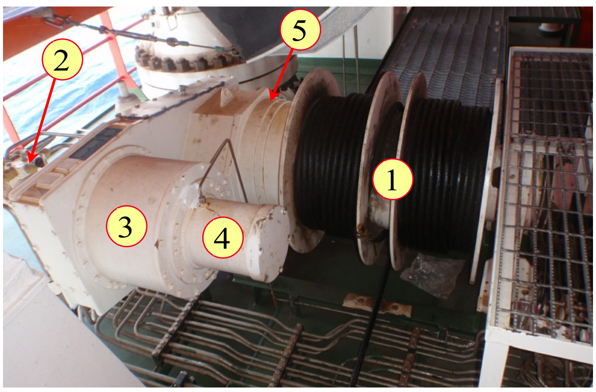


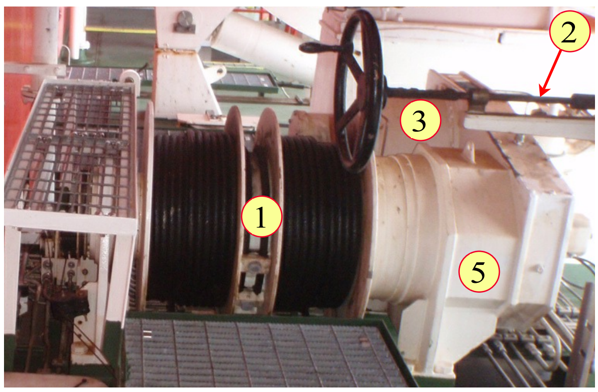


The descent speed of the cables from davits#1 & #2 must be the same, The solution commonly used is to use only one winch (see #3) with a single two-section drum.

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.

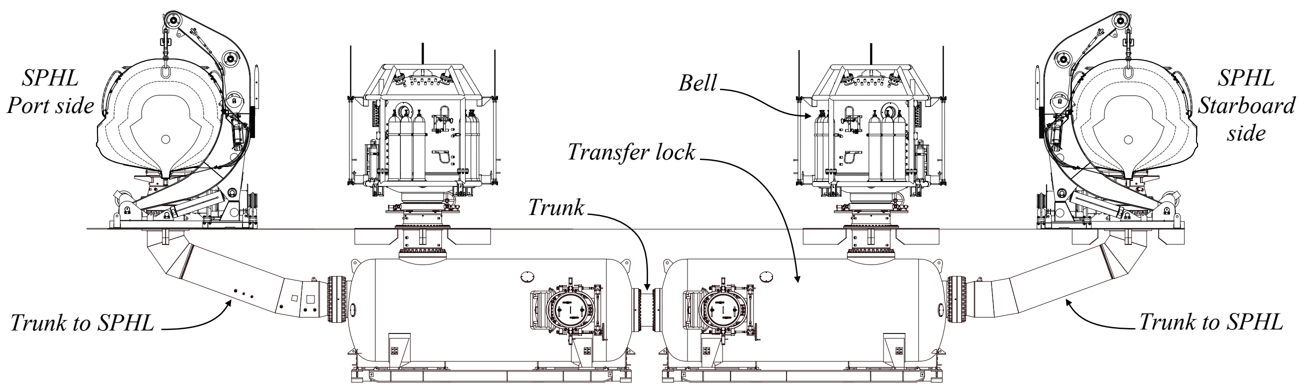
  Also, the name of the ship and port of registry of the ship to which the lifeboat belongs must be marked on each side of the lifeboat's bow in block capitals of the roman alphabet with the number of persons for which the lifeboat is approved. In addition the weight in air of the unit and the safe lifting 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.

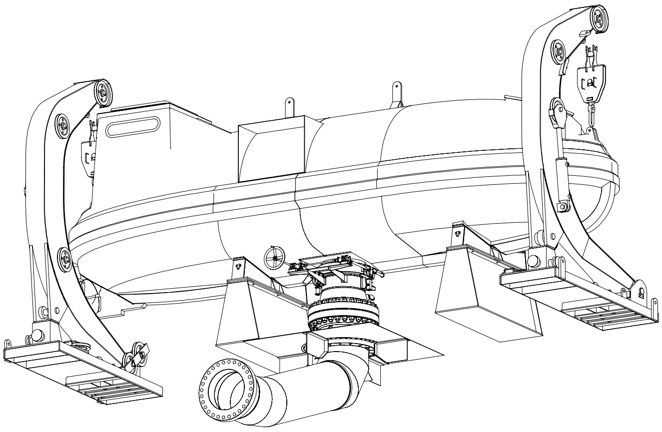
- Fastening points should be provided on the hyperbaric evacuation unit to secure it to the deck of a rescue vessel. Note that relevant cradles should be installed on the rescue vessel and supplied with suitable attachment points.
- Regarding the recovery of the Hyperbaric Rescue unit, IMCA D 051 says 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.

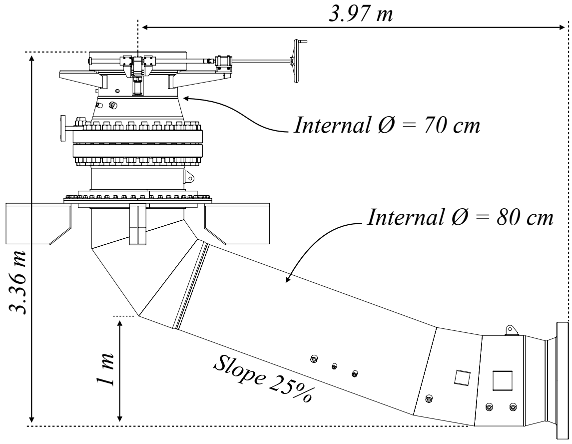
2.3.20.3 - Self Propelled Hyperbaric Lifeboat: Transfer trunk

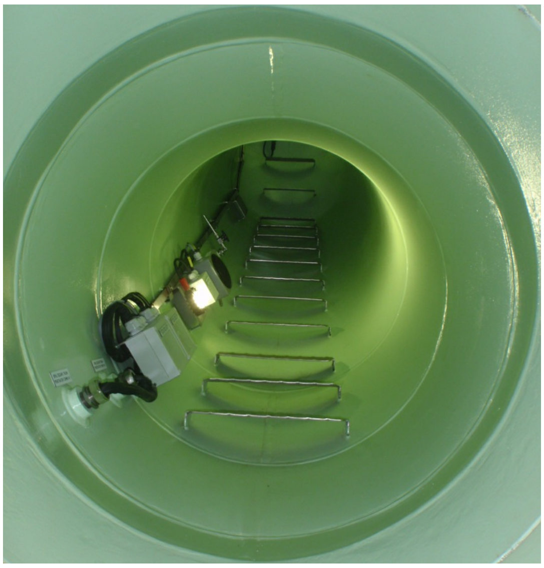
The chamber of the Self Propelled Hyperbaric Lifeboat (SPHL) is connected to the diving system by a disconnectable trunk that is situated at the bottom of the unit and is similar to the model used to connect the bell. The divers access to this connecting trunk through the transfer lock. Note that a lot 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)

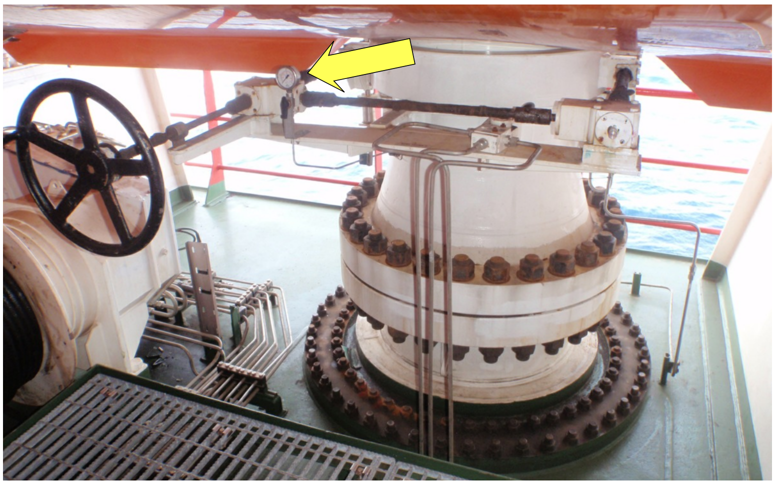
Arrival inside the chamber of the SPHL

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.



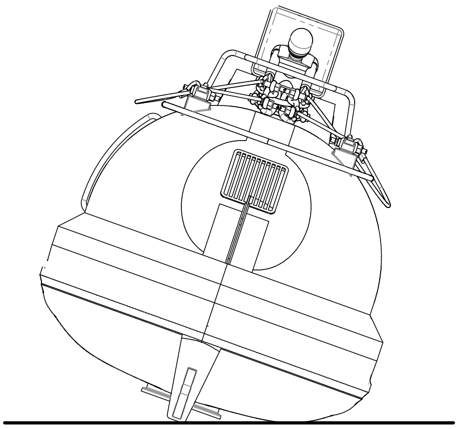
SPHL clamp arrangement with pressure gauge

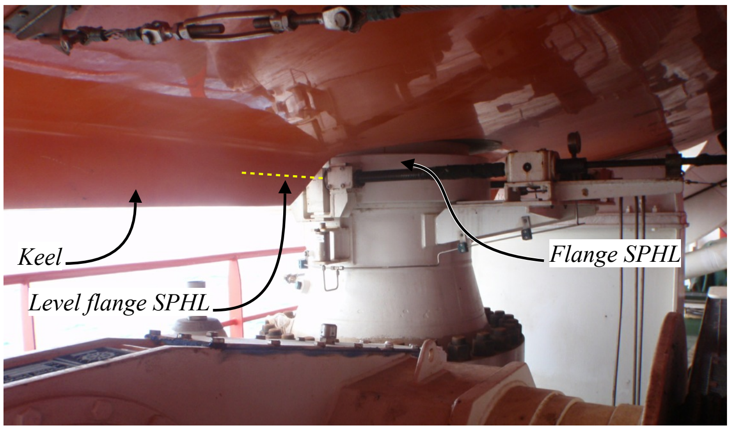
Autoclave door of the SPHL

- 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 2.3.15.2 *"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:

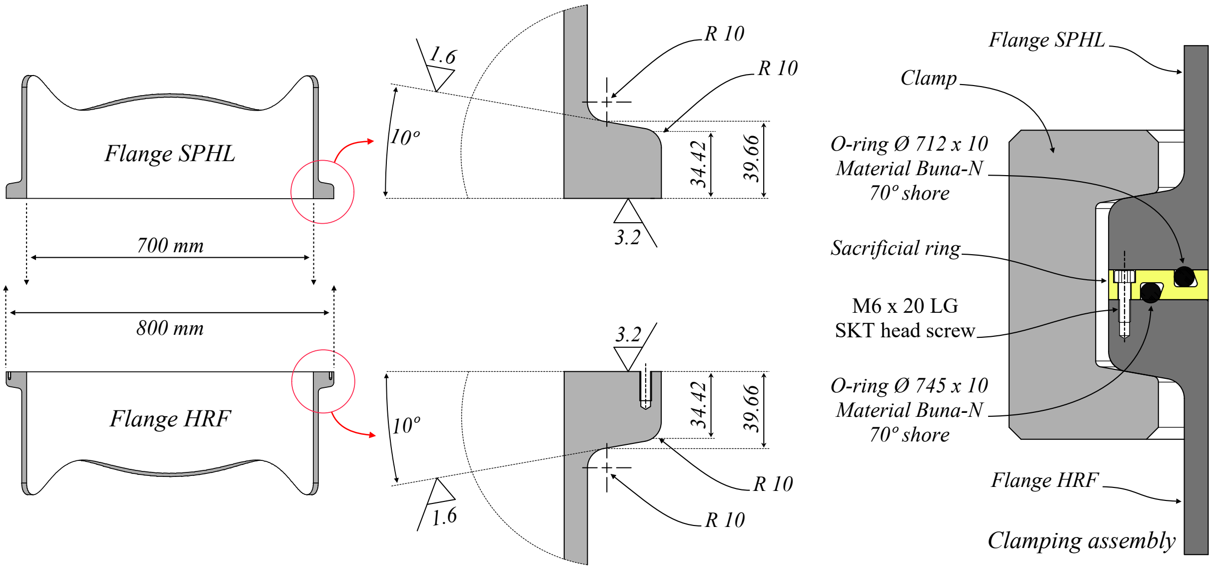
- The Hyperbaric Rescue Unit flange should be protected within the hull of the craft and should not require additional protection. Thus, should the boat be unloaded where cradles, blocks, or sandbags are not available, the flange should remain within the protective envelope provided by the keel and the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



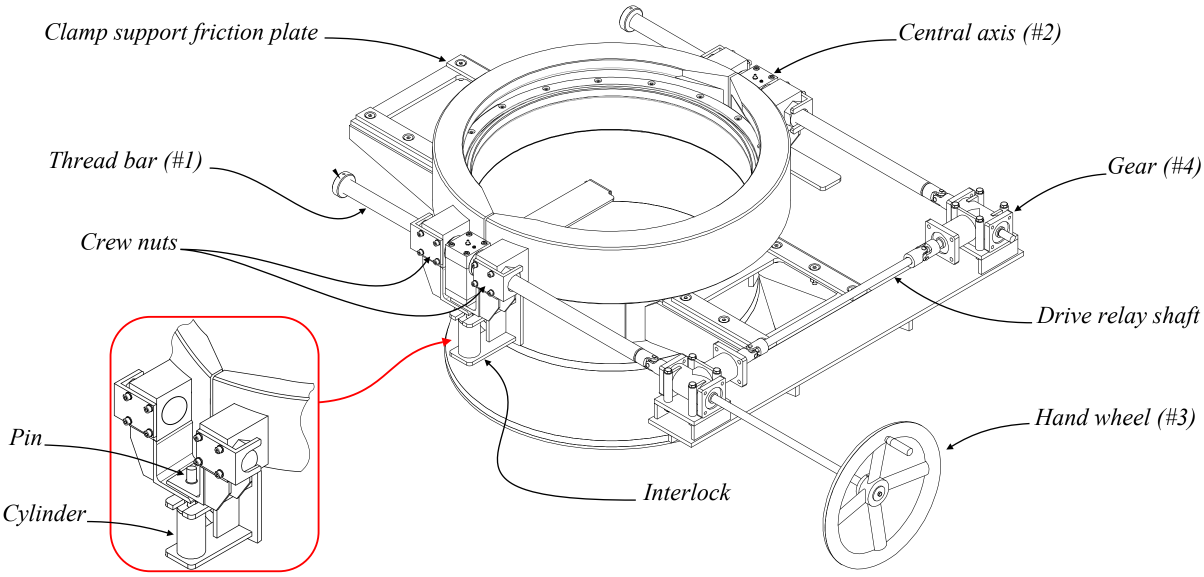


- Regarding the compatibility of flanges, IMCA has published several drawings of an ideal flange that members of the association are invited to adopt *(see next page)*. The idea is to have only one flange profile in the future, and thus avoid mating problems. For this reason, IMCA says that the hyperbaric 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.

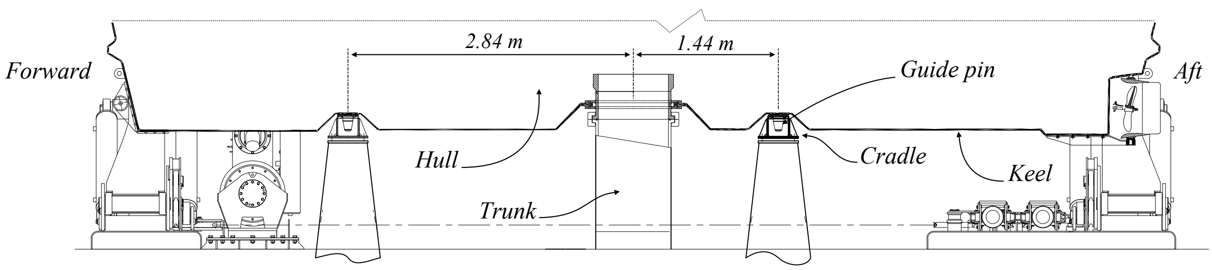


The mechanism of the trunk consists of two half-clamps, with internal profiles in angle with the taper indicated above, that are approached around the flanges by two thread bars (see #1 below) secured on their middle at the central axis of the flanges (see #2) and designed with threads of the opposite 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.



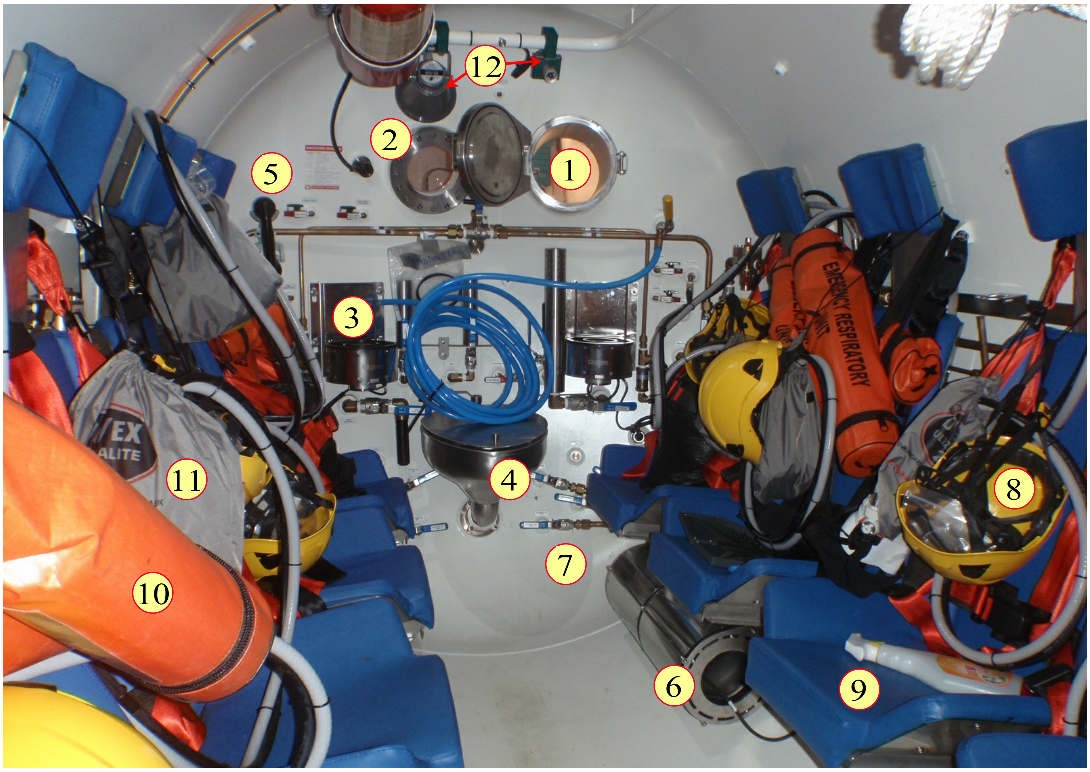
- Means of controls that are not necessary in short trunks must be in place in long or convoluted units such are those that are used with built-in systems.
  - IMCA says that means of communication between divers in the trunk and life support control should be provided: This intercom can be seen on the 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.

2.3.20.4 - 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.

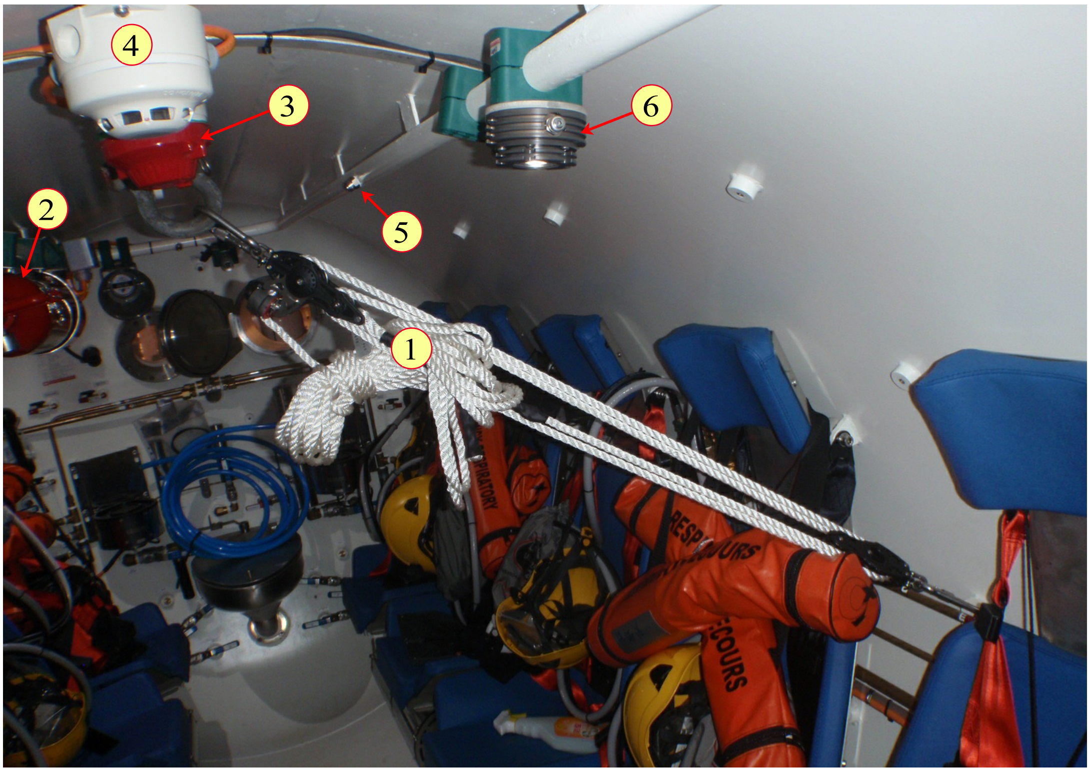
- The following points are to be taken into account:
  - Manufacturers usually provide chambers for 12, 15, 18, or 24 divers.
  - IMCA says that the chamber must be certified if it has been built after the 1st of July 2014.
  - IMCA says that hyperbaric evacuation chambers manufactured after 1 January 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 2.3.15.2.
  Fixed fire fighting systems similar to those described in point 2.3.15.2 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
2 - Hyperbaric extinguisher
3 - Heat detector
4 - Smoke detector
5 - Sprinkler (fixed fire fighting system)
6 - Low Emitting diodes (LED) light

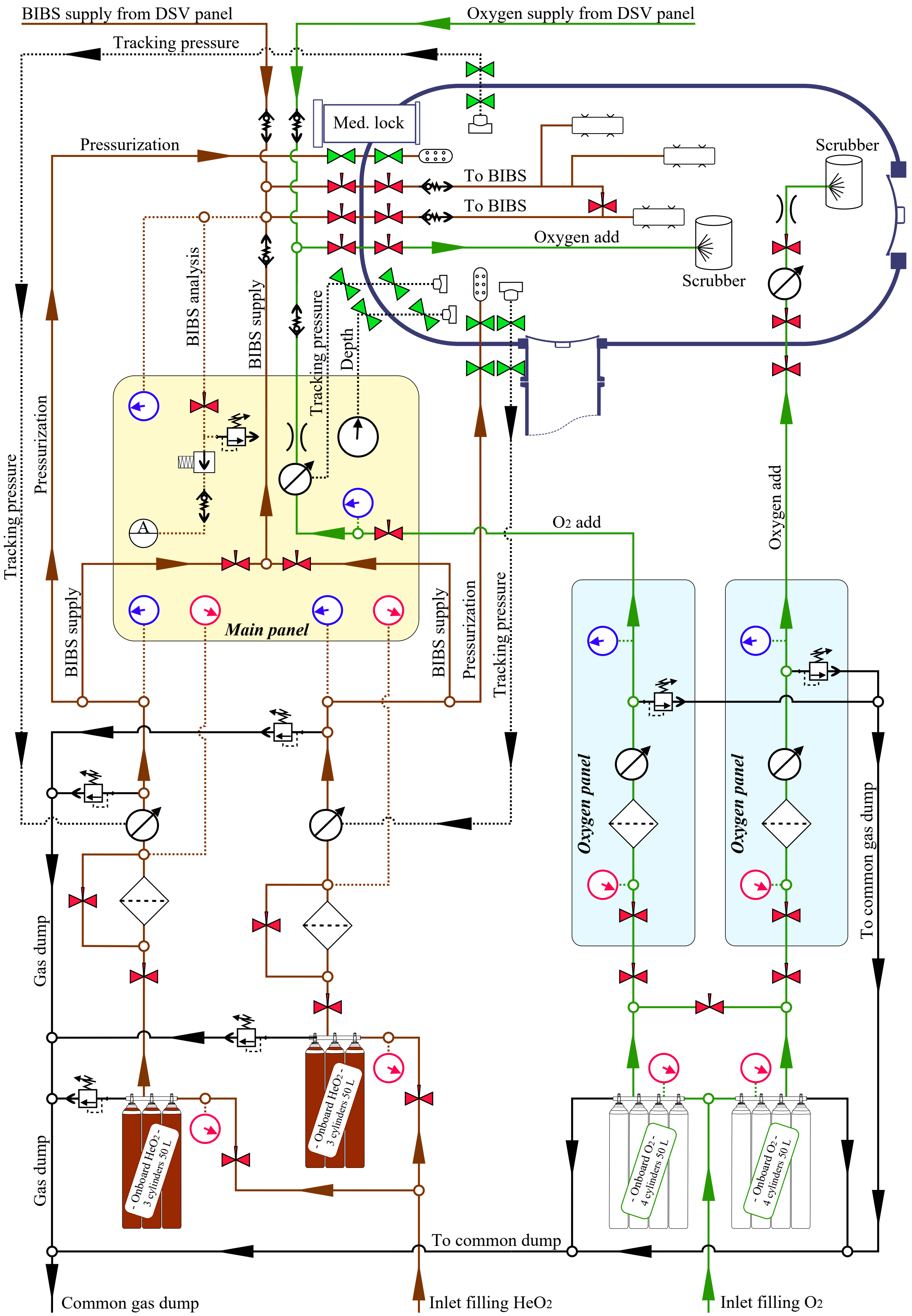
- In addition to the kit DMAC 15, sea sickness tablets, vomit bags, paper towels, waste disposal bags and all necessary operational instructions for equipment within the compression chamber should be available within the chamber.

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.

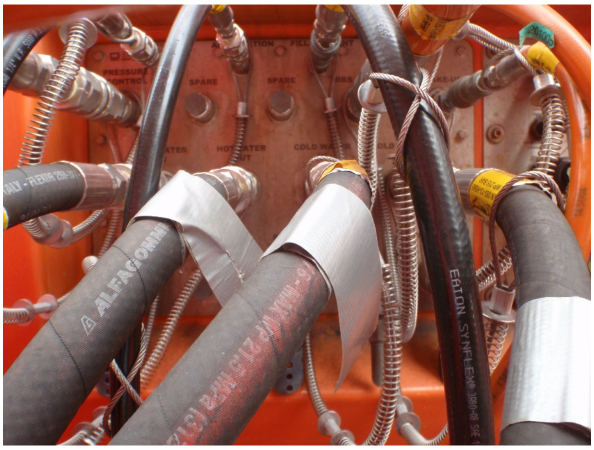


See the legends on the next page

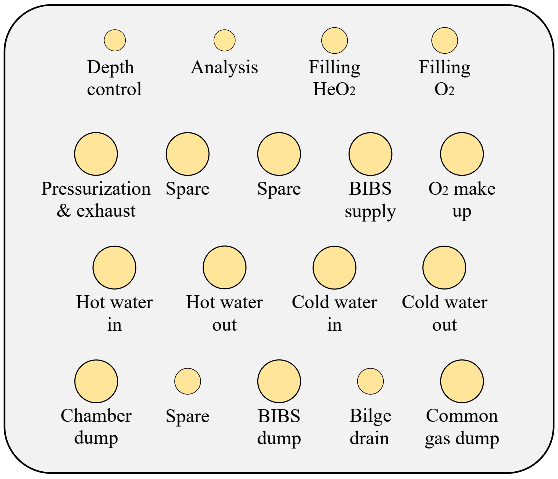
Legends of the schemes on the previous and the next pages

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

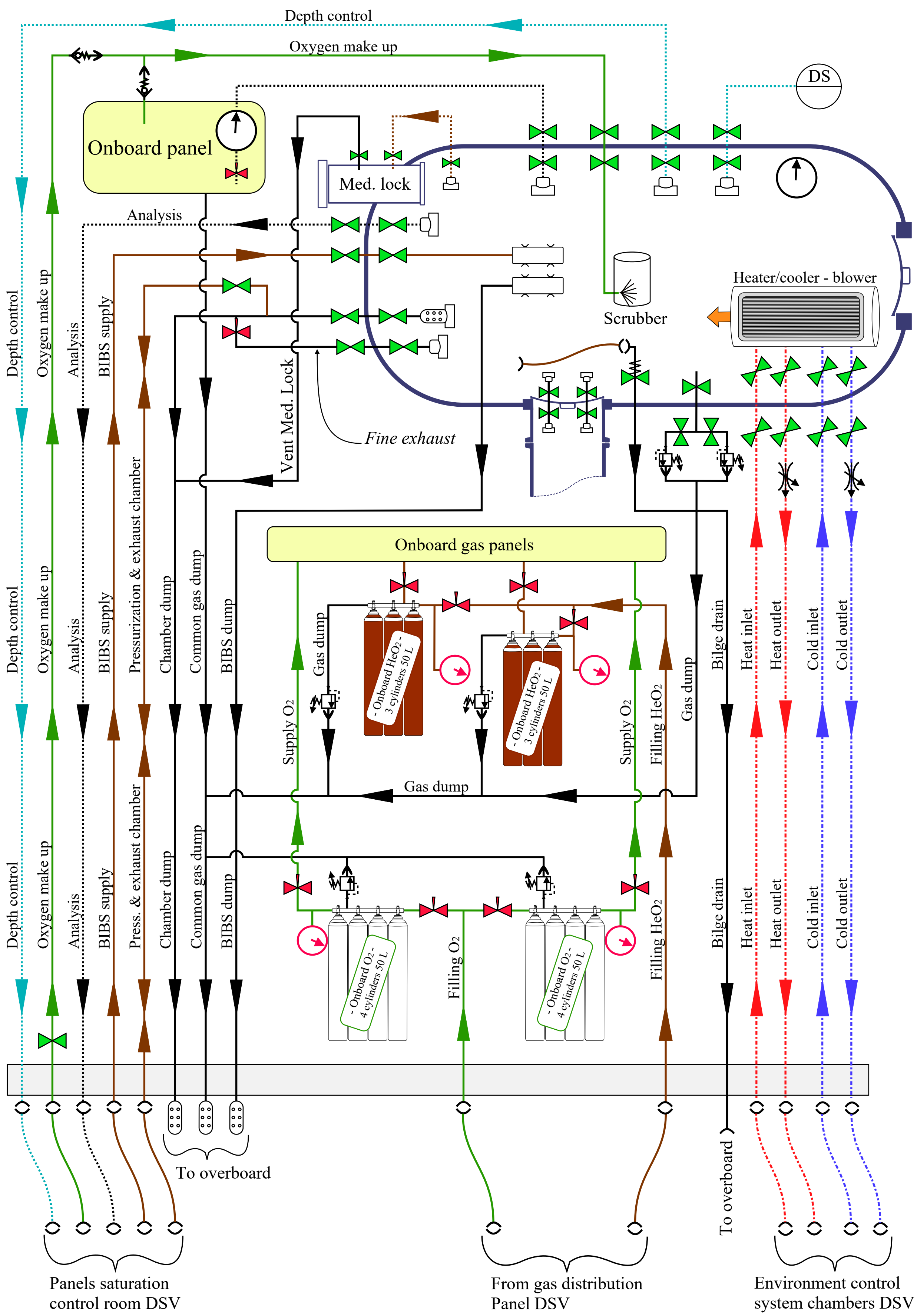


As the Self Propelled Hyperbaric Lifeboat is designed to be quickly launched, the hoses are connected by "snap-tite couplings" (quick connectors.). These connections must be compatible with those of the dedicated Life Support Package (LSP) or the supplies from another LSP. For this reason, NORSOK U100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

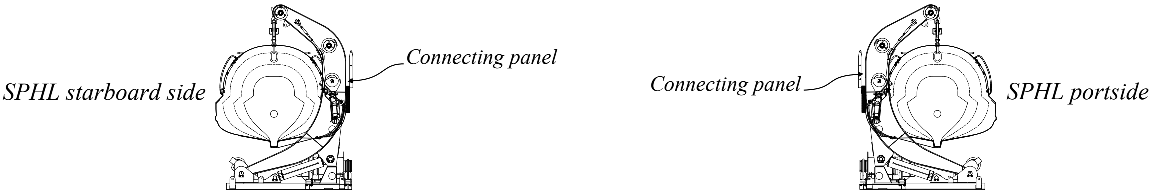
- CONN EO: "Electro Oceanics" - trademark - underwater electrical connector. Also called "Crouse Hinds Underwater Electrical Connectors WATERMATE, EO (alternatively E/O, E-O or E.O.).
- S/BVHN and S/BVHC are "Snap-tite" types couplings.



Notes: Charging panels are used to fill the onboard reserves with oxygen and the relevant heliox mix *(see* *point 2.3.19.4**)*.

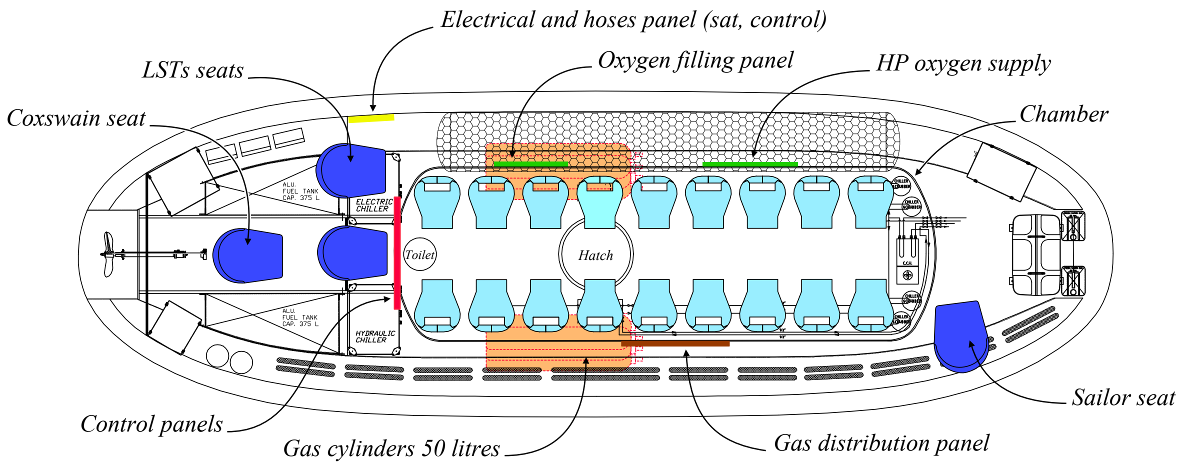
It is recommended install a forced ventilation system to reduce moisture and extreme temperatures into the cockpit area whilst the Self Propelled Hyperbaric Lifeboat is attached to the system *(see IMCA D 051)*.

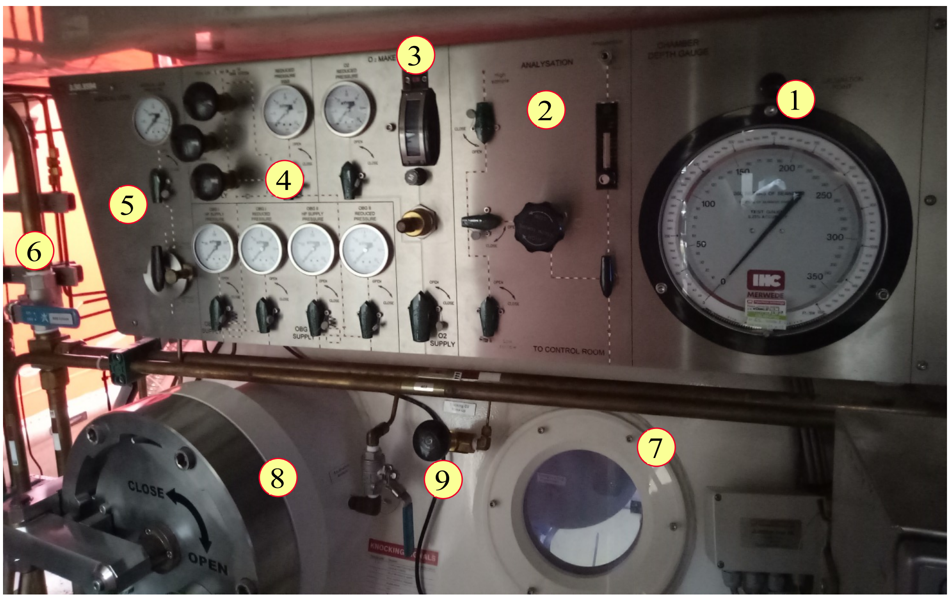
Note that the connecting panel of the Self Propelled Hyperbaric Lifeboat (SPHL) is organized to be deck side of the unit. Thus, a SPHL that is installed on the starboard side of the ship has its connecting panel on its portside and a SPHL installed on the portside of the ship has its connecting panel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

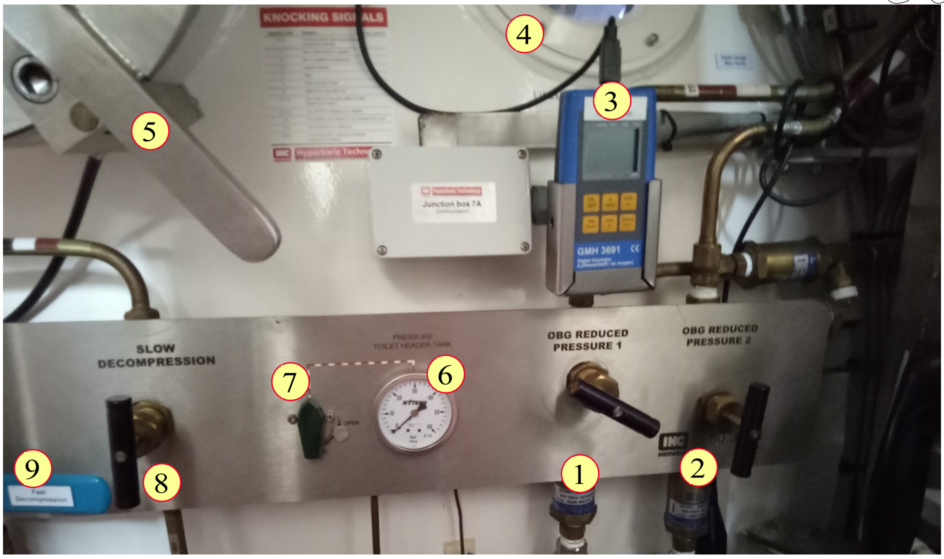
6 - BIBS exhaust

7 - Viewport

8 - Medical lock

9 - Tracking O2

Topside of the chamber control panel.



1 - Primary supply
2 - Secondary supply
3 - O2 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

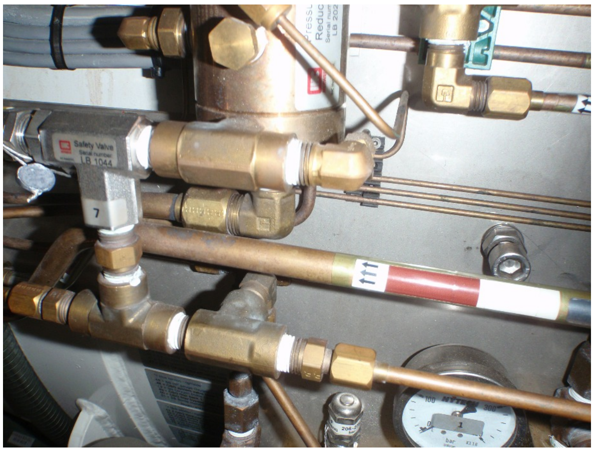
- Control panels must be designed with a minimum controls, and provided with the same protection devices as those provided in the diving and saturation controls.
  - The depth gauge must have a scale appropriate to the duty and operates in the range 25 to 75% of full-scale deflection and operates in 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 O2 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.

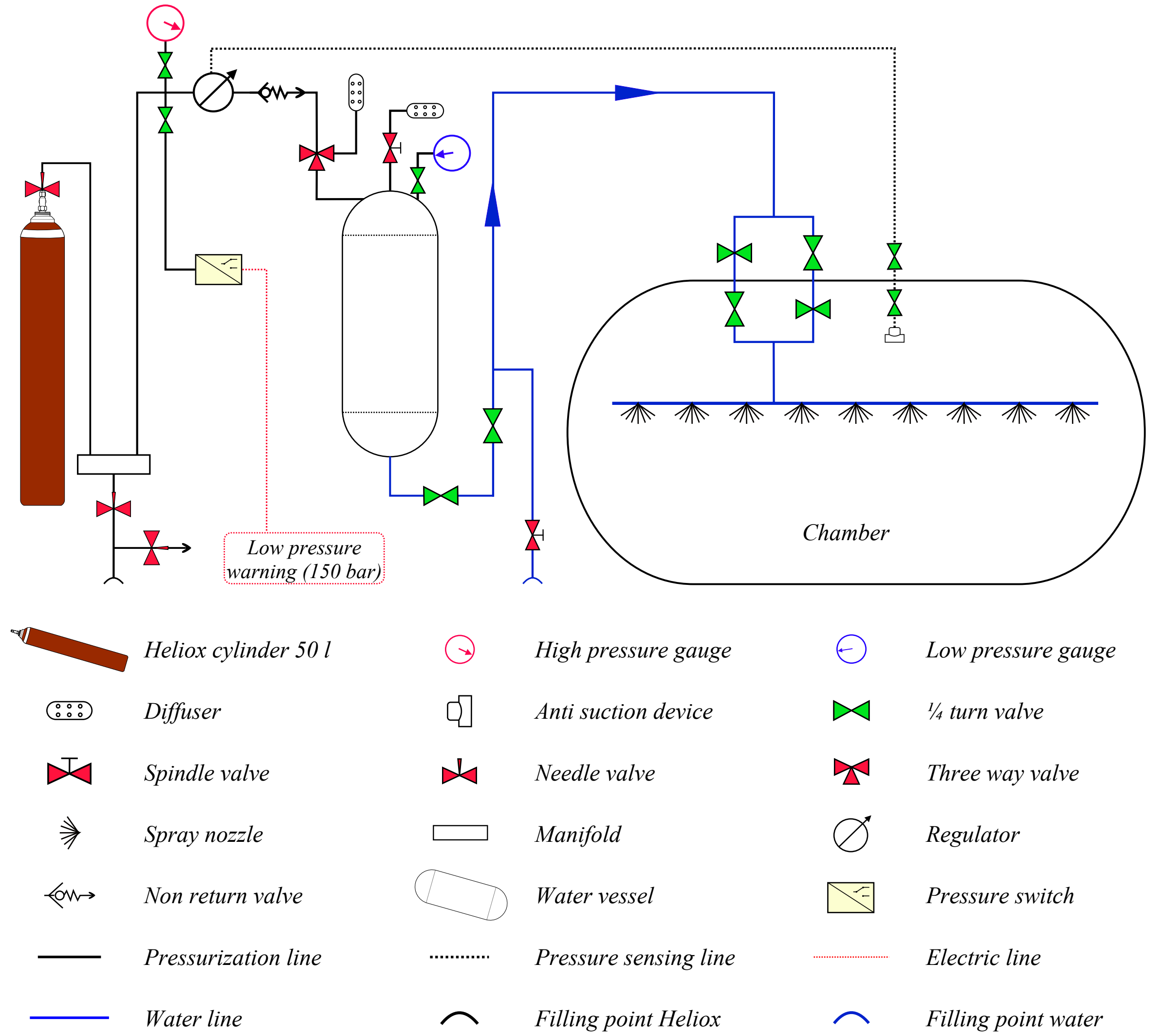
- The necessary level of lighting for the operation of the various panels and the reading of documents is provided through Light Emitting diodes (LED), that offer more light than filament bubbles, on the new units. Also, an emergency lighting system sufficiently powerful to continue the operations must 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 and already described in point 2.3.14.4. 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.



2.3.20.5 - *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

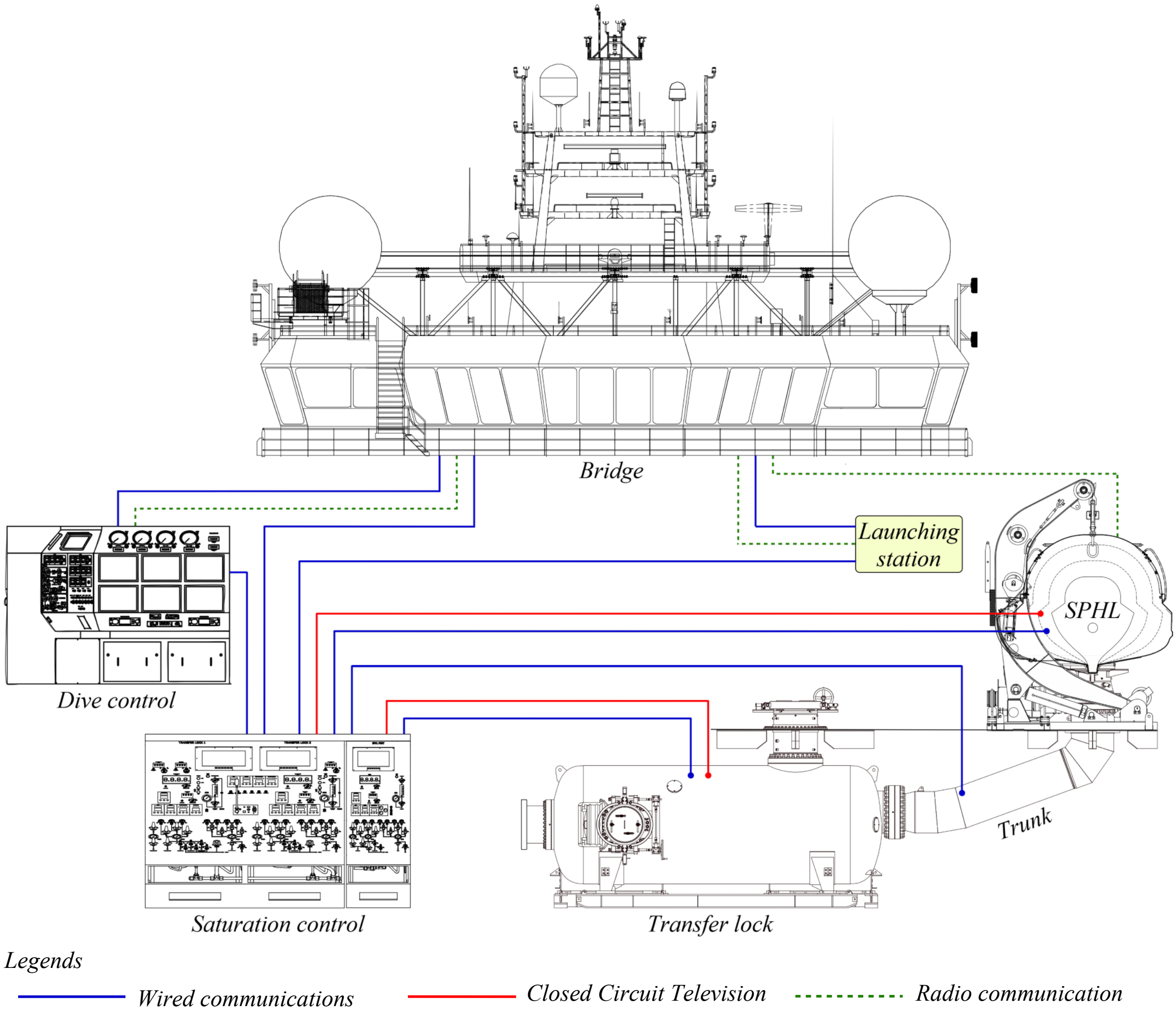
Access to the winch and the clamping system.

2.3.20.6 - 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.



2.3.20.7 - 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.

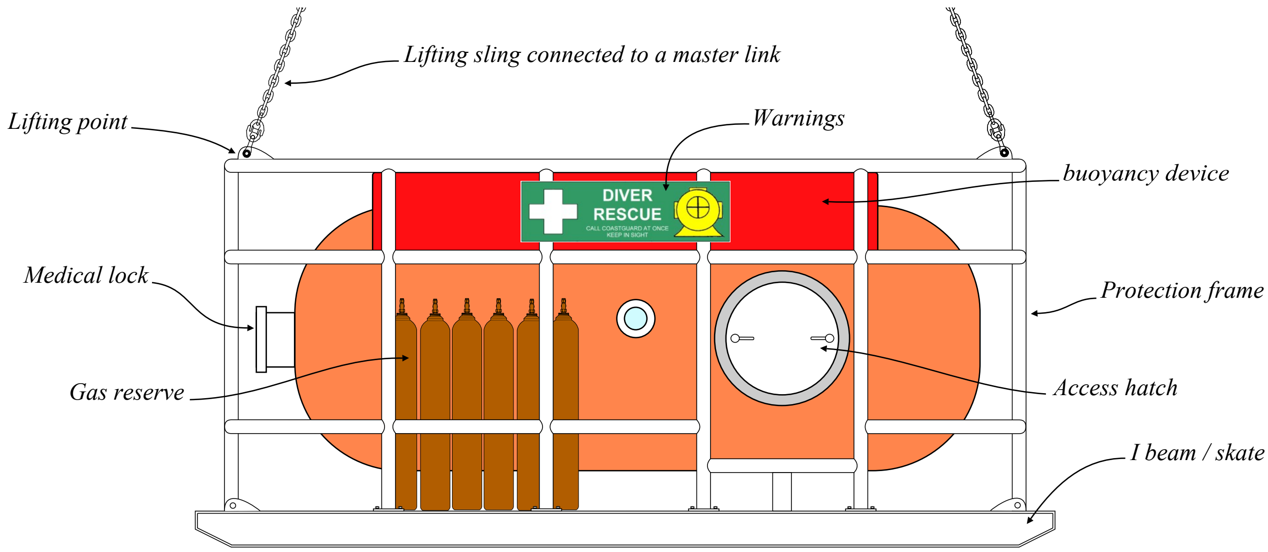
Note that several means of evacuation should be provided in case of operations with diving teams stored at depths that are too far to allow for a reasonable compression time to the deepest storage level to be able to evacuate the divers quickly. As an example, if a team is stored at 100 m and another one at 300 m. 32:20 hours are necessary to compress the divers stored at 100 m to 300 m using the Norman 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.

2.3.20.8 - Hyperbaric Rescue Chamber (HRC): Description

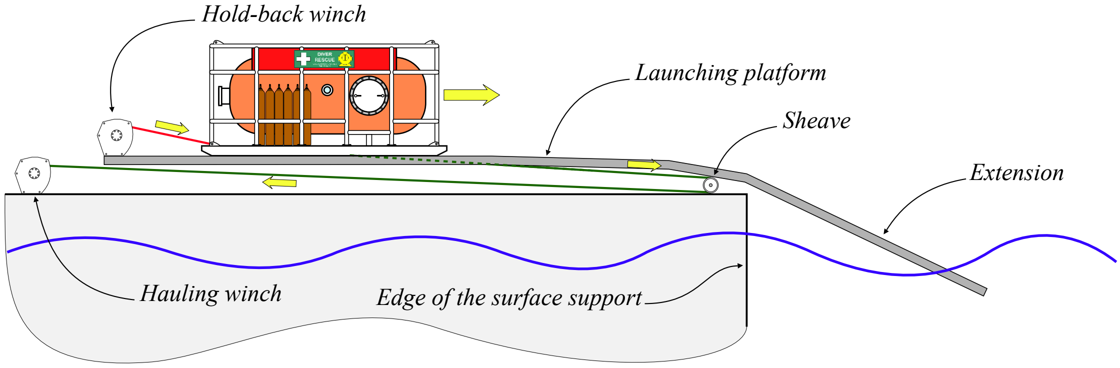
As indicated in point 2.3.20.1, Hyperbaric rescue chambers are floating units usually found with portable systems. Although most manufacturers have ceased to propose them, they have been produced until very recently. For this reason, we can expect to have such evacuation systems for a long time.
The 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.

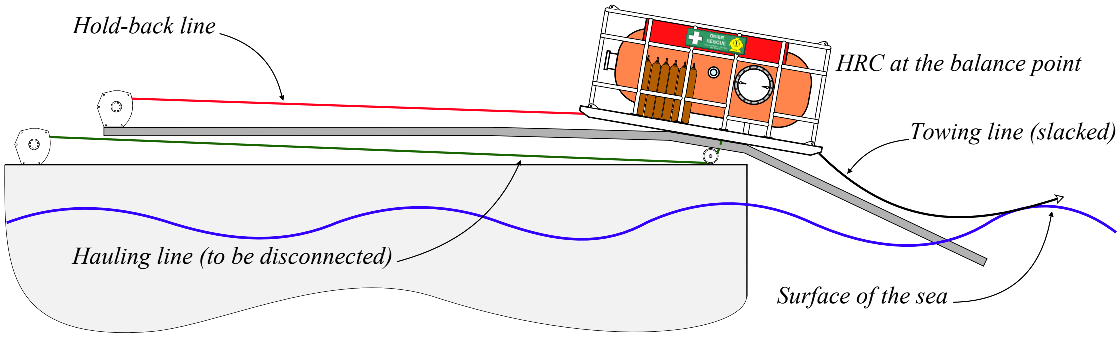
The Hyperbaric rescue chambers are maintained at the surface by their buoyancy and a series of buoys that are installed on the upper parts of a sturdy frame that protects it from shocks. This frame, to which four lifting points are fitted, also protects the connecting panels, reserves of gas, and the 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 2.3.20.2 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.

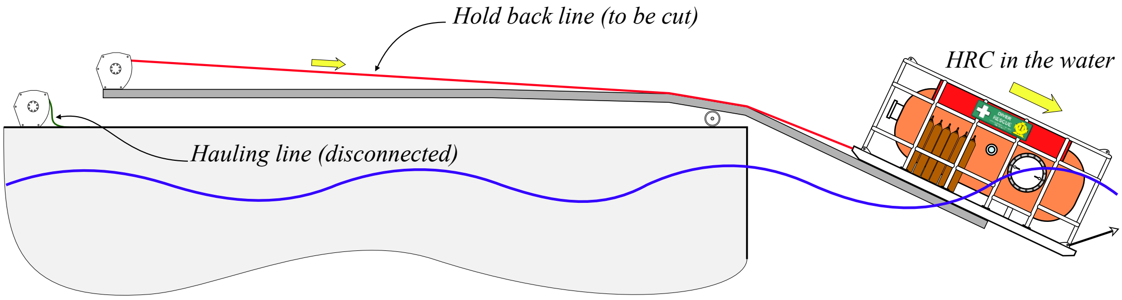


Some Hyperbaric rescue chambers can be launched using davits. However, most models is service use a launching platform, the onboard crane if available, or the “float off” method if none of the previous technic is possible. Launching using the crane is possible only if the weather conditions and the condition 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.



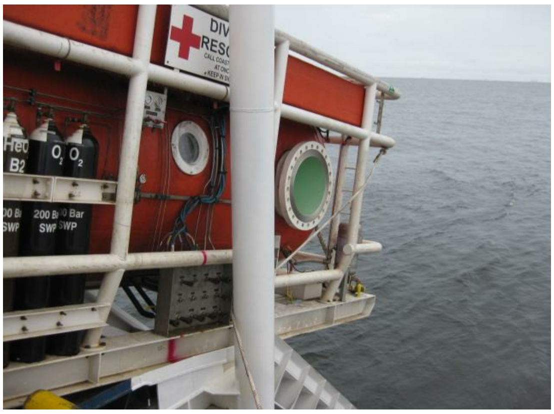




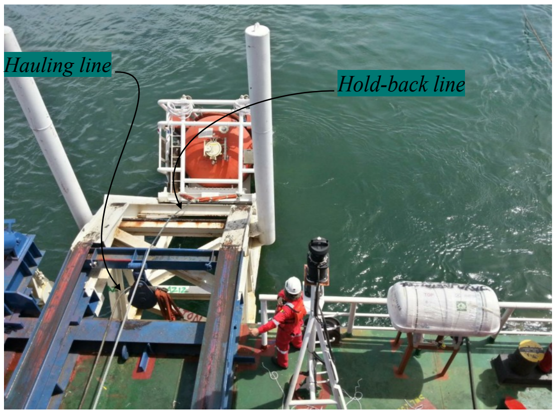

Hold back winch


Hauling winch

Launching platform at the stern of a lay barge



HRC at the balance point

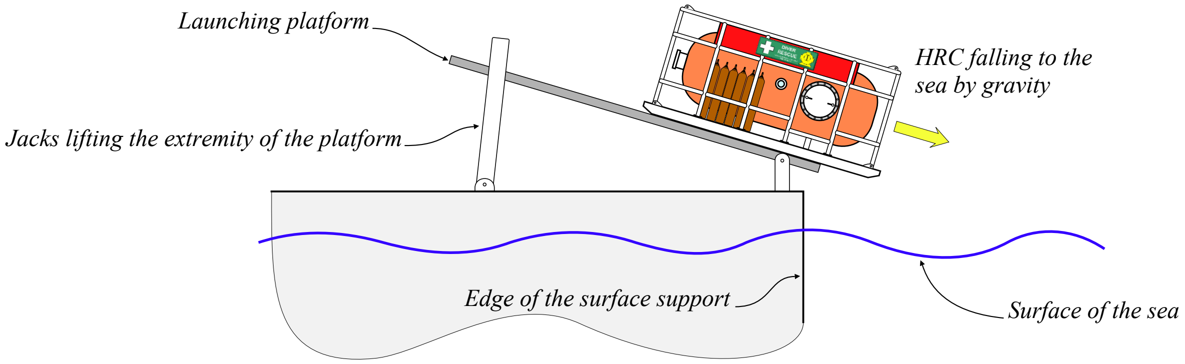


HRC at the end of the launching platform

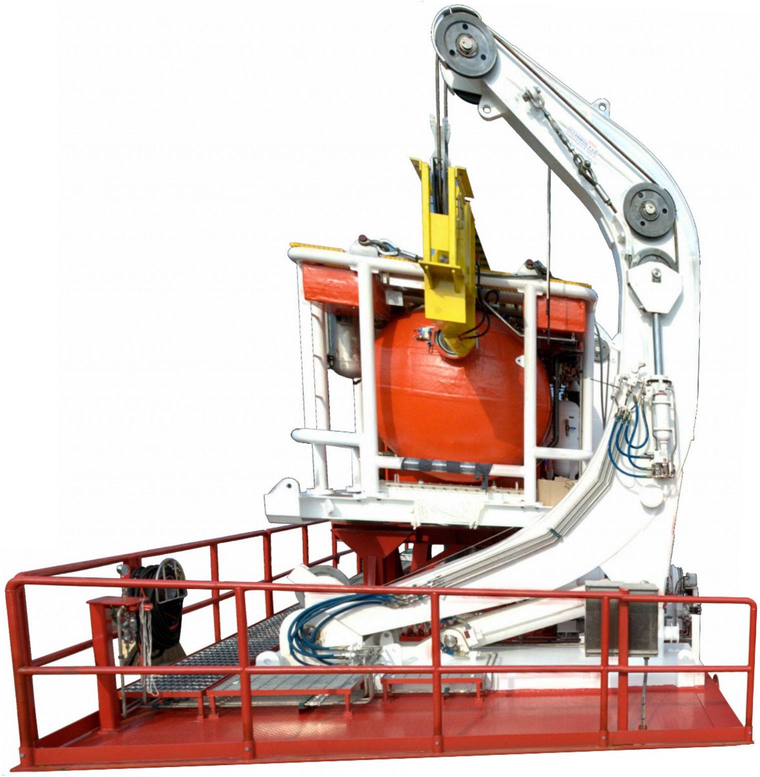
HRC at the end of the launching platform

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.



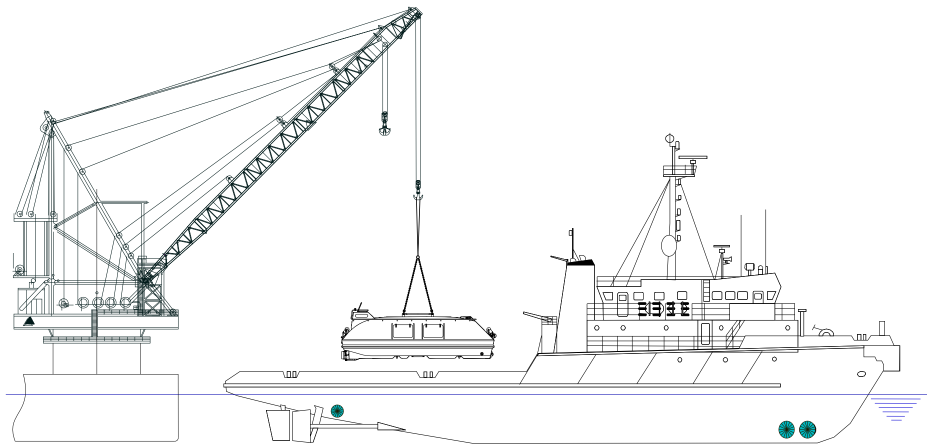
Float off procedure is an ultimate procedure that consists of disconnecting every element that may retain the chamber to the boat to ensure that it will float when the ship sinks. It is to be used only if the progression of the events is too fast to allow for sufficient time to launch the chamber overboard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

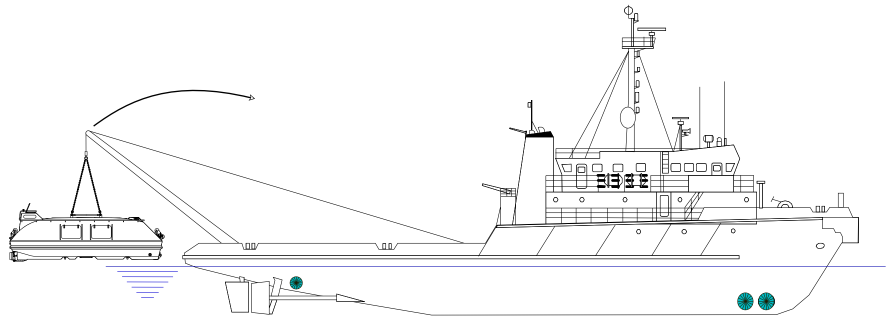
2.3.20.9 - Transfer the Hyperbaric Rescue Unit onboard the rescue vessel

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:

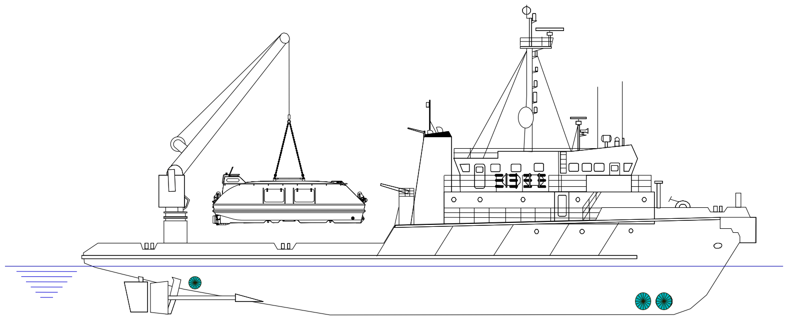
1. Transfer using a crane installed on a platform or a vessel located at the proximity of the worksite:
   The hyperbaric rescue unit sails or is towed toward the crane and is then lifted out of the water and transferred to the deck of the rescue vessel. Note that the transfer may be difficult or impossible 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.



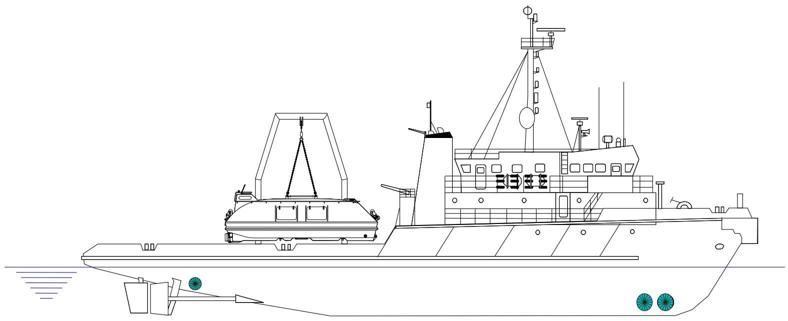
2. Transfer using an "A-frame", or a slope, installed at the stern of the rescue vessel:
Ships equipped with an "A-frame" are the most common. The advantage of this system is that the "A-frame" (or the slope) allows to precisely land the HRU to its dedicated place. The inconvenience is that the pickup 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.



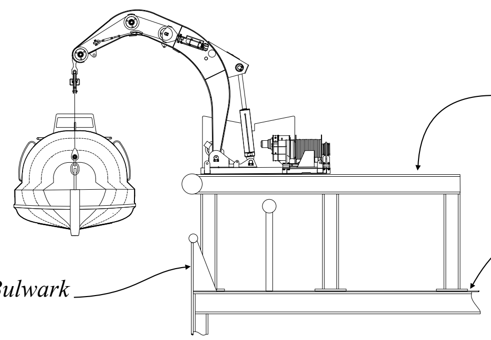
3. An offshore crane installed on the rescue vessel:
Similarly to those provided with "A-frames", such ships offer the advantage that they can be operated independently from other units. Another advantage of vessels fitted with a crane is that no lifting frame installation is required, which is an advantage 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.

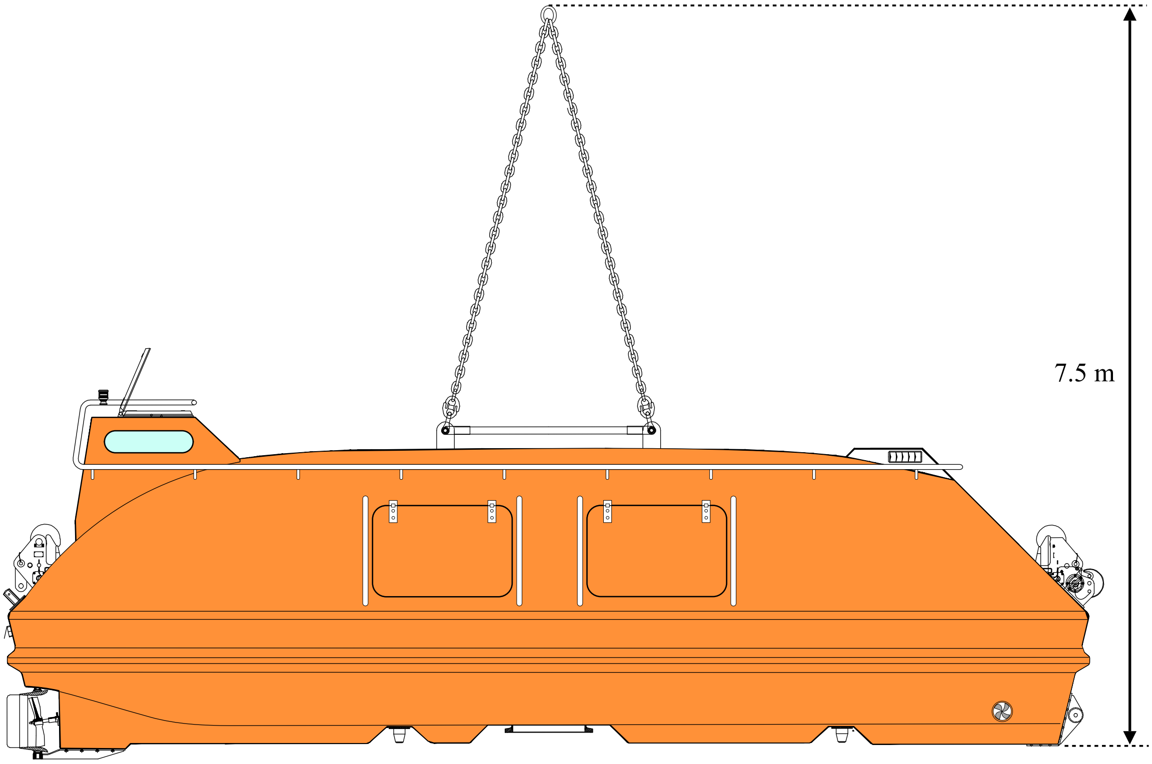


5. Another solution to recover the SPHL from the water is to use davits:
Davits allow excellent control of the load as they provide two distant lifting points. However, their installation often requires a reinforced structure to pass above the bulwark. Also, the connection of the slings may be complicated 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.



2.3.20.10 - 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.



2.3.20.11 - 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			

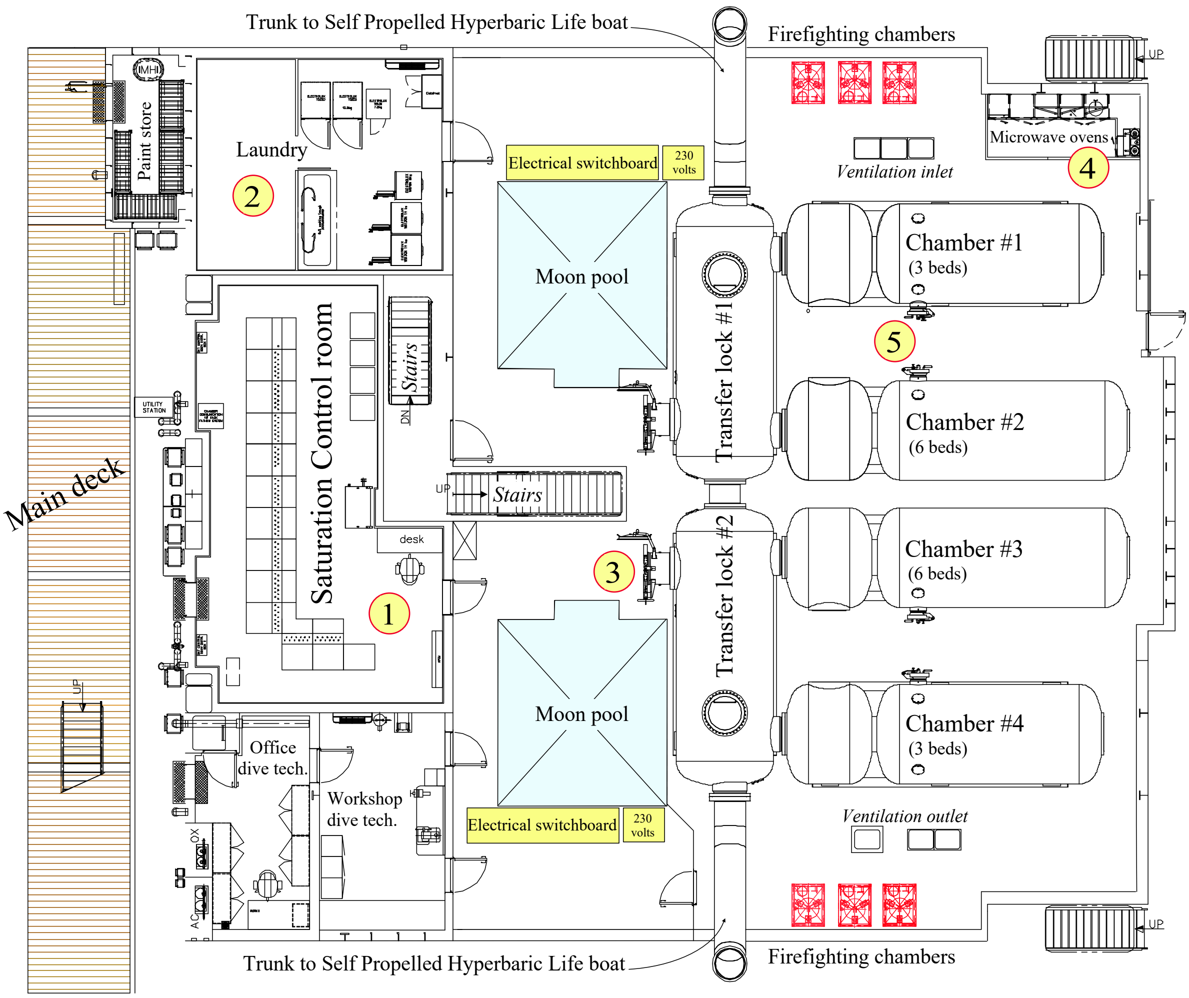
Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure*	*Other*
HRU without external life support control - Comms	6 months			
HRU without external life support control - Gauges	6 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			

2.3.21 - Saturation control

2.3.21.1 - 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).

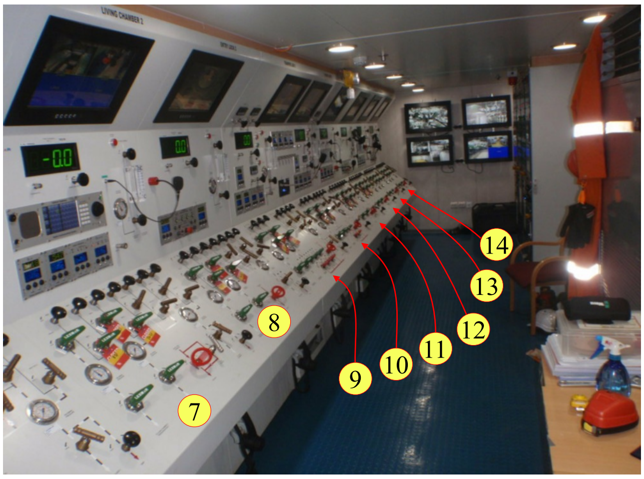


2.3.21.2 - Control panels

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

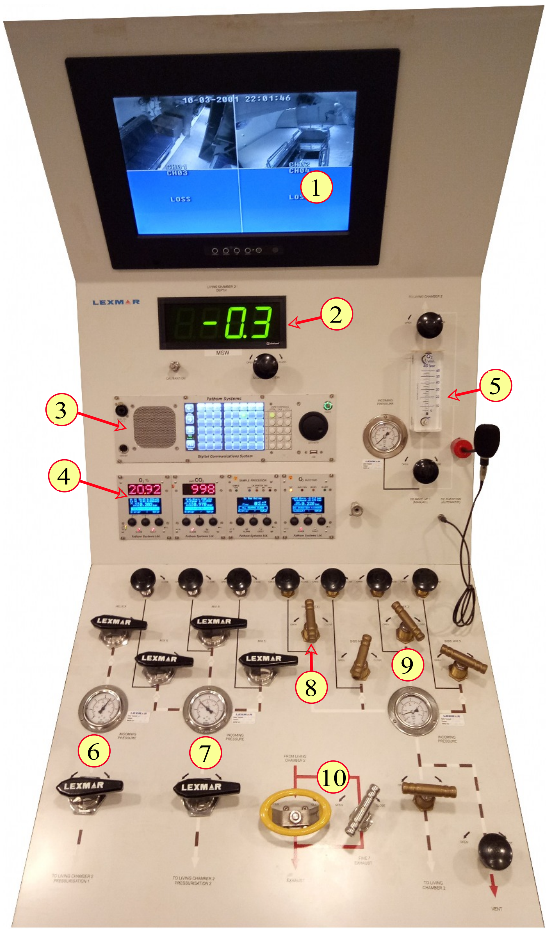
- Living chamber #4
- Entry lock #4



- 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

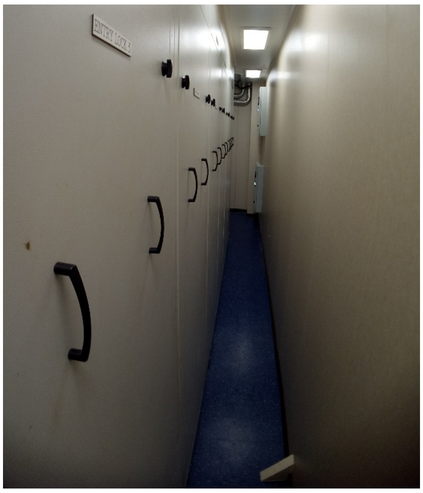
- 7 - Living chamber #2 - 8 - Entry lock chamber #2
- 9 - Transfer lock #1 - 10 - Transfer lock #2
- 11 - Living chamber #3 - 12 - Entry lock chamber #3
- 13 - Living chamber #4 - 14 - Entry lock #4

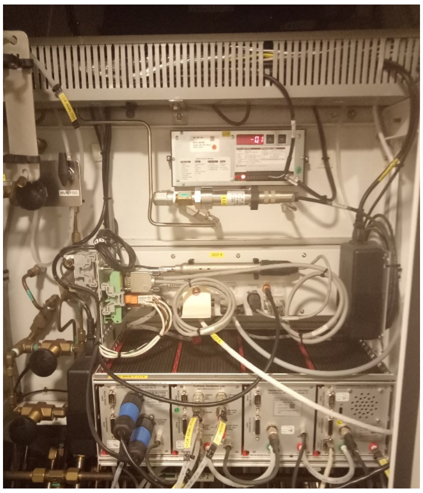
Each panel provides the following functions that are mandatory and may be arranged differently according to the chamber to control and the design promoted by the manufacturer:



- Close circuit television that allows observing the divers at rest. Cameras are described in point 2.3.15.2 of the chapter 2.3.15 “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

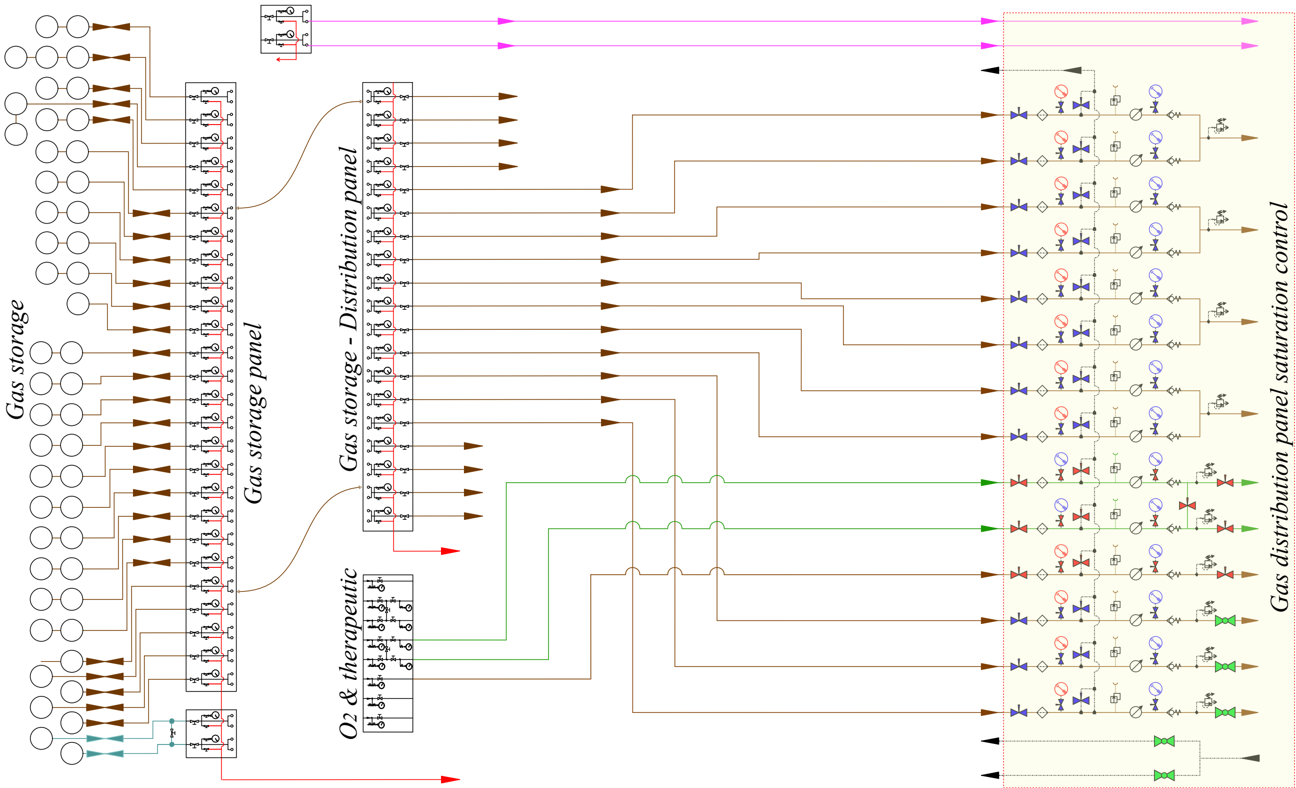

Electronic components inside a cabinet


Pipework inside a cabinet

2.3.21.3 - 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 2.3.21.2**)*. This panel is connected to the “gas storage and distribution system”, which is described in point 2.3.19.4, and its supplies must be separate from those of the dive control *(see below)*.

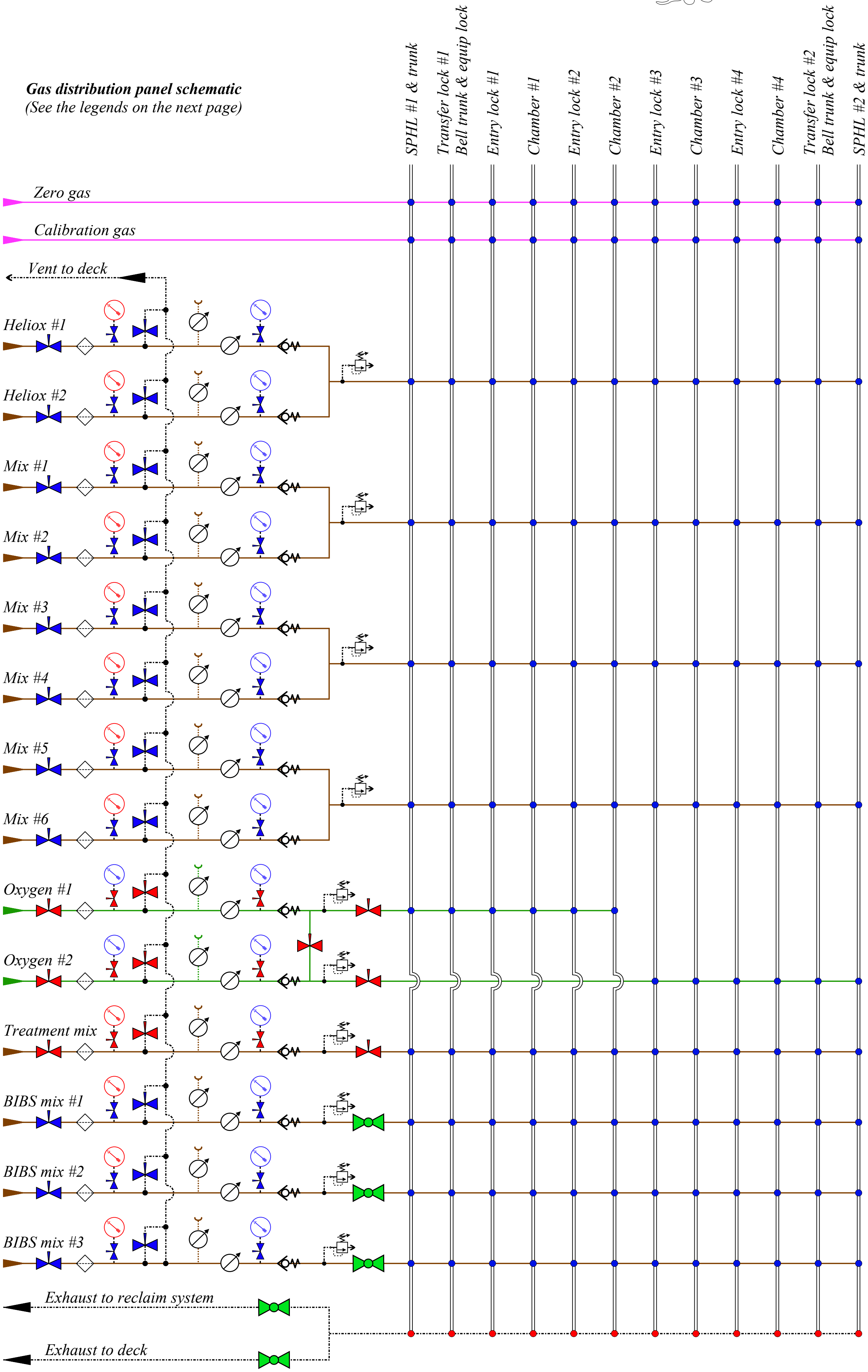


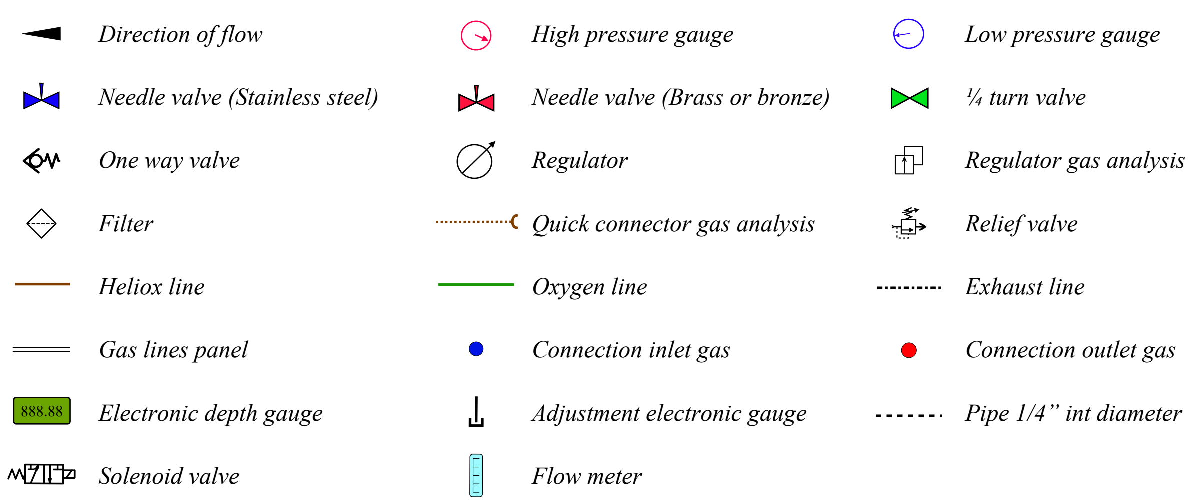
The inlet lines that compose the gas distribution panel are all similar and composed of the following:

- 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.

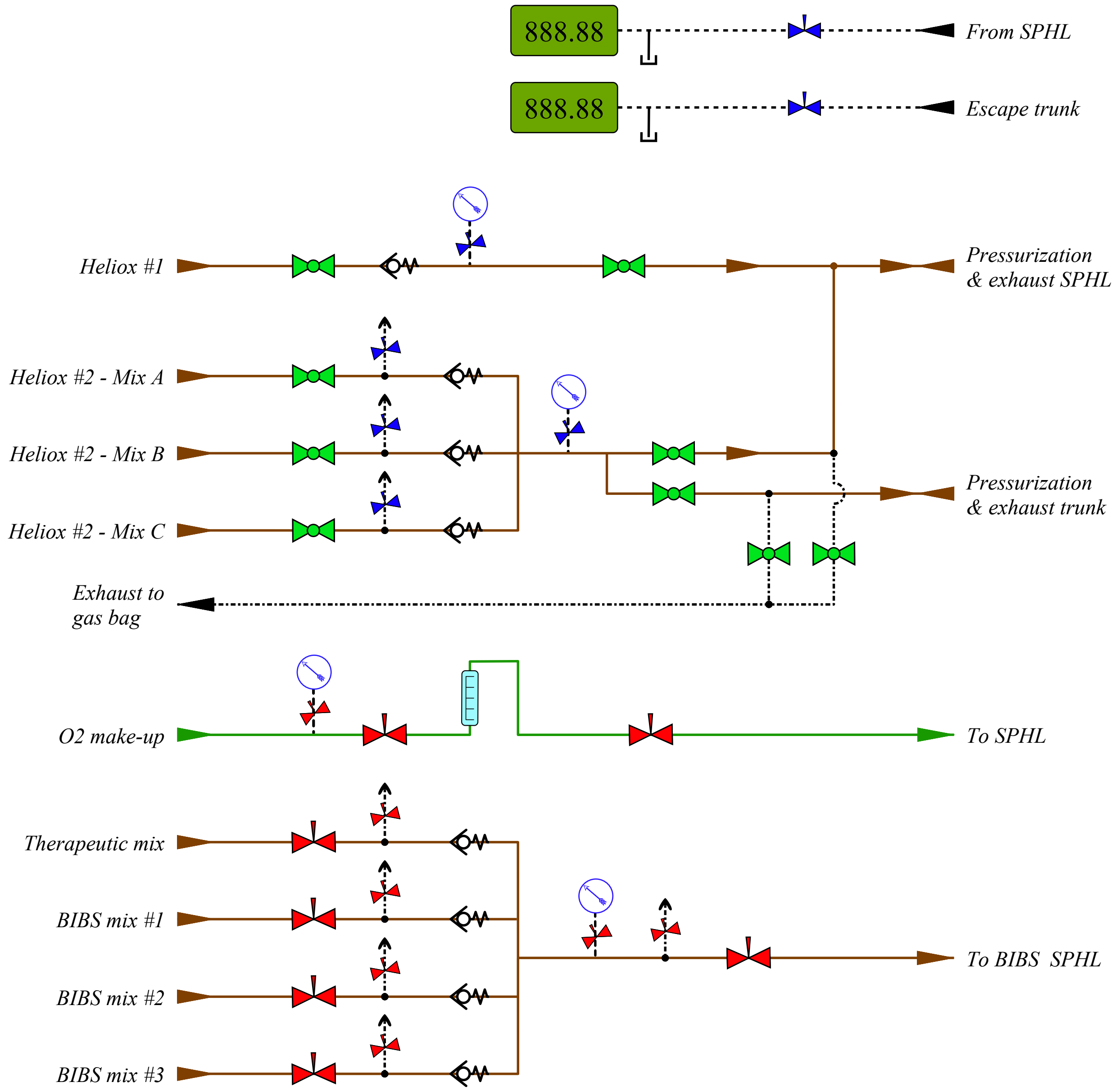
Gas distribution panel schematic
(See the legends on the next page)





- 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 2.3.21.2**)*. These control panels are also used to control the escape trunks to the SPHLs.

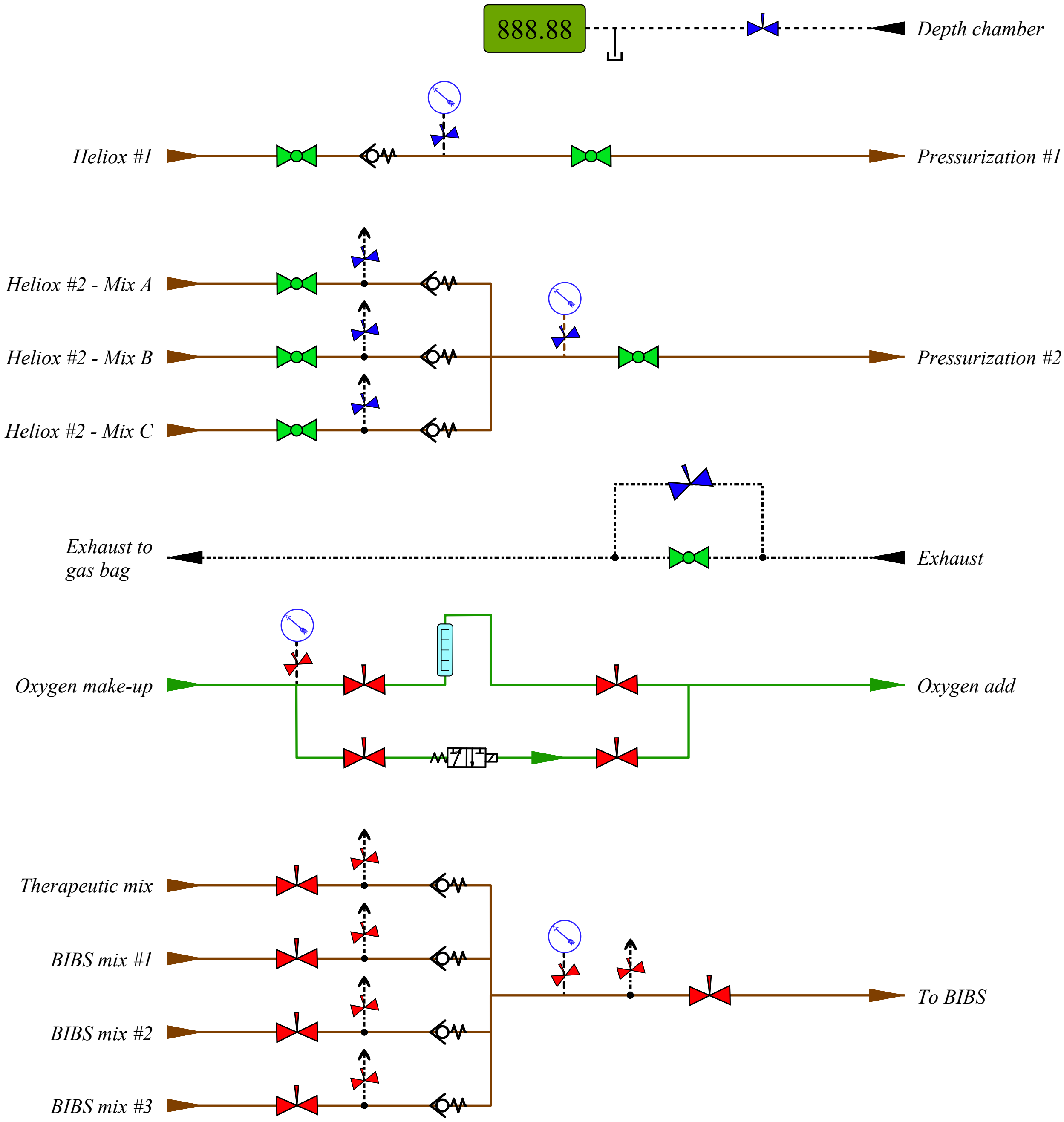


- This panel is designed to manage two devices (SPHL & escape trunk). For this reason an additional depth gauge and controls are provided.
- Pressurization and exhaust are grouped in one line (as with the bell). Each pressurization line has at least two separate gas supplies. Also, gas supply #2 has 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 2.3.21.2**)*.

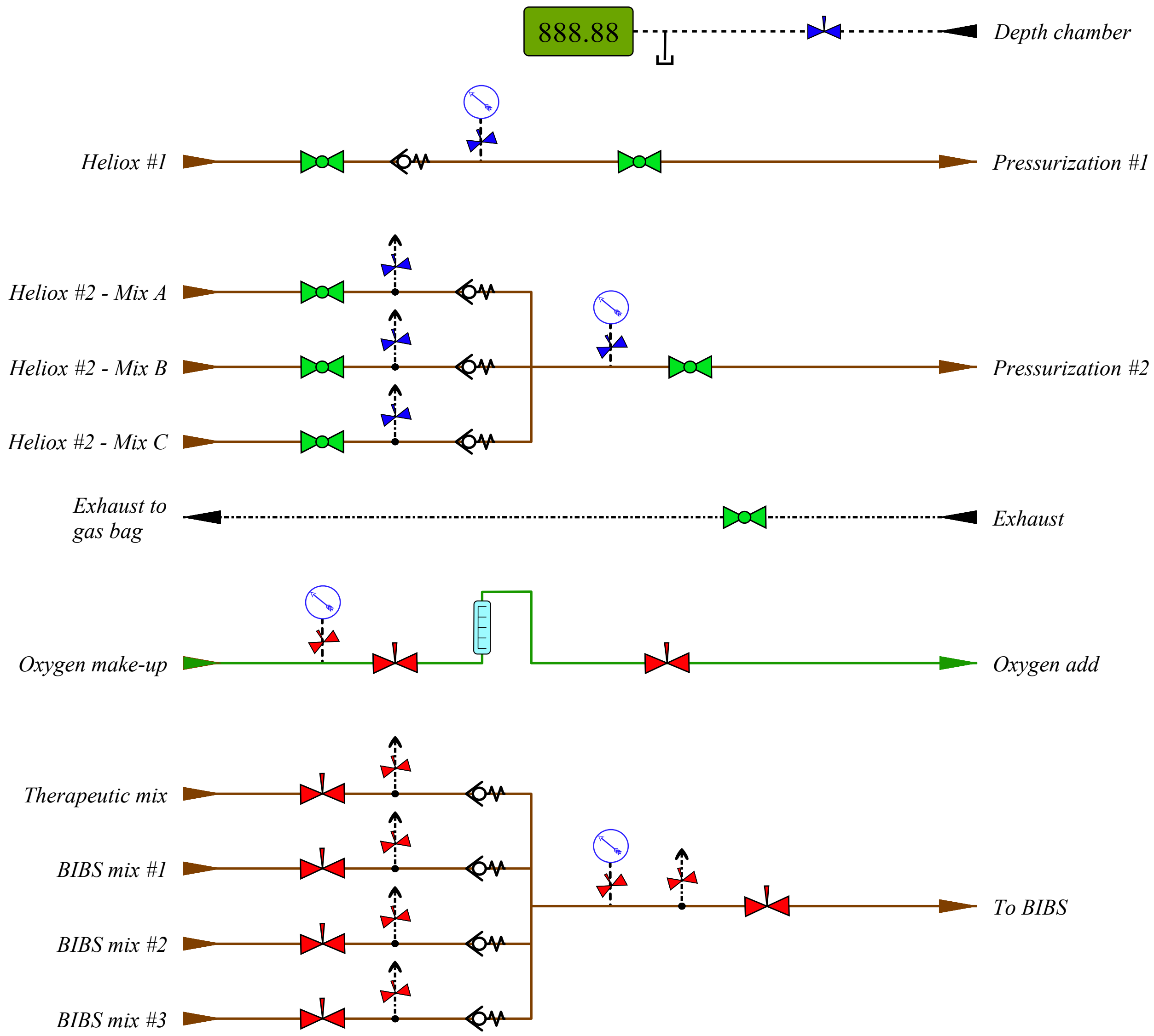


- This panel is designed to manage only one living chamber. It is designed for decompression.
- Pressurization and exhaust lines are separate. There are two pressurization lines with separate gas sources.
- Pressurization line #1 has one gas source and pressurization line #2 has three gas sources.
- 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.

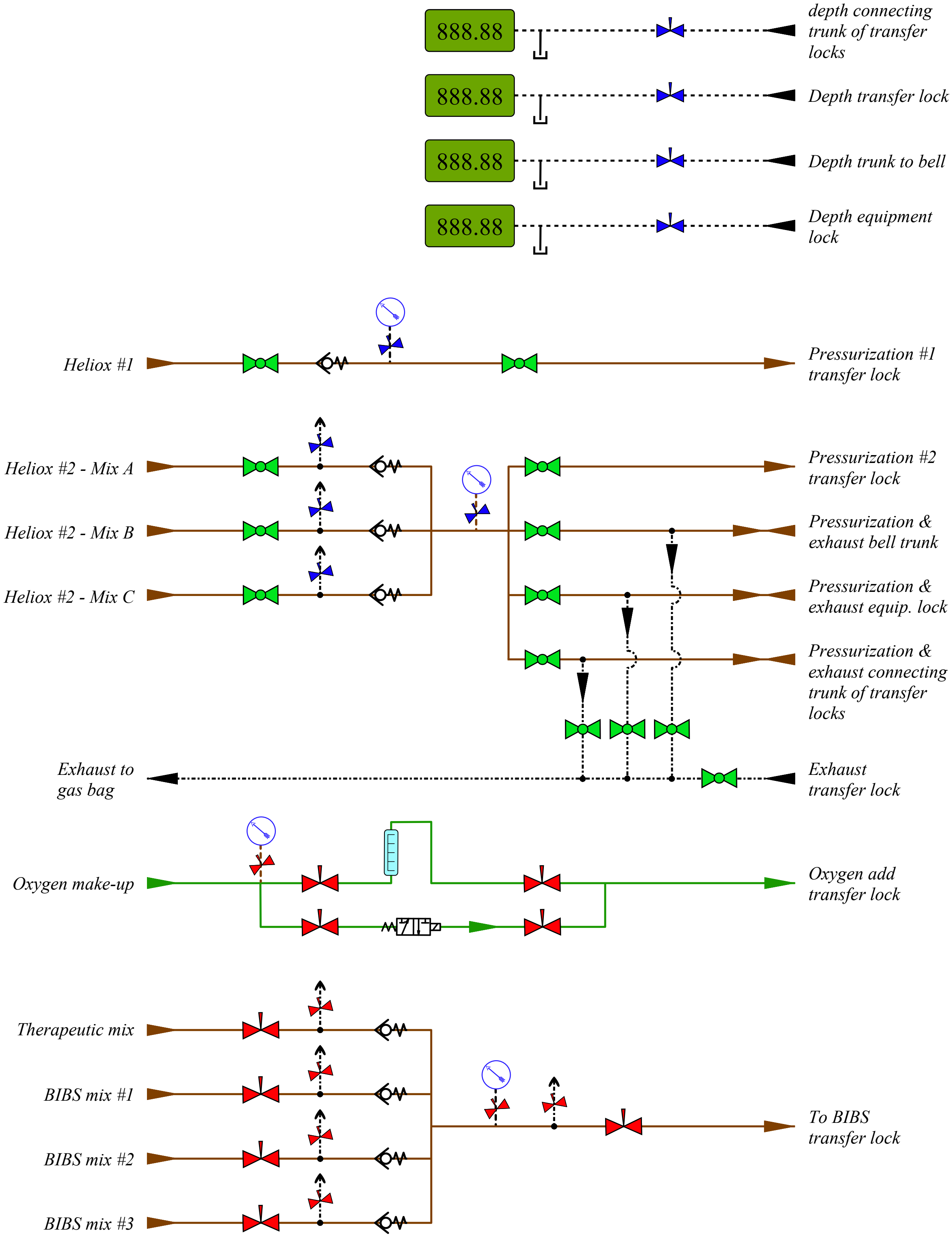
- Pressurization and exhaust lines are separate. There are two pressurization lines with separate gas sources.
- Pressurization line #1 has one gas source and pressurization line #2 has three gas sources.
- Exhaust to the gas bag is designed with a ¼ tun valve that is used for fast recovery . There is 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 2.3.21.2**)*. 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.



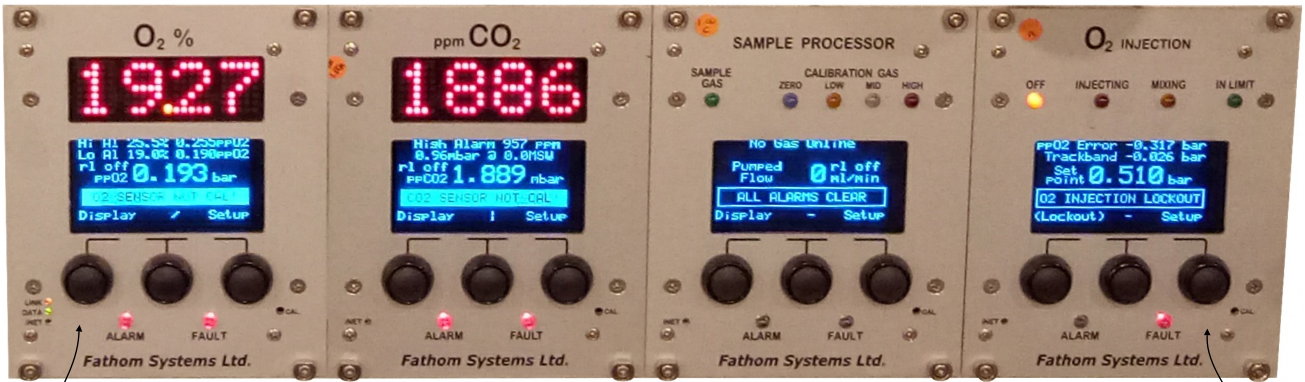
2.3.21.4 - Analysis and automatic oxygen injection system

Analysers used with chambers are usually of the same model of those used in the dive control *(see point 2.3.12.4)*. As a reminder, the analyser used with the saturation systems taken as references are designed by Fathom. 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”.

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.

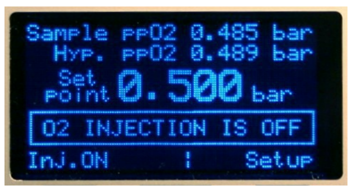
- An injection control system allows for efficient and predictable O2 mixing periods. Also, an optional audible warning is given during injection periods. The O2 injection solenoid is powered from an external power supply switched by the internal safety relays inside the oxygen injection controller.
- 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:

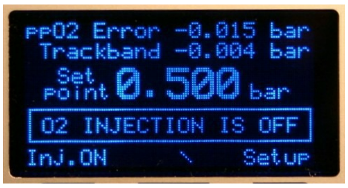
1. Oxygen injection off:
   This mode can be selected by the operator (by turning off the function) or can be the result of an automatic trip that disables the injection for safety reasons. As a result, the controller is idle and does not inject oxygen.
    - The light “off” is illuminated.
    - The 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

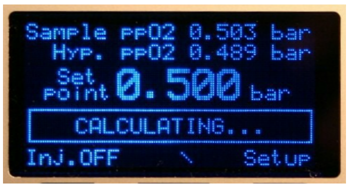
error means that the chamber requires O_2 to be injected.

- "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.

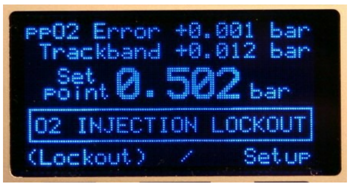


2. Oxygen injection switched on - PPO_2 within the setup limits:
When the injection is switched on, the current ppO_2 is calculated and compared to the desired set-point. If the PPO_2 is within the setup limits no injection takes place, and the system repeatedly calculates the injection parameters but 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)*.

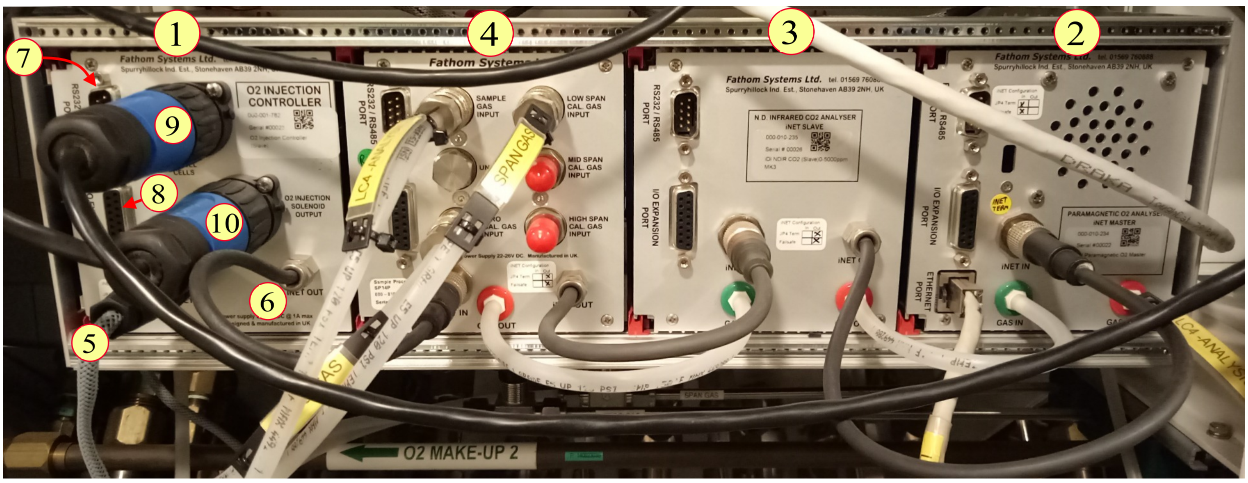
7. Oxygen injection switched on - Continuation of the oxygen injection process after mixing:
   When the mixing is completed, the current PPO2 is calculated and compared to the desired set-point. So the process of oxygen injection starts again from point #2.

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.



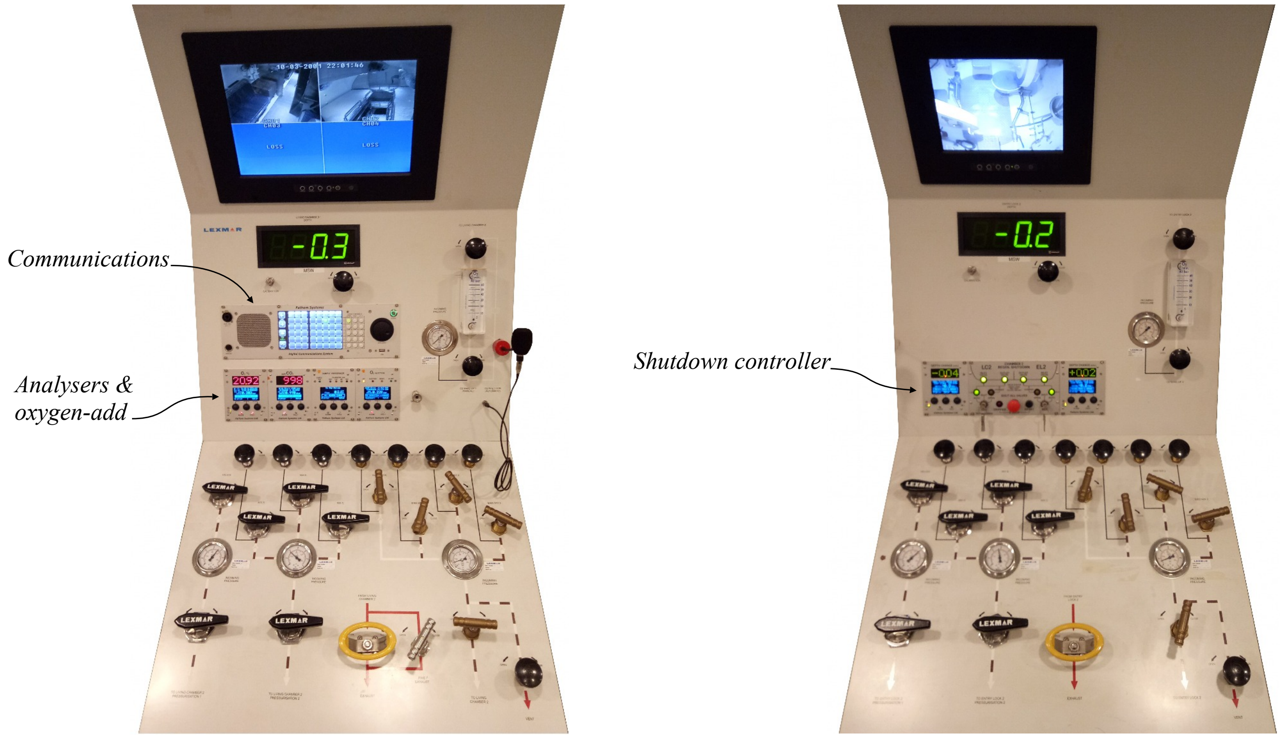
- The "iNET in" connector *(see #5 in the photo on the previous page)* is used to connect the 24 volts DC power to the injection controller module. It is an industry standard "5-pole M12 male panel-mounting type" similar to the one of the oxygen analyzer master module *(see point 2.3.12.4)*. As the oxygen 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.
  As a reminder, of what is said in point 2.3.12.4, 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)*.

2.3.21.5 - Regeneration shutdown controller

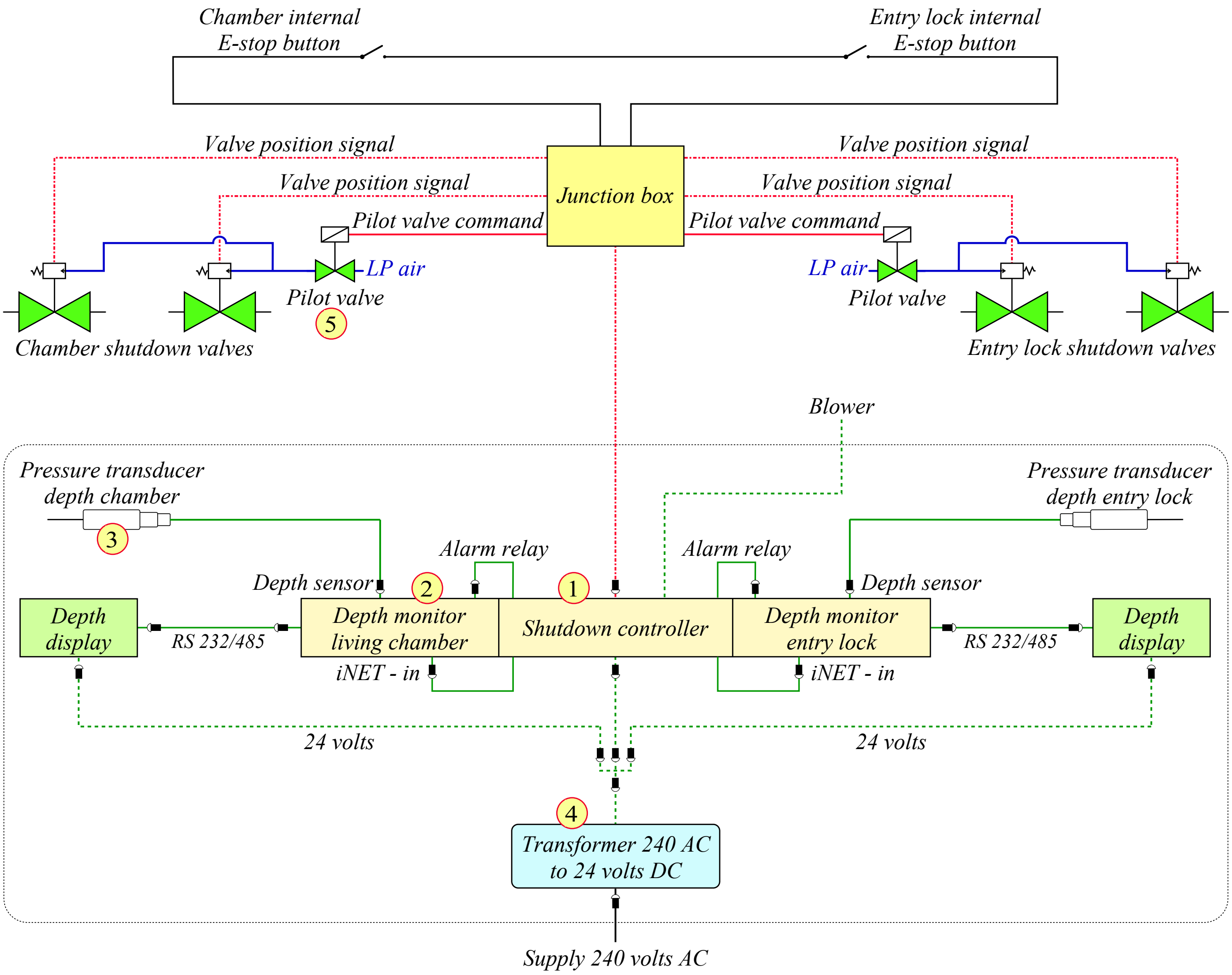
This system is also present in the saturation controls of the system taken as references but not with all systems. However, we can expect that most last generation systems will adopt it in the future.
In point 2.3.15.1 of the chapter "Chambers", it is said that IMCA recommends that large pipes such as 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 2.3.17.1 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 2.3.17.1)*. 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*

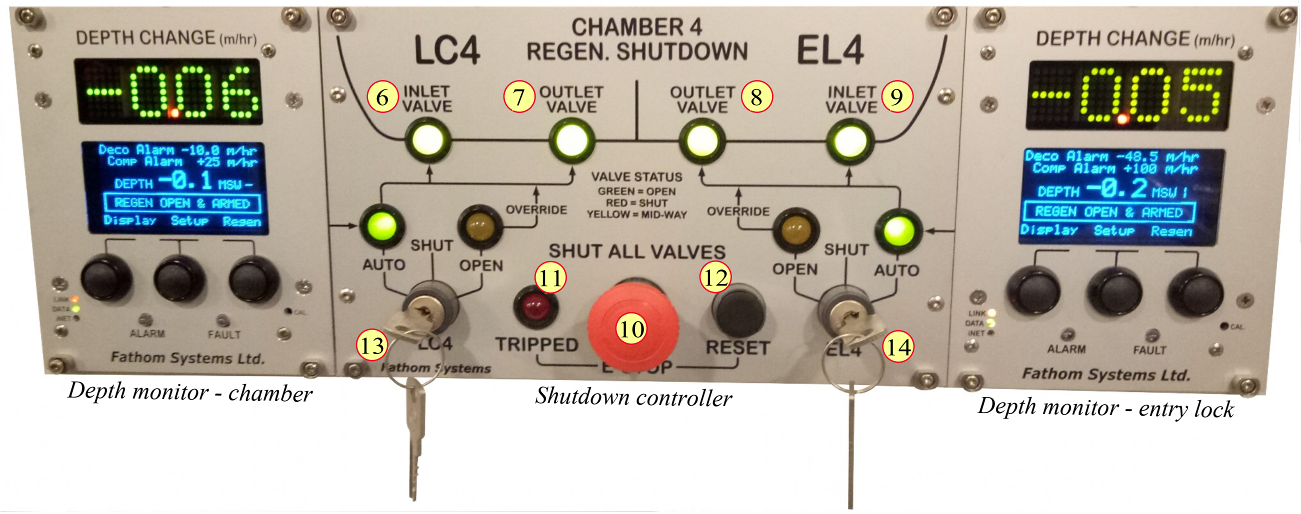
The scheme below shows how the system is organized *(See the explanations on the next page):*



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.

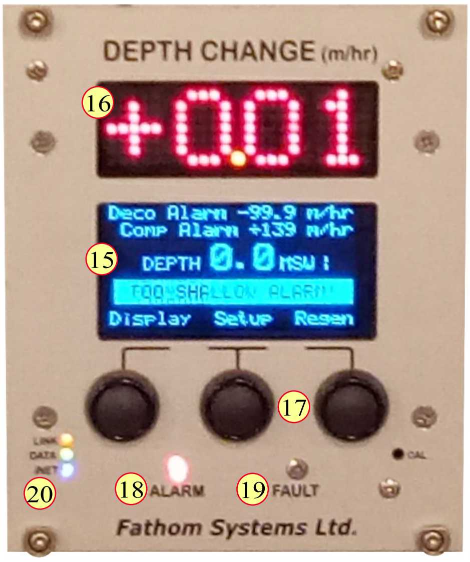
The E-Stop loop circuit use "normally closed" contact switches at each location and form a series-connected electrical "loop" around the system. This loop is broken when a switch is operated, in turn activating the chamber shutdown. In this case, an indication is displayed on the Shutdown Controller 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:

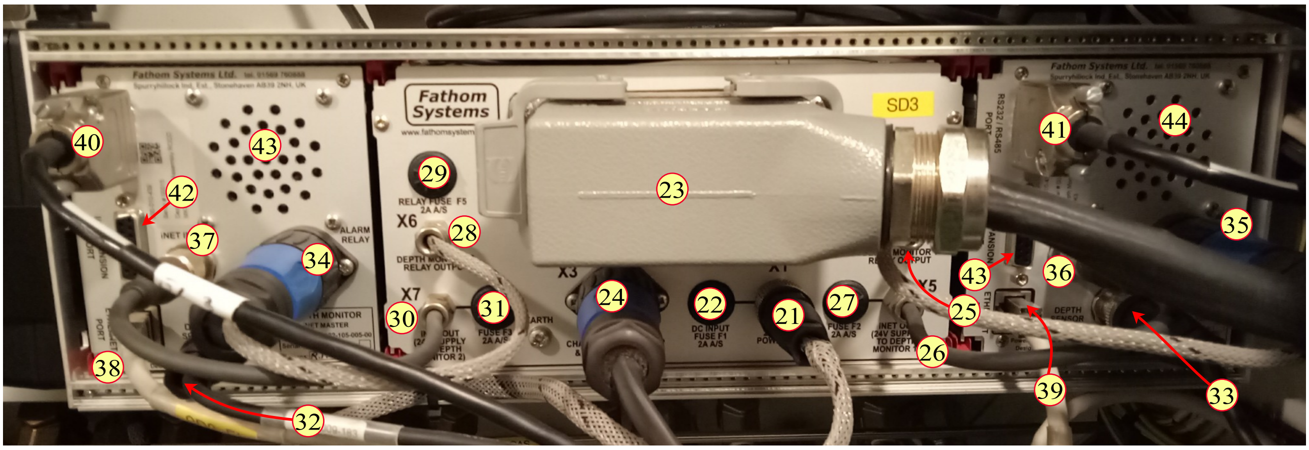
- "Auto armed open mode":
It is the normal operating mode where the regeneration valve is open, but is the decompression rate change is continually monitored and compared this to the flow-fuse trip set-point. The depth change screen display is green and the condition of the valve is indicated on the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

2.3.21.6 - 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 point 2.3.14.4 "Communications with divers breathing heliox". 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 described in the chapter "dive control", which units are visible in the photos of *point 2.3.21.2.*

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	

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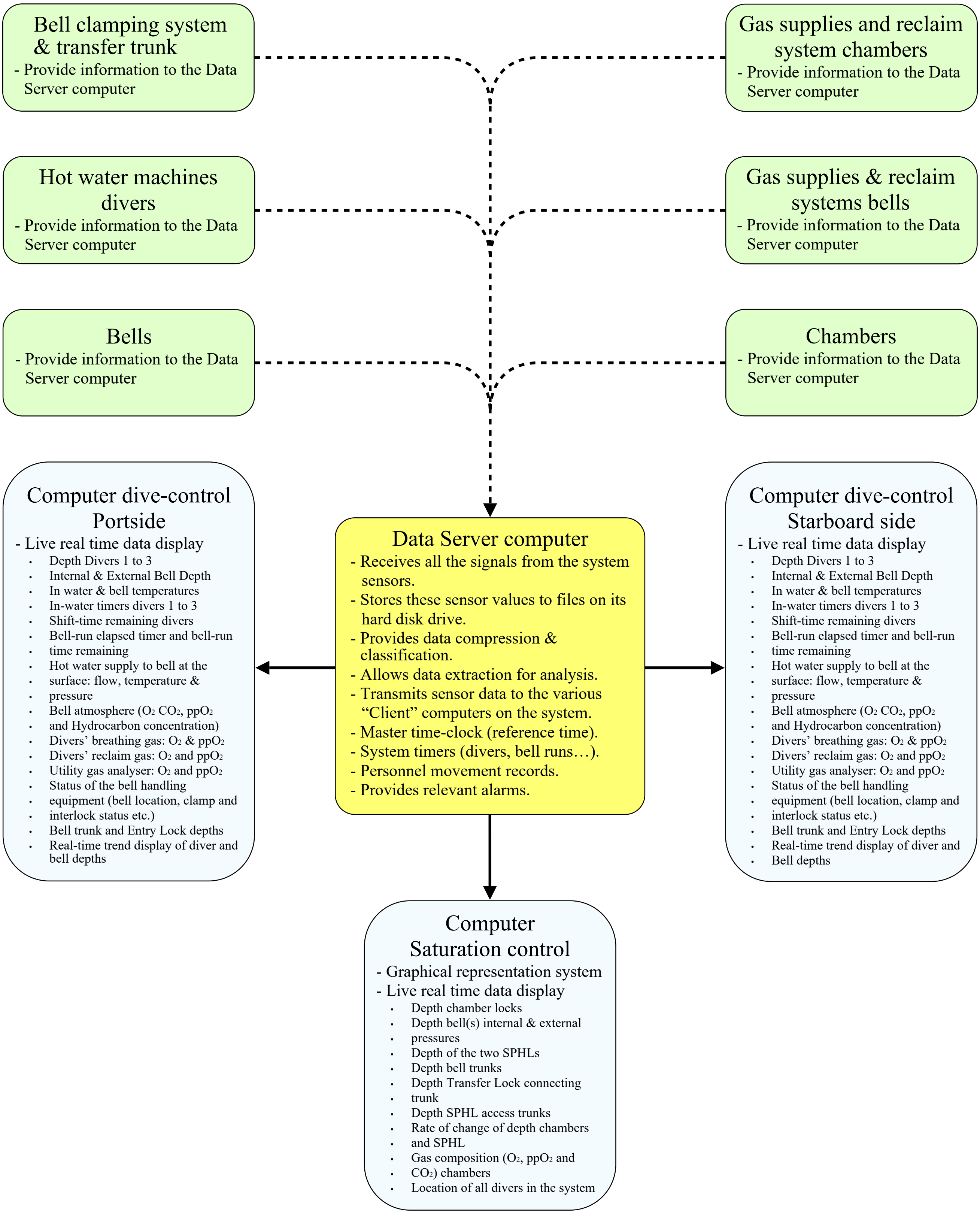
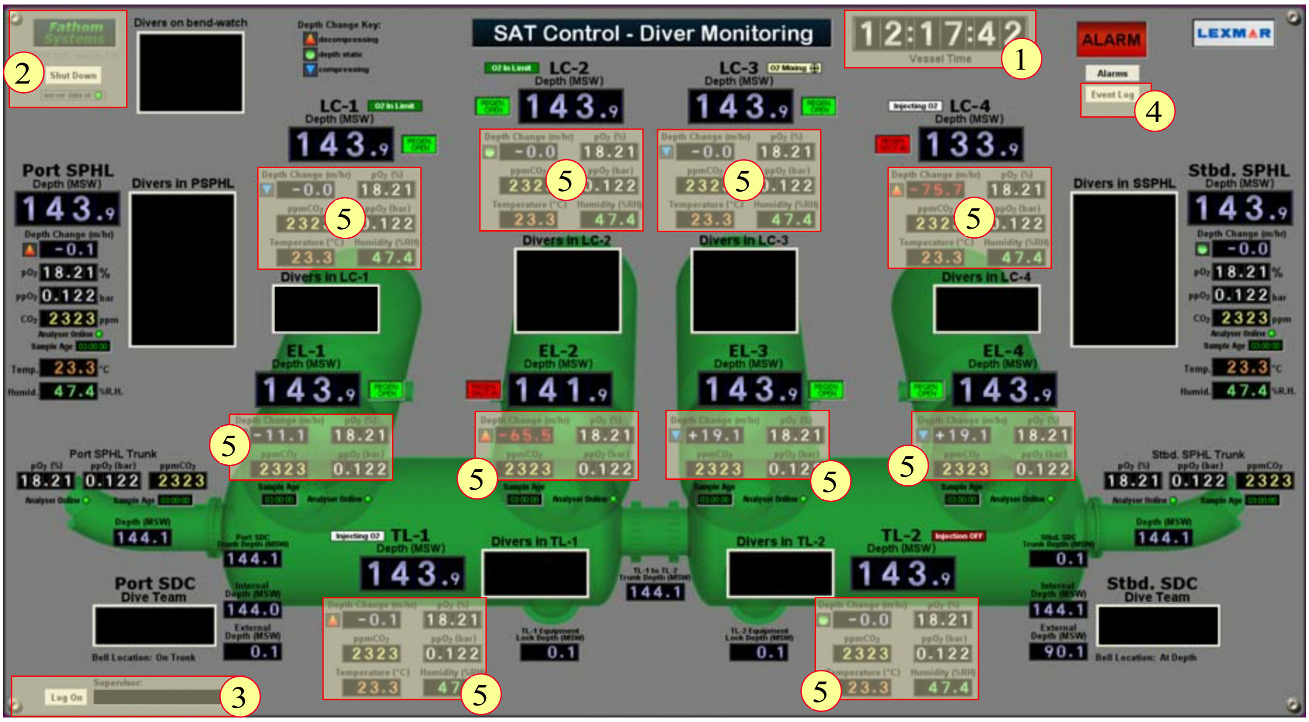
2.3.21.7 - Diver Monitoring System (DMS)

The Diving Monitoring System in place in the saturation control room is the complement of the one in place in the dive control and described in point 2.3.14.6, to which it is linked as shown in the scheme below.
As a reminder, the Diver Monitoring System (DMS) is composed of networked computers which 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.

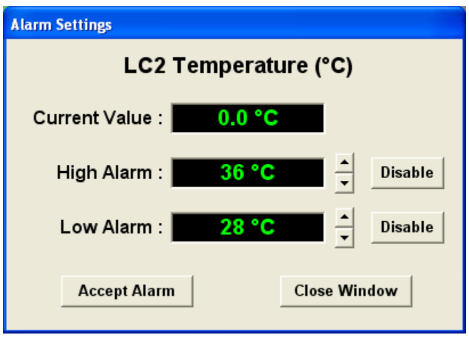
2) - Shutdown button, server indicator & version information *(see #2 above):*
It allows the Life Support Supervisor (LSS) to shut down the saturation control client display software. The LSS can also see the details of the software revision status of the application by clicking on the "Fathom Systems"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



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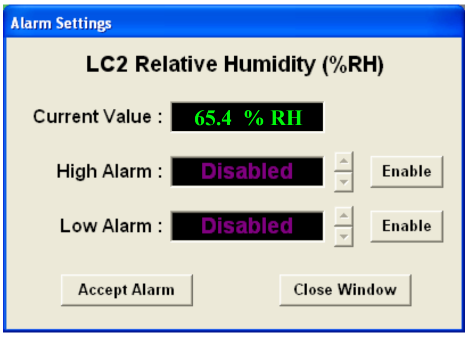
5.2 - Humidity (%R.H.) *(Living Chambers, Transfer Locks and SPHLs only)*

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.

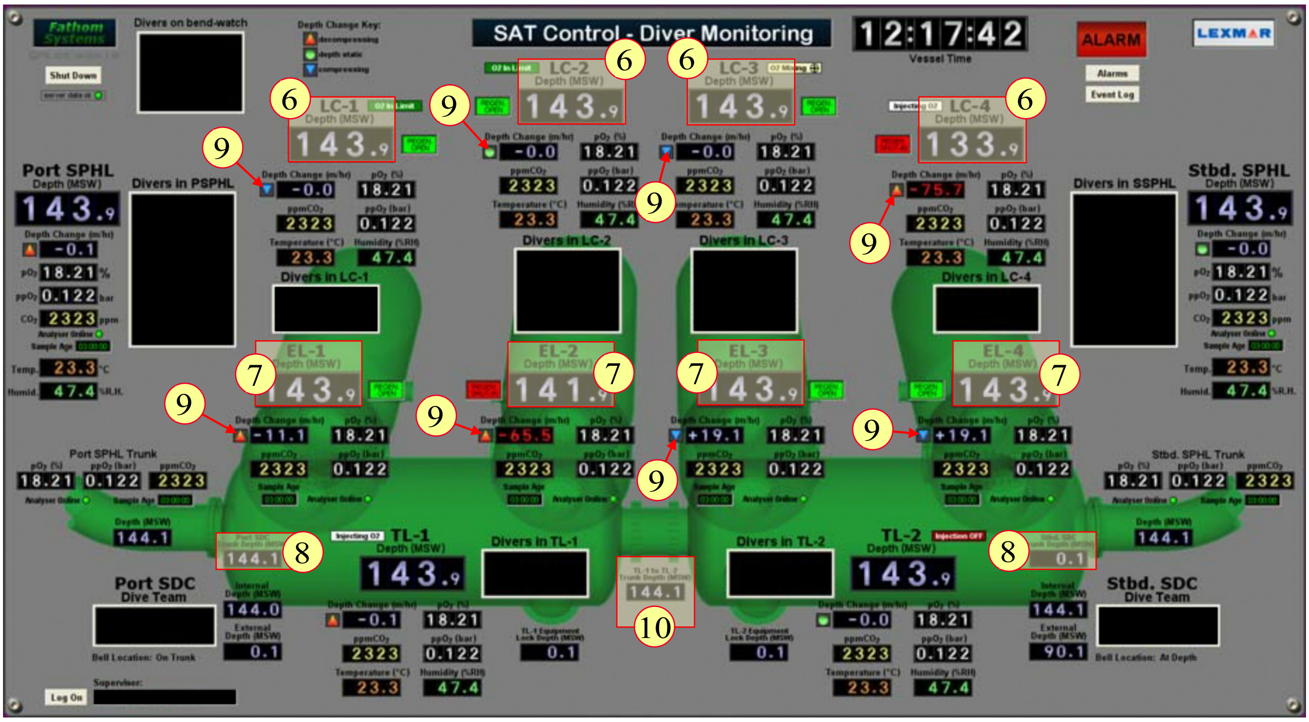
5.4 - Oxygen partial pressure

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)*:

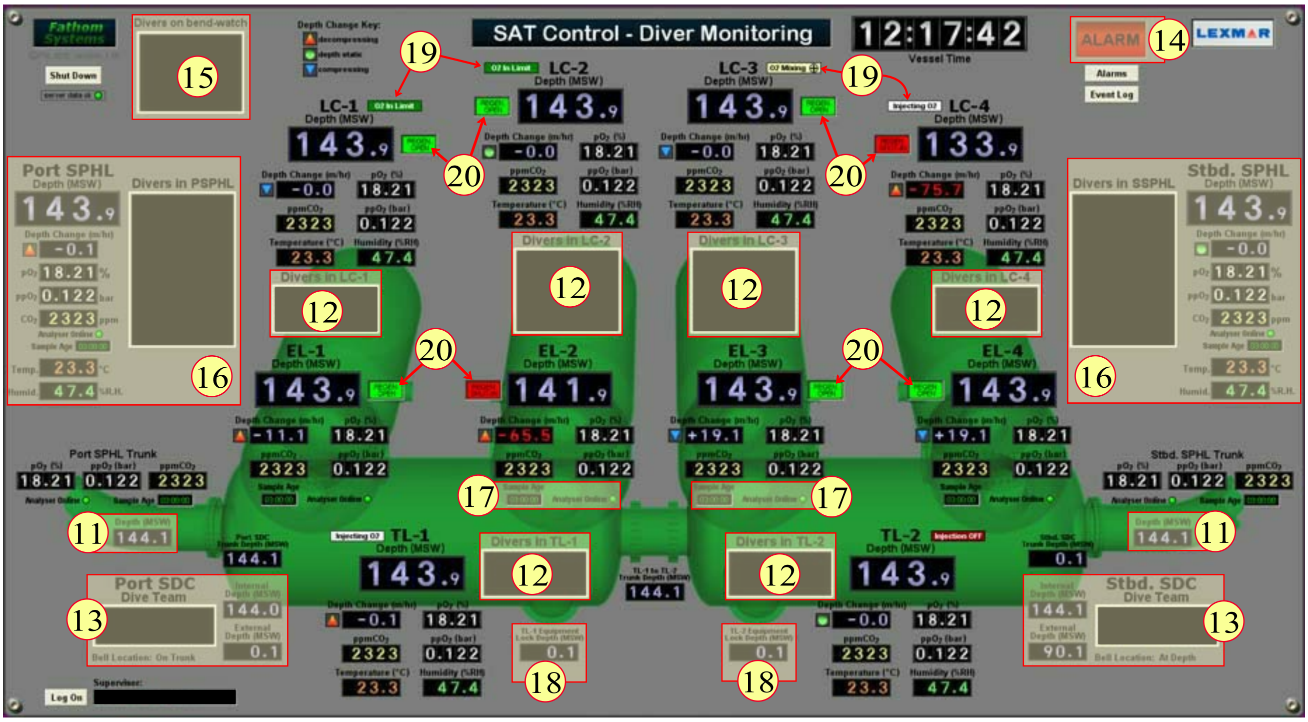
This display is generated from the signal from the analog depth transducer located in the trunk gauge line. There is no alarm for this display.

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.

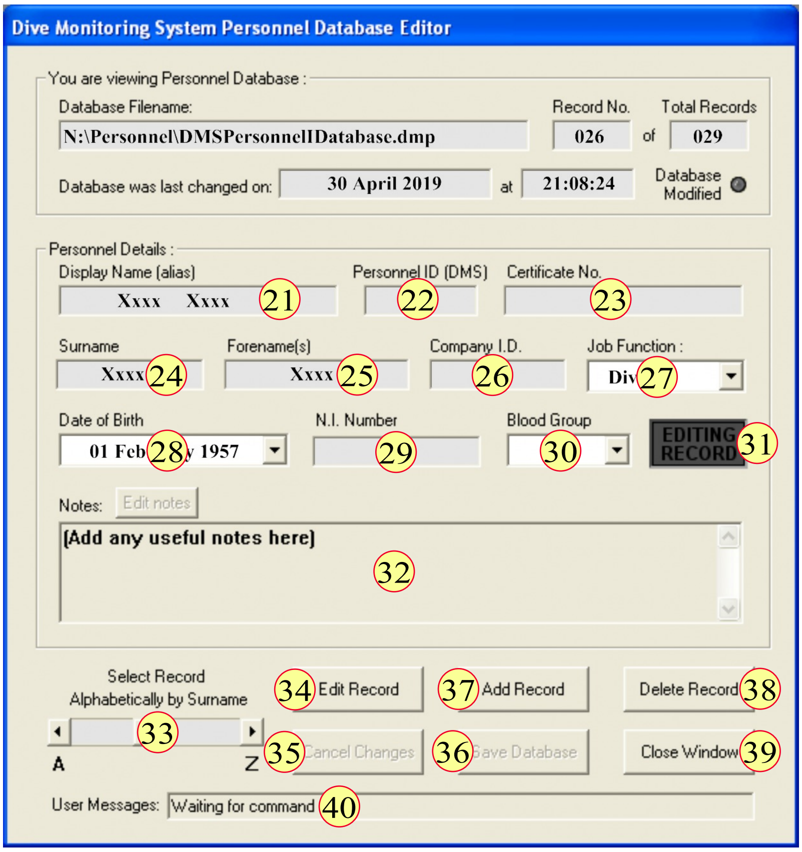
19) - O_2 Injection Status *(see #19 above)*:
This display indicates the data from the oxygen injection modules explained in point 2.3.21.3.

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 2.3.21.4

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.

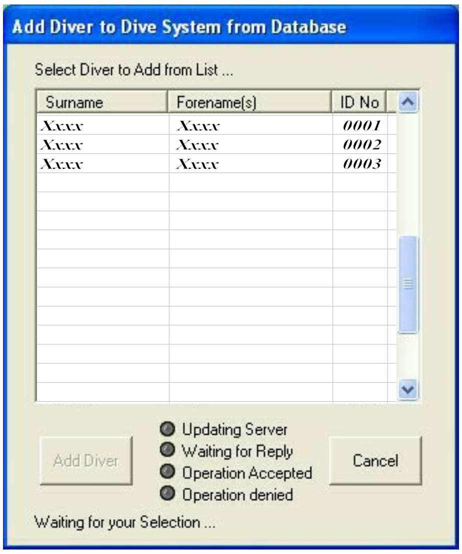
37) - Add Record button *(see #37 in the scheme on the previous page):*
When clicked, this button appends a new record to the end of the database, initially populated with blank fields, ready for editing. The editing mode is automatically started, and the LSS is free to type in the details of the person 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.

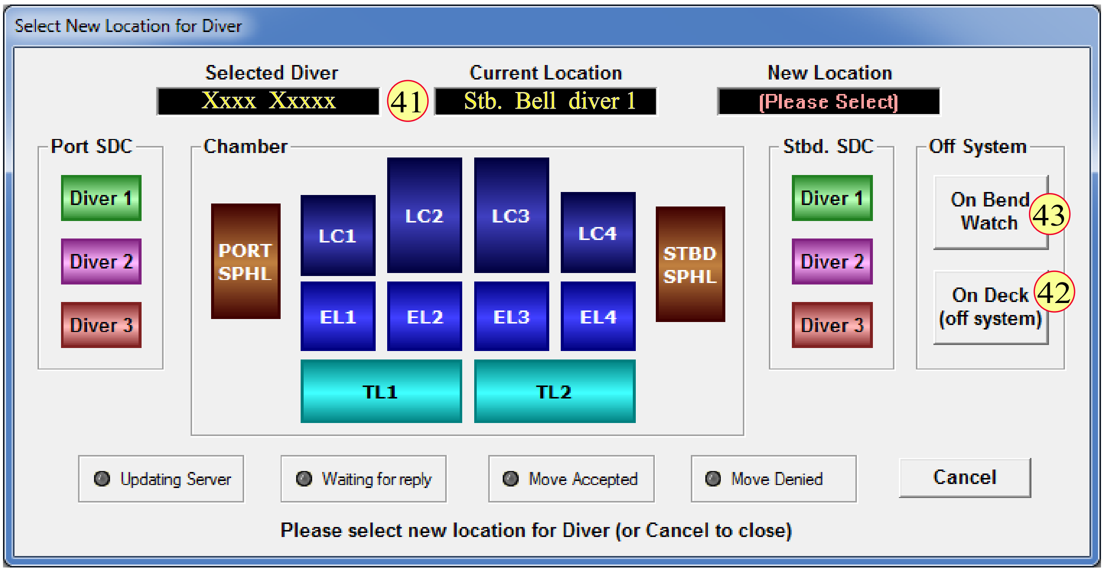
39) - Close Window button *(see #39 in the scheme on the previous page):*
When clicked, this button finishes the database editing session and closes the database editor window. It cannot be clicked during the editing.

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.

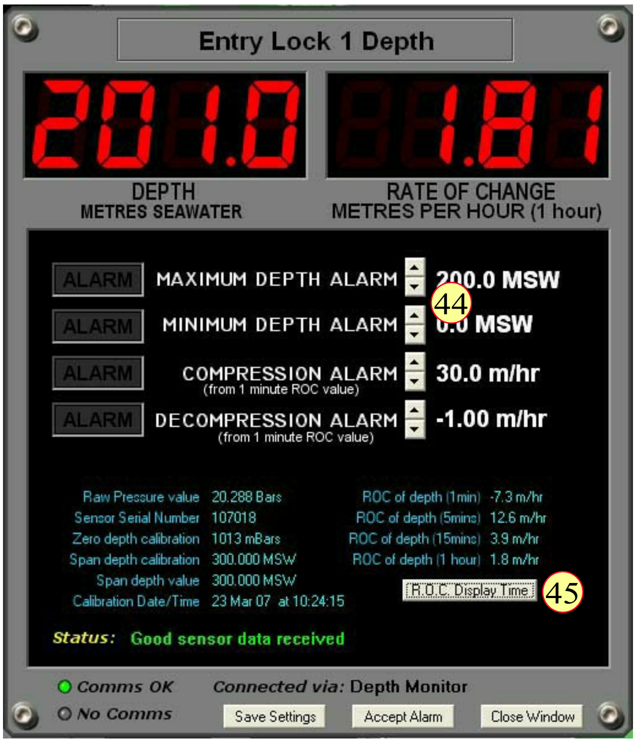


To move a divers from the chamber he is stored to another part of the system, the Life Support Supervisor right clicks or double clicks his name in the "diver location window" *(#12)* of the living chamber. In the menu that is opened, he selects the option "move Diver". As a result, a window similar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



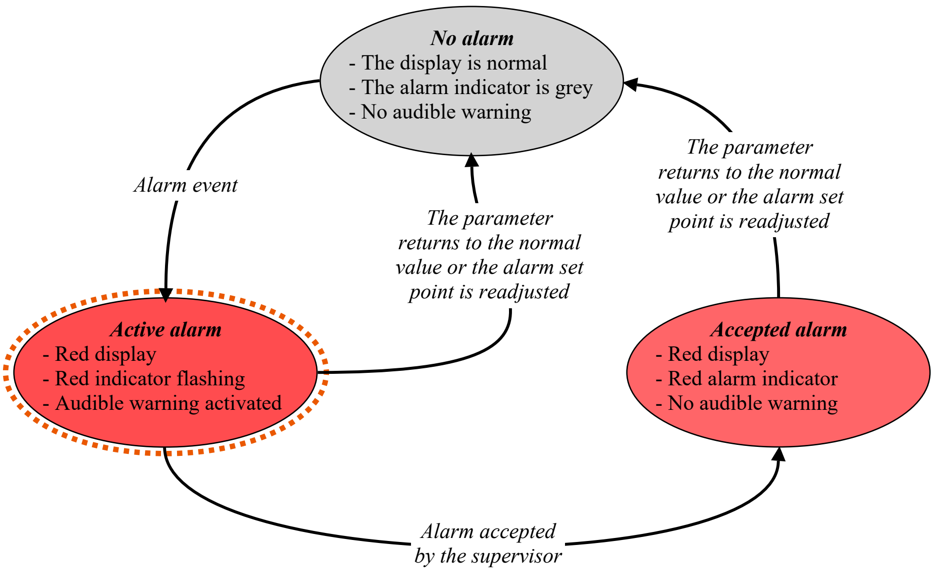
The alarms can be adjusted to the desired values using the sliders *(see #44 above)*. When the setup is completed but not saved, the text colour changes from white to yellow until the operator clicks the title "Save settings"
The LSS can select the time base periods of rate of change of depth by clicking 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 2.3.21.4, 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 already explained in point 2.3.14.6:

- 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.

2.3.21.8 - 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.
As already explained in point 2.3.14.2, 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 point 2.3.12.4 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.

2.3.21.9 - Fire fighting systems, general alarms, and means of escape

The systems to protect the dive control from fire and escape from it must be the same as those in place for the dive control and explained in point 2.3.14.7. So, firefighting arrangements must be made for all areas critical for life support, including the control area. It may be by means of permanent ship or platform provided equipment or by means of portable extinguishers, and be capable of dealing with any type or size of foreseeable fire hazard.
Also, IMCA D 024 says that the vessel/installation general alarm system must be linked to the life support control, or sited close by so that it can be clearly heard by the life support personnel. As for the dive control, there must be the possibility to mute or cancel any audio alarm if it is so noisy or obtrusive that it does not allow the life support personnel to hear their other communications.

The saturation control room is also the place from which the firefighting system of the saturation system is managed. Depending on whether the system is portable or built-in and the country where the diving operations are carried on, the fire fighting system of the chambers can be portable or fixed:

- In the case of a portable system installed on the deck, it is common that the external fire fighting systems are extinguishers and fire lances, so there is no remote control from the saturation control room. Also, a lot of systems currently in use are not equipped with fixed internal fire fighting systems such as deluge systems in the chambers, so only extinguishers are provided. Nevertheless, note that fire detection and firefighting systems that can be activated independently both in the chamber and externally in the saturation control room are mandatory with NORSOK standards U100 and in some countries.
- Fire fighting systems of integrated saturation systems are generally in accordance with the recommendations of NORSOK U100, and must also comply with the requirements from SOLAS *(International Convention for the Safety of Life at Sea)*. As a result, the external fire protections are usually those in place to protect the internal parts of the vessel and are composed of smoke, heat detectors, and sprinklers in all rooms. In addition, portable extinguishers and fire lances are provided. With modern ships, the sprinkler system is automatic and designed to be activated from the "central control station" that is usually in the bridge and in which the following functions are centralized:
    - 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.

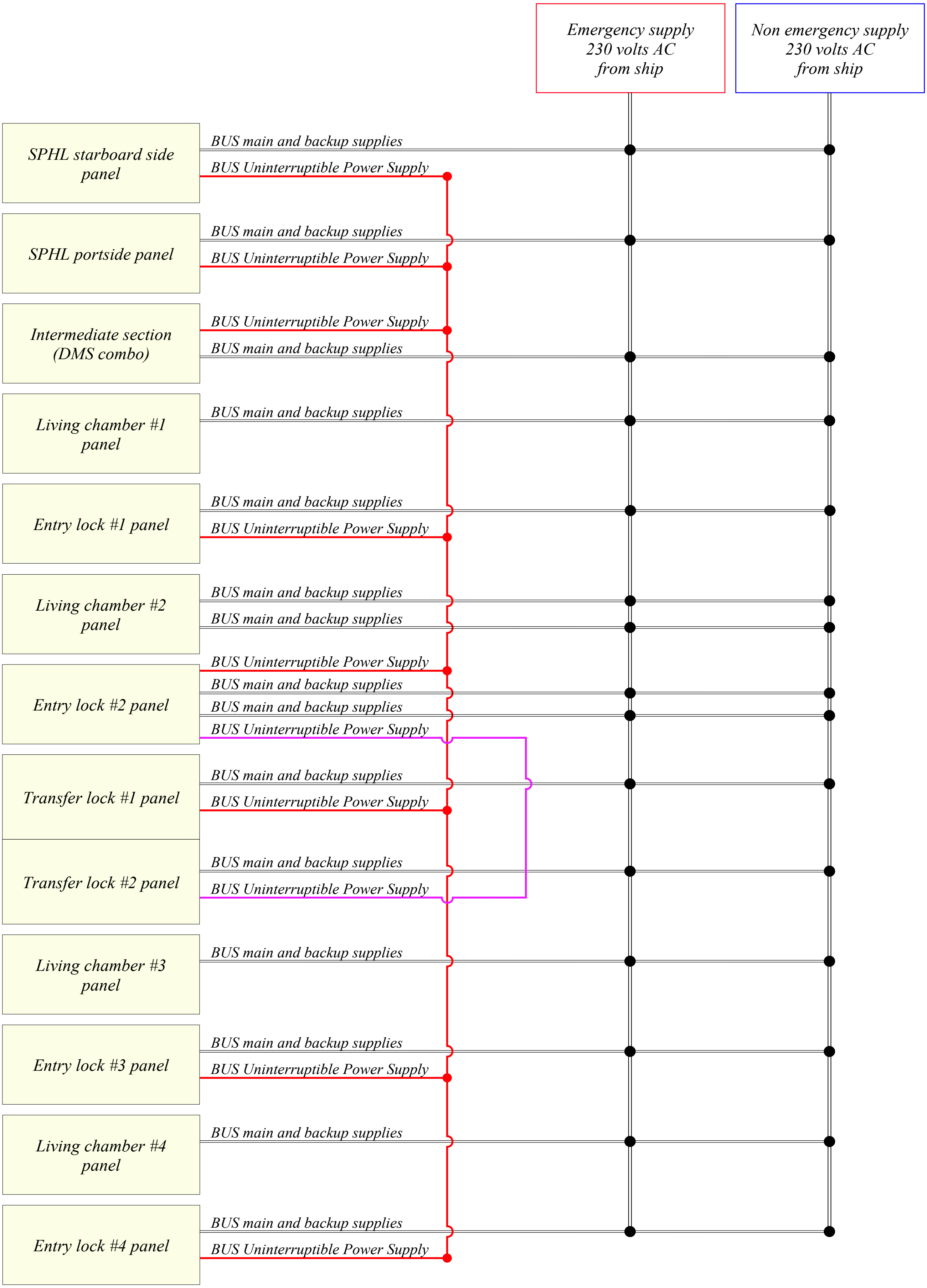
  Manual triggering must be also possible from the inside of the chamber *(see point 2.3.15.2)*.

2.3.21.10 - 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.

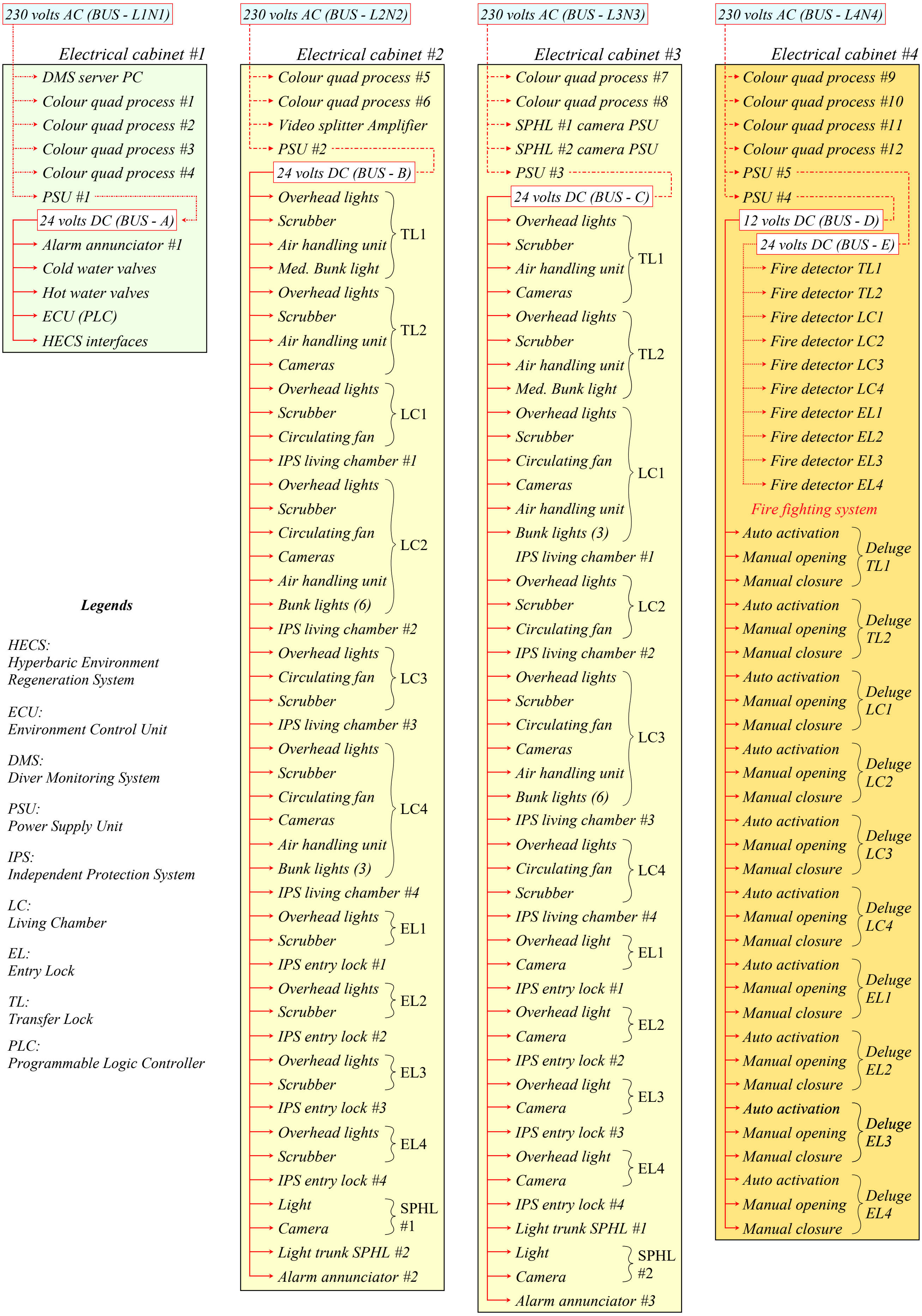
The scheme below represents the power supplies of the control panels of the systems taken as references. Note that each connection is protected by a relevant breaker.
Note that apart from those equipped with "regeneration shutdown controllers", the control panels are not used to control the electrical 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 Tables 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.



2.3.21.11 - 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 2.3.21.6)*. Note that systems such as the Fathom communications described in point 2.3.14.4 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.

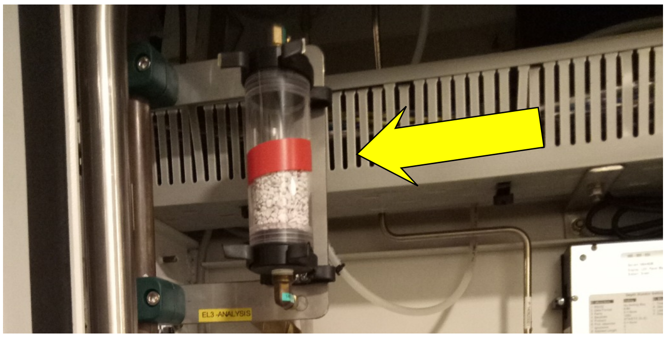
2.3.21.12 - Maintenance

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.

2.3.22 - Life support package

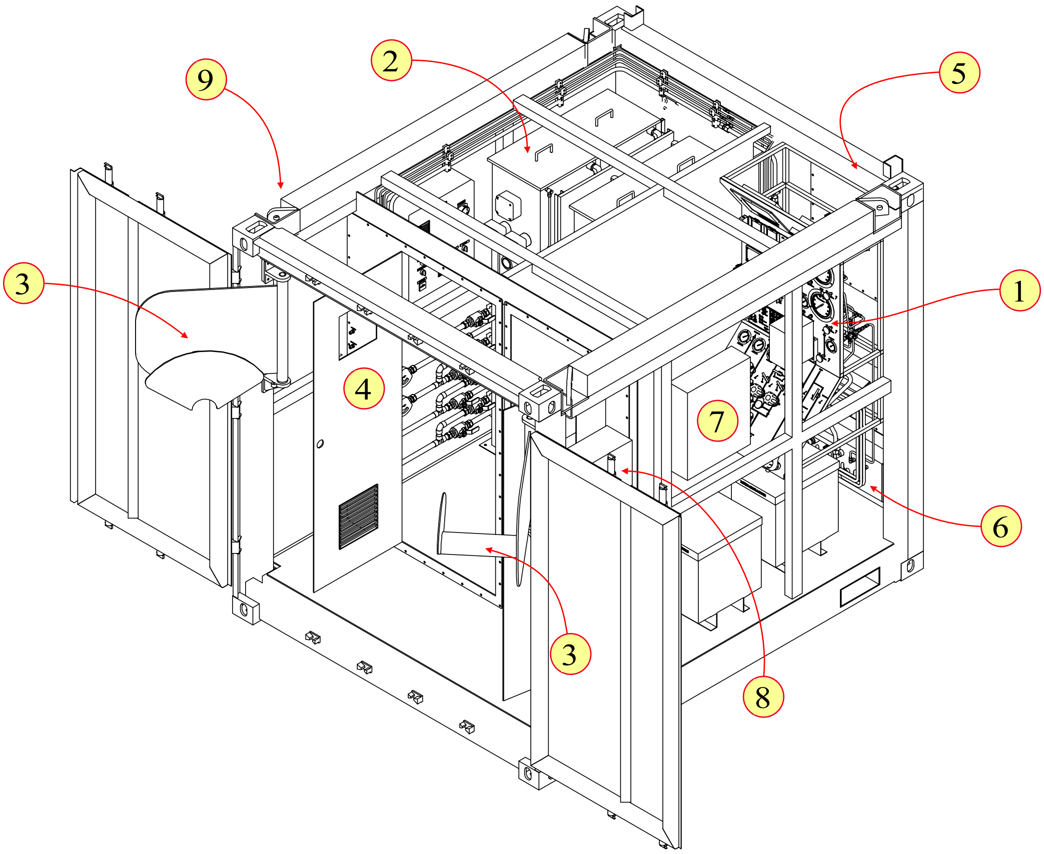
2.3.22.1 - Purpose

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.

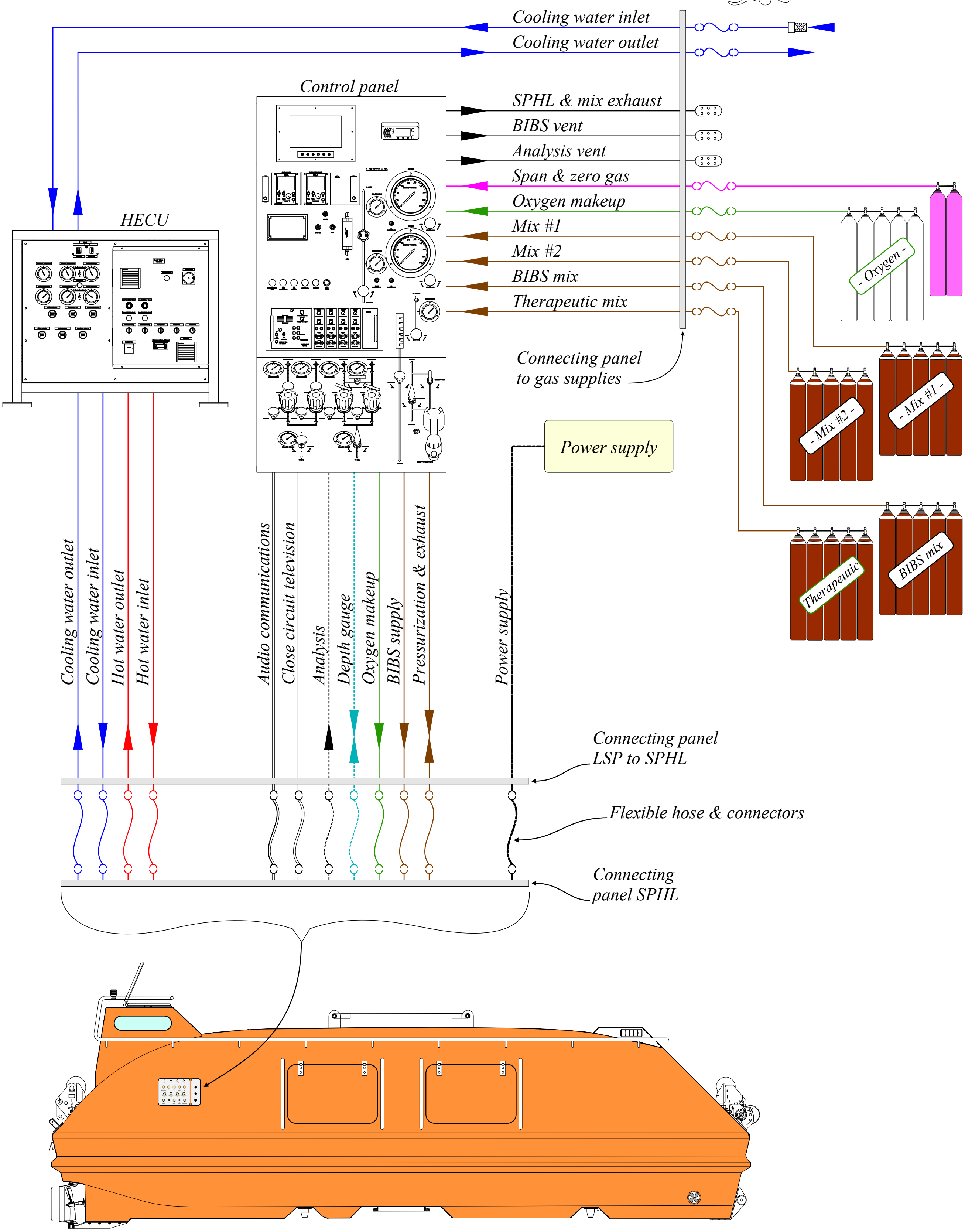
2.3.22.2 - General design

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 2.3.20.4 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:

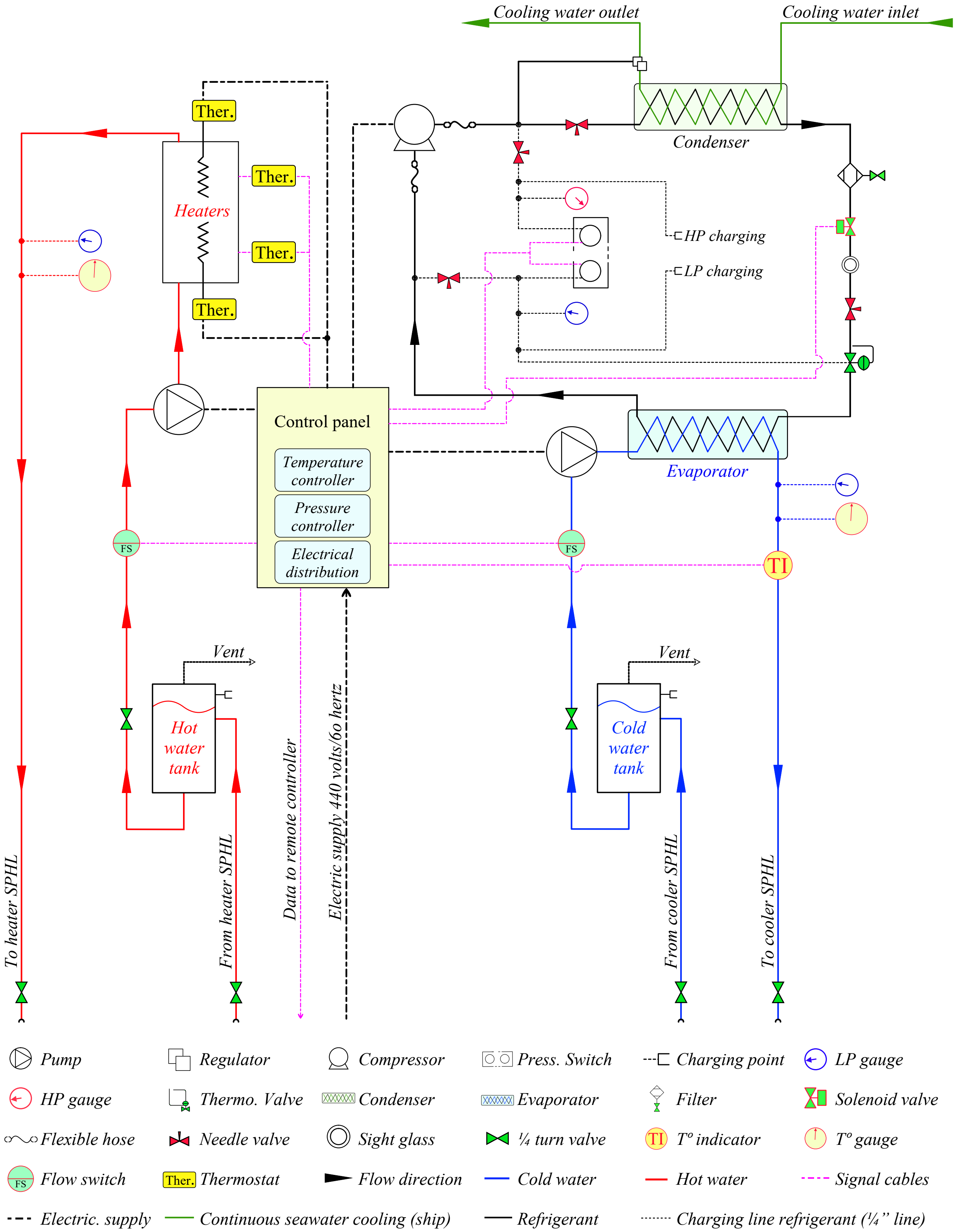
- It must be isolated against weather conditions and noises, and well illuminated:
    - Depending on the area where the operation are undertaken, heating and/or cooling systems must be present to maintain an ideal temperature (It should be between 19 to 25 degrees).

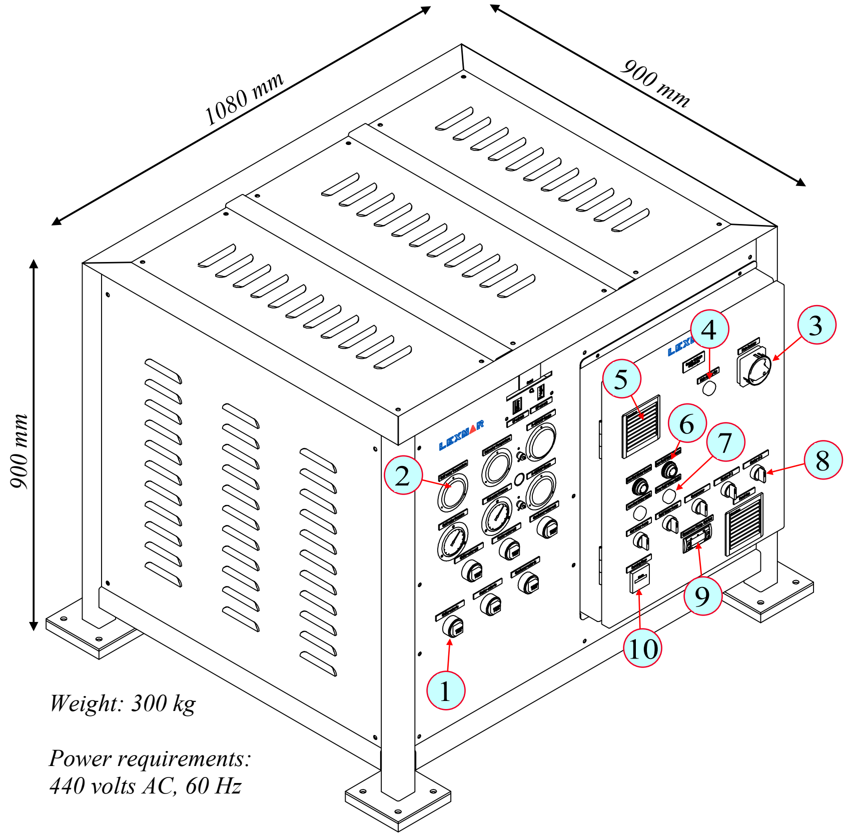
  - Noise emissions should be reduced to 65 dB maximum.
  - Illumination should be as indicated in point 2.3.21.11 of this document, so 300 Lux in all areas of the room and a minimum of 500 Lux near the control panels and desks.
- Fire alarms and fire fighting systems (fixed or portable) must be in place. 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 2.3.21.8, 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 2.3.17.1 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).





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 2.3.17 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 2.3.17 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 2.3.17 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:

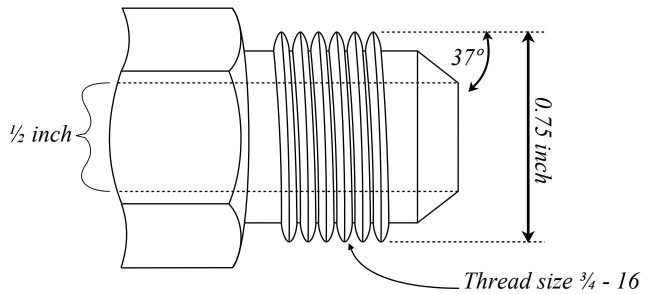
- The number of divers in the Hyperbaric Rescue Unit, and their depth.
- Whether the life support package is to be used to maintain the divers at depth and in optimal conditions during the transit to the Hyperbaric Reception Facility, or to be used to carry on a full or a partial decompression.
- The 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 2.3.20.4. 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.

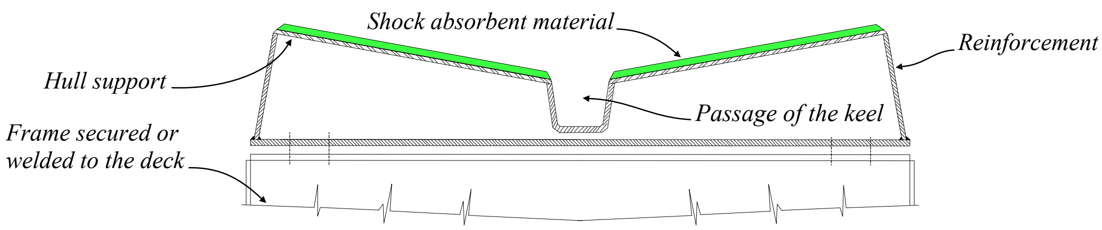
2.3.22.3 - Installation

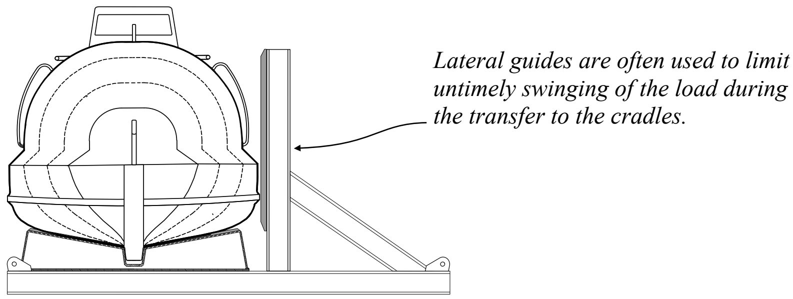
The Life Support Package (LSP) must be installed on the deck or inside the vessel in the same manner that the other elements of the saturation system. Note that this system must be designed to be operated by reduced personnel during catastrophic events. For this reason, it should be ready to be started 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

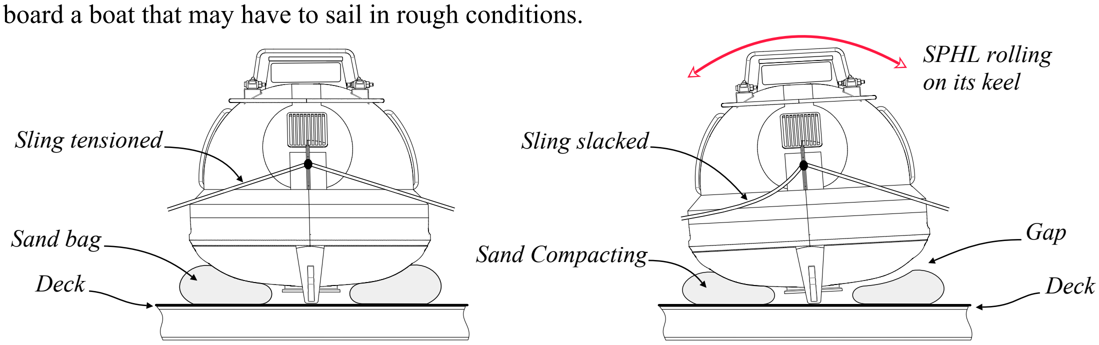
areas where gauges have to be read, and connections and maintenance performed. Based on the same document, 300 Lux should be required. Note that IMCA says that there must be a main and backup supply. Also, battery-powered emergency lighting should be available in addition to portable lights.

- 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.

2.3.22.4 - 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.

2.3.23 - Hyperbaric Reception Facility (HRF)

2.3.23.1 - 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.

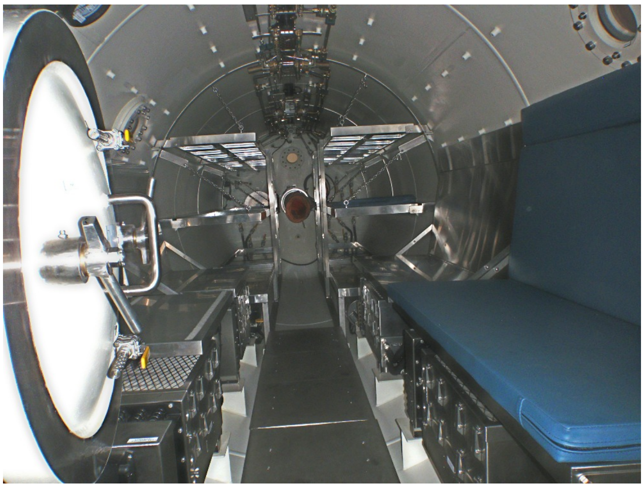
The elements that compose the Hyperbaric Rescue Facility are designed in the same manner as for saturation systems installed on diving surface supports. Thus, the rules for construction and inspection, which are described in IMCA D 053, are identical to those indicated in IMCA D 024, apart from some 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.

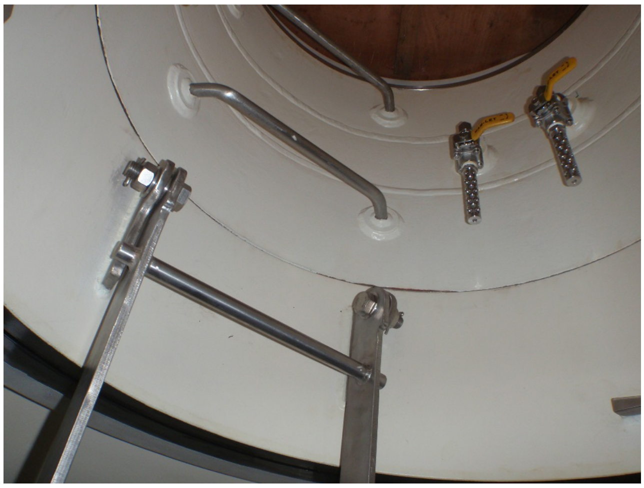
- Section #3 "HRU handling arrangements and interfaces" is specific to Hyperbaric Reception Facilities. So, is not indicated in IMCA D 024.
- Section #4 "Life support control" is identical to section #6 of IMCA D 024, except that the hyperbaric evacuation system and the general alarm indicated in IMCA 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.

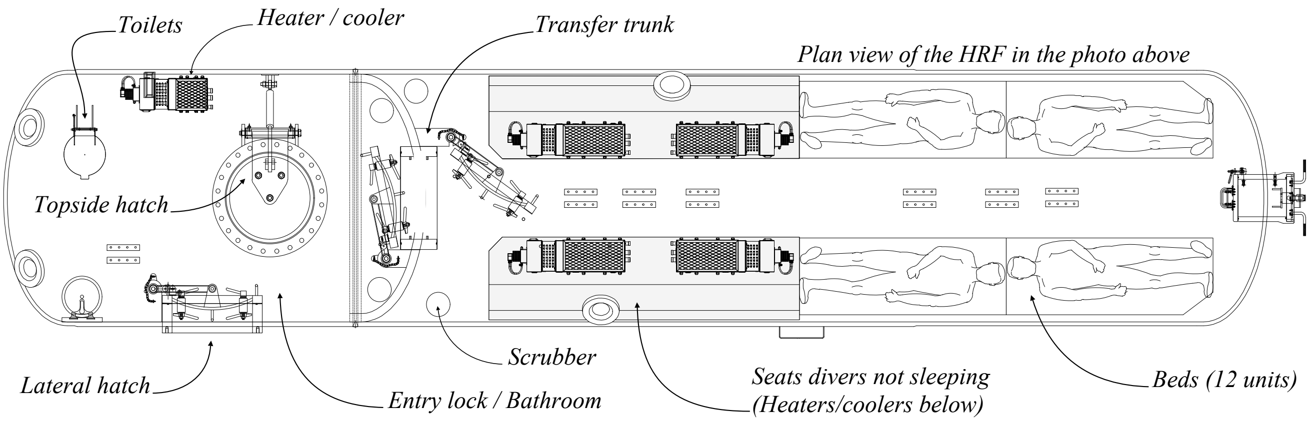
As with every saturation chamber, toilets and shower are mandatory and are provided in the entry lock. Also, the divers transferred into the Hyperbaric Reception Facility may have been a long time in the Hyperbaric Rescue Unit (HRU) during unfavourable sea conditions, so their clothes may have been contaminated 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)



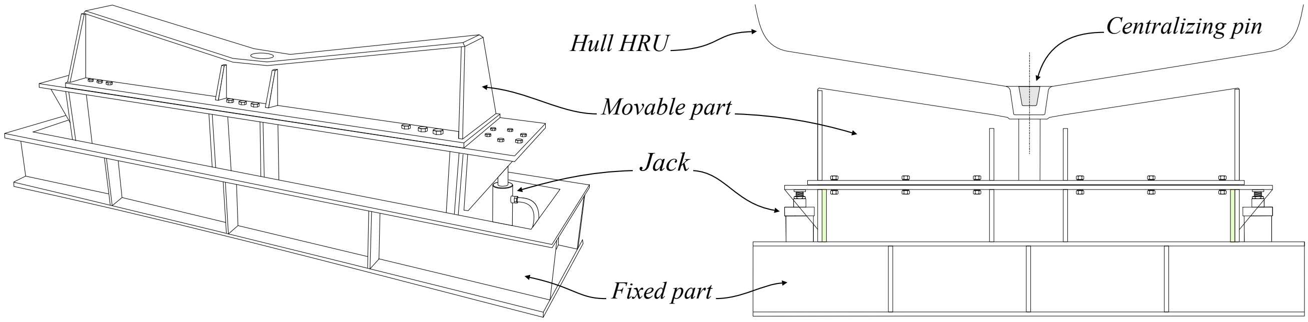
Plan view of the HRF in the photo above

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.

2.3.23.2 - Handling arrangements and interfaces

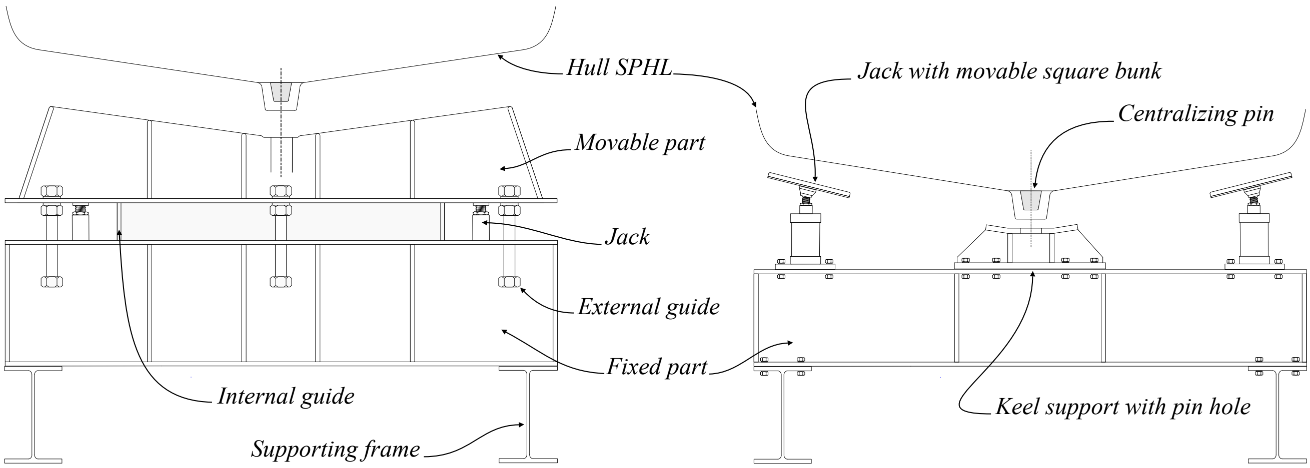
The connection of the flanges is a critical operation that requests precautions and methodology. It must be remembered that if the seal between the Hyperbaric Rescue Unit and the Hyperbaric Reception Facility cannot be established, the Life Support Supervisor is obliged to decompress the divers in the 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)*.

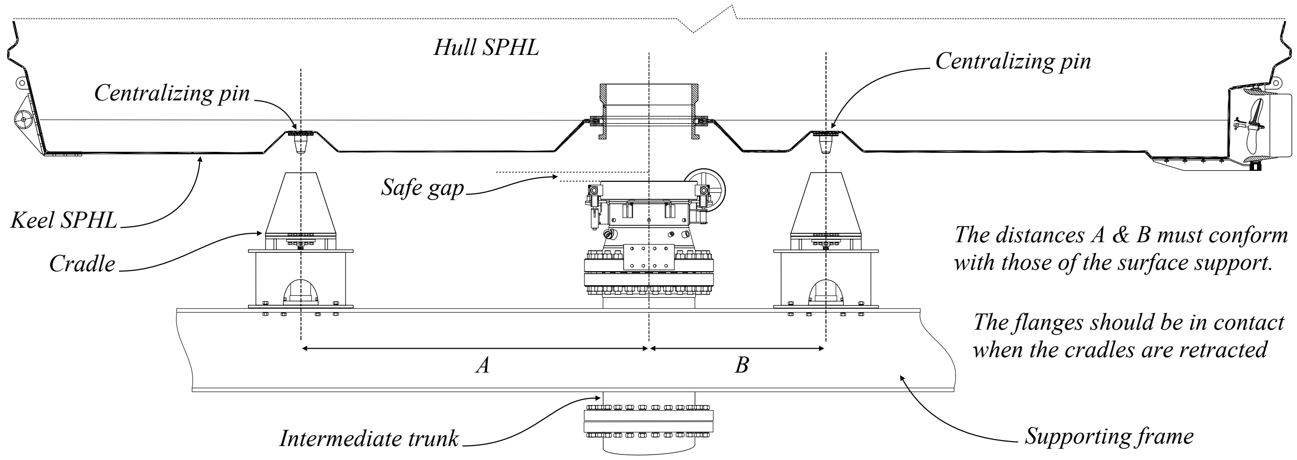


Manufacturers propose numerous models of lifting cradles. Their configuration depends on whether the HRF is designed to accommodate various types of hyperbaric rescue units or only one or two models, and the necessary space to protect the clamping system. We can classify these adjustable supports into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

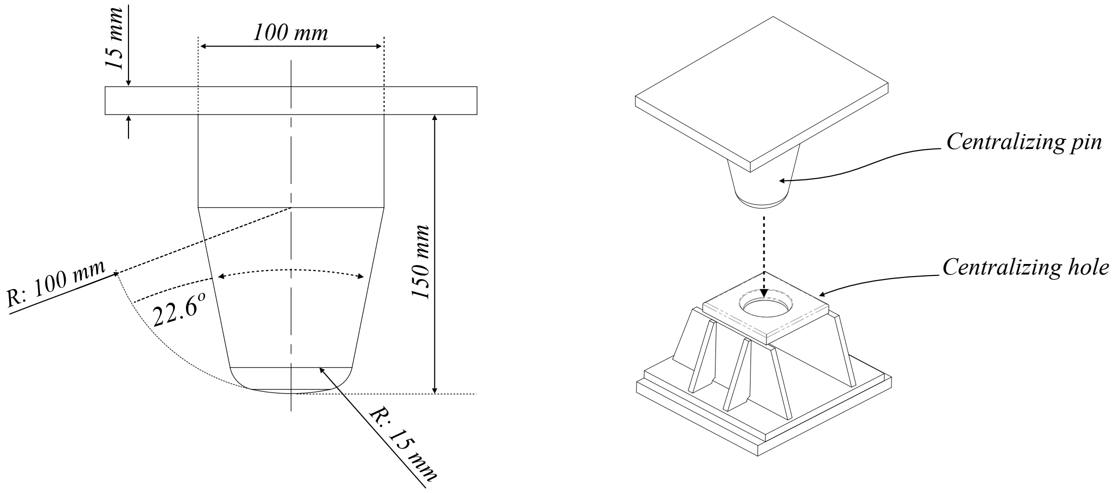


Note that the descent of the HRU must be organized such that the gap between the two flanges is perfectly regular to obtain a perfect matching. For this reason, the cradles are precisely adjusted at the recommended height to receive the unit, and the hydraulic jacks are all connected to a central pump, 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 2.3.20.2, 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.

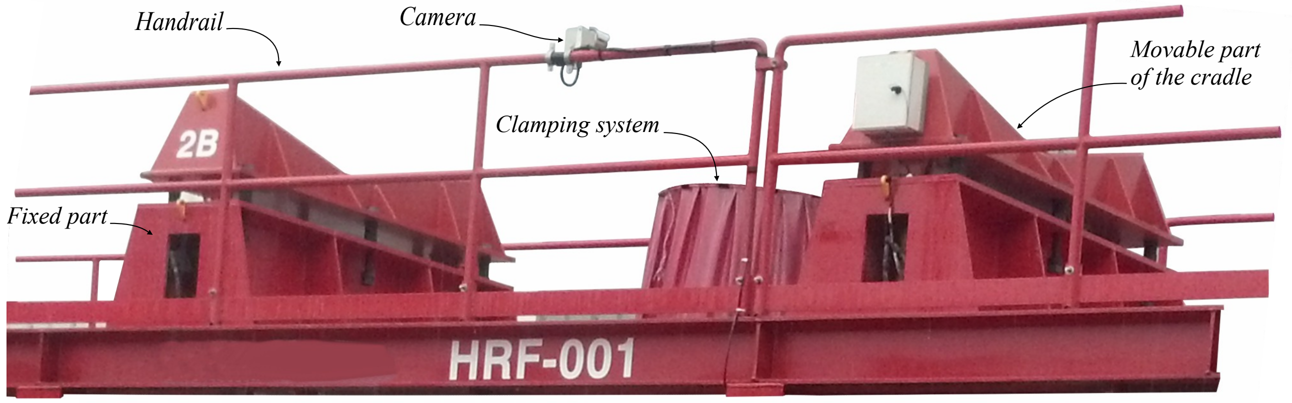


Note: IMCA recommends that the flanges are separated by at least 25 mm when the HRU is temporarily supported above its final mating position. However this minimum gap is often wider to protect the clamping mechanism.

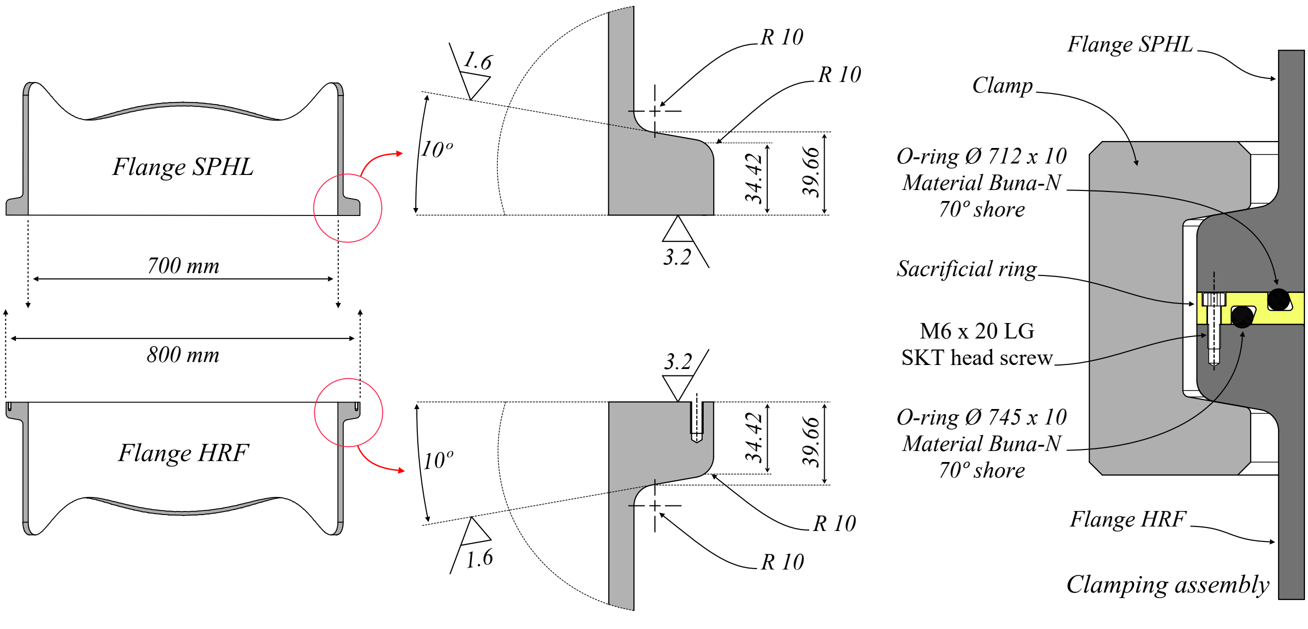
Note that the centralizing hole of the cradles must perfectly fit with the corresponding pin of the HRU. However, the pin of the HRU may be of a different size, which results that the use of an adaptation could be necessary. To avoid such a problem, IMCA D 051 recommends the measurements below with the 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 2.3.20.3 *(see the scheme below)*.

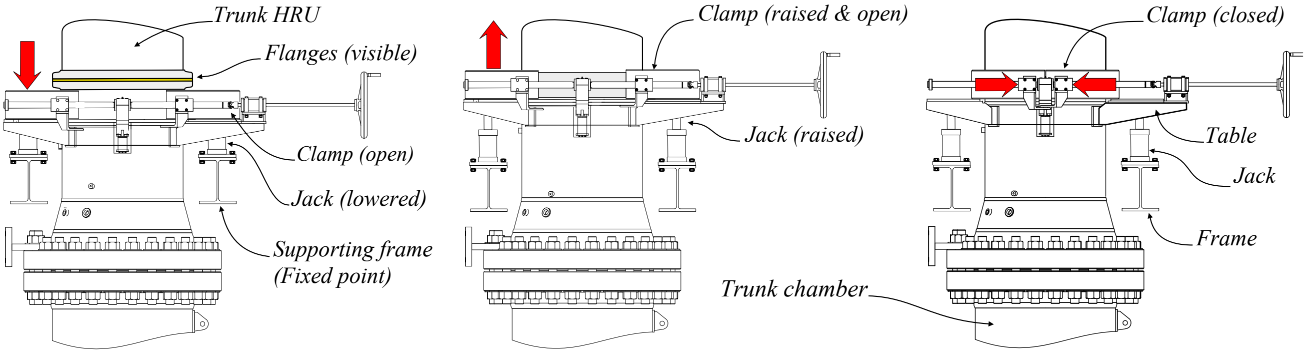


Several sacrificial rings and o-rings should be available, so those in place can be immediately replaced if they are damaged. Spare "SKT head screws" and tools to remove or extract them should also be ready for use.

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 2.3.20.2. 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.

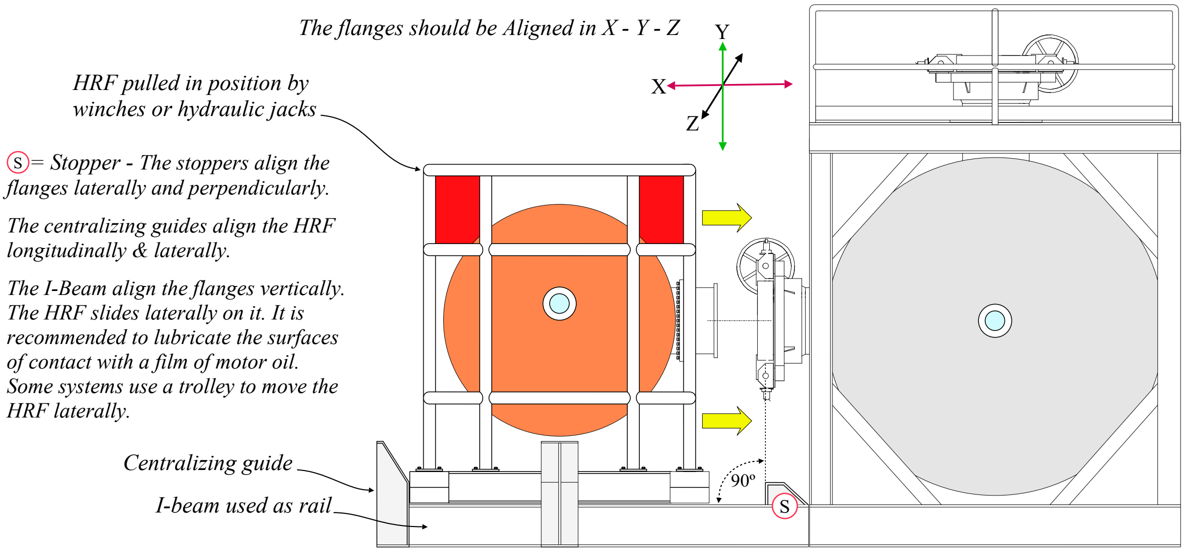
2) When the flanges are in contact, the supporting table of the clamps is raised using the jacks until the clamps can be closed.

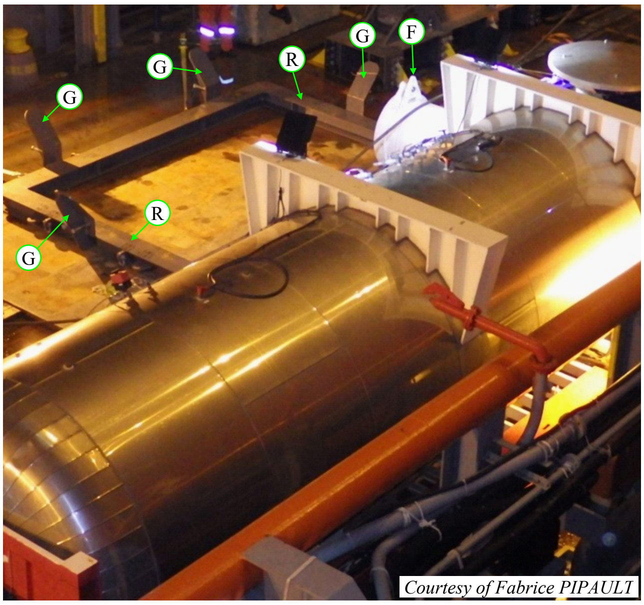
3) When the clamps are in position for closing, the supporting table is secured, and the clamps are shut. Then, the trunk is checked for leaks.

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.

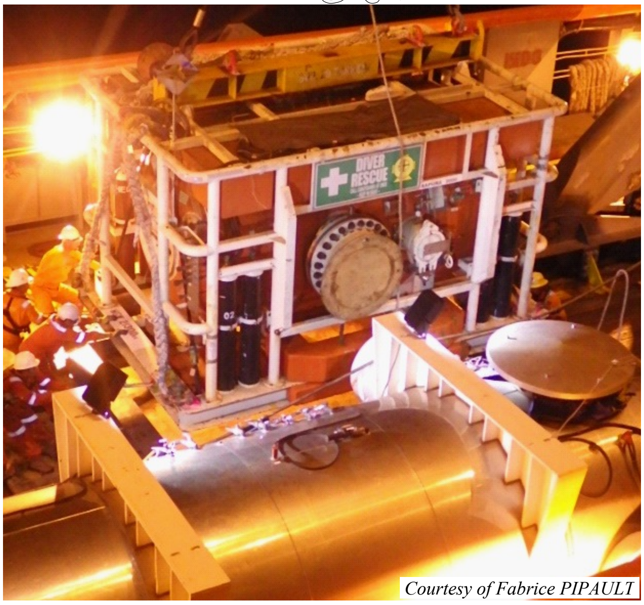
IMCA D 051 does not explain the mating of Hyperbaric Rescue Units (HRU) that are connected to the side of the hyperbaric reception facility (HRF). The procedure of approach and matching, that is mostly used with Hyperbaric Rescue Chambers (HRC) has a similar problem as for Hyperbaric Rescue Units connected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





Courtesy of Fabrice PIPAULT



Courtesy of Fabrice PIPAULT

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.

2.3.23.3 - Transfer of divers saturated at different depths

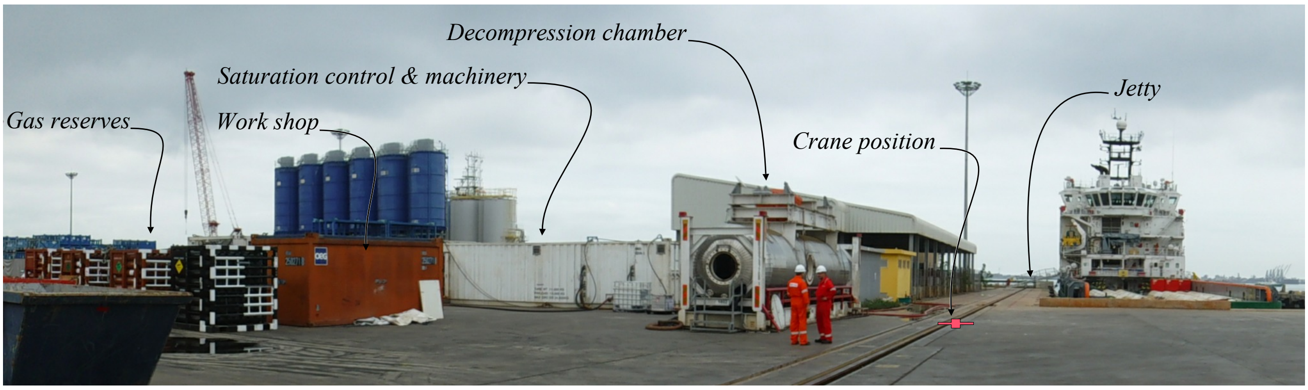
In point 2.3.20.7, it is said that several means of evacuation should be provided in case of operations with diving teams stored at depths that are too far to allow for a reasonable compression time to the deepest storage level to be able to evacuate the divers quickly. Also, the Hyperbaric Reception 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.

2.3.23.4 - 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.

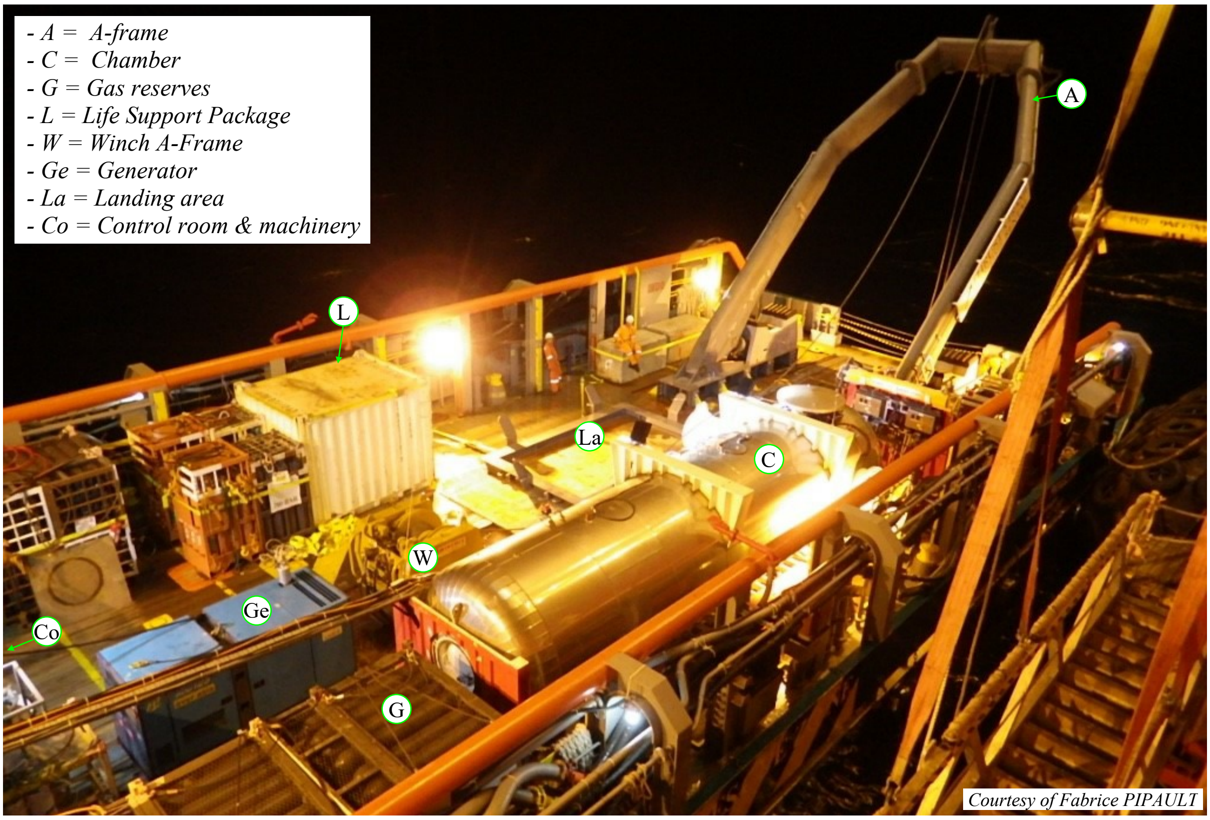


However, it may happen that the team is obliged to install it in a yard, which may oblige to organize for a transfer by truck and two cranes (one on the jetty and one in the yard).

- 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 2.3.20.9, 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.



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 2.3.23.2)*, 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	

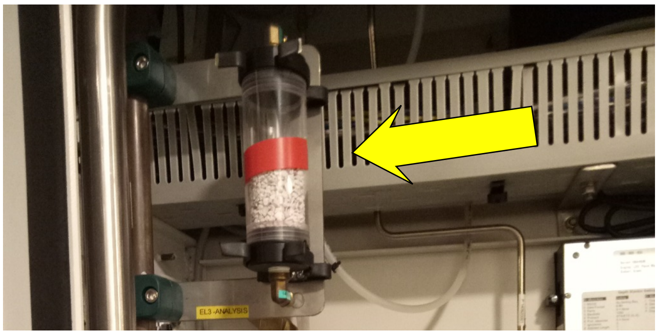
Items	*Visual external + function test , calibration*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure / 1.5 max working load lifting*	*Other*
Electrical control room	6 months			Test resistance + continuity: 6 months
Portable 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.

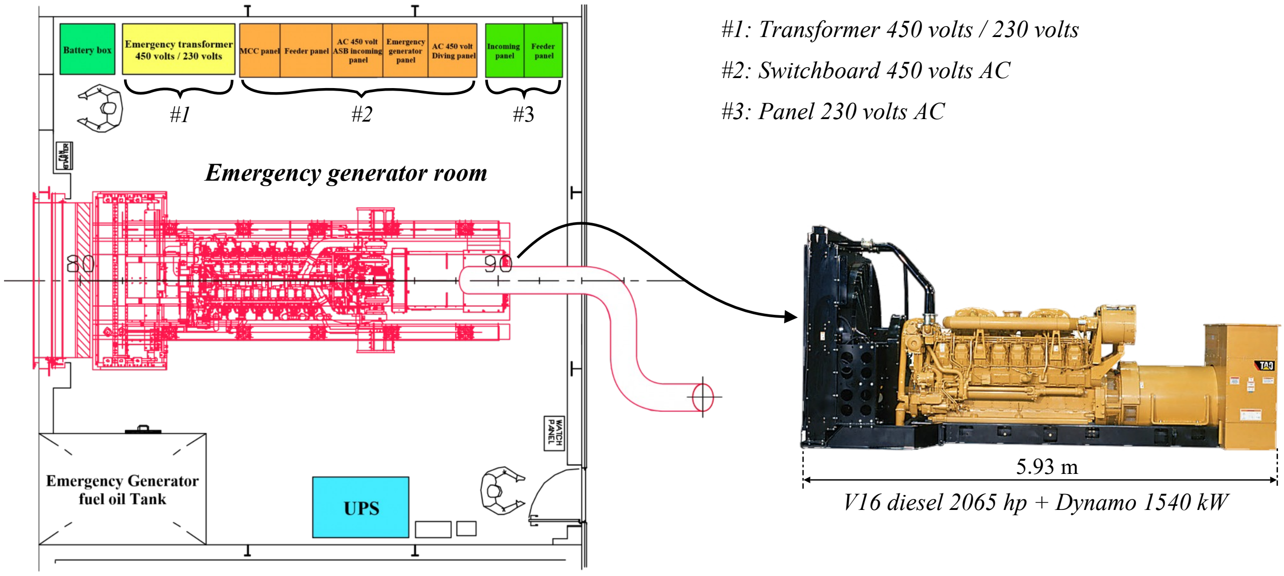
If the installation is equipped with a chamber regeneration system and a shutdown controller, the manufacturer recommends the following:

- 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

2.3.24 - Generators

2.3.24.1 - Emergency generators of built-in systems

On vessels that are equipped with permanent built-in saturation systems, the main and harbor generators are installed below the flotation line and they may be lost in the case of flooding of their compartments.
For this reason, an emergency generator is installed on the shelter deck, so on a deck that cannot be flooded, and at the vicinity of the dive control.
This generator, that is not powerful enough to energize the thrusters, can be used to energize the dive system, the ballast pumps, the fire pumps, the navigation and communication systems, and the systems for the evacuation of the ship if needed. As an example, the model installed on UDS Lichtenstein is composed of a V16 diesel engine developing 1901 kW (2549.3 hp) at 1800 rpm, and a maximum torque of 8704 Nm at 1450 rpm. The dynamo that is coupled to it delivers 1540 kW (2065 hp) at 1800 rpm. This diesel engine measures 2.98 m long x 1.97 height and 5.93 m long when assembled to the dynamo. Like the main units, this generator must comply with international classification rules.
Note that an emergency switchboard panel and a transformer are installed in the emergency compressor room with a separate fuel oil supply tank, so the generator can be operated independently and connected to the essential electrical systems described above.



2.3.24.2 - Generators of mobile systems

Dive systems installed on rented vessels may need to be powered by portable primary and backup generators when the electrical power of the boat is not sufficiently strong enough for that.
Note that these generators should be installed on decks that are above the waterline of the ship so they can't be flooded by waves in rough weather conditions.

Mobile electrical generators used to energize the dive systems are designed to provide electricity with voltages up to 450 volts and are powered by diesel engines.
Two main safety problems have to be considered that are also those of built in systems:
- The problems linked to the electricity
  - The machine and the electrical systems must be designed to avoid any accidental electrocution.
  - The electricity delivered must be compatible with the components of the system to energize and that the power delivered is sufficient.
- The problems linked to the use of a thermal engine
  - The machine must not emit sparks which could ignite in an explosive atmosphere.
  - The machine must not emit harmful gases in excess.

Note that the international standard IEC 61892, gives guidelines for the electrical installations on mobile and fixed offshore units.

2.3.24.3 - Protection against electrical shocks

System earthing must be performed for all electrical power supply systems to control and keep the system's voltage to earth within predictable limits. It must also provide for a flow of current that will allow detection of an unwanted connection between the system conductors and earth, which should instigate automatic disconnection of the power system from conductors with such undesired connections to the earth.
Earth indicating devices should be so designed that the flow of current to earth through it is as low as practicable, but in no case should the current exceed 30 mA.

In addition to the previous point, a “residual current circuit breaker” (RCCB), also called “residual-current device” (RCD), must be installed on the generator, or just at the current outlet of the generator. These devices are designed to disconnect the circuit if there is a leakage of current. By detecting small leakage currents, and disconnecting quickly enough, they may prevent electrocution. To prevent electrocution, the “Residual Current Circuit Breakers” should operate within 25-40 milliseconds with any leakage of current (through a person) of greater than 30 milliamperes, before the electric shock can drive the heart into ventricular fibrillation, which is the most common cause of death through electric shock.

The rules applied for the construction of the boat should apply for portable systems installed on them: All electrical equipment should be constructed or located in such a way that live parts cannot be inadvertently touched. Also, electrical equipment should be so selected and located or protected that the effects of exposure to sea-air, water, steam, oil or oil fumes, spray, ice formation, etc., are minimized. It should be located well clear of boilers, steam, oil or water pipes, and engine exhaust pipes and manifolds, unless specifically designed for such locations. If pipes must be run adjacent to electrical equipment, there must be no joints near the electrical equipment.
Besides, when due to the size of the vessel, it is impossible to install all the generators on the upper deck as recommended before, the generator that is installed on the main deck, which could be exposed to waves, must be installed in the most protected part of this deck, and on legs with a minimum 40 cm height to allow the waves to pass freely underneath and not invade it. The installation of a generator on the main deck must be risk assessed, and this condition must be entered in the audit of the system. The auditor has the authority to reject such installation if he considers that the equipment is too exposed.

Insulating materials and insulated windings should be resistant to moisture, sea air, and oil vapour unless special precautions are taken to protect insulants against such agencies.
Cable glands or bushings, or fittings for screwed conduits, should be provided according to the way in which the cables enter the equipment. All entries must maintain the degree of protection offered by the enclosure of the associated equipment. The connectors should be marine waterproof type.

The equipment should be unaffected by vibration and shock likely to arise under normal service. The connections shall be secured against becoming loose due to vibration.

2.3.24.4 - Provision for maximum electrical load

All conductors, switchgear and accessories shall be of such size as to be capable of carrying, without their respective ratings being exceeded, the current which can normally flow through them. They shall be capable of carrying anticipated overloads and transient currents, for example the starting currents of motors, without damage or reaching abnormal temperatures.
In general, all electrical equipment must be constructed of durable, flame-retardant, moisture-resistant materials, which are not subject to deterioration in the atmosphere and at the temperatures to which they are likely to be exposed.

2.3.24.5 - Hazardous areas

Every electrical apparatus must, as far as possible, be located in non-hazardous areas. It must be remembered that diving operations are not possible in hazardous areas. But, activities alongside platforms are standard, and an incident may happen. As a reminder, hazardous areas are classified into zones based upon the frequency of the occurrence and duration of an explosive gas atmosphere, as follows:

zone 0: Area in which an explosive gas atmosphere is present continuously or for long periods. These areas include:

- areas within process apparatus developing flammable gas or vapours;
- areas within enclosed pressure vessels or storage tanks;
- areas around vent pipes which discharge continually or for long periods;
- areas near surface of flammable liquids in general.

zone 1: Area in which an explosive gas atmosphere is likely to occur in normal operation. These areas include:

- areas above roofs and outside the sides of storage tanks;
- areas with a certain radius around the outlet of vent pipes, pipelines and safety valves;
- rooms without ventilation, with direct access from a zone 2 area;
- rooms or parts of rooms containing secondary sources of release where internal outlets indicate zone 2, but where efficient dilution of an explosive atmosphere cannot be expected because of lack of ventilation;
- areas around ventilation openings from a zone 1 area;
- areas around flexible pipelines and hoses;
- areas around sample taking points (valves, etc.);
- areas around seals of pumps, compressors, and similar apparatus, if primary source of release;

zone 2: Areas in which an explosive gas atmosphere is not likely to occur in normal operation and, if it does occur, is likely to do so infrequently and will exist for a short period only. These areas include for example:

- area around flanges, connections, valves, etc…
- areas outside of zone 1, around the outlet of vent pipes, pipelines and safety valves.
- areas around vent openings from the zone 2 area.

A procedure to escape safely from hazardous atmosphere area should be part of the emergency response plan.

Emergency stop controls for motor driven fuel-oil transfer and fuel-oil pressure pumps should be provided at a readily accessible point outside the compartments in which the pumps are situated. The controls should be of the manual re-set type and suitably labelled *(IEC 61892)*.

The generators are powered by diesel engines and “spark arrestors” are mandatory to enter in an oilfield.
A properly installed and maintained spark arrester can greatly reduce the threat of fire and explosion by trapping the carbon particles. Home made spark arrestors are not acceptable. The device should be manufactured according to guide lines of the European directive ALTEX 94/9 EC and the norm EN 1834-2 /98/37/EC or similar *(For example USA and Canada have their own, but very similar, standards)*.
Note: A device conforming to the directive ALTEX 94/9 EC should have the logo Ex in addition to the name of the manufacturer and the traceability code.

2.3.24.5 - Harmful gases emissions

This point should be covered by the European directive “97/68 EC - stage I/II” which is adopted by numerous countries such as Thailand, Singapore, China… and harmonized with some others like the USA, Japan, Canada…
The equipment covered by the standard include industrial drilling rigs, compressors, construction wheel loaders, bulldozers, non-road trucks, highway excavators, forklift trucks, road maintenance equipment, snow-ploughs, ground support equipment in airports, aerial lifts, and mobile cranes.
This directive imposes the maximum emissions of carbon monoxide, hydrocarbons, nitric oxide, and particles. The emissions are calculated according to the power of the thermal engine:

Note:
The emissions should be measured on the ISO 8178 C1 8-mode cycle and expressed in grams of emissions per kWh (G/kWh).
Stage I/II engines are tested using fuel of 0.1-0.2% (wt.) sulfur content.

Legends:
CO: Carbon monoxide
HC: Hydrocarbons
NOx: Oxides of nitrogen
PT: particulates

Cat	***Net power***	***CO***	***HC***	***NOx***	***PT***
	KW	***G/kWh***			
Stage 1 - Spark ignition engines					
A	$130 \leq P \leq 560$	*5*	*1.3*	*9.2*	*0.54*
B	$75 \leq P < 130$	*5*	*13*	*9.2*	*0.7*
C	$37 \leq P < 75$	*6.5*	*1.3*	*9.2*	*0.85*
Stage 2 - Compression engines (diesel)					
E	$130 \leq P \leq 560$	3.5	1	6	0.2
F	$75 \leq P < 130$	5	1	6	0.3
G	$37 \leq P$ 75	5	1.3	7	0.4
D	$18 \leq P < 37$	5.5	1.5	8	0.8

2.3.24.6 - Other hazards

- Noise:
  Silencers should be used where the sound level caused by exhausting air or the engine is above that permitted by applicable codes and standards. The noise emitted by the generator should be below 85 Decibels. In cases of levels above this value, the document HSE “Control of Noise at Work Regulations 2005 (CoNWR05)” should be referred to. This document is part of the module “Diving accidents” in the chapter “Harmful noise”.
- Protection from moving and scalding parts:
  The methods of avoiding injuries to operators are to make use of a minimum gap and to enclose the moving and scaling parts of the machine.
  - Barriers should be erected to ensure that only the authorized personnel is around the machine
  - Access to moving parts should be restricted by devices which prevent any unintentional contact. A safety device stopping the machine, and preventing to start it when the protections are open/removed is recommended.
- Fire fighting:
  Fire can start in the generator despite the precautions indicated before. For this reason, care should be implemented to ensure that a starting fire will be quickly extinguished. Appropriate fire fighting systems (B + C) should be provisioned in the direct vicinity of the machines, and fire detection systems should be installed. Note that extinguishers integrated into the engine compartments exist and are recommended.

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3) Avoid & manage breakdowns

3.1 - Organize a reliable saturation diving system

3.1.1 - Purpose

Saturation systems are not mass-produced items, and for this reason, they are expensive investments that represent several millions of dollars in which amortization is rarely possible at short term notice. Also, built-in systems are part of ships that have been built around them in such a manner that their replacement would imply a partial dismantling and reconstruction of the vessel.
Besides, the previous chapter shows that these sophisticated pieces of machinery are assemblies of complex components that are interconnected such that they can be in the breakdown due to the failure of one of them. As a result, minor disruptions can rapidly extend to the entire system and then may lead to more significant breakdowns that may have the potential of threatening the divers and their supporting teams if they are not detected and solved sufficiently early.
For these reasons, it is the primary importance of organizing a relevant maintenance system that can solve unexpected breakdowns and manages to have such events not happening.

3.1.2 - Elements necessary to implement a maintenance system

Two types of maintenance are to be organized with diving systems:

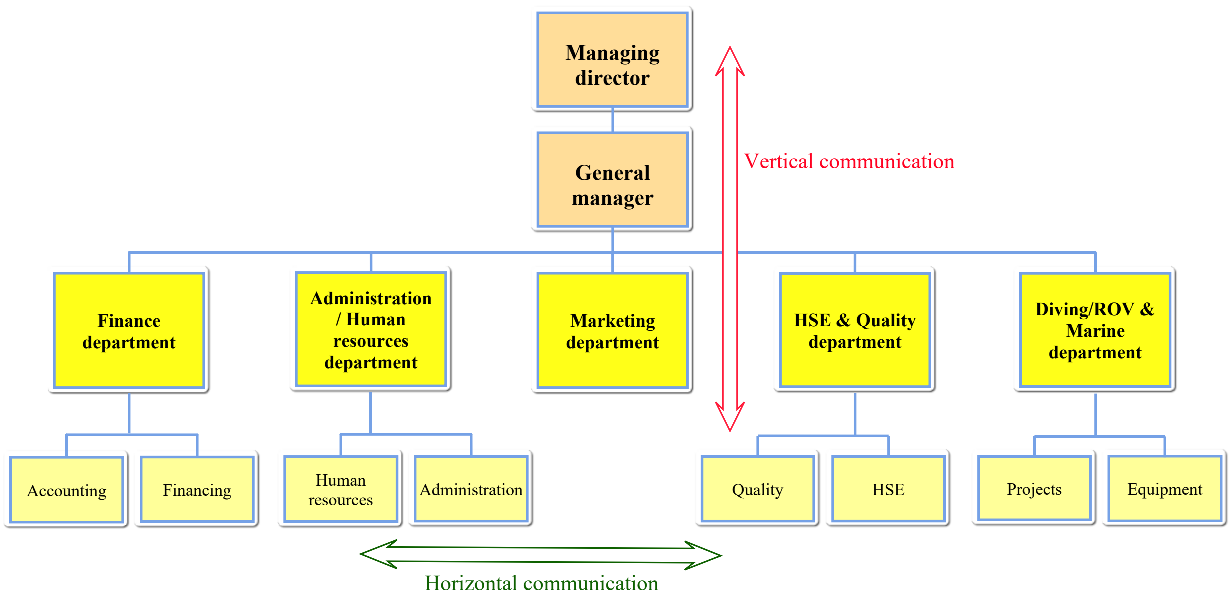
- The solving of breakdowns of systems during the operations.
- The preventive maintenance of systems in use and stored.

As a result, the maintenance of saturation systems implies an organization that cannot be implemented at the last minute of a project. For this reason, companies have to organize a specific structure for this purpose. Note that clients and international organizations for quality management systems such as ISO (International Standards organization), OSHA (Occupational Safety and Health Administration), and others request such a structure.

3.1.2.1 - Organization of the management system of a company and maintenance structure

To be able to work efficiently, diving and maritime companies are structured in departments that are grouped by function. This basic organization is the same for all companies. However, depending on whether the company is a multinational company introduced on the stock market or a family structure, this organization may slightly differ.

In the basic classical scheme displayed below, which is from a small existing diving contractor, each department is organized to perform the function that has been assigned to it, and under the responsibility of a manager who reports to the "General manager" who reports directly to the "Managing Director" who oversees the operations of the company.
For more efficiency, the department can be divided into "branches". Each branch manages a dedicated part of the missions assigned to the department. These branches can be divided into smaller sections.
With this organizational system, the lower levels of the organization give information to employees that are at a level immediately above and follow the commands from these employees who are doing the same with the level directly above them. Thus, the transmission of information and orders to and from the management are made vertically, and the transfer of information between people, divisions, departments, or units within the same level of the organizational hierarchy is made horizontally.
This type of organization that reflects a hierarchy is called "Pyramidal structure". It aims to organize the full control of the key elements by the "managing director". Note that more complexes systems of management exist, but this one is the most encountered.



In the example above, the company has several diving systems but is not sufficiently powerful to have boats. So the boats are rented, and for this reason, the marine department and diving department are grouped. However, such departments are often separate in more powerful organizations.
When creating a maintenance structure, the problem of management teams is to ensure that they have adequate controls on it, and that it can work efficiently without being disturbed by too many administrative controls. For these reasons, they usually organize it such a way that it works closely with the following departments:

- Human resources:
  This department is in charge of recruiting personnel according to the necessary competencies for staff performing maintenance work and others. For this reason, the requirements and method of sourcing should be evaluated with the management in charge of the maintenance structure. Note that besides, this department is usually in charge of the organization of training or other actions to achieve or increase the necessary competencies of the personnel.
- Finance department:
  Finance departments are usually divided into several sub-departments such as accounting, purchasing, financing, procurement, etc., where each of them has a particular function. Maintenance of equipment means that spare parts have to be bought and that interventions of external suppliers have to be organized. As a result, a system for selecting and paying these suppliers should be in place. This selection is not only based on the prices practiced but on the quality of the services proposed by suppliers, which can be analyzed by competent technicians only.
- Heath, Safety, Environment (HSE), and Quality departments:
  These functions are often grouped with small companies and separate in more important organizations. The HSE department makes sure of the consistent quality of services by developing and enforcing good safety practices, validating processes, and providing documentation and safety specialists.
  The aim of quality management is to fulfill the customer's expectations in terms of quality, delivery, budget, and safety.
  People in charge of the maintenance of the diving systems are involved with these two departments as the safety of the divers and the quality of the services of a company depends on the reliability of the saturation system.

To conclude with this point, the structure in charge of the maintenance of the diving systems must be part of the management system of the company, and work in symbiosis with the other departments. These relationships must be in place at all times, as the efficiency of the maintenance team could be compromised if it is not the case.

3.1.2.2 - Select the technicians and define their function

This point is the most crucial for the implementation of the maintenance system: Managers will not be successful in implementing it if there are not good competent people to do it.

Competence is a combination of knowledge, skills, experiences and behaviour that give a person the ability to perform a specific task successfully.

- Knowledge is the information a person has in a specific work area. Example: A diving supervisor is supposed to know the physiology associated with diving.
- Skills are the ability to perform certain mental or physical tasks. Example: The ability to perform underwater welding, or the ability to manage a team.
- Traits are physical characteristics and consistent responses to situations. Example: Physical fitness and self-control are essential for divers.
- Experience is the accumulated knowledge or practical wisdom gained from what one has observed, encountered, or undergone. As an example, a young diver has knowledge but limited experience.
- Behaviour is the manner of conducting oneself. Two elements that have impact on behaviour are often highlighted:
  - Motives are the reasons for a certain course of action whether conscious or unconscious.
  - Self-esteem is a term used to refer to how someone thinks about, evaluates, or perceives himself.

A competency model categorizes which core skills are needed to be successful in a particular position. This process is often called "competency mapping" by the specialists. The following steps should be performed:

1. Conduct a job analysis.
2. Identify a competency model.
3. Once a clear competency model has been identified, ideal candidates can be identified by matching them against the identified criteria.
4. Taking the competency model one step further, an evaluation to identify in what competencies individuals need additional development or training is made.

The required competencies for a particular position are identified into a matrix. This matrix should be categorized into several parts: Knowledge, skills, experience and behaviour.

Competency guidance have been developed by IMCA to provide a framework on which competence schemes can be built. These guidelines aim to:

- Specify minimum standards for qualifications and, where applicable, minimum experience required to ensure that personnel are competent to fulfil their safety-critical and other relevant responsibilities and fulfil their roles.

- Specify a competence assurance framework showing how proficiency can be developed, demonstrated, accepted and maintained.
- Provide a reference document detailing the procedures, criteria and recording system to be applied when assessing the competence of personnel engaged in all positions but especially safety-critical positions.

IMCA C 003 says that a dive technician should possesses detailed knowledge of one or more of the following: Electrical, electronic, mechanical or hydraulic engineering. This knowledge should be obtained through academic education or experience and qualification in a military environment.
Note that some diving schools such as Interdive http://www.interdive.co.uk/ or the National Hyperbaric Center (NHC) https://www.jfdglobal.com/training propose a dive technician module.

Also, a lot of IOGP members request the dive technician to be certified by an agreed training establishment. In addition, some IOGP members ask that the technicians have gauge calibration and high-pressure regulator maintenance certificate in addition to their mechanical and/or electrical qualification. These clients also require that at least one technician is in possession of a Divex Ultra Jewel Reclaim certificate or equivalent.
However, these requirements aim to be sure that the technician is appropriately trained do not fully take into account the complexity of modern systems.
For this reason, it is important to keep in mind that the level of training required and the level of competence for an individual will depend upon the complexity and range of equipment he/she is to work on, and that many last generation saturation systems that are fully computerized require specific competencies that were not asked for in the past.
For these reasons, the owners of the last generation saturation systems should ensure that the technicians are familiar with the design and computer programming procedures of the system they work on in addition to its particular mechanical and electronic designs.
Also, the level of the technicians working on a system must be classified according to their competencies and degrees of experience. To answer to this problem, the last IMCA guidance D 001 “Dive technician - Competence and training” give the following classification and recommendations:

- New entrants to the industry should be considered as trainees until they are considered sufficiently experienced to work without supervision. Also, they should hold a certificate of qualification from a recognized organization.
  - Electronics
  - Mechanical engineering
  - Hydraulic engineering
  - Electrical engineering
  - Marine engineering
  - Motor vehicle engineering
  - Aviation technician (any discipline)
  - Agricultural machinery maintenance and repair
  - Plumbing
  - Shipbuilding
  - Telecommunications

  Based on the skills and the previous experience of the person, a training programme should be in place. IMCA says that this training can be shared between periods on the job and periods in various training establishments. This training plan should be part of the competence assurance and assessment scheme of the company.
- A confirmed dive technician is a person who has demonstrated sufficient experience and competence to work without supervision. IMCA say that it implies that this person has been assessed by his/her employer. He/she should be qualified for one or several topics listed above
- IMCA D 001 says that a senior dive technician is expected to have the knowledge of the equipment he/she is in charge and demonstrate problem-solving and diagnostic abilities. That includes certification, testing, maintenance requirements, and permit to work and other administrative routine procedures.

The dive technician must:

- Ensure that the diving system is working correctly and is suitable for the planned operations
- Maintain the system, and make sure that the certifications are up to date through the Periodic maintenance system
- Report any equipment faults
- Know the routine and emergency procedures;
- Report any potential hazards, near misses or accidents.
- Take reasonable care for his own safety and that of other persons who may be affected by his acts or omissions at work;
- Where he/she does not have any other additional role and if he/she is employed by the diving contractor the technician may also be used in non-specialist functions, e.g. winch operator, where competent to do so.

Note that it is recommended to select dive technicians with complementary skills to cover all the technical aspects of the diving system. Also, one technician should be a senior technician
Discontinuities in the maintenance of these complex pieces of machinery may result in breakdowns and catastrophic

events. For this reason, it is recommended to organize for the same senior technicians to be in charge of a system. If it is decided to assign them to other tasks, the persons who replace them should be sufficiently competent to take over.

3.1.2.3 - Select suppliers and service providers

Dive systems are assemblies of elements in which some parts require particular skills the technicians in charge do not have, or which need the use of expensive tools which investment in is not justified. For this reason, most companies use the services of external service providers. Also, diving companies use the services of manufacturers and resellers who provide them the equipment they need.
Note that gains to be made in cost, time and quality through working in partnership with suppliers are significant. Nevertheless, choosing a supplier involves much more than scanning a series of price lists. The choice will depend on a wide range of factors such as value for money, quality, reliability and service.
The most effective suppliers are those who offer products or services that match, or exceed the needs of a company.
It is important to have a choice of sources, as buying from only one supplier can be dangerous: While exclusivity may spur some suppliers to offer a better service, others may simply become complacent, or not be able to serve the company properly during the critical phase of a project. Also, commercial issues may happen that can let the company in a critical Situation.

- Criteria for evaluation

Supplier performance is usually evaluated in the areas of pricing, quality, delivery, and service.
Note that the lowest price is not always the best value for the money: The balance between cost, reliability, quality and service should be considered.

- Pricing
    - The prices proposed should be favourably comparable to those of suppliers providing similar product and services.
    - Prices should be reasonably stable over time. Also, there should be a notice prior to any change in price.
    - The prices indicated on the invoices conform with those indicated on the purchase orders.
    - Invoices are easy to read and understand. The average length of time to receive invoices should be reasonable.
- Quality
    - The supplier should comply with terms and conditions stated in the purchase order.
    - The products or services conform to the specifications identified in the proposal and the purchase order.
    - The equipment sold by the supplier is reliable: They have limited breakdowns and reasonable durability.
    - A quality support program with immediate response and resolution of the problems is available.
    - Repairs of equipment are acceptable.
    - The length and provisions of warranty protection offered is reasonable: Problems are resolved in a timely manner.
    - The supplier offers products and services that are consistent with the industry standards.
- Delivery
    - The supplier delivers products and services on time.
    - The vendor delivers the correct items or services in the contracted quantity.
    - The average time for delivery is at least comparable to that of other vendors for similar products and services.
    - Packaging is sturdy, suitable, properly marked, and undamaged. Pallets should be of the proper size.
    - Proper documents (packing slips, invoices, technical manual, etc.) with correct material codes and proper purchase order numbers are provided at the delivery .
    - The supplier can organise emergency delivery if requested.
- Service
    - The supplier's representatives are courteous and professional. They handle complaints effectively.
    - The supplier answers promptly to demands of quotation. He provides regularly up-to-date catalogues, price information, and technical information.
    - The supplier should display knowledge of the company needs. It should also be helpful.
    - An efficient emergency support for repair or replacement of a failed product is in place with a follow-up on status of problem correction.
    - The supplier should have sufficient cash flow and a line of credit to fulfil his obligations.

- Suppliers can be found through a variety of channels such as:

- Recommendations.
- Directories such as yellow pages, Internet research engines etc.
- Trade associations such as IMCA.
- Business advisors such as international business organisations, governmental agencies, or private consultants.
- Exhibitions (they offer the opportunity to talk with a number of potential suppliers).
- Trade magazines (advertisements).

- List of selected suppliers

A price enquiry with a precise description of what is required is transmitted to the potential suppliers.
Wherever possible it is a good idea to meet the potential suppliers, and see how their business operates. A list of the suppliers that are compliant is then established. It is important to keep this list for further research. Nevertheless, it is also important to record the suppliers that are not compliant to avoid contacting them again during subsequent research.

- Selecting the supplier

Once the list is established, the team in charge of the evaluation compares the potential suppliers. A decreasing classification is established with the most compliant supplier at the top and the least compliant at the bottom.
Note that lower prices may reflect poorer quality of goods and services that, in the long run, may not be the most cost-effective option.
If the selection is for a short term business, and the relation with the supplier not strategic, only the rate quality - price may be considered. Nevertheless, the supplier must be able to handle the mission for which he has been engaged.
For this reason, the team should make sure that the supplier is sufficiently solid, or that the goods delivered can be easily found with another vendor.
When the supplier is selected, the company can move on to negotiating terms and conditions and drawing up a contract. This part of the work is usually finalised by the Procurement Department and controlled by the general manager or the person he has nominated for this purpose.
Note that when the supplier is only occasional, it often happen that a purchase requisition with the complete file of evaluation based on the elements described previously is transmitted to the procurement department.

3.1.2.4 - Create a library and implement processes that are mandatory in the industry

Numerous standards have been used during the manufacturing of the diving system that must be kept and updated. Also, organizations emit new standards and guidelines that have to be collected and transmitted to the technicians in charge of the maintenance of the system. For this reason, a library which function is to update the standards in force in the company and collecting useful documents should be created.

Also, several tools have been developed for the diving industry to increase the quality of the equipment in service and protect the divers from failures Such as:

1. Certification and classification
2. Failure Mode Effect Analysis (FMEA)
3. Planned Maintenance System (PMS)
4. Auditing

A significant function of the maintenance team is to implement the procedures indicated in these documents and maintain these processes updated for every equipment under their responsibility. These four tools are to be used together and are unavoidable documents as the clients and the safety organizations request them at all times. For this reason, they are described in detail in the next chapters.

3.1.2.5 - Organise training

Continuous training is a crucial element to make sure that the personnel involved in the maintenance of the diving system can perform their work in the best manner. Also, continuous training provides opportunities for promotion and motivates valuable employees.

To achieve the training targets, a plan must be established, discussed, and approved by the company director or the nominated competent person, who is usually the person in charge of the human resources. There are two sorts of training plans:

- A training plan linked to a project, that outlines the objectives and the required activities for developing, conducting, and evaluating the training during the project. It also establishes the costs of these activities and how the project team organizes to cover these costs.
- Individual educational plans, that are part of the strategy of the company, and are in place to increase its competencies. They apply to employees who want or need to reach an upper technical level. They are not linked to a particular project and can be external and/or internal.

Training can be given through the services of external establishments or internally.

- External training can be performed through relevant schools such as those involved in the formation of dive technicians like Interdive (http://www.interdive.co.uk/), and the hyperbaric diving center (https://www.jfdglobal.com/training). Also, specific courses regarding special equipment have to be organized with manufacturers. It is the case when a brand new system is bought or for particular items such as helmets, Compact Bailout Rebreathing Apparatus (COBRA), and others.
- Internal training is usually organized through senior technicians. However, it is also common to hire a specialist for such purpose.

3.1.2.6 - Organise equipment replacement and new acquisition

The function of the senior technician is not limited to repairing and maintain diving equipment. They are also involved in the process of evaluation of the items used in the dive system through the FMEA, Planned Maintenance system, and audits. Based on their reports, decisions can be taken to change some elements if those in service are unsatisfactory. The finance (accounting) department is usually associated with such a decision. Note that Senior technicians are generally involved in the selection of specialized equipment, and the conception of a new saturation system, as they are the most qualified to decide if the technical design proposed suits to their needs regarding the ease of maintenance. Note that besides, life support and diving supervisors must be involved in such a process.

Also, a company rarely has the financial resources to buy such equipment without the help of a financing establishment due to the considerable investment it represents. For this reason, the financing department is always involved in calculating whether the cost of such machinery is sustainable by the company, and the way the investment can be paid and amortized. That may open a long process of discussion between the company and financing structures, which may result that the company needs to review its original plan.

However, other options than buying a system can be used to perform safe and efficient saturation dives. As an example, Ultra Deep Solution rents the Diving Support Vessels taken as examples for the description of a saturation system in this document. That allows a small company to challenge efficiently more established actors with diving systems and ships of the latest generation, and supplied supporting teams that are at the same level or above these potential challengers. Manufacturers are also able to provide a saturation system through their numerous contacts. The advantage of renting a system is that the owner of the system usually performs its maintenance and that the rented system is considered an expense and not an asset in the calculation of the taxes to be paid by the user. Note that renting is common in the transportation aviation industry, as such a solution provides more flexibility to the airways companies, in addition to the advantages previously discussed.

3.2 - Certification and classification

3.2.1 - Certification process

Certification is is a process of evaluation that is used to establish the technical level of equipment and whether it conforms to the specifications that arise from published standards and guidelines that are in force through national and international laws and directives. Note that an item cannot be put in service if it is not certified for the operations it has been designed for by a legal authority. This process is also used to check the condition of the equipment and determine prospects for repair and modernization.
The manufacturer usually certifies the equipment he produces according to selected standards and rules that are typically those in force in the area the item is planned to be used. During this process, all working parameters, controls, and regulation systems are checked, and the functions of the given equipment are precisely defined. Calculations such as kinematics and power are made, operating, and maximum tolerable parameters such as temperature and pressure are determined, and optimal operating modes are fixed.
In addition to what is said above, the tests for the certification of the components of diving systems are based on criteria issued by the authorities and also, technical notes, guidelines, and codes issued by recognized organizations involved in diving activities such as IMCA, NORSOK, ADCI, and others. Guidelines from oil companies are also commonly used, with those published by classification societies.

The certification bodies edit handbooks for their auditors and clients that explain the organization of the tests. Such documents describe elements to be in place, such as:

- Where and how the item to test must be installed
- The elements to be connected to the item to test
- The parameters to be applied. As an example, the pressure and flow, or the electrical voltage and amperage
- The elements to measure and criteria for the acceptance
- The personnel to be involved in the test
- The way the test is scheduled
- The documents to provide (Usually; drawings & specifications)
- What the auditor should look for and the reason the tests are applied

At the end of the certification process, a certificate, which is a technical document that contains information on the essential functions and particular applications of the equipment is issued. Usually, the document includes:

- The name of the manufacturer
- The product code
- The function of the item
- The standards the product conforms to
- The date of the certificate

Detailed information on the maximum capacity of the item are added on some certificates.
The reference number of the certificate is usually stamped on the equipment with the logo of the standardisation body. As an example “CE” for an item that has been tested according to the European standards and is usable in the countries applying these standards.

3.2.2 - Classification

Marine classification is a process of investigation used to verify the structural strength, integrity, reliability of the essential parts of a ship, facility, or equipment to be used at sea. The international and national statutory regulations applied in this process are those published by the flag administration of the vessel.
Classification societies are independent non-governmental organizations that are usually used to verify compliance with these rules on behalf of the flag authorities.
Note that a lot of clients, particularly the members of the “International association of Oil & Gas Producers (IOGP)”, request that the saturation systems used on their oilfields are classified.

3.2.2.1 - United Nations Conventions and classification societies

The United Nations Convention on the Law of the Sea (UNCLOS) indicates the rules and principles of the general international law of the sea and its uses, including the registration of a ship by a state.
Once a boat is registered, the flag state has duties laid out in the United Nations Convention on the Law of the Sea, particularly in article 94, that says that "Every state shall effectively exercise its jurisdiction and control in administrative, technical and social matters over ships flying its flag".
Regarding the construction and the maintenance of ships, it is said that every state must:

- Maintain a register of vessels containing the names and particulars of ships flying its flag, except those which are excluded from generally accepted international regulations on account of their small size.
- Take measures that are necessary to ensure safety at sea with regard to the construction, equipment, and seaworthiness of ships flying its flag.
- Ensure that each ship, before registration and thereafter at appropriate intervals, is surveyed by a qualified

surveyor of ships and has on board such charts, nautical publications, and navigational equipment and instruments as are appropriate for the safe navigation of the ship.

It often happens that states do not have the resources to ensure these duties through their administration, or want to promote “free trading”, and for these reasons, delegate these duties to independent organizations. The resolution A.739(18) “Guidelines for the authorization of organizations acting on behalf of the administration”, adopted the 4th of November 1993, covers this point.
This text says that under the provisions of regulation l/6 of SOLAS 74, article 13 of load lines 66, regulation 4 of annex 1 and regulation 10 of Annex 2 of MARPOL 73/78 and article 6 of tonnage 69, many flag states authorize organizations to act on their behalf in the surveys and certification and determination of tonnages as required by these conventions.
The text also says that control in the assignment of such authority is needed in order to promote uniformity of inspections and maintain established standards. Therefore, any assignment of authority to recognized organizations should determine that the organization has adequate resources in terms of technical, managerial, and research capabilities to accomplish the tasks being assigned, in accordance with the minimum standards for recognized organizations acting on behalf of the administration:

- The relative size, structure, experience and capability of the organization commensurate with the type and degree of authority intended to be delegated thereto should be demonstrated.
- The organization should be able to document extensive experience in assessing the design, construction and equipment of merchant ships and, as applicable, their safety-management system.
- For the purpose of delegating authority to perform certification services of a statutory nature in accordance with regulatory instruments which require the ability to review applicable engineering designs, drawings, calculations and similar technical information to technical regulatory criteria as dictated by the administration and to conduct field survey and inspection to ascertain the degree of compliance of structural and mechanical systems and components with such technical criteria, the following should apply:
    - The organization should provide for the publication and systematic maintenance of rules and/or regulations in the English language for the design, construction and certification of ships and their associated essential engineering systems as well as the provision of an adequate research capability to ensure appropriate updating of the published criteria.
    - The organization should allow participation in the development of its rules and/or regulations by representatives of the Administration and other parties concerned.
    - The organization should be established with a significant technical, managerial and support staff, catering also for capability of developing and maintaining rules and/or regulations; and a qualified professional staff to provide the required service representing an adequate geographical coverage and local representation as required.
    - The organization should be governed by the principles of ethical behaviour, which should be contained in a “code of ethics” and as such recognize the inherent responsibility associated with a delegation of authority to include assurance as to the adequate performance of services as well as the confidentiality of related information as appropriate.
    - The organization should demonstrate the technical, administrative and managerial competence and capacity to ensure the provision of quality services in a timely fashion.
    - The organization should be prepared to provide relevant information to the administration.
    - The organization’s management should define and document its policy and objectives for, and commitment to, quality and ensure that this policy is understood, implemented and maintained at all levels in the organization.
    - The organization should develop, implement and maintain an effective internal quality system based on appropriate parts of internationally recognized quality standards no less effective than ISO 9000 series, and which, among other things, ensures that:
        - the organization's rules and/or regulations are established and maintained in a systematic manner; .
        - the organization's rules and/or regulations are complied with;
        - the requirements of the statutory work for which the organization is authorized, are satisfied;
        - the responsibilities, authorities and interrelation of personnel whose work affects the quality of the organization's services are defined and documented;
        - all work is carried out under controlled conditions;
        - a supervisory system is in place which monitors the actions and work carried out by the organization;
        - a system for qualification of surveyors and continuous updating of their knowledge is implemented;
        - records are maintained, demonstrating achievement of the required standards in the items covered by the services performed as well as the effective operation of the quality system; and
        - a comprehensive system of planned and documented internal audits of the quality-related activities in all locations is implemented.
    - The organization should be subject to certification of its quality system by an independent body of auditors recognized by the Administration.
- For the purpose of delegating authority to perform certification services of a statutory nature in accordance with regulatory instruments which require the ability to assess by audit and similar inspection of the relevant safety-management system attributes of shore-based ship management entities and shipboard personnel and systems, the following should, in addition, apply:

- The provision and application of proper procedures to assess the degree of compliance of the applicable shore-side and shipboard safety-management systems.
- The provision of a systematic training and qualification regime for its professional personnel engaged in the safety management system certification process to ensure proficiency in the applicable quality and safety-management criteria as well as adequate knowledge of the technical and operational aspects of maritime safety management.
- the means of assessing through the use of qualified professional staff the application and maintenance of the safety-management system, both shore-based as well as on board ships, intended to be covered in the certification.

Resolution A.739(18) also says that there must be formal written agreement between the administration and the organization being authorized which should as a minimum include the elements listed below, or equivalent legal arrangements:

1. Application
2. Purpose
3. General conditions
4. The execution of functions under authorization
    - Functions in accordance with the general authorization
    - Functions in accordance with special (additional) authorization
    - Relationship between the organization's statutory and other related activities
    - Functions to co-operate with port States to facilitate the rectification of reported port State control deficiencies or the discrepancies within the organization's purview
5. Legal basis of the functions under authorization
    - Acts, regulations and supplementary provisions
    - Interpretations
    - Deviations and equivalent solution
6. Reporting to the Administration
    - Procedures for reporting in the case of general authorization
    - Procedures for reporting in the case of special authorization
    - Reporting on classification of ships (assignment of class, alterations and cancellations), as applicable
    - Reporting of cases where a ship did not in all respects remain fit to proceed to sea without danger to the ship or persons on board or presenting unreasonable threat of harm to the environment
    - Other reporting
7. Development of rules and/or regulations - Information
    - Co-operation in connection with development of rules and/or regulations liaison meetings
    - Exchange of rules and/or regulations and information
    - Language and form
8. Other conditions
    - Remuneration
    - Rules for administrative proceedings
    - Confidentiality
    - Liability
    - Financial responsibility
    - Entry into force
    - Termination
    - Breach of agreement
    - Settlement of disputes
    - Use of sub-contractors
    - Issue of the agreement
    - Amendments
9. Specification of the authorization from the Administration to the organization
    - Ship types and sizes
    - Conventions and other instruments, including relevant national legislation
    - Approval of drawings
    - Approval of material and equipment
    - Surveys
    - Issuance of certificates
    - Corrective actions
    - Withdrawal of certificates
    - Reporting
10. The Administration's supervision of duties delegated to the organization
    - Documentation of quality-assurance system

  - Access to internal instructions, circulars and guidelines
  - Access by the Administration to the organization's documentation relevant to the Administration's fleet
  - Co-operation with the Administration's inspection and verification work
  - Provision of information and statistics on, e.g., damage and casualties relevant to the Administration's fleet

In addition to the elements indicated above, the administration should:

- Specify instructions detailing actions to be followed in the event that a ship is found not fit to proceed to sea without danger to the ship or persons on board, or presenting unreasonable threat of harm to the marine environment.
- Provide the organization with all appropriate instruments of national law giving effect to the provisions of the conventions or specify whether the Administration's standards go beyond convention requirements in any respect.
- Specify that the organization maintains records which can provide the Administration with data to assist in interpretation of convention regulations.

To finish with this point, the administration should establish a system to ensure the adequacy of work performed by the organizations authorized to act on its behalf. Such a system should, among other things, include the following items:

- Procedures for communication with the organization
- Procedures for reporting from the organization and processing of reports by the Administration
- Additional ship's inspections by the Administration
- The Administration's evaluation/acceptance of the certification of the organization's quality system by an independent body of auditors recognized by the Administration
- Monitoring and verification of class-related matters, as applicable.

To reinforce resolution A.739 (18), the International Marine Organization (IMO) has published resolution A.789 (19) "*Specifications on the survey and certification functions of recognized organizations acting on behalf of the administration"* which has been adopted the 23rd of November 1995.
This document contains additional specifications for organizations recognized as capable of performing statutory work on behalf of a flag state administration in terms of certification and survey functions connected with the issuance of international certificates. It covers modules such as: Management, technical appraisal, surveys, and qualifications and training, and says the following:

1. Management:
   The management of the Recognized Organization (RO) should have the competence, capability and capacity to organize, manage and control the performance of survey and certification functions in order to verify compliance with requirements relevant to the tasks delegated and should, among other things:
   - Possess an adequate number of competent supervisory, technical appraisal and survey personnel.
   - Provide for the development and maintenance of appropriate procedures and instructions.
   - Provide for the maintenance of up-to-date documentation on interpretation of the relevant instruments.
   - Give technical and administrative support to field staff; provide for the review of survey reports and provision of experience feedback.
2. Technical appraisal:
   - Regarding hull structure, the Recognized Organization should have the appropriate competence, capability and capacity to perform the following technical evaluations and/or calculations pertaining to longitudinal strength; local scantlings such as plates and stiffeners; structural stress, fatigue and buckling analyses; materials, welding and other pertinent methods of material-joining, for compliance with relevant rules and convention requirements pertaining to design, construction and safety.
   - Regarding subdivision and stability, the Recognized Organization should have the appropriate competence, capability and capacity to perform the technical evaluations and/or calculations pertaining to intact and damage stability; inclining test assessment; grain loading stability; watertight and weathertight integrity.
   - Regarding load line and tonnage, the Recognized Organization should have the appropriate competence, capability and capacity to perform the following technical evaluations and/or calculations pertaining to freeboard calculation; conditions of assignment of freeboard; and tonnage computation.
   - Regarding structural fire protection, the Recognized Organization should have the appropriate competence, capability and capacity to perform technical evaluations and/or calculations pertaining to structural fire protection and fire isolation; use of combustible materials; means of escape; ventilation systems.
   - Regarding safety equipment, the Recognized Organization should have the appropriate competence, capability and capacity to perform the following technical evaluations and/or calculations pertaining to life-saving appliances and arrangements; navigation equipment; fire detection and fire alarm systems and equipment; fire-extinguishing system and equipment; fire control plans; pilot ladders and pilot hoists; lights, shapes and sound signals inert gas systems.
   - Regarding oil pollution prevention, the Recognized Organization should have the appropriate competence, capability and capacity to perform technical evaluations and/or calculations pertaining to monitoring and control of oil discharge; segregation of oil and ballast water; crude oil washing;

protective location of segregated ballast spaces; pumping, piping and discharge arrangements; shipboard oil pollution emergency plans (SOPEP's).

  - Regarding prevention, the Recognized Organization should have the appropriate competence, capability and capacity to perform technical evaluations and/or calculations pertaining to list of substances the ship may carry; pumping system; stripping system; tank-washing system and equipment; underwater discharge arrangements.
  - Regarding radio, the Recognized Organization should have the appropriate competence, capability and capacity to perform technical evaluations pertaining to radiotelephony; radiotelegraphy; Global Maritime Distress and Safety System (GMDSS). Alternatively, these services may be performed by a professional radio installation inspection service company approved and monitored by the RO according to an established and documented programme. This programme is to include the definition of the specific requirements the company and its radio technicians are to satisfy.
  - Regarding carriage of dangerous chemicals in bulk, the Recognized Organization should have the appropriate competence, capability and capacity to perform technical evaluations and/or calculations pertaining to ship arrangement and ship survival capacity; cargo containment and material of construction; cargo temperature control and cargo transfer; cargo tank vent systems and environmental control; personnel protection; operational requirements; list of chemicals the ship may carry.
  - Regarding carriage of liquefied gases in bulk, the Recognized Organization should have the appropriate competence, capability and capacity to perform technical evaluations and/or calculations pertaining to ship arrangement and ship survival capacity; cargo containment and material of construction; process pressure vessels and liquid, vapour and pressure piping systems; personnel protection; use of cargo as fuel; operational requirements.

3. The Recognized Organization should have the appropriate competence, capability and capacity to perform the required surveys under controlled conditions as per the Recognized Organization's internal quality system and representing an adequate geographical coverage and local representation as required. The work to be covered by the staff is described in the relevant sections of the appropriate survey guidelines developed by the Organization.
4. Qualification and training
   - The Recognized Organization personnel performing, and responsible for, statutory work should have as a minimum a qualifications from a tertiary institution recognized by the Recognized Organization within a relevant field of engineering or physical science (minimum two years' programme), or qualifications from a marine or nautical institution and relevant sea-going experience as a certificate ship officer, and should have proficiency in the English language commensurate with the work.
     Other personnel assisting in the performance of statutory work should have education, training and supervision commensurate with the tasks they are authorized to perform.
     The RO should have implemented a documented system for qualification of personnel and continuous updating of their knowledge as appropriate to the tasks they are authorized to undertake. This system should comprise appropriate training courses, including, among other things, international instruments and appropriate procedures related to the certification process, as well as practical tutored training. It should provide documented evidence of satisfactory completion of the training.
   - Surveys may be done by a professional radio installation inspection service company approved and monitored by the RO according to an established and documented programme. This programme is to include the definition of the specific requirements the company and its radio technicians are to satisfy, including, among other things, requirements for internal tutored training covering at least radiotelephony; radiotelegraphy; Global Maritime Distress and Safety System (GMDSS); initial and renewal surveys.
     Radio technicians carrying out surveys should have successfully completed, as a minimum, at least one year of relevant technical school training, the internal tutored training programme of his/her employer and at least one year of experience as an assistant radio technician. For exclusive radio surveyors to the RO, equivalent requirements as above apply.

A classification society is an organization that complies with the above requirements and is authorized by one or several flag administrations to verify the compliance of the construction of a vessel with its published rules and to periodically check this compliance during the classed ship's service life. Also, the classification society publishes a register of classed ships on behalf of the administration.
Note that the requirements asked by the International Marine Organization (IMO), are more specific to boats rather than dive systems. However, this description indicates the high level requested IMO to these organizations, and this technical level is also the one required for dive systems. Also, note that dive systems that are integrated into a boat are considered a part of the vessel and must be classified with it.

3.2.2.2 - Classification societies member of the International Association of Classification Societies (IACS)

There are approximately 50 organizations that define their activities as marine classification services providers in the world. However, not all of them meet in full the requirements of the IMO resolutions A.739 (18) and A.789 (19) given in the previous point. For this reason, a lot of clients require that the organizations issuing classification certificates are a member of the International Association of Classification Societies (IACS). It is, for example, the case of Total.
This association that has been officially founded the 11th of September 1968 is a not for profit membership organization of classification societies that establish minimum technical standards and requirements that address maritime safety and

environmental protection and ensures their consistent application. The association provides a quality system certification scheme that its members comply with, as an assurance of professional integrity and uniformly high standards. IACS is recognized as the principal technical advisor of IMO.
The association is currently composed of the following members:

Name and used abbreviation	***Year of creation***	***Head quarters***	***Date membership***	***Comments***
Lloyd's Register of Shipping (LR)	*1760*	*London*	*11/09/68*	*This company is one of the founders of the association.*
Bureau Veritas (BV)	*1828*	*Paris*	*11/09/68*	*This company is one of the founders of the association.*
Registro Italiano Navale (RINA)	*1861*	*Genoa*	*11/09/68*	*This company is one of the founders of the association .*
American Bureau of Shipping (ABS)	*1862*	*Houston*	*11/09/68*	*This company is one of the founders of the association .*
DNV GL (DNV)	*1864 & 2013*	*Oslo*	*11/09/68*	*This company is from the merger of two founders of the association in 2013: Det Norske Veritas and Germanischer Lloyd*
Nippon Kaiji Kyokai (NKK)	*1899*	*Tokyo*	*11/09/68*	*This company is one of the founders of the association.*
Russian Maritime Register of Shipping (RS)	*1913*	*Saint Petersburg*	*01/11/69*	*Previously called "USSR Maritime Register of Shipping"*
Korean Register of Shipping (KR)	*1960*	*Busan*	*01/09/75*	
China Classification Society (CCS)	*1956*	*Beijing*	31/05/88	
Indian Register of Shipping (IR Class)	*1975*	*Mumbai*	22/06/10	
Croatian Register of Shipping (CRS)	*1858*	*Split*	03/05/11	
Polish Register of Shipping - Polski Rejestr Statków- (PRS)	*1936*	*Gdansk*	03/06/11	

Note that the five companies on the top of the list are those the most involved regarding the classification of the diving systems. However, other companies may be occasionally engaged or plan to enter this market. It must be considered that classification societies are commercial organizations whose purpose is also to make a profit through the development of their business. For this reason, each company selects markets where it is more competitive than others. For this reason, it is not surprising to see that some IACS members are not very involved with diving.

Comments regarding the selection of a classification society:
It has happened several times that clients have rejected diving systems because of the organization in charge of the classification of the boat and the diving system that was not approved by their technical services. For this reason, it is of primary importance to select a reputed classification society that is accepted everywhere. Considering the fact that some clients also require that the classification societies of the vessels and systems operating on their oilfields are members of IACS, the wise strategy should be to select one of the members of this association.

3.2.2.3 - Classification process of a diving system

For the reasons explained before, the general rules explained in this point are those promoted by IACS members.

As indicated in the previous point, a lot of clients require that the saturations systems used on their oilfields are classed. That is still not mandatory with all companies, but there is a risk that it will be the case in the future. So, another wise decision when investing in a new saturation system is to class it.
Note that integrated (built-in) systems are considered a part of the ship where they are installed and should be classified at the same time. As a result, only the classification of portable systems is to be done separately from their surface supports.

The main difference between a non-classed and a classed diving system is that the non-classed system may be constituted of elements from various origins that are assembled to create a diving system. In contrast, the provenance, suitability, and design of the items that are parts of a classed system have been thoroughly checked according to selected standards. Also,

their interaction with the other components of the diving system is reviewed. Thus, the diving system is entirely tested for safety, efficiency, robustness, and conformance to the standards selected by the classification society. So the system complies with what is indicated in the United Nations Convention on the Law of the Sea (UNCLOS) and is considered safe for the operations it has been designed for by a recognized competent body.
Common scopes of the classification of diving systems include:

1. The reviewing of the specifications and drawings
   - Manufacturer documentation review
   - Audit of the quality management system
   - Evaluation of the materials and equipment planned
   - Review of the general design and the interface with the support vessel.
   - Evaluation of the design criteria, and verification that they are in accordance with specified codes and standards
   - Additional calculations for certain systems and components
   - Final review and acceptance of the design for construction
2. The survey during the construction
   - Evaluation of the manufacturing management system and the quality management system and implement corrective actions.
   - Evaluation of the fabrication methods, and confirmation of compliance with the planned manufacturing specifications or implement corrective actions.
   - Review of the manufacturing procedures and qualification tests
   - Surveillance based on spot checks during the construction of the system to ensure that the delivered products have been produced in accordance with the established manufacturing specification
   - Review the final documentation of the elements that are part of the diving system

   Note: During this phase, the person in charge for the classification society ensures that the design, certificates and tests planned are in place. As an example, regarding the construction of the hulls of the chambers:
   - Metal plates, bolts, extrusions, and forgings must conform to relevant standards of fabrication.
   - Plates are ultrasonically examined and toughness testing is common for forgings and steel plates.
   - All welding procedures and the qualifications of the welders are to be submitted and approved.
   - Identification of the elements welded and their alignment is checked with the penetration of the welds. Nondestructive examination and impact testing are common for this purpose, and the procedures used for these tests must conform to those of the classification society.

   The table below summarizes the major verifications and tests performed on a saturation system during the preparation and the construction processes. Note that more checks may be required.

Elements	***Raw material verification***	***Welding procedures***	***Pressure tests***	***Function tests***	***Product certificate***	***Design review***
Chambers and bells						
Hull	X	X	X		X	X
Doors, clamps, and mating devices	X	X	X	X	X	X
Viewports	X		X		X	X
Penetrators (pipes and electrical)	X		X		X	X
Valves	X		X	X	X	X
Relief valves	X		X	X	X	X
Pressure gauges				X	X	X
Communication systems				X	X	X
Close Circuit Television (CCTV)				X	X	X
Through water communications (Bell)				X	X	X
Bell transponder				X	X	X
Scrubbers				X	X	X
Analysers (O2 & CO2)				X	X	X

Elements	***Raw material verification***	***Welding procedures***	***Pressure tests***	***Function tests***	***Product certificate***	***Design review***
Thermometer and hygrometer				X	X	X
Fixed fire fighting system chambers						
Pressure vessels	X	X	X		X	X
Valves, pipes, and fittings	X		X	X	X	X
Sprinklers and nozzles	X			X	X	X
Fire detection				X	X	X
Portable fire fighting systems						
Portable extinguishers					X	X
Gas distribution systems						
Gas panels	X		X	X	X	X
Oxygen pipeworks (including regulators)	X		X	X	X	X
Other Pipework	X		X	X	X	X
Flexible hoses and couplings	X		X		X	X
Pressure relief valves	X		X	X	X	X
Manifolds and filters	X		X	X	X	X
Built in Breathing Systems (BIBS)			X	X	X	X
Compressors and blowers						
Compressors and blowers			X	X	X	X
Electrical supplies				X	X	X
Pipeworks	X		X	X	X	X
Relief valves	X		X	X	X	X
Gas storage						
Seamless gas cylinders	X		X	X	X	X
Pipeworks quads & tubes	X		X	X	X	X
Gas reclaim system						
Compressors			X	X	X	X
Scrubbers			X	X	X	X
Filters				X	X	X
Gas bag			X	X	X	X
Hot water system bell and divers						
Hot water machine				X	X	X
Pressure vessels &	X	X	X	X		X
Manifolds	X	X	X	X	X	X

Elements	*Raw material verification*	*Welding procedures*	*Pressure tests*	*Function tests*	*Product certificate*	*Design review*
Pumps				X	X	X
Flexible hoses			X	X	X	X
Pipework	X		X	X	X	X
Environmental control unit						
Chiller	X	X		X	X	X
Boiler	X	X		X	X	X
Pressure vessel	X	X	X	X	X	X
Heat exchanger			X	X	X	X
Pipework	X		X	X	X	X
Potable water system						
Pumps				X	X	X
Pressure vessel	X	X	X	X	X	X
Pipework	X		X	X	X	X
Sewage system						
Sewage tank	X	X	X	X	X	X
Pipework	X		X	X	X	X
Umbilicals						
Bell umbilical			X	X	X	X
Bell umbilical winch	X			X	X	X
Diver umbilical			X	X	X	X
Launch And Recovery System (LARS)						
Bell lifting winches	X			X	X	X
Lifting wires	X			X	X	X
Lifting frame	X	X		X	X	X
Heave compensation				X	X	X
Electrical & electronic systems				X	X	X
Electrical installation dive system						
Switchboards				X	X	X
Electrical motors and generators				X	X	X
Batteries				X	X	X

3. Installation (Built in systems only)
   - Evaluation of the installation management systems
   - Verification of the procedures of installation
   - verification of the conformity of the installation with the layout drawings and specifications

- Surveillance during installation activities: The checks listed on the previous page are usually performed.

4. Testing and commissioning
   When the installation is completed, or the portable system is ready for use, the diving system must be tested in compliance with an approved test program in the presence of the person in charge for the classification society.
   - Procedures review to ensure that the test procedures are in accordance with the design requirements.
   - Verification of the conformity of the installation with the layout drawings and specifications.
   - Verification of the certificates of the diving system components and the marking plates.
   - Verification of the cleanliness of the breathing gas piping and their marking in accordance with the official colour code.
   - Verification of the oxygen gas storage area, piping, valves and alarms
   - Surveillance during testing and completion activities. The diving system is tested at sea trials according to an approved programme.
     - Pressure vessels for human occupancy pressure testing and gas leak testing (chamber complex, diving bell, Hyperbaric Rescue Unit)
     - Visual examination of the insulation of Pressure Vessels for Human Occupancy (PVHO)
     - Visual examination of the doors, hatches and their locking mechanisms. Also, visual examination of the medical and transfer tools locks.
     - Visual examination of the flow fuses and valves used for the same function.
     - Breathing gas system testing (piping, fittings and gas cylinders).
     - Diving control panel and life support control panel testing.
     - Depth gauges calibration and testing.
     - Sanitary system (toilets, sewage and fresh water), Chamber bilge drain system testing.
     - CO_2 removal testing (chambers and diving bell).
     - Gas reclaim system testing.
     - Gas transfer system testing.
     - Fire-fighting system testing
     - The launch and recovery system is tested to the maximum depth.
     - Bell function tests
     - Diver heating system
     - The ability to transfer an injured diver to the chamber, and to compress the chamber, within the time frame stipulated by the applied decompression tables are checked.
     - Testing of the ballast release system in water, when relevant.
     - Testing of the bell emergency systems
   - The final commissioning usually includes a non-manned diving test with the diving bell lowered to the rated depth:
     - Leak tests
     - Checks of electrical and communication systems
     - Breathing gas supplies and recovery system
   - Reviewing of the final documentation.
   - Delivery of the classification document.

3.2.2.4 - In service surveys and renewal of the classification

The validity of the class certificate is usually five years. However, a classed system cannot be modified without the approval of the classification body. Also, the system must be audited at regular intervals to ensure that it is well maintained and safe for use. Note that the class certificate of the diving system ceases to be valid if its owner neglects to perform these audits.

IACS members follow similar rules regarding the frequencies of inspections that should be done in addition to the normal IMCA audits D 024 & D 053 (These audits apply to IMCA members, but are required by the majority of clients):

- The annual survey usually consists of performing function tests such as:
  - Function test and calibration of the instruments
  - Function test of the main and back up systems such as gas & electrical supplies, bell main and emergency systems, etc.
  - Function test of the handling systems
  - The heat protection of the bell can be partially removed with some penetrators to check possible corrosion and deterioration.
  - Hyperbaric evacuation system testing (Drills should be performed)
- The intermediate survey is performed between the 2nd and the 3rd year after the delivery of the certificate (so, 2,5 years). In addition to the elements tested during the annual survey, the following test are usually performed:
  - Gas leaks and function test of the safety valves
  - Function test of the fire detection and firefighting systems
  - Function tests of the life support and alarm systems
  - Function tests of the mechanical and electrical systems
- The class renewal is performed every 5 years. In addition to the elements tested during the annual and

intermediate surveys, the following test are usually performed:
   - Bell buoyancy materials, heat protection, penetrators, windows and attached members are removed for inspection of possible corrosion and deterioration. Viewports are checked and should be replaced every 10 years.
   - Pressure tests and inspections are carried out according to the procedures selected by the classification society.
   - The working mass of the bell of pressure containing equipment is checked.
   - Static load tests of the bell handling systems are performed
   - If applicable, the bell's releasable ballast system with attachments are checked and tested (load tests)
- Occasional surveys for damage, repairs, reactivation and alterations:
  An inspection either general or partial according to the circumstances should be made every time a defect is discovered or an accident occurs which affects the safety and certification of the diving system or whenever a significant repair or alteration is made. The inspection should prove that the repairs or alterations carried out have been done effectively and are in full compliance with the guidelines of the classification body.
- Additional rule for portable systems:
  The rule applied is that the diving system is to be inspected and tested in accordance to the commissioning procedure before it is put back into service. For this reason, The owner of the system must inform the classification society about any installation and decommissioning operations of a portable diving system.
- Systems temporarily not used:
  It may happen that the equipment is not to be used for a long period. In this case, some classification societies propose specific procedures where periodic inspections are organized until the system is re-commissioned, so the class certificate is on hold, but not lost.

Alternative inspection techniques:
- Some classification societies say that it may be acceptable to carry out a pneumatic pressure test in lieu of hydraulic pressure testing. In this case, specific safety precautions, and downgrading the existing working pressure by the applicable safety factor provided in their documents (minimum 1.3) are to be applied.
- Another alternative promoted by some organizations is the use of Eddy current inspection techniques. In this case, upon completion of a successful leak test carried out to the Maximum Allowable Working Pressure (MAWP), eddy current testing is carried out on the weld surface of all external welds of windows, locks and interconnecting trunks.
- Also, note that classification societies usually accept test of seamless gas cylinders using acoustic emission in accordance with EN 16753, and also described in point 5.7 of the diving study CCO Ltd “Organize the maintenance of diving cylinders” that can be downloaded for free.

Systems downgraded to lower depths:
The classification society may decide to downgrade a system to a lower depth for various reasons such as:
- Carry out periodical pressure testing pneumatically.
- Following the installation of elements with a lower design pressure than the chambers
- Any other causes which may or may not imply a reduction of strength of the pressure vessel. It is often the case with old dive systems that are usually downgraded to a lower maximum depth by precaution.

3.2.2.5 - Select the classification society

As indicated previously, the organizations the most involved with the classification of diving systems are:
- DNV-GL (DNV)
- Bureau Veritas (BV)
- American Bureau of Shipping (ABS)
- Lloyd’s Register of Shipping (LR)
- Registro Italiano Navale (RINA)

Other organizations may propose their services. However, the description of modern saturation systems demonstrates that they are intricate pieces of machinery. For this reason, an engineer specialized in boats will be lost if he has not a minimum experience of diving operations and diving systems.
Also, even though the organizations indicated above are among the most reputed and powerful classification companies, they are not well represented everywhere. For this reason, the selection of the classification society must not depend on only the financial and reputation aspects but also on the services the organization can provide in the country where the diving contractor acquiring the new system operates.
Also, the owner of the system must be aware that his choice will engage him with this organization for the life of the system. Changing a service provider is indeed possible. However, that will imply additional costs as, for such cases, most classification bodies re-start the process of classification from scratch. Nevertheless, in case that the new and the previous classification society involved with the classification of the dive system are members of IACS, the following process is usually applied:
- Examination of the drawings and documents (that must be stamped by the previous IACS member)
- Examination of materials and components certificate.
- Close examination of the diving system

For these reasons, it is recommended to:

- Ensure that the construction surveyors proposed are experienced with diving systems.
- Ensure that the relationship of the classification surveyors with the personnel of the company is smooth.
- Ensure that the relationship of the classification surveyors with the manufacturer is also smooth.
- Ensure that the classification society is established in the country for a long time.
- Ensure of the availability of the organization (as an example, can they intervene quickly for the mobilization of a portable system?)

Note that manufacturers are used to work with the classification societies they select. However, in case a problem is detected, the client has usually the possibility to ask for another certification body.

3.3 - Failure Mode Effect Analysis

3.3.1 - Purpose

The primary function of the Failure Mode Effect Analysis (FMEA) is to provide a comprehensive, systematic and documented system of investigation which establishes if the effects of the failure of one or more components of the saturation ensemble would lead to a life-threatening situation for the personnel, or unacceptable damage to the diving system or the environment, or a loss of production. Also, the Failure Mode Effect Analysis is a tool that is to be used to:

- Identify the weaknesses of equipment and which are its sensitive parts. Such records should be used for the implementation of corrective actions, and be transmitted to the manufacturer for guarantee purposes and help him to improve his products.
- Identify the control measures that can be implemented to increase the reliability of the equipment, solve the problem identified, and reduce the potential of failure. A lot of solutions can be implemented, internally or with the help of the manufacturer or external specialists such as increasing the maintenance frequency, modify the design of the machine, modify the operating procedures, modify the maintenance procedures, replace some genuine parts by others that are more reliable, etc.
- Select new equipment: The assessment of the reliability of the device may lead to its replacement with more reliable equipment if the control measures above are not satisfactory. The records of the problems encountered can be used when selecting the brand new device.
- Identify the spare parts to provide in priority: The records of the systems or components whose failure could be critical to the safe operation allow to mitigate such events by carrying essential spares.
- Identify the immediate control measures to be in place in case of failure of the equipment to make sure that the divers will never be in a life-threatening situation. These control measures can be backup systems ready for use, and procedures to alert the divers and recover them as soon as possible to a safe place. These procedures are to be introduced in the diving manual.
- Identify the necessary personnel for the maintenance of the system and their interfacing with the dive team and other parties on the worksite. Identification of the staff includes the number of people and their competencies to be sure of having 24 hours of assistance during the diving operations. Also, it allows identifying the persons who should be in charge of the maintenance of the system when it is not in use.

Note that an FMEA is usually required to comply with safety and quality requirements such as the certification and classification processes of equipment, ISO 9001, and others.

Common steps for performing an FMEA include:

1. The creation of a competent team.
2. The definition of the scope, and the establishment of guidelines.
3. The gathering of relevant documentation.
4. The identification of the items and processes to be analyzed.
5. The identification of the failures with their causes, effects, and their possible controls
6. The verification onsite of the issues identified and their corrective actions
7. The revision of the corrective actions and the re-evaluation of the risks.
8. The publication of the preliminary document and its final evaluation
9. The publication and the distribution of the final document.

3.3.2 - Types of Failure Mode Effect Analysis

There are many types of Failure Mode Effect Analysis that companies adapt to cover their industrial activities and differ with their risk evaluation methods. Three main approaches are commonly used, which are classified into two categories: The FMEA (Failure Mode Effect Analysis), and the FMECA (Failure Mode Effect Critically Analysis).

- "Risk Priority Numbers" (RPN) is a system of analysis used with Failure Mode Effect Analysis (FMEA) process that is based on the product of three criteria: Severity, likelihood, and detection.
    - Severity encompasses what is essential for safety, environment, production continuity, and damaged reputation. A score between 1 and 10 is often assigned *(see below)*, but some specialists prefer more simplified rates.
        - 1 = No disturbance
        - 2 = Effects extremely limited - Divers or/and surrounding, and company reputation not affected
        - 3 = Negligible effects - Divers or/and surrounding, and company reputation very slightly affected
        - 4 = System slightly affected - Divers or/and surrounding, and reputation slightly affected.
        - 5 = Some restriction of usability - Divers or/and surrounding, and reputation moderately affected
        - 6 = Failure of a few main functions - Divers or/and surrounding, and company reputation affected
        - 7 = Functions affected - Divers or/and surrounding, and company reputation highly affected
        - 8 = Major disruptions - Divers or/and surrounding, and company reputation extremely affected
        - 9 = Divers or the surrounding threatened - Violation of law possible
        - 10 = Extreme threat - Violation of the law.

- The likelihood indicates the frequency of an error. It is also often ranked between 1 and 10.
  - 1 = No failure recorded
  - 2 = Extreme low probability of failure
  - 3 = A very little number of failures may happen
  - 4 = A few failures are probable
  - 5 = Occasional failure may happen
  - 6 = Medium number of failures are probable
  - 7 = Failures are probable
  - 8 = High number of failures are probable
  - 9 = A failure is almost certain
  - 10 = A failure will certainly happen
- Detection is the possibility to be warned of the problem before it happens, and is also often ranked from 1 to 10.
  - 1 = Immediate detection
  - 2 = Very high probability
  - 3 = High probability
  - 4 = Occasionally high probability
  - 5 = Medium probability
  - 6 = Almost medium probability
  - 7 = Little probability
  - 8 = Very little probability
  - 9 = extremely low probability
  - 10 = No detection

The scores of these three criteria are multiplied to calculate the Risk Priority Number *(RPN = Severity x likelihood x detection)*. Then, the team decides on the evaluation of the Risk Priority Number. Two methods are commonly used:

- A lot of organizations select an RPN limit to determine which failure mode requires corrective action and which risks are acceptable. As an example, 125 (5 x 5 x 5) is often considered a maximum limit, and values between 50 and 125 considered "As Low As Reasonably Practicable (ALARP)" with rankings based on ten levels.
  Some specialists say that the risk with this method is that the team may trend to minor values to be below the threshold, which can result in critical situations. The example of the matrix below is based on this method.

			Likelihood												
			No failure	*Extremely low*	*Very little probability*	*Few failures probable*	*Occasional failure*	*Medium number*	*Probable*	*High number*	*Almost certain*	*Certain*			
			1	2	3	4	5	6	7	8	9	10			
Severity	No disturbance	1	1	2	3	4	5	6	7	8	9	10	1	Immediate	Detection
	Extremely limit	2	4	8	12	16	20	24	28	32	36	40	2	Very high probability	
	Negligeable	3	9	18	27	36	45	54	63	72	81	90	3	High probability	
	Slightly affected	4	16	32	48	64	80	96	112	128	144	160	4	Occasionally high	
	Some restrictions	5	25	50	75	100	125	150	175	200	225	250	5	Medium	
	Failure few main functions	6	36	72	108	144	180	216	252	288	324	360	6	Almost medium	
	Functions affected	7	49	98	147	196	245	294	343	392	441	490	7	Little probability	
	Major disruptions	8	64	128	192	256	320	384	448	512	576	640	8	Very little probability	
	Threats	9	81	162	243	324	405	486	567	648	729	810	9	Extremelly low	
	Extreme threats	10	100	200	300	400	500	600	700	800	900	1000	10	No detection	

- Other organizations address the corrective action for the top RPNs. After that, the team resets and find another top RPNs for the next improvement process. Some specialists prefer this method as it is reputed to promote continuous improvement. Nevertheless the absence of an upper limit may also lead to a condition where too high risks are accepted.

- The "quantitative criticality analysis" is a method of evaluation used with Failure Mode Effect Critically Analysis (FMECA) that consists in:
  - Defining the unreliability of each item at a given operating time.
  - Identifying the portion of the items that can be attributed to each potential failure.
  - Rating the probability of severity that results from each failure that can happen.
  - Calculating the criticality for each potential failure by the product of the three factors: *Item unreliability x Ratio of unreliability x Probability of severity.*
  - Calculating the criticality of each item by the sum of the criticalities for each failure that has been identified: *Item Criticality = SUM of Mode Criticalities.*

- The "qualitative criticality analysis" is another method used with Failure Mode Effect Critically Analysis (FMECA) that consists in evaluating risks and prioritising corrective actions:
  - The severity is evaluated similarly as for a risk assessment, so a rate is given according to the potential effects of the failure on people, environment and asset. See below an example with three levels:

	Harm to people	*Impact on environment*	*Damage to equipment*
Low = 1	Minor injury	Minor impact	Minor damage
Medium = 2	Serious injury	Serious impact	Serious damage
High = 3	Fatality and multiple injuries	Major impact	Major damage

  - The likelihood of occurrence is evaluated and rated. See below an example with four levels:

Very low = 1	*May occur only in extreme circumstances*
Low = 2	*Unlikely to occur*
Medium = 3	*Would probably occur*
High = 4	*Likely to occur within a very short period*

  - The failures are compared using a matrix that indicates the severity on one axis and the likelihood on the other one to determine whether the risk is low, medium, or high using a preset risk tolerance.

1 = Low	*No warning: The activity can continue as the risk reducing are adequate*
2 to 5 = Medium risk	*Warning: The activity may continue, provided that the additional control measures identified in the task risk assessment are implemented.*
6 to 12 = High risk	*Danger: The activity must be stopped as long as the risk is not eliminated or adequately mitigated.*

	Likelihood			
Severity	*1*	*2*	*3*	*4*
3	3	6	9	12
2	2	4	6	8
1	1	2	3	4

The selection of the system of analysis is generally decided by the team during the process. It usually depends on the complexity of the system and the purposes for which the FMEA is designed. However, FMEAs using "Risk Priority Numbers", and FMECAs using "qualitative criticality analysis" seems more frequently used in our industry than FMECAs based on "quantitative criticality analysis".
Note that the final document published must provide immediate answers to solve any problem encountered as soon as possible, and ensure that the divers are never in a threatening situation.

3.3.3 - Creation process of a Failure Mode Effect Analysis system

IMCA D 039 provides detailed guidelines for the creation of an FMEA that can be downloaded at this address: https://www.imca-int.com/publications/228/fmea-guide-for-diving-systems/. This guidance should be used as a reference for the creation of an FMEA adapted to diving systems. However, other sources can be gathered as a complement to create a model fully adapted to the diving system in service and the needs of the people operating it.

1 - Creation of a competent team:

IMCA says that the team in charge should be multi-disciplined. These people can be in-house personnel or third-party specialists from different companies. However, they must be competent for this task, and for this reason, there should be a system in place to identify the minimum standards for their selection, such as an example:

- Excellent knowledge of the guidelines to apply.
- Competencies in management controls, communications, and administration.
- A technical level based on experience in the industry and relevant academic qualifications.
- A level of expertise in FMEA, risk analysis, and diving system auditing.
- Track records and references relating to previous similar works.

Regarding the selection of third party personnel, note that a lot of companies prefer using the services of classification societies. The advantage of this choice is that these competent bodies are generally involved in the evaluation, and the creation of FMEAs as these documents are among the supporting documentation they request for the classification process of diving systems. So they are fully qualified for such tasks. Some companies also use the services of independent specialists referenced by a government or recognized competent bodies.

IMCA says that a typical team should be composed with at least the following competencies:

- A leader who manages the overall process, and can be a specialist in a particular technical domain.
- A mechanical engineer with experience and knowledge of the components of dive systems such as gas systems, hydraulic systems, pressure vessels, handling systems, etc.
- An electrical engineer with knowledge of power distribution, control, and instrumentation systems.
- Operational input from diving supervisors, life surface supervisor, and people involved with the system.

In addition to what IMCA says, we can see in chapter #2 of this book that computing applications are today parts of saturation diving systems and that this trend is now increasing. So a computing specialist should be included in such a team. Also, the team leader should be multidisciplinary. The reason is that although he is not the most competent in each domain, he is the person who must have an overall picture of the process ongoing. Also, he is the person in charge of the communication of the team with the management of the company and external entities, so having such skills is essential for such a task. Note that the number of team members may vary during the process according to particular help the core team may need.

2 - Definition of the scope and establishment of guidelines:

To clarify the scope of work and the guidelines for the creation of the FMEA, an essential task is to investigate the boundaries of the design and the operating procedures of the diving system and the conditions it is planned to be used. Note that IMCA says that the functional design specification of the system should define:

- The environments in which the diving system is expected to operate and the performance level expected with the environmental conditions that can be the source of failures.
- The diving system class notation and the limitations imposed by the classification society or the certifying authority.
- The boundaries of the equipment to be assessed as part of the diving system.

As a result of this first description, and based on previous experiences, the team should have a rough idea of the scope of work and of the guidelines to be implemented to eliminate or mitigate the impact of unacceptable failures to ensure that the protections of the divers are in place with adequate redundancy.

In addition, IMCA says that an adequate timescale must be given for the creation process with deadlines for:

- Issue of the preliminary FMEA report, including any recommendations and necessary sea trial tests.
- Closing out of those recommendations made as a result of the FMEA: It is essential that every recommendation made is addressed and the action taken is recorded, even if a decision is taken not to take action.
- Issue of the final FMEA report, including the actions taken as a result of any recommendations made and the results of the sea trial tests.

Note that it is prudent to calculate for additional time than necessary instead of the opposite not to put the team under pressure in case of unexpected problems are found.

IMCA also says: *"For a new diving system, the FMEA should ideally be commissioned as early as possible in the project. It is advisable that a high-level analysis at the design outline stage is specified, so that the initial FMEA output can be used as guidance in the engineering phase"*. Regarding this point, we can say that the FMEA is today usually at the responsibility of the manufacturer as this document is part of the certification process that is typically performed by an independent competent body. Thus, most FMEA undertaken today by diving contractors are linked to modifications of an existing system, the replacement of equipment by a different one, or a quality and safety process such as the implementation of a new management system. Nevertheless, it is usual that the diving contractor delegate some personnel to be involved in the FMEA process when a new system is bought.

3 - Gathering the relevant documentation:

When the steps above are completed, the team members select and collect the supporting documents they need. Regarding this point, IMCA says that the team should have access to the necessary IMCA documentation. In complement, we have seen that diving systems are also built according to other standards the team must have access to. For this reason, a list of relevant guidelines and standards should be established, and a library created. Additional documents may be necessary during the design process of the FMEA. The references used for the creation of the FMEA will have to be then listed in the final document.

Note that IMCA guidelines are available for free for IMCA members, but not for the others. Also, the majority of the published standards are to be bought and they are often expensive. For this reason, a budget must be provisioned for this purpose. Of course, the documentation to be gathered includes calculation notes and construction drawings of the diving system. Regarding this point IMCA gives the following list:

- General arrangement drawings.
- Electrical and control system single-line drawings and circuit schematics.
- Gas system single line drawings and circuit drawings/schematics.
- Fluid systems single line drawings and circuit drawings/schematics.
- Handling system drawings and schematics.

- Operating and emergency manuals.
- Planned maintenance details and defect reports.

In addition to this list from IMCA, the software designs of the components of the system should be documented. Also, the six months and one-year audit, and the certification, and classification files, should be available if the system is already in service.

4 - Identification of the items and processes to be analyzed:

When the team has the relevant documentation indicated above, the identification of the processes to be analyzed can start, so the team can establish a list of the systems, subsystems, and components to be analyzed.
It is crucial to classify the elements to analyze so that they can be easily identified and referenced. Teams often rank them according to their criticalities. As the diving system works through the interaction of many components and subsystems, such classification is not easy to organize, and the teams often reference the main elements and then their subsystems that may require a particular FMEA. Nevertheless, depending on the solution selected by the team, it is possible to link the main components to the Diving Equipment Systems Inspection Guidance Notes (DESIGN) IMCA D 024 and IMCA D 053 and the Planned Maintenance System (PMS) on the "general" FMEA, so the items referenced there can be easily found by the supervisors and indicated to the technician when a problem is detected.
Also, IMCA D 039 says that applying FMEA techniques to a diving system can yield a great deal of information relating to its failure behavior, but can be time consuming and expensive. For this reason, this guidance recommends to understand and define the objectives of the analysis clearly. This topic is more discussed in point 3.3.1.

5 - Identification of the failures, their causes, effects, and their possible controls:

When the systems and process to be analysed are identified, the team can work in detail on them, so that critical operating modes can be detected and addressed. Based on the documents and the limitations of the system, the team is normally fully aware of the process to follow to identify potential hidden failures and determine their effects. Note that such a process may highlight some problems of conception that will have to be addressed. The team should also be able to decide which method of analysis is the most appropriate. Thus, select an FMEA or an FMECA format.
This phase of the task must be fully documented using the drawings, engineering calculations, and safety evaluations.
These analysis are usually performed on worksheets. Regarding this point, IMCA says that for each failure mode the team should identify:

- The effect of a system or component failure on the particular system, sub-system or component.
- The effect of such a failure on other related systems or sub-systems.
- The effect of such a failure on the continued safe operation.

6 - Verification onsite of the issues identified, and their corrective actions:

The worksheets should be verified onsite to confirm that the analysis is relevant. IMCA says that this review should include the verification of the accuracy of the data provided to perform the analysis, and focus on the implementation of mitigation features for identified failure modes such as:

- Redundancy of components.
- Operating and emergency procedures.
- Spare parts stockholding and maintenance procedures.

IMCA also says that the testing phase, which data are to be incorporated into a trials report and then the final report, is necessary to confirm:

- That the hardware is installed and operated in the manner that is set out in the FMEA, and that mitigation features set out in the FMEA worksheets are in place and effective.
- That the system operators and maintainers are fully familiar with the operation of the equipment and systems, including emergency features or procedures, and that the findings of the analysis are accurate.

7 - Revision of the corrective actions and re-evaluation of the risks:

At the end of the initial testing phase, the suitability of the corrective actions should be carefully assessed to ensure that there is no unseen problem. Also, this testing phase may not be fully successful, and that some problems that require other solutions or additional control measures may have to be addressed and may require additional tests.

8 - Preliminary document and last verification:

A preliminary document should be published that can be used as support for the final tests. Then, as recommended in IMCA D 039, trials in operational conditions should be performed that focus on the failure modes identified in the analysis phase which have an impact on safety, pollution, financial impact or other determining factors. The trial documents should set out each test protocol and should include:

- The systems, sub-systems, or components to be tested.
- How each test should be performed, with the expected results, and the actual results.
- Whether the tests are satisfactory with appropriate comments.
- Following the last trial, the final FMEA document should be finalised, and transmitted to all parties for acceptance.

9 - Publication and distribution of the final document:

The final document is to be published through the management system of the operator. This document is usually a full file that explains:

- The methodology for the creation of the FMEA.
- The description of the system analysed.
- The analysis performed, and the reasons for this choice
- The failures discovered, and the solutions implemented to solve them.
- The conclusions, and the recommendations.
- Drawings, charts, analysis matrix, and guidelines to solve problems.

Note that conclusions and recommendations from the FMEA are to be included in the operational manuals.

3.3.4 - Updating the Failure Mode Effect Analysis procedures

The FMEA is a document that provides safety solutions and means of investigation and interventions according to the technology available and the working practices in force during the period it has been created. It will become obsolete as a result of changes in operating procedures and modifications of the diving system such as an example, the change of a component by another one from another manufacturer, or the upgrading to a new technology such as the adaptation of a diving monitoring system to an old generation system. Also, some solutions published in the final document may be perfectible and unexpected events may happen. For these reasons, the FMEA should be checked and reviewed at regular intervals:

- IMCA suggests performing a trial every year and at each mobilization for the portable systems, which is, in fact, the frequency of auditing of a diving system.
- Undesirable events that may happen should be recorded, investigated, analyzed, and be adequately solved. For this reason, a system of reporting must be in force. Detailed recording of events is usually the responsibility of the senior dive system technician in charge of the diving system, who communicates directly with the equipment manager of the company.
- A system of updating of the operating procedures of contractors is usually asked by the clients, notably the IOGP members. It is admitted that, depending on the quality of the manuals, the size of the company, and the complexity of the equipment it uses, such reviews can be made at a frequency between one and three years, except for updates that require immediate implementation.
  Based on the fact that the revision of the company operating procedures may have an impact on the way the equipment is used and may lead to technical modifications, we can say that the update of the FMEA of the dive systems should be scheduled at the same period. However, it must be considered that the full revision of an FMEA takes time and that the company may use numerous diving systems that cannot be checked at the same time. For this reason, such updates are to be organized through the Planned Maintenance System.
  Regarding this point, IMCA suggests that provided that any changes that are made during the life cycle of the diving system are appropriately analyzed, and the FMEA is updated following the change control management procedure, it may not be necessary to update the FMEA formally regularly, and that, depending on the contractor, a frequency between one or two years could be acceptable.

Note that IMCA D 039 proposes a model of a worksheet and another one for the record of the change in its appendix:

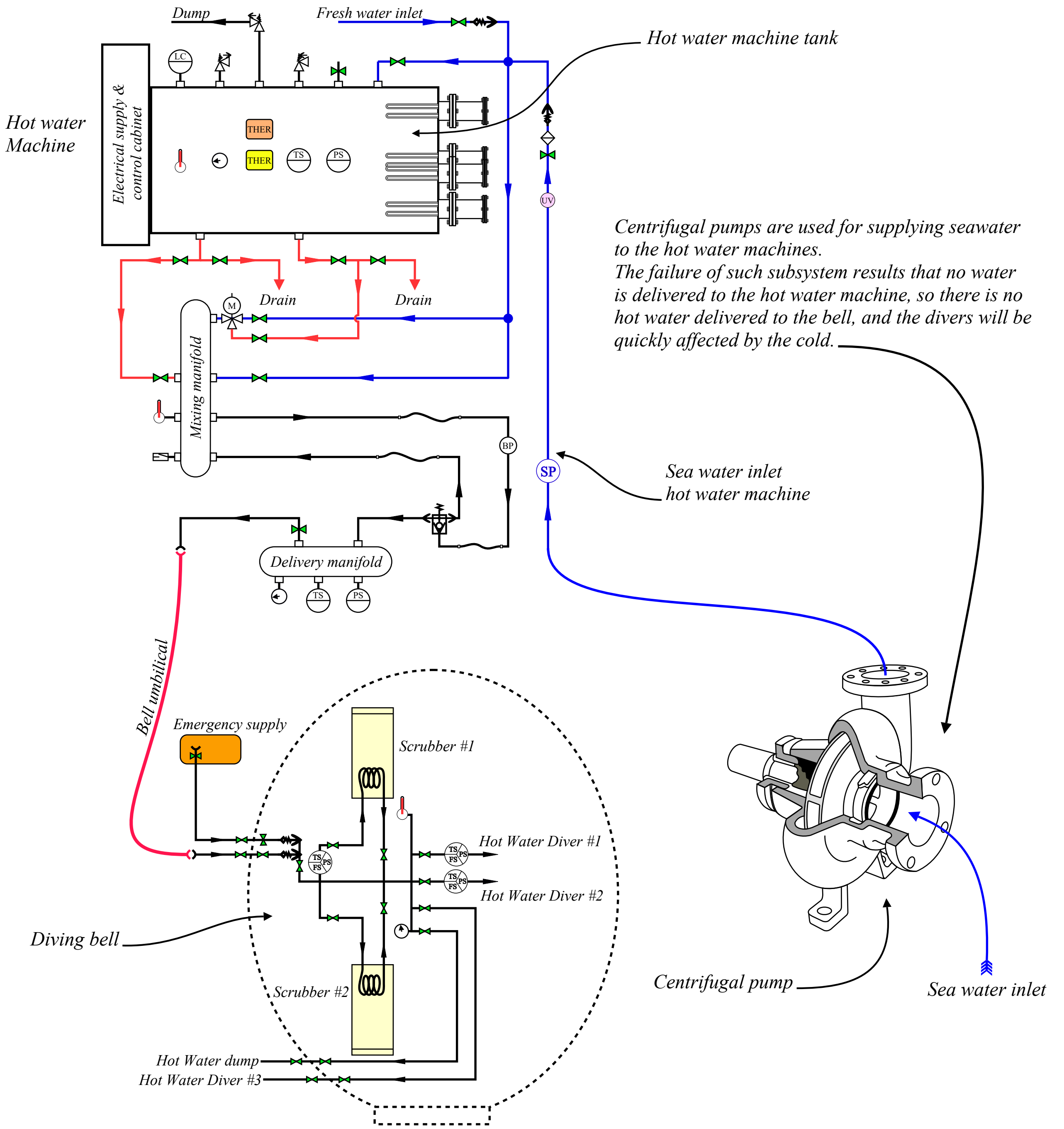
- The worksheet records the following elements:
  - Identification of the system
  - Function and operating mode
  - Failure mode identified and the cause of this failure
  - The effects of the failure
  - Critical analysis
  - Mitigation and notes
- The FMEA management of change sheet indicate the following elements:
  - Diving system identification
  - Date
  - Reference FMEA
  - System and item affected
  - If the change results from an incident
  - The reasons for the change
  - Effect of the change on the diving system
  - Whether the change affects the FMEA
  - Whether function tests and FMEA trials have been carried out
  - Whether the change affects the company manuals
  - Whether the change applies to other company diving systems
  - The circulation list *(dive supervisors, Life support supervisors, Chief engineer, dive system technicians)*
  - The technical department supervisor signature
  - The Operation manager signature

These documents are completed by a list of the systems and sub-systems that may be used as a guide.

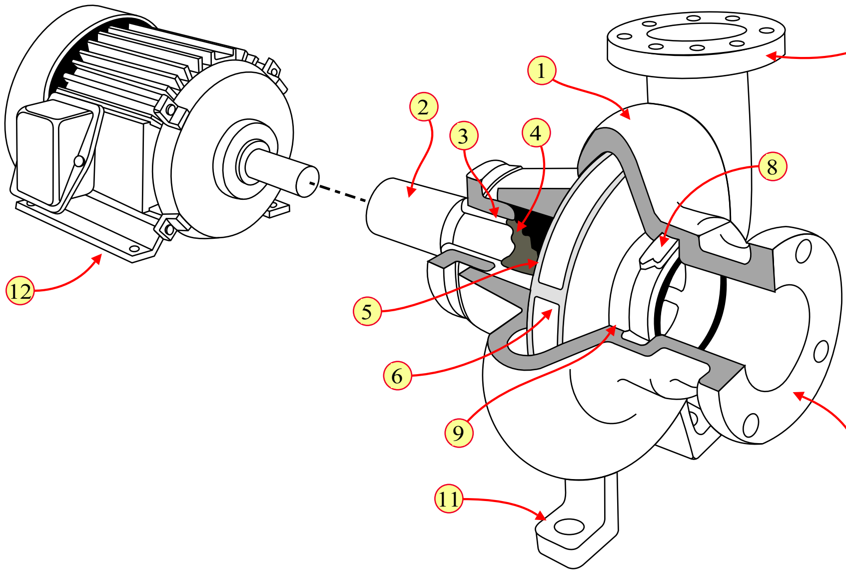
3.3.5 - Failure Mode Effect Analysis forms adapted to dive systems

It often happens that several FMEA formats are used with a diving system. The reasons are that diving systems are ensembles of elements from several manufacturers who provide the FMEAs they consider the most appropriate for the products they design and sell. In addition, although a FMEA may be sufficient to describe the primary function of the diving system, subsystems may have criticalities that need to be specified through a FMECA. Of course, during the process of certification of the diving system, the acceptance of the FMEAs of the manufacturers is usually the responsibility of the competent body in charge who has the authority to require modifications.

Numerous formats can be selected or adapted to the needs of a contractor, and some operators may prefer having a FMEA system that uses one or a limited amount of company forms to ensure that everybody discusses the same elements of their diving systems. However, the difficulty of such a management procedure is to create suitable formats that cover the main systems, subsystems, and the components of theses subsystems that are needed by the people who operate the diving system.
As already said in step #4 of point 3.3.3, It is necessary to give a limit, because an FMEA can yield a great deal of information relating to failure behavior that can be time-consuming to record, challenging to organize and interpret, and finally not really useful for the personnel operating the dive system.
As an example, the centrifugal pump used to feed seawater to the hot water machines that supply the bell and the divers *(see the description in point 2.3.13.2)* is a subsystem in which the breakdown results that no more seawater is coming into the tank of the hot water machine. Then, no more hot water is supplied to the bell and the divers. who will be quickly affected by the cold. It is the reason a backup device should be ready to go online. So, the FMEA of the supervisor may not need to be developed further as his concern is to be sure that he has a control measure, to supply the divers with hot water in such a situation.



If the team decides to provide further details, it is necessary to describe the components of this subsystem which is an assembly of the following elements which some of them can be a source of breakdown:



Nb	Item	Function	Possible failure
1	Housing	It houses the impeller and the parts that allow it to rotate and create a suction. It is the frame of the pump.	It can be damaged by the failure of the parts in movement in it, or a dropped object if the pump is not installed in a protected place.
2	Shaft	It is connected to the driving motor and transmits its motion to the impeller.	It can be damaged by the failure of the parts that hold it that may create exaggerated gaps leading to vibrations and wear.
3	Bearing shaft	It maintains the shaft and the impeller in line and allows them to turn freely. It usually has bronze rings, ball-bearings, or roller-bearings.	Its failure results in the shaft and the impeller possibly being damaged. Such damages can extend to the housing as well.
4	O-rings	They are usually in the shaft sleeve and designed to make a perfect seal.	A failure results in a leak with water coming out, and the suction that cannot be established.
5	Junction shaft - impeller	Attachment of the impeller to the shaft. It can be bolted or welded.	Bolt failure is possible as a result of vibrations. However, such a breakdown is rare.
6	Impeller	Create the suction and the ejection of the water as a result of its rotation.	It can be damaged by foreign objects entering the housing if there is no filtration, or by cavitation effects if the piping is improperly designed, or the failure of one of the parts indicated above.
7	Connecting flange to the outlet pipe	It allows for a perfect mechanical connection and seals with the outlet pipe. It is usually bolted	The failure of the seal results in water coming out and the sealing of the pipe that cannot be established. A similar problem should happen in the case of loosened bolts.
8	Bearing impeller	Same function as #3	Same failure as #3
9	O-ring impeller	Same function as #4	Same function as #4
10	Connecting flange to the inlet pipe	It allows for a perfect mechanical connection and seals with the inlet pipe. It is usually bolted	The effects are those indicated in #7, with in addition the suction that cannot be made.
11	Fixation legs	They maintain the pump in place on the chassis it is installed on. The fixation is usually by bolting. Silent blocks may be used to absorb noise and vibrations.	A loosen bolt may generate exaggerated vibrations that will impact the elements listed above and transmit to other parts of the system through the vibrations generated to the piping.
12	Electric motor	It is the subsystem that drives the pump. It is composed of a rotor, bearings, shaft, stator, etc.	A failure of the motor results in the pump that is not in motion, so it is unable to supply water.

The example above shows that introducing too many sub-systems obliges to deal with numerous information that can lead to a complex presentation, and at last a document that becomes unreadable because too many things are in it. For this reason, the main FMEA should be limited to a reasonable level to which more specific FMEAs that can be from manufacturers can be linked.
Note that a lot of suppliers provide their FMEA on formats that are designed to be updated by the operator of the diving system or the manufacturer.
The example on the next page is a compilation of several FMEA company formats using “Risk Priority Number” (RPN)

Hyperlink Tables of contents

The sheet below is oriented in the “portrait” mode for convenience. However, landscape orientation is usually employed with FMEAs forms.
The purpose of this example is not to publish the “ideal sheet”, but to explain how they are usually designed. For this reason it is intentionally limited to the main subsystems. It is to the people organizing the FMEA to add additional levels or not, taking into account the problems highlighted on the previous pages.

1- Identification	***Failure Mode Effect Analysis (Name + logo company)***			
	Dive system: *Lichtenstein*	***Revision number:*** *1*	***Document #:*** *01*	
	Date: *7/5/20*	***Auditors:*** *Chris*	***Sheet number:*** *1 of ...*	
	Part of the system: *Diver heating system*	***Item:*** *Hot water machine*	***Manufacturer:*** *Comanex*	
2 - Identification component and description of the potential failures	***Component***	*Centrifugal pump seawater inlet*	*Centrifugal pump*	*Component #2*
	Function item	*Supplying seawater to the machine*	*Idem*	
	Operating mode	*Automatic when the machine is started*	*Idem*	
	Identified failure modes	*Leaks*	*Electric motor*	
	Main/local effect	*No suction / pressurization: No water supply to the hot water machine*	*Pump not actuated*	
	Subsequent failures & effects	*No hot water to the divers*	*No hot water*	
3 - Controls	***Existing safeguards***	*Daily visual inspection & close inspection every month*		
	Additional control measures	*Backup hot water machine ready*		
4 - Initial Risk analysis (RPN)	***Severity (Rate: 1 to 10)***	*4*		
	Likelihood (Rate: 1 to 10)	*3*		
	Detection (Rate: 1 to 10)	*3*		
	RPN = Severity x Probability x detection	*36*		
5 - Identification and description of the rectifications implemented	***Suggested rectification***			
	Person in charge			
	Planned date of rectification			
	Rectification performed			
	Rectification trial			
	Rectification completion date			
6 - Residual Risk analysis (RPN)	***Residual severity (Rate: 1 to 10)***			
	Residual probability (Rate: 1 to 10)			
	Residual detection (Rate: 1 to 10)			
	RPN = Severity x Probability x detection			
7 - Notes	***Notes / recommendations***			

- 1 - FMEA record sheets are to be identified. The following information are usually displayed:
  - Name and logo of the manufacturer or of the owner of the system is usually displayed.

- Reference of the dive system.
- Reference of the document and its revision number.
- The number of the sheet and the total number of sheets
- Date of audit
- Names of the auditors
- Part of the diving system analysed and the item (Main component of this part)
- Manufacturer *(not used when the FMEA is performed by the manufacturer)*

- 2 - The 2nd step is the identification of the component and the description of its potential breakdowns. These columns that are usually on the left side of the sheet when it is oriented in “landscape” mode, give the following information:
  - Identification of the component and its function
  - The operating mode of the component
  - Identified failure modes
  - The direct effect of the failure
  - Subsequent effects of the failure

- 3 - The 3rd step is the identification of the protections in place to mitigate the effect of breakdowns.
  - Existing safeguards
  - Additional control measures *(note that a lot of companies group the means of control in only one box)*

- 4 - Step #4 is the analysis of the initial risk using the method of analysis selected *(“Risk Priority Number” (RPN) in this example).*

- 5 - Step #5 is the identification of the corrective actions to mitigate the effect of breakdowns.
  - Suggested rectification
  - Person in charge
  - Planned date of rectification
  - Rectification performed
  - Rectification trial *(a trial should be performed to ensure the the rectification is adequate)*
  - Completion date *(the date when the equipment can be or has been returned to service)*

- 6 - Step #6 is the analysis of the residual risk after rectification.

- 7 - There is usually a box where the persons in charge of the analysis can give recommendations and other comments.

To conclude with this point:
When studying the FMEA, the ideal solution is to involve people in charge of the exploitation of the diving system since the beginning of the process to obtain documents that suit to the procedures in force in the company, and easy to exploit. As demonstrated, the most significant difficulty will be to define the extends of this document to be sure it suits the needs for efficient control of the saturation system, which is sophisticated machinery.
One of the functions of the FMEA is to allow investigating a technical problem to make an immediate decision regarding the safety of the divers, and then repair the breakdown. For this reason, it may be preferable to develop a model that is simple and describes only the main functions of the diving system to which FMEAs of the sub-systems (that could be those made by the manufacturers) can be linked, instead of doing a more detailed FMEA which may be challenging to design and exploit, and finally not to be an efficient tool.

3.4 - Planned maintenance system (PMS)

3.4.1 - Purpose

The Planned Maintenance System (PMS) allows diving operators to carry out the maintenance of their diving systems at scheduled intervals according to the requirements of manufacturers, classification societies, IMCA, and other diving or safety organizations. Also, note that this equipment management system is mandatory by most of the organizations indicated above, the clients, and also in International Maritime Organization (IMO) that says in the International Safety Management Code (ISM): *The Company should establish procedures to ensure that the ship is maintained in conformity with the provisions of the relevant rules and regulations and with any additional requirements which may be established by the Company. In meeting these requirements the company should ensure that:*

I. *inspections are held at appropriate intervals,*
II. *any non-conformity is reported with its possible cause, if known,*
III. *appropriate corrective action is taken, and*
IV. *records of these activities are maintained.*

Because diving systems used offshore are onboard vessels, we can say that the implementation of the planned maintenance system of diving systems is mandatory for all companies working at sea. The senior dive system technician usually supervises this task onboard the vessel, and communicates with the equipment manager in the headquarters.

3.4.2 - Elements to be in the record documents

The planned Maintenance System must be organized and the documents recorded as follows:

- There should be a chart indicating how the maintenance system is organized and how the documents must be filled. Also, the language used should be understood by everybody. For this reason, English is used.
- There should be the inventory of the items included in the maintenance program.
- The certificates must be updated and available for the diving & life support supervisors, and every person involved in the organization and the following of the dives. IMCA says that there should be no doubt on which day maintenance has been carried out and by whom. IMCA also says that it important that more than one copy of these documents exists. So a copy or the original should be kept in the office onshore. Note that every copy should provide evidence that conforms to the original.
- The intervals at which the maintenance jobs are to take place must be indicated. The scheduling of the maintenance, documentation used, and procedures applied should be according to the recommendations of the manufacturers and the classification society.
- Also, as I recommend using the Diving Equipment Systems Inspection Guidance Notes IMCA D 024 & D 053 for the audits of the dive systems, the recommendations from these documents and the guideline IMCA D 018 "Code of practice for the initial and periodic examination, testing and certification of diving plants and equipment" should be followed as well. Note that if a conflict arises between the manufacturer rules and those from IMCA, the most stringent standard should be applied.
- When maintenance work is performed, the documentation used as a guideline should be indicated in the records. Also, these records should show the planned and the unplanned works performed. In the case of an unexpected intervention, the document should also specify the reason for this intervention. If the repair follows a breakdown that resulted in an incident, that must be indicated with the file of the incident report in the attachment. If the maintenance of an item is delayed, the reasons for the delay and the date planned for the intervention must be indicated with the control measures in place not to affect the safety of the people.
- The previous maintenance jobs carried out should be recorded and kept available in the history files of each element of the dive system. IMCA D 018 says that certificates should be retained in a register for a minimum period of two or five years depending on the item of equipment and its application. As already indicated, there should be several copies of these documents.
- The availability of adequate spares to allow routine and non-routine replacement should be indicated.
- There must be traceability to the person who carried out the work on an item of equipment. For this reason, precise reports must be filled and signed by the technician in charge. Such documents should be checked and also signed by the senior technician in charge of the system.

3.4.3 - Organize the Planned Maintenance system

3.4.3.1 - Personnel in charge

As already indicated in point 3.1.2.2, managers will not be successful in implementing an efficient Planned Maintenance System if there are no competent people to do it. Thus, this point is the most critical and challenging to implement.
Also, there are maintenance operations that cannot be performed by every technician, so the people in charge must ensure to provide such competencies. Regarding this point, the document IMCA D 018 that gives guidelines regarding the appointment of competent persons says: *No official body appoints competent persons for the purpose of examining and testing diving plant and equipment. This is entirely a matter to be decided by the person or organisation which wishes to obtain the certification. The competence of any particular individual or organisation may, however, be challenged by any relevant national authority in its enforcement role.*

IMCA D 018 references four levels of competencies for the examination of diving plants and equipment:

1. An IMCA or equivalent level diving or life support supervisor duly appointed by the diving contractor: His competency should be limited to external visual examinations and function tests of the equipment he is familiar with, unless he has additional specific training.
2. A technician or other person specialising in such work who may be an employee of an independent company, or an employee of the owner of the equipment (unless specific legal restrictions apply), in which case his responsibilities should enable him to act independently and in a professional manner.
3. A classification society or insurance company surveyor, or chief engineer certificated in accordance with IMCA C 002 guidelines and competence tables: Marine Division (Job Category A06) but who may also be an "in-house" chartered engineer or equivalent (unless specific legal restrictions apply), or person of similar standing.
4. The manufacturer or supplier of the equipment, or a company specialising in such work which has, or has access to, all the necessary testing facilities. That may also be a technician employed by the owner of the equipment provided that he has been fully trained and certified for the specific operation and has access to all necessary equipment and facilities.

Note that, as indicated in point 3.1.2.3, the use of external service providers is usual for the maintenance of saturation diving systems that are assemblies of elements in which some parts require particular skills the technicians in charge have not, or which need the use of expensive tools which investment is not justified. The selection of these providers should be performed according to the guidelines also indicated in point 3.1.2.3.

3.4.3.2 - Prepare relevant documents

The principle of the Planned Maintenance System has been invented before the democratisation of computers during the nineties. These initial equipment management systems were based on intervention sheets and store lists that were recorded in a book where the operations performed and planned were logged by hand-writing. There is probably no company using such a not computerized system today. However, the same organizational frame is conserved for the creation of management systems using computers.

A diving system is composed of many items that are identical but installed in different parts of the system. It will be necessary to identify each of them, as each component of the dive system must be appropriately tested and maintained. As an example, there are many gauges on a saturation ensemble, and each one has a particular function. For this reason, the technician in charge of the maintenance of the system must be able to identify each gauge. That obliges the people organizing the Planned Maintenance System to indicate:

- The diving system where the item is installed
- The part of the system the gauge is installed
- The function of the panel where the gauge is installed
- The function of the gauge (depth gauge or gas supply gauge)
- The model and the name of the manufacturer, and whether it is analog or digital
- The position of the gauge on the panel

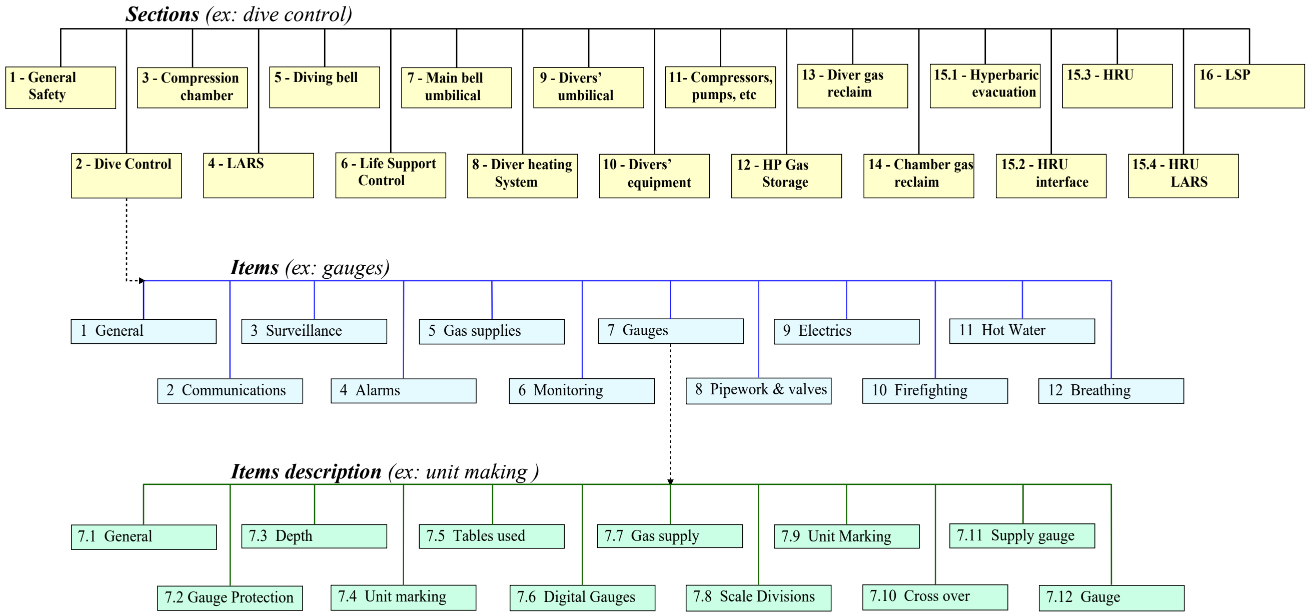
Reference numbers are the identification system most used. It usually allows to indicate where the element is installed, and its function and model. These reference numbers must be listed and also indicated in a reference document.
To locate the exact position of the elements, a precise scheme/drawing of the system where all the elements are precisely indicated must be edited. Photos can also be used as a support to avoid confusion. These scheme and drawings must be attached to the Planed Maintenance System and the documents used to audit the diving system.
Note that if acronyms are used they must be explained in a glossary that is attached to the list and the drawings.

Another point regarding the reference numbers is that they are linked to the way the dive system is referenced, as some differences exist regarding this critical point that is linked to the management system of the company exploiting it, and whether it is permanently installed onboard the surface support or is a portable unit. No specific rule is currently published for the moment except that the technicians and people working with the diving system must be able to find the maintenance documents they need quickly. For this reason, numerous technics of referencing exist that would be too long to describe. However, we can roughly classify the methodologies encountered as follows:

- Some companies arrange their referencing scheme according to the IMCA Diving Equipment Systems Inspection Guidance Notes (DESIGN), so they can refer to the IMCA audits of the system to find the corresponding maintenance documents and prepare the next ones. The advantages of such system is that the preparation of the IMCA DESIGN audits D 024 & D 053 is more comfortable and that this method of reference is based on documents that have proved their efficiency regarding the identification and the following of the components of a diving system. However, this method may conflict with others referencing procedures.
- Some companies base their PMS on the system used by the classification company during the classification process of the system. The advantage is that the preparation of the surveys planned by the classification society is easier, but that oblige the contractor to classify the documents in another manner if the classification society uses another system of reference than the one used in the IMCA documents D 024 and D 053. Thus, to avoid having double tasks, the wise idea is to ask the classification society to organize a Planned Maintenance System that can be used for the two audits. Such discussion is essential during the process of selection of the manufacturer and the classification society, as to be obliged to use several systems of referencing leads to additional costs and possible confusion.
- Some contractors prefer using a system of reference that can be one of the mother organization that owns the

company (in case the company is part of a group), the one in force on the boat the diving system is installed, or merely the method used by the software used to manage such operations. The inconvenience of such classification is that it may create additional tasks to link the documents of the Planned Maintenance System to the class surveys and the IMCA audits.

Note that the IMCA Diving Equipment Systems Inspection Guidance Note (DESIGN) D 024 is organized as follows:

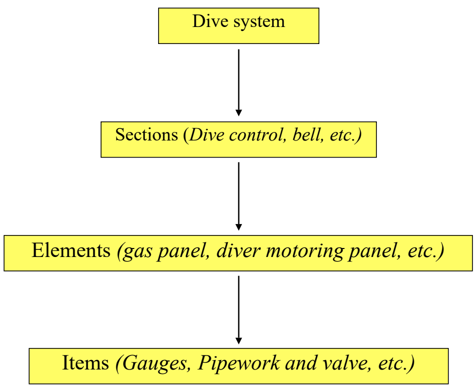


With this method of referencing, the items (as an example, the gauges) are grouped by function in the dive control. As an example, the gauges are all listed in the same file where the role and situation of each of them are to be indicated.

Some people may prefer a system of referencing that describes these items (gauges, valves, etc.) and their function in the elements that compose the dive control, such as those indicated below:

- Gas supply panel
- Gas reclaim management panel
- Gas analysis panel
- Diver monitoring panel
- Wired communications to and from the divers and through water communication
- Communications to the bridge and other parts of the boat
- Diver monitoring system
- Video recording system
- Hot water machine control panel
- Power supply controls

In this case, the referencing procedure is organised as follows :



To organize the structure of the planned maintenance system, people referencing the items must lean on the drawings and organizational scheme of the diving system to locate each element and provide support the reader can refer to. For this reason, a folder should be created where the drawings of the elements constituting the dive system are grouped. These schemes/drawings can be those made by the manufacturer or by a competent person category 2 or 3. The person in charge must ensure that:

- If some modifications have been made they are precisely indicated.
- That the drawings/schemes are easy to read.
- That the drawings/schemes are easy to find.
- That a copy of each drawing is in a safe place.

The documents used during the construction of the dive system must be available. For this reason, the folder where the drawings are classified should also contain:

- The documents that have been used for the "classification" of the diving system plus the certificate of classification.
- The elements that have been used to write the Failure Mode Effect Analysis (FMEA) plan plus the FMEA plans that are classified chronologically.

When the structure of the Planned Maintenance System is established, the people in charge should make sure that the items can be easily identified. For this reason, they should:

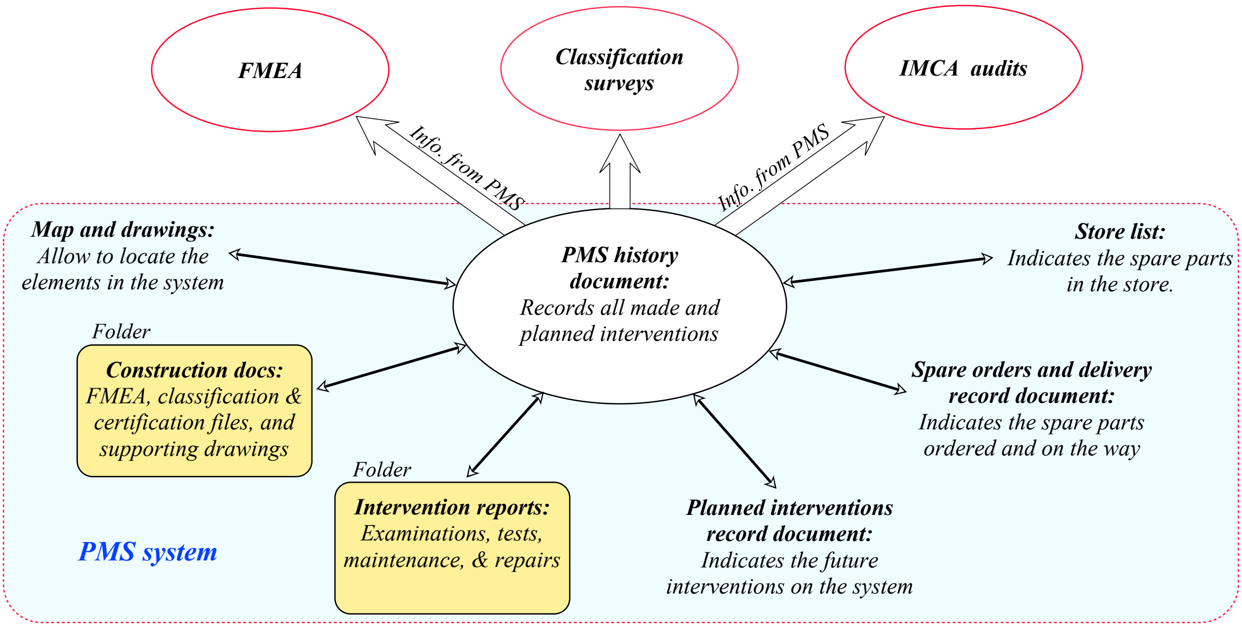
- Make sure that each item is precisely located and easy to find. If necessary photos can be used.
- Give a reference number or code to each item
- Write a glossary of acronyms or codes that are used
- Write a list of the items that are represented on the schemes/drawings and indicate where to find their detailed drawings and technical documents.

It is necessary to create forms that can be used by the technicians to log the maintenance and examinations performed on each item that composes the dive system, and that give a history of these various interventions.
As indicated in points 3.4.1 & 3.4.2, it is mandatory that the planned Maintenance System provides a history of the interventions performed on the system. Also, as discussed in point 3.3 "FMEA", the planned maintenance system is a tool that allows detecting the problems encountered with an item, and take appropriate decisions regarding its preventive maintenance, or its modification, or its replacement by a more reliable model to avoid unexpected breakdowns.
So a document that summarizes the examination, testing, certification, and maintenance that have been carried out on an item or a sub-Item and from which the testing and intervention reports can be easily found is essential. Remember that IMCA says that depending on the article, the history should be at least 2 to 5 years. However, IMCA gives a minimum, and the recommendation is to have the history of all the components since the system has been put in service. Forms reflecting the history of components should provide the information, indicated previously such as, but not limited to:

1. Identification of the item:
   - The reference of the diving system.
   - The description of the item, and in which part of the system it is installed *(drawings can be used).*
   - The reference number from the manufacturer.
   - The reference number of the item in the diving system.
2. The date *(day/ month/ year)* of each intervention.
3. Examinations, tests, and maintenance performed:
   - Description of the examinations, test, maintenance performed, and spare parts changed.
   - The reference numbers of the recording documents and certificates emitted during in-house and external examinations, tests, and repairs, and where these documents are stored. Copies of these documents should be linked by hyperlinks, so they are easy to find.
4. The supporting documents used
   - The Reference of the sheet IMCA D 018.
   - The recommendations from the manufacturer.
   - Other supporting documents that have been used.
5. Description of the planned next intervention:
   - The date and purpose of the planned next intervention.
   - Spare parts to order for the next intervention.
6. Traceability:
   - The name and signature of the technician in charge.
   - The name and credential of the third parties involved
   - The name and signature of the senior technician in charge.
   - Stamp of the company

Note that the document above usually does not allow the technician to log all the steps of a repair. For this reason, a detailed intervention reports should be used. It is also the case for the interventions performed externally, and the tests and examination certificates. As already indicated, in-house and 3rd party reports and certificates must be linked to the document that provides the history of the elements that compose the dive system. It is important to classify these documents in a specific folder, so they can be easily found. People in charge of these documents must always remember that they must be available at any time and that 3rd party auditors performing classification or a DESIGN audits are not employed to look for lost certificates.
Also, the attached reports of maintenance must provide very comprehensive information on the operations performed, so that a person reading these documents can understand what has been done and the reason it has been done. For this reason, the elements relating to the identification, date, operations performed, supporting documents used, and traceability should be clearly visible. So, a certificate from a service provider with incomplete information should be rejected.
In addition to the documents above, a form that records the spare parts ordered and the following of their delivery, and another one that records the next examination and preventive maintenance of the entire diving system should be implemented. Such documents are usually based on calculation sheets (as an example, Microsoft Excel) to which "conditional formatting of the cells" are applied to create alerts such as cells changing of colour when the next test or

examination is to be performed. Note that a lot of websites provide useful tutorials *(follow the links)*.



3.4.3.3 - Backup the documents

It is asked several times to make copies of the original documents in the previous texts. This point is crucial as a catastrophic event may happen that results in the company archives being destroyed. For this reason, it is prudent to have one or several back-ups of all the documents saved in another place.

3.4.4 - Software designed for Planned Maintenance System

The elements indicated in point 3.4.3.2 may become complicated to implement with companies using several saturation systems. Also, employees must have a minimum knowledge to use calculation sheets (Microsoft Excel) efficiently, and format them takes some time that can be used more efficiently with other tasks.
For this reason, most companies use specific software that provides all the tools they need to manage their diving systems. A lot of software for the management of equipment and asset management can be found through the internet. The selection of such software depends on the management system of the company and also whether it is compatible with other applications. It would be too long to describe all the products that are proposed. For this reason, two specific applications that are common in the industry have been selected for this purpose: "DiveCert", which is offered by Namaka subsea, and "TM Master V2" that is proposed by Tero Marine.

3.4.4.1 - DiveCert

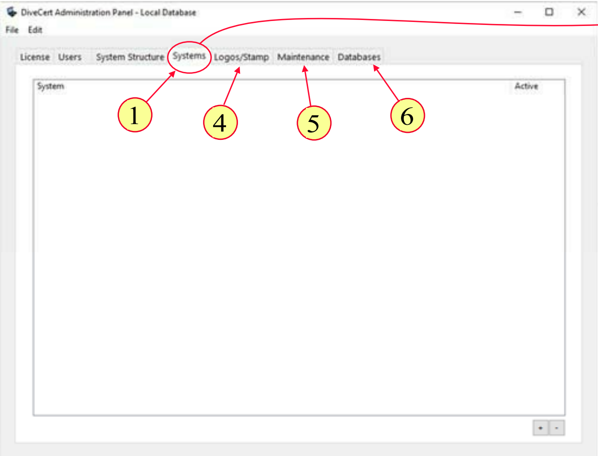
DiveCert is a certification, asset management, and planned maintenance software system, specifically designed for the diving industry by Namaka subsea that is designed to work with “Microsoft Windows” and “Apple OSX” operating systems. This software is designed to eradicate issues in the planned maintenance System and preparing IMCA audits efficiently. It is based on the following IMCA guidelines:

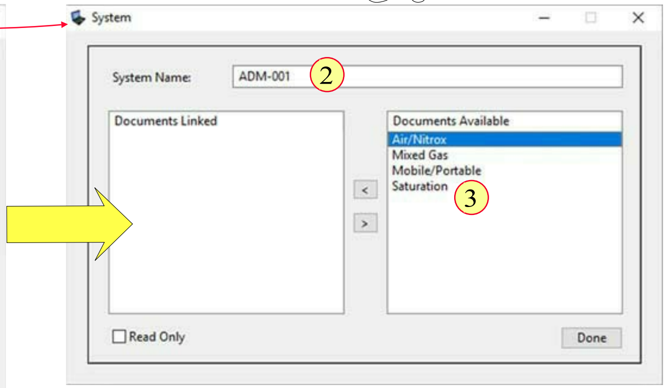
- IMCA D 018 - “Code of practice for the initial and periodic examination, testing and certification of diving plant and Equipment”
- IMCA D 023 - “Diving Equipment Systems Inspection Guidance Note for surface orientated (air) diving systems”
- IMCA D 024 - “Diving Equipment Systems Inspection Guidance Note for saturation (bell) diving systems”
- IMCA D 037 - “Diving Equipment Systems Inspection Guidance Note for surface supplied mixed diving systems”
- IMCA D 040 - “Diving Equipment Systems Inspection Guidance Note for mobile/portable surface supplied systems

This software can also be adapted to include additional (non-diving) equipment or alternative guidance documents.

The installation of the software on a machine running Microsoft Windows is as simple as every software. However, the installer does not include the database files that need to be installed by a member of the DiveCert support team. For the installation on a machine running “Apple OSX”, it is necessary to ask for the support of Namaka subsea, as the software must be installed manually.

The admin application of the software is designed to provide restricted access to only authorized people. Also, it allows to give several degrees of privileges to the users from read-only to the control of assets associated with all systems within the database, which includes the creation, modification, transferring and printing of asset lists.
When the system is unlocked, several windows allow to control the diving systems used by the company. As an example, the tab “system” allows a window to open where the several systems under control are logged *(See #1 on the next page)*



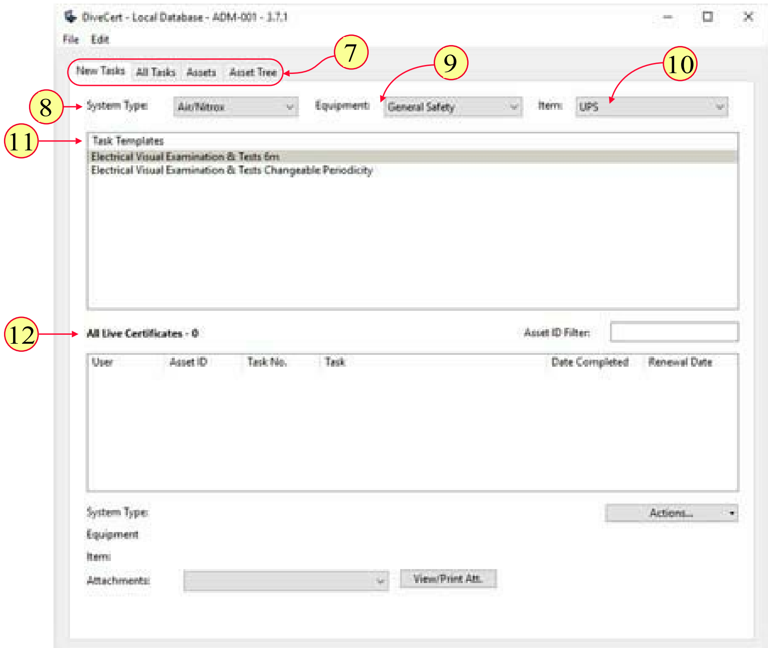


When the window “System” is opened, the operator can give a name to the dive system by highlighting the ‘System Name’ and retyping the name he desires *(See #2),* and select the type of system among the documents types *(see #3)*

There are four main document types available by default which are Air/Nitrox; Mixed Gas; Mobile/Portable; Saturation.
To link a document type to the company system, the operator selects one of them and clicks on the left pointing arrow.
To remove a document type, the operator reverses this process by clicking on the right pointing arrow.

The software allows the user to add a company stamp and a header or footer that will be printed on any documentation produced. A program that can be accessed by clicking the tab "Logo/stamp" allows the operator to choose or add the desired logo *(see #4 in the screenshot above)*.
Note that the tab "Maintenance" in the screenshot above *(see #5)* opens a restricted access section that is designed to allow the Namaka Subsea support team to carry out system maintenance when required. So the user cannot open the menu of this section.
The tab "Database" *(see #6 in the screenshot above)* gives access to the user to the menu allowing managing and mapping databases to different locations.
To log into the system, the user must select the dive system and then enters his name and password. So a technician cannot log into a diving system in which he is not authorized to intervene.
When the operator is logged into the system, a window opens with a taskbar in which four tabs "New Tasks", "All Tasks", "Assets" and "Asset Tree" give access to relevant menus *(see # 7 in the screenshot below)* . Some user interfaces may have an additional tab called “Global Assets” if they have been given permission on setup.
Other commands are displayed on the taskbar below:

- "System Type" allows selecting between "Air/Nitrox", "Saturation", "Mixed Gas" or “Mobile /Portable”, depending on how the system is set up *(see #8)*.
- “Equipment” allows selecting between different equipment found on diving, depending on what ‘System Type’ has been selected *(see #9)*.
- “Item” allows selecting between different items of equipment, depending on what “Equipment” has been selected *(see #10)*.



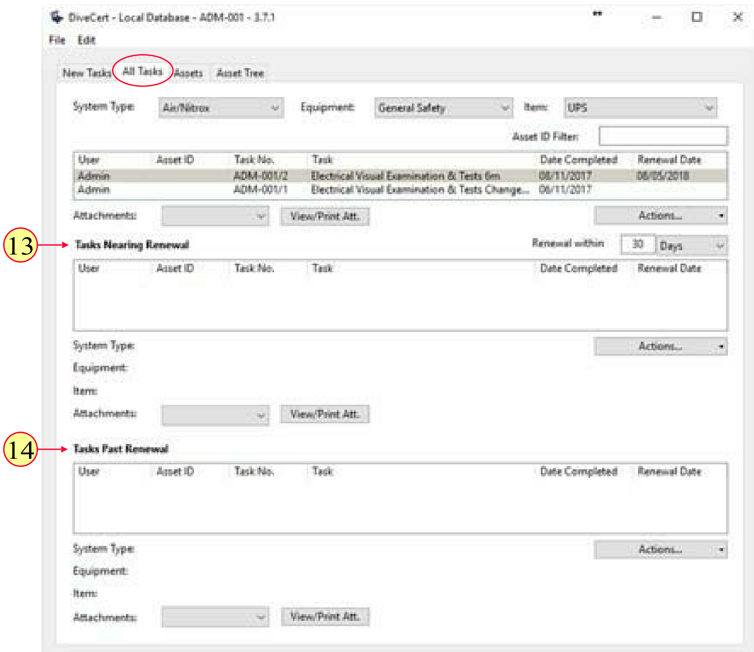
Two menu are visible when the tab "New Tasks" is selected:

- "Task Templates" *(see # 11)* displays the different task templates available.

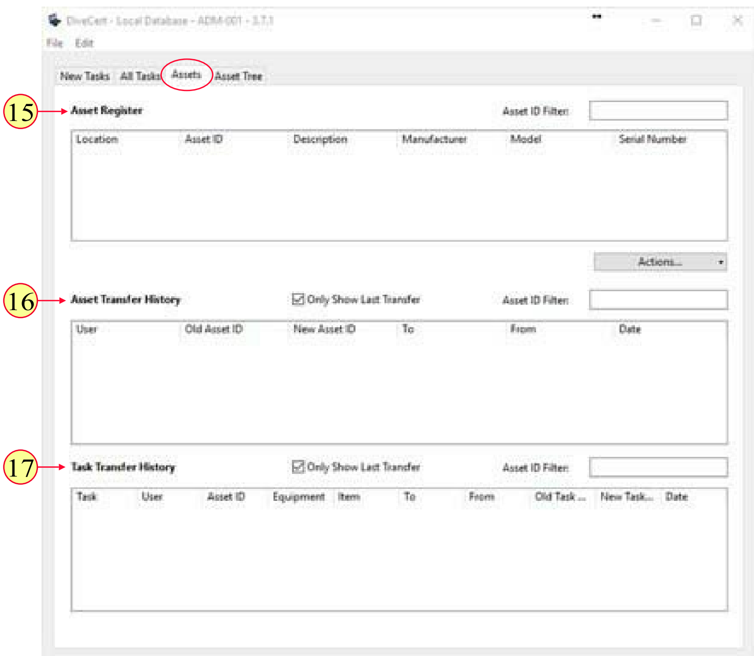
- "All Live Certificates" *(see # 12)* displays the current system live certificates, date completed, and renewal dates. This function of this section is the reviewing of live documents. Clicking the "Actions" button opens options such as:
  - "Print": Printing out a single selected certificate.
  - "Print all": Printing all currently archived certificates.
  - "Retire": Removing selected certificates from the system, which can still be viewed at any time.
  - "View": Allows examining any selected certificate.
  - "CSV report": This function allows producing a CSV file with detailed information of all certificates and assets. Note that a Comma-Separated Values (CSV) file is a delimited text file that uses a comma to separate values. These files are often used for exchanging data between different applications such as databases, listing, etc.
  - "Import Tasks" Allows importing a group of tasks.

When the tab “All tasks” is selected the taskbar "System Type" that allows selecting between "Air/Nitrox", "Saturation", "Mixed Gas" or “Mobile /Portable” is still present. The other menus "Task Templates" and "All Live Certificates" are replaced by two other menus:

- “Tasks Nearing Renewal” shows all tasks that are within 1 month of expiry, the periodicity is pre-determined to give the user advanced notice of task/work order renewal dates *(see #13)*.
- “Tasks Past Renewal” shows all tasks/work orders that are past their renewal dates, the periodicity is pre-determined to give the user advanced notice of task/work order renewal dates *(see #14)*.

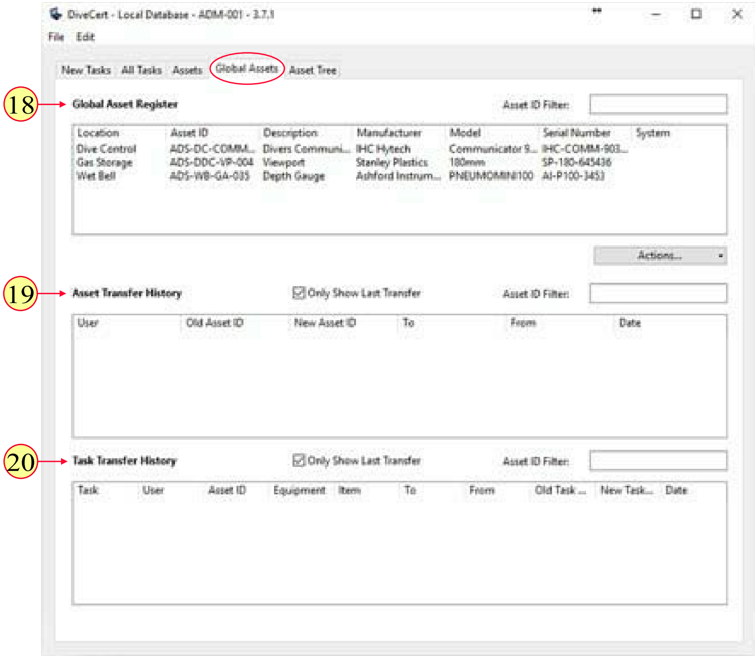


Clicking on “Asset” tab opens a window that shows the assets for the system the user has logged into. This panel allows to see the “Asset register” *(see #15)*, “Asset transfer history” *(see #16)*, and “Task transfer history” *(see #17).It* is accessible to all users that are limited by the privileges given by the software administrator.



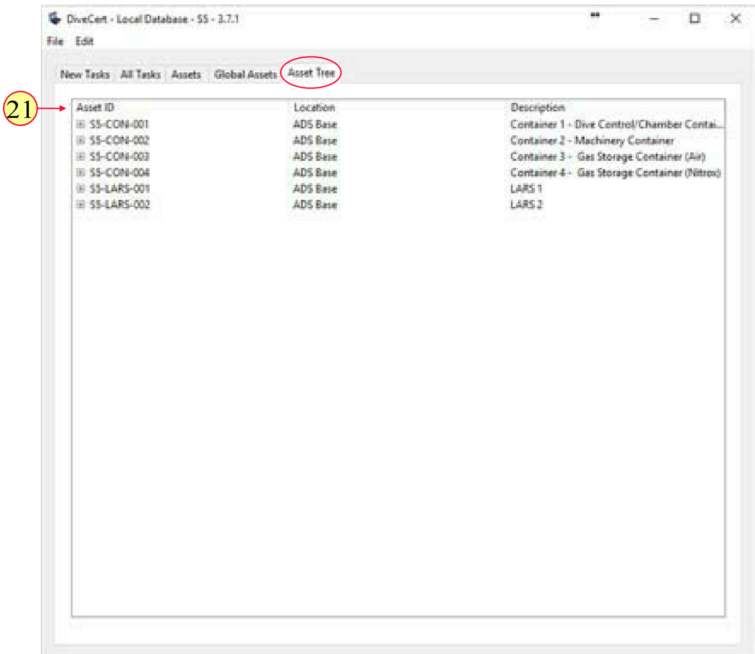
- “Asset Register” shows all the system asset identifications and descriptions, filtering the system assets can be achieved easily by using the Asset identification filter if required.
- “Asset Transfer History” shows the logs that are automatically performed when transferring an asset. The program identifies the asset location as well as dates of transfer. These logs can be filtered as above.
- “Task Transfer History” allows to see the logs provided to ensure all tasks are tracked between the system location or between multiple systems. The program identifies the task locations as well as dates of transfer. These can again be filtered as required.

Clicking on “Global Assets” tab opens a window that shows all assets for all available systems within the company database. Note that only users with access privileges will be able to view, this panel that shows "Asset register" *(see #18)*, "Asset transfer history" *(see #19),* and "Task transfer history" *(see #20)*. A lot of different actions can be carried out like in the "Assets panel", all of which are accessible from the "Actions" menu on the right of the panel.



- "Global Asset Register" shows all system asset identifications and descriptions within the company database, filtering the system assets for ease of location can be done by using the "Asset Identification Filter" function.
- "Asset Transfer History" shows the logs performed when assets are transferred. The program identifies the asset locations as well as the dates transferred. These logs can be filtered for ease of searching.
- "Task Transfer History" provides the logs performed when transferring a task. The program identifies the task locations as well as the dates of transfer. Again, filters can be used for ease of searching.

The “Asset Tree” tab allows the operator to see the structure between Parent & Child assets. Creating a relationship between assets allows a full transfer of an asset structure between systems/projects, including all associated documentation, with the click of a button *(see #21)*.



As a conclusion of the presentation above, this software is flexible and allows to manage all kind of scenarios that can happen when implementing a Planned Maintenance System (PMS). Also, the software designer provides a comprehensive manual that indicates step by step procedures to:

- Setup a new database
- Create assets, or import them from a Microsoft Excel spreadsheet template *(Note: There are many other office suites that provide similar programs than Microsoft. However, whether some suites are perfectly compatible, it is not the case of all)*
- Create custom tasks: The program that provides 700 templates allows to create custom tasks and templates.
- Import tasks: Tasks can be imported into the program via a Microsoft Excel spreadsheet template.
- Printing work-orders
- Renewing a task after a work-order has been completed and all relevant work carried out on equipment
- Importing & Exporting Systems: Any systems created within the software can be exported and imported when and if required.
- Transferring Assets: It is possible to transfer assets between systems within the same database.
- Produce a certification pack & Diving Equipment Systems Inspection Guidance Note (DESIGN): This function only applies to those who have the Dive DESIGN module add-on.
- Map a new Task: This document informs the system of what information to collate from the software and place into the live DESIGN document
- Backup & restore data. Suggestion: Save the backup on another hard disk.

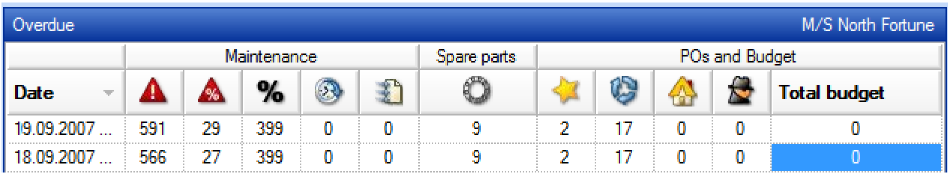
Note that Namaka Subsea provides online technical support and can organize training

3.4.4.2 - TM Master V2

"TM Master V2" is an integrated marine information system proposed by Tero Marine, comprising modules for ship maintenance, procurement, human resources and quality assurance. This software that is designed for Microsoft Windows, starting from the “XP” version, provides the following modules: Fleet, Vessel, Inventory, Maintenance, Purchasing, My place, System, Tools, Contacts, and Chat.

- 1 - “Fleet” module gives an overview of the entire fleet through the nine following tools:

- Key Performance Indicators (KPI): This window, which is accessible through a button, gives an overview of all the jobs and orders to all of the ships in the fleet. Predefined Key Performance Indicators , fleet-wide due calculations, and history review are indicated. This windows is read only.

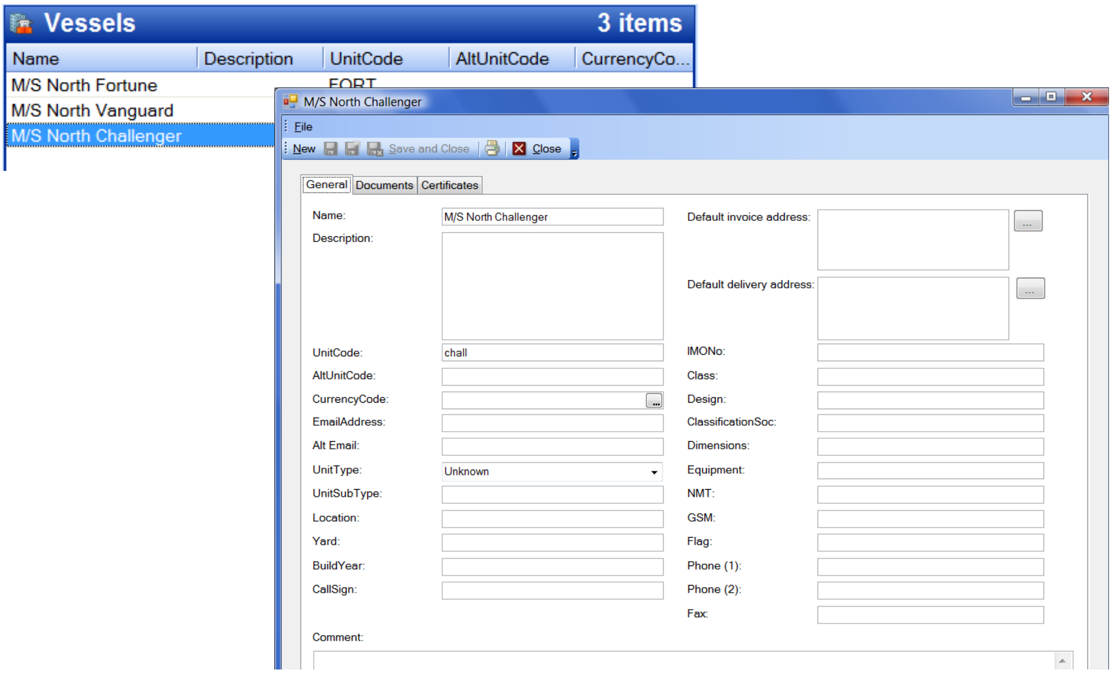


Overdue — M/S North Fortune

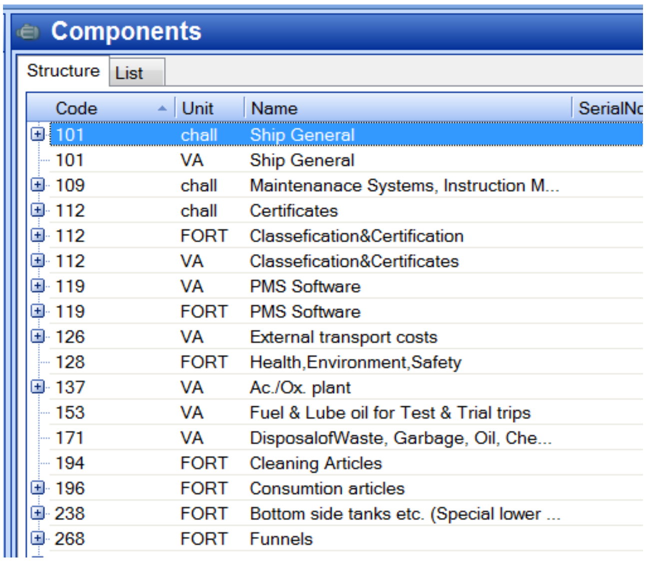
	Maintenance					Spare parts	POs and Budget				
Date			%								Total budget
19.09.2007 ...	591	29	399	0	0	9	2	17	0	0	0
18.09.2007 ...	566	27	399	0	0	9	2	17	0	0	0

  - “Maintenance” shows the number of jobs that are due with the percentage of actions overdue, the percentage of Key Performance Indicators, the jobs that have been postponed.
  - “Spare parts” shows how many spare parts have reached a low stock level.
  - "PO and budget" shows the number of drafts and requisitions, the active orders, the number of orders that have been delivered, the orders received by the agent.

- Vessel: Gives an overview of all the units within the fleet.



- Components: Show the components and systems of all vessels across the fleet.

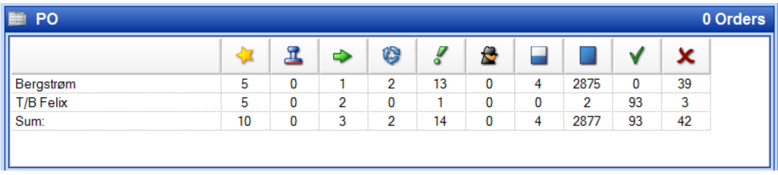


Components

Structure | List

Code	Unit	Name	SerialNc
101	chall	Ship General	
101	VA	Ship General	
109	chall	Maintenanace Systems, Instruction M...	
112	chall	Certificates	
112	FORT	Classefication&Certification	
112	VA	Classefication&Certificates	
119	VA	PMS Software	
119	FORT	PMS Software	
126	VA	External transport costs	
128	FORT	Health,Environment,Safety	
137	VA	Ac./Ox. plant	
153	VA	Fuel & Lube oil for Test & Trial trips	
171	VA	DisposalofWaste, Garbage, Oil, Che...	
194	FORT	Cleaning Articles	
196	FORT	Consumtion articles	
238	FORT	Bottom side tanks etc. (Special lower ...	
268	FORT	Funnels	

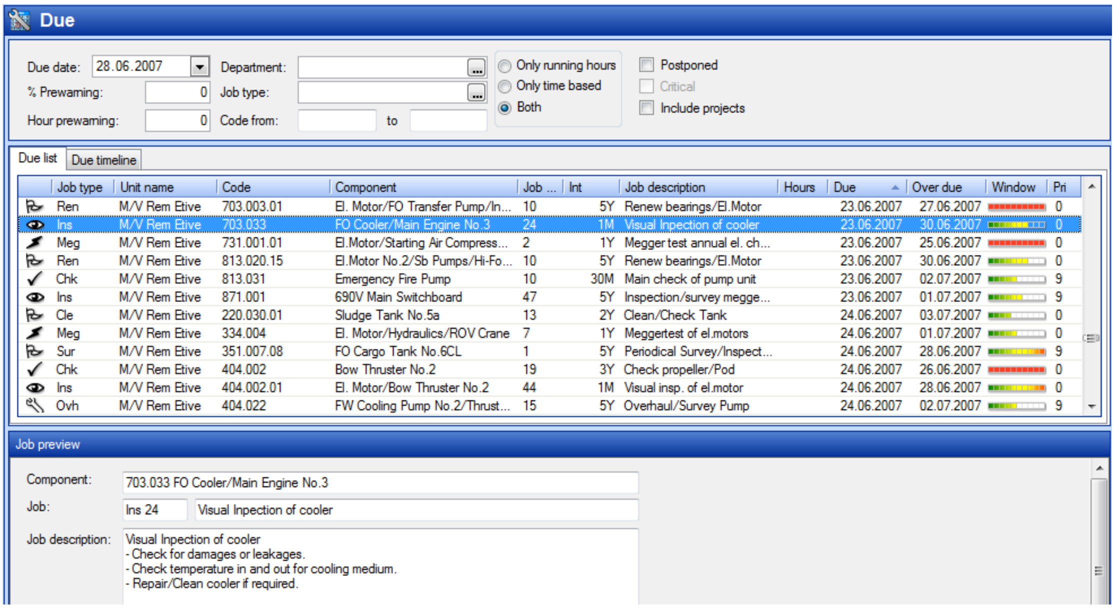
- "Purchase Orders (PO)" gives an overview of all Purchase Orders from the whole fleet such as:
  - Numbers of orders that aren't approved yet.
  - Orders that are approved, but not sent.
  - Orders sent, but not started.
  - Orders that have been sent but have not been received by the supplier yet.
  - Orders which are sent to the supplier.
  - Orders have been received by agents
  - Orders which are split and only partially received.
  - Orders that have been received.
  - Orders that are fully received and paid.
  - Orders that have been cancelled.



PO 0 Orders

Bergstrøm	5	0	1	2	13	0	4	2875	0	39
T/B Felix	5	0	2	0	1	0	0	2	93	3
Sum:	10	0	3	2	14	0	4	2877	93	42

- Due: Gives an overview of scheduled jobs such as:
  - Checking jobs.
  - Annual survey, certificate renewal, service, check/clean components jobs.
  - Visual inspection type jobs
  - Lubrication and oil change jobs
  - Megger test jobs *(The Megger test is a method of testing making use of an insulation tester resistance meter that will help to verify the condition of electrical insulation)*.
  - Overhaul jobs



Due

Due date: 28.06.2007 | Department: | Only running hours | Postponed
% Prewarning: 0 | Job type: | Only time based | Critical
Hour prewarning: 0 | Code from: to | Both | Include projects

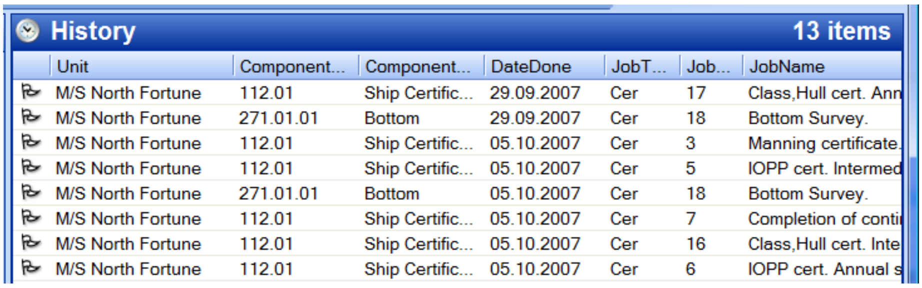
Due list | Due timeline

Job type	Unit name	Code	Component	Job ...	Int	Job description	Hours	Due	Over due	Window	Pri
Ren	M/V Rem Etive	703.003.01	El. Motor/FO Transfer Pump/In...	10	5Y	Renew bearings/El.Motor		23.06.2007	27.06.2007		0
Ins	M/V Rem Etive	703.033	FO Cooler/Main Engine No.3	24	1M	Visual Inpection of cooler		23.06.2007	30.06.2007		0
Meg	M/V Rem Etive	731.001.01	El.Motor/Starting Air Compress...	2	1Y	Megger test annual el. ch...		23.06.2007	25.06.2007		0
Ren	M/V Rem Etive	813.020.15	El.Motor No.2/Sb Pumps/Hi-Fo...	10	5Y	Renew bearings/El.Motor		23.06.2007	30.06.2007		0
Chk	M/V Rem Etive	813.031	Emergency Fire Pump	10	30M	Main check of pump unit		23.06.2007	02.07.2007		9
Ins	M/V Rem Etive	871.001	690V Main Switchboard	47	5Y	Inspection/survey megge...		23.06.2007	01.07.2007		9
Cle	M/V Rem Etive	220.030.01	Sludge Tank No.5a	13	2Y	Clean/Check Tank		24.06.2007	03.07.2007		0
Meg	M/V Rem Etive	334.004	El. Motor/Hydraulics/ROV Crane	7	1Y	Meggertest of el.motors		24.06.2007	01.07.2007		0
Sur	M/V Rem Etive	351.007.08	FO Cargo Tank No.6CL	1	5Y	Periodical Survey/Inspect...		24.06.2007	28.06.2007		9
Chk	M/V Rem Etive	404.002	Bow Thruster No.2	19	3Y	Check propeller/Pod		24.06.2007	26.06.2007		0
Ins	M/V Rem Etive	404.002.01	El. Motor/Bow Thruster No.2	44	1M	Visual insp. of el.motor		24.06.2007	28.06.2007		0
Ovh	M/V Rem Etive	404.022	FW Cooling Pump No.2/Thrust...	15	5Y	Overhaul/Survey Pump		24.06.2007	02.07.2007		9

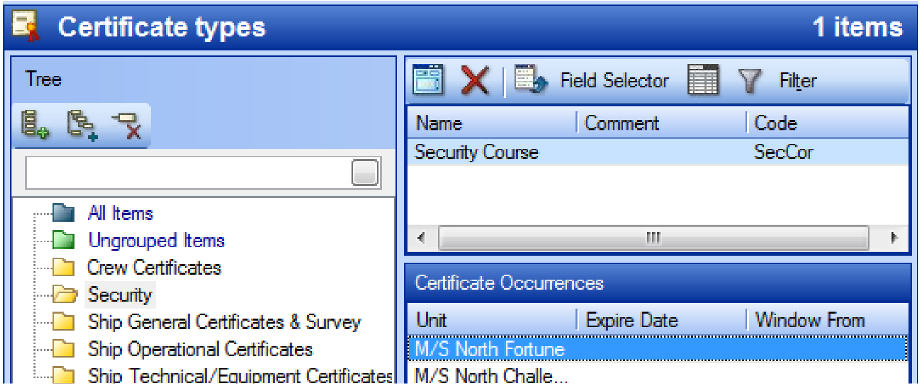
Job preview

Component: 703.033 FO Cooler/Main Engine No.3
Job: Ins 24 Visual Inpection of cooler
Job description: Visual Inpection of cooler
- Check for damages or leakages.
- Check temperature in and out for cooling medium.
- Repair/Clean cooler if required.

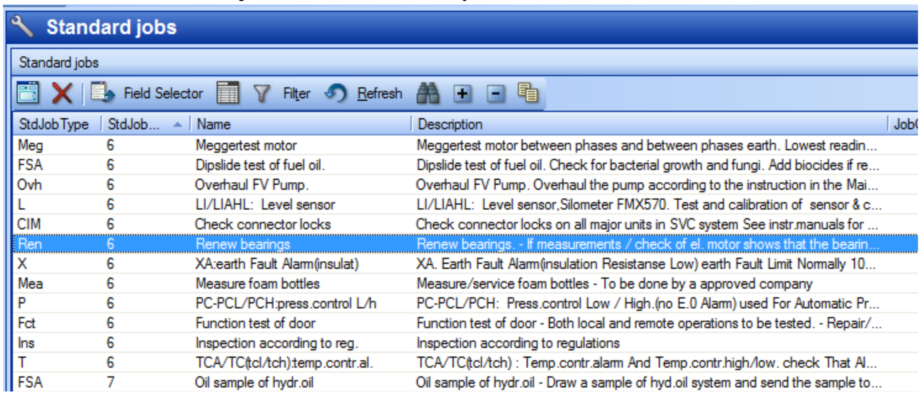
- History: shows all jobs that have been done on components on all vessels within the fleet.



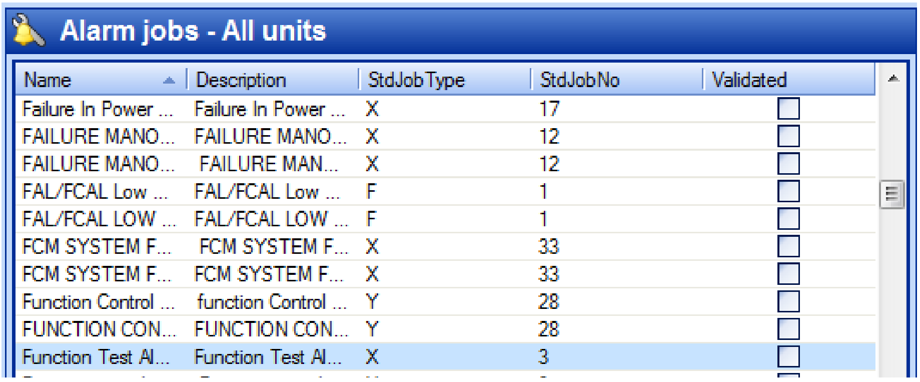
- Certificates overview: Shows an overview of the certificates within the fleet.



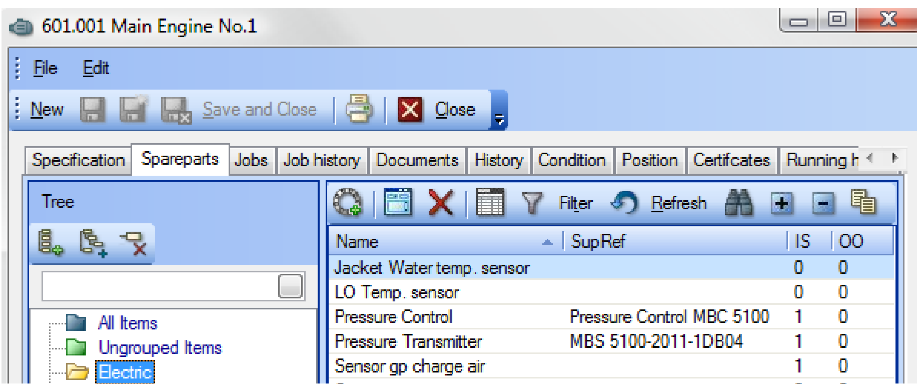
- Standard jobs: Shows all standard jobs defined on the system.



- Alarm jobs: Shows all alarm jobs set in the system



- Stock: Shows stocks across the fleet.



Hyperlink Tables of contents

- 2 - "Vessel" module gives an overview and details of active orders, file-exchange (replication), and non-Conformances of a boat. The windows provided are of the same style as those used for the entire fleet. The following windows can be accessed:

- "Overview" gives a general view of the orders, online users, job progress, non-conformities status, and certificates status.
- "Details" shows all details regarding the vessel such as name, description, unit code, IMO number, email, phone number, etc.
- "Crew" is the function allows to enter the personnel onboard and the people who have signed off, so it is possible to identify which person has performed s job.
- "Change log" gives a cross fleet overview of all the major changes done to the component such as change of code, deleted codes and changes of standard jobs.

- 3 - "Inventory" module allows to control the components of the vessel. It provides the following tools:

- "Components" program allows to list and locate all the components of the vessel.
- " Catalogs" is a program that allows importing and classify catalogs.
- " Spare parts" function shows all the items which are defined as spare parts. In the main window the operator can see general details about the spare parts, such as: Location, quantity, on order, etc.
- "Alarm system" is a function that inform the user about boat alarms and jobs to perform to solve these problems. The overview window indicates: the criticality, the code, the system and component involved, the alarm type and description. Four tabs are provided to access to programs such as:
  - "General" is a program that gives general information about the alarm, such as "Alarm code", "alarm type", set point , etc.
  - "Jobs" that shows all the alarm jobs that are to be performed on the alarm, with details like interval and the next due date.
  - "Job history" that shows all jobs that have been done on the alarm.
  - "Change log" that shows the changes made on the alarm.
  - "Certificates" function gives an overview of the different types of certificates.
  - "Stock" function shows all the storage locations on board the vessel. Special filters are available such as "List Min Stock" function, that lists the items which are below the minimum specified quantity, "List Max Stock" function, that lists the items which are over the maximum specified quantity, and "List Expired Date" function, that shows the items which have expired or expire soon.
  - "Running hours" is a program that logs the running hours of each component of the vessel.
  - "Contact" provides the full contact list.
  - "Medical" is a program that provides a combination of a catalogue of different medicines and medical equipment that can be purchased, and a stock management of the medical items on board the vessel.

- 4 - "Maintenance" module allows to control the maintenance of the vessel that provide the following programs:

- "Due List" is a program that allows the user to check and organize the due jobs: Codes, components, job description, planned intervals, date of intervention, and differential with the planned dates are indicated.

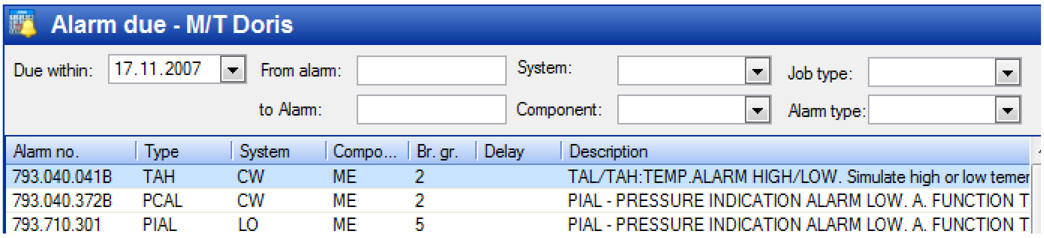
Due list | Due timeline

Code	Component	Job type	Job ...	Survey code		Job description	Int	Hours	Prewarning	Due	Diff	Window	Pri
625.043	FW Cooler/Main Generator No.1	Ovh	12			Overhaul/Survey FW Cooler,FO	5Y		31.01.2007	03.08.2007	-14D		9
635.013.02	Cooling Pump/Freq.Converter/...	Ovh	15			Overhaul/Survey Pump	5Y		31.01.2007	03.08.2007	-14D		9
702.011.01	El. Motor/Feed Pump/FO Sep. ...	Meg	2			Megger test annual el. check	1Y		25.06.2007	03.08.2007	-14D		0
711.002	LO Filling Pump/Main Engines	Ovh	19			Overhaul of pump unit	5Y		24.01.2007	03.08.2007	-14D		0
713.008	LO Priming Pump ME No.4	Ins	81			Inspection of pump	5Y		31.01.2007	03.08.2007	-14D		9
722.082	Heat Exchanger/Preheat-Heat ...	Ovh	29			Survey/Overhaul of heat exch.	5Y		25.01.2007	03.08.2007	-14D		9
731.001.02	Water Separator/Starting Air C...	Ins	23			Visual inspection of unit	1M		31.07.2007	03.08.2007	-14D		0
792.002	E0/Communications Jobs	Fct	14			Test gr.alarms and exten.to...	5Y		25.01.2007	03.08.2007	-14D		0
813.020.02	Pump No.2,Ps/Hi-Fog System	Chk	17			Main check of pump	1Y		22.06.2007	03.08.2007	-14D		0
871.005.05	Freq.Converter/Ballast/FO/OR...	Cle	7			Clean/renew air inlet filters	1M		26.07.2007	03.08.2007	-14D		0
895.005.10	Heating Fan/Emergency Gener...	Ins	26			Visually inspection of unit	1M		29.07.2007	03.08.2007	-14D		9
220.010.02	FO Daytank No.2	Sur	1			Periodical Survey/Inspection	5Y		28.01.2007	04.08.2007	-13D		9
220.010.04	FO Daytank/Emergency Gener...	Sur	1			Periodical Survey/Inspection	5Y		24.01.2007	04.08.2007	-13D		9
220.050.21	WB-Roll Reduction Tank No.22	Sur	1			Periodical Survey/Inspection	5Y		01.02.2007	04.08.2007	-13D		9

This program allows to:

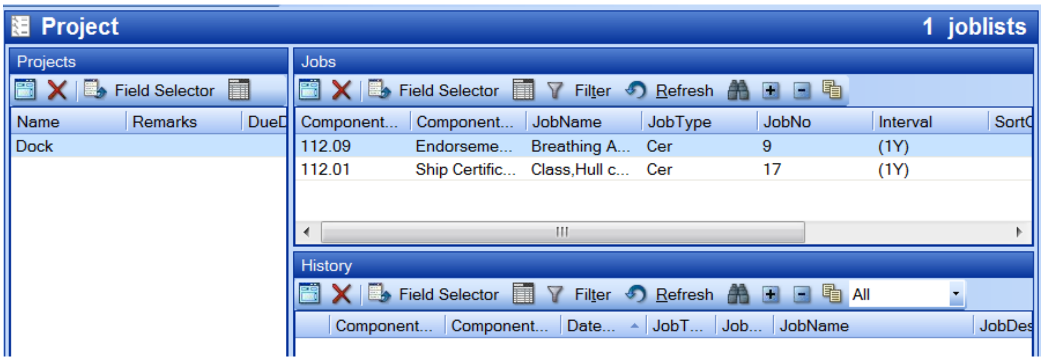
  - search for jobs
  - indicate due job work details
  - organize and check the interval between two interventions
  - automatically withdraw spare parts from the stock if the job always require the use of particular spare parts.
  - designate the person in charge and the crew for the job, and enter an estimate for how long the job should take.
  - log the risk analysis for the tasks
  - attach any kind of document or file to the job. As an example, scanned pages from the instruction manual, or actual photographs of the job being performed.
  - log all changes made on the job, such as changes on the interval.
  - sign out a job and enter details about the job performed.
  - indicate a job status.
  - postpone a job

- “Alarm due” is a function that gives a list of all alarms that are due, and gives details about the alarm, and the status of alarm jobs done.

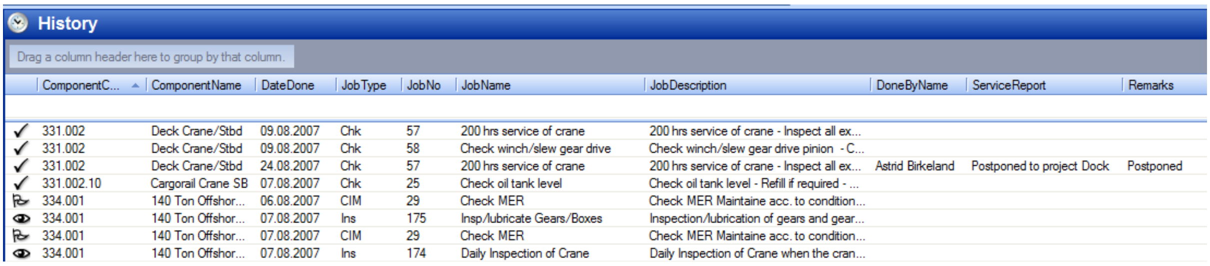


This program provide tabs that open windows that give details about the alarm, and allow to close the job.

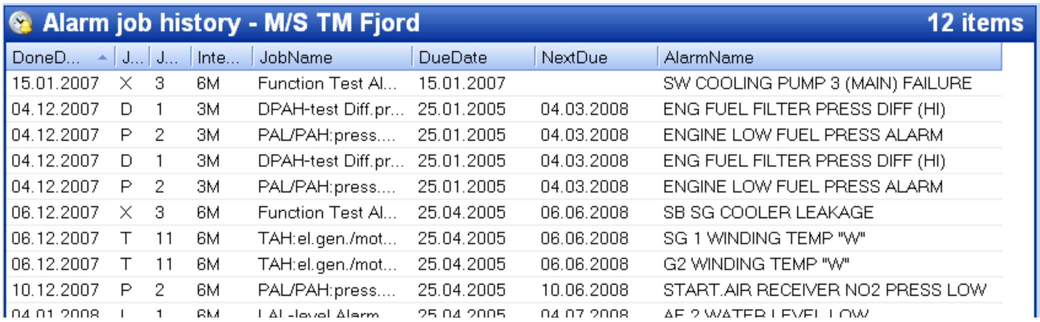
- “Project” is a function that allows the user to collect and group different jobs. If the user wants to postpone tasks until the vessel is going to dry dock, it is possible to create a project and delaying the job to this project.



- “History” is a function that shows the jobs which have been done. With the use of grid techniques like filtering, grouping and sorting, the user can separate specific job histories.



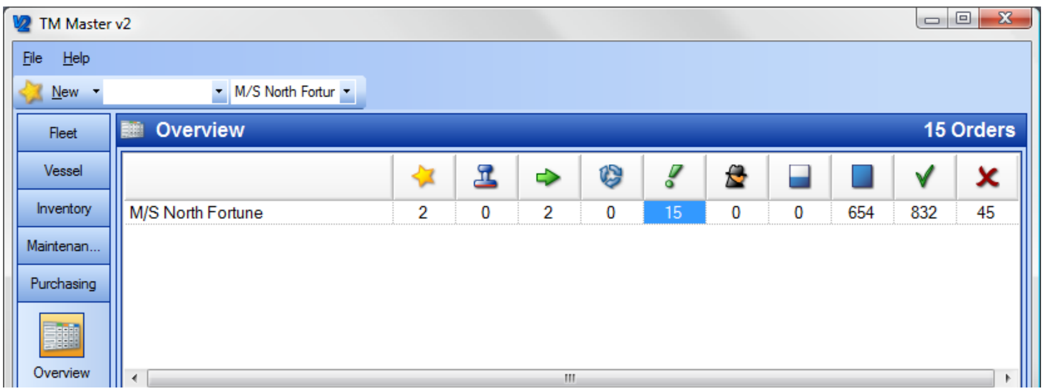
- “Alarm job history” is a function that shows the tests that have been done on alarms.



- “Standard Report Forms” is a function that provides templates that can be either a Microsoft Word template or Excel template.
- “Contacts” provides contact list with companies and contact persons.

- 5 - “Purchasing” module allows to control orders that have been made.

- The overview grid shows you how many orders there are within the different order status categories.

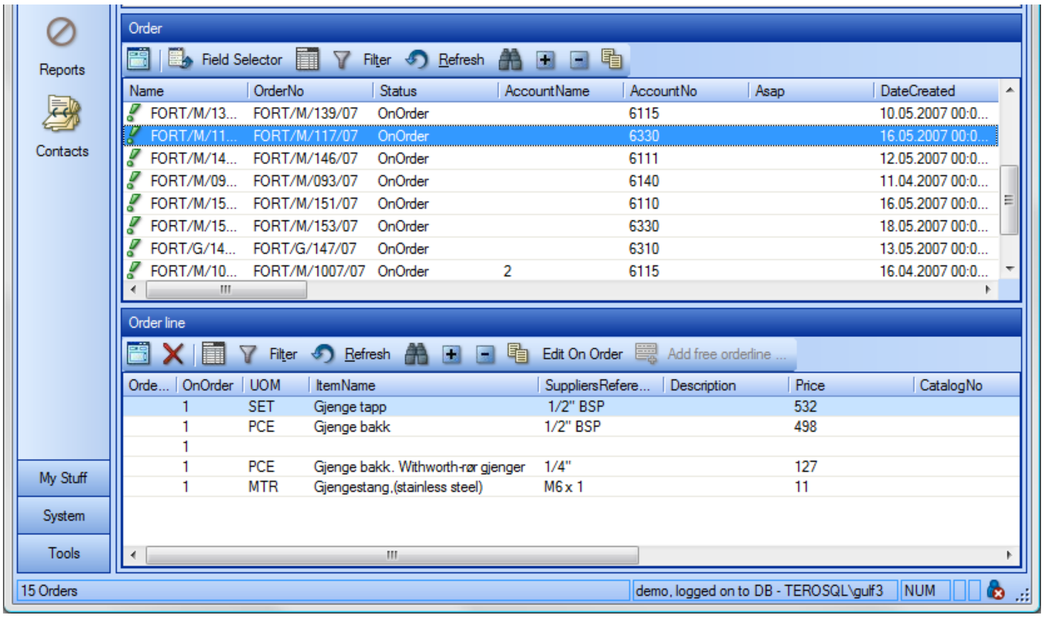


This window provides the following information:

- Orders not yet approved.
- Order approved as a direct order.
- Approved orders.
- Sent orders
- Orders in progress.
- Order delivered to an agent.
- Partially received order
- Received orders

Also, the user can create any from this window by clicking on the start “new” in the upper left had side of the taskbar. The program provides appropriate menu to archive this task easily.

- The order grid is displayed on the overview window below the general status described above, and provides details of the categories listed, the items ordered such as their status, price, supplier, reference, etc. Note that the program allows to delete or cancel an order.



- “Account” is a function that can be created with this program for a group of identified expenses such as insurance, equipment, consumable, etc.
- “Print Label” is another function that allows printing labels on any printer compatible with the computer.
- As with the previous module, the user can access a contact list.

\- 6 - “My place” is a module that allows the user to control his/her orders, tasks, projects etc.

- “Overview” is a function that gives a general view of the user’s orders, tasks, projects etc. The light blue titles in the overview window are also shortcuts to the functions, so by clicking them it is possible to access these functions.

- “Messages” *(see on the right side in the picture above)* is a small e-mail application for the ship. As opposed to an ordinary e-mail application, you can only send messages to users of TM Master v2.
- “Orders” is a function that lists the user’s orders.
- “Handover” is a small text editor, similar to Word pad and Microsoft Word, where the user can write important information for the person who is going to relieve him at the end of his duty time.
- “Filter” is a function that allows to organize elements on the most convenient way for the user.
- “v2 Online” is an internet page where the software designer gives information about the development of TM Master v2, such as new features to come, and informs about new upgrades to the software.
- “Preferences” is a function that allows the users to modify the starting mode and grid colours to their convenience.

\- 7 - “System” is a module that allows to control users, settings, codes, and logs.

- “Users” is a function that allows the administrator of the software to define a user.
- “User groups” is a function that groups user profiles to ensure that all users in the group have the same access to the system. When a user is defined, the administrator must declare which user group the new user has access to.
- “Setting” is the function that allows organizing how the system works (path through the system, data storing, etc.).
    - To send E mails, the Simple Mail Transfer Protocol (SMTP), which is a communication protocol for electronic mail transmission, must be entered.
    - “Upgrade” is the function that ensures that the software is always the latest version. The update address is where the system finds upgrade files from the web page of the software designer. The system can be setup to periodically check for updates, to do so, the administrator ticks “Check for updates” and gives an interval.
- “Unit groups” is a function that allows the user to create groups of vessels to limit his view in certain modules if there are a lot of vessels.
- “Replication” allows the user to find information about the files that are replicated between the vessel and office. Replication interval is how often replication is carried out. The software manages the replication and keeps an overview of the next file it is expecting. The service then sends a request to the other system to resend the file once more. If the data has still not been received after the re-request time out, it sends an error message to system administrators.
- “Multi-sign” is a function that allows to setup with the company policy for multi-signing. It is possible to allow multi-sign jobs based on the components critical category or by the maintenance job priority.
- "Order settings" allows to manage what is allowed when creating an order:
    - Account and supplier can be a mandatory field that must be filled out when creating an order.
    - If direct orders are allowed, the “Direct orders allowed” must be ticked, otherwise, the system always creates a requisition when the orders are being approved.
- “Codes” is a function that allows creating new codes.
- “Log” is a module that shows all system messages, both system errors and messages about the replication between the vessel and the office.

- 8 - “Tools” is a module that allows to perform database cleaning, reports, codes, and data imports & exports.

- “Company Cleaning” is a tool that allows the user to validate (approve) contacts in the contacts list.
- “Job cleaning” is a tool to merge similar standard jobs. This operation can be done even though other users are working on the system. The changes will be distributed to all the vessels of the fleet.
- “Reports” module, allows the user to make aesthetic changes to the reports in the system, such as add the company logo, use other fonts, and move the different fields in the report.
- “Import & Exports” is a program that allows to import and export files and documents. This module can cause harm to the system if the user is not 100% sure of the source.

- 9 - “Contact” is a module that allows access to the list of contacts from within most of the different modules of the software.

- 10 - “Chat” uses the real time communication system “instant messenger” to send short messages to other stations of the company. Real time means that as the user types the message it appears on the other person’s screen immediately.

3.4.4.3 - To summarize

"TM Master V2" provides applications for managing a fleet of vessels while DiveCert is primarily designed for diving systems. This difference between the two software is the reason they have been presented.
Note that a lot of similar products to "TM Master V2", such as an example "K-fleet maintenance" from Kongsberg, are proposed. Also, note that DiveCert is currently the only software based on the IMCA guidelines designed to manage dive systems on the market.
The selection of the software to be used will depend on the management system, the size of the company, and the number of dive systems that are integrated into boats. Other things a company may consider are whether it is preferable managing its diving systems separately or with the other components of its ships, and which software the personnel in charge prefers.
Of course, the price of the software is an additional element of selection. However, considering that the consequences of documents improperly stored and examinations and tests not performed on time will be quickly more expensive than the value of the software, the price should not be the first criterion. Opposite of that, a software suite the technicians are comfortable to work with is a criterion of selection that should have priority.

3.5 - IMCA audit

3.5.1 - Purpose of the DESIGN documents

The International Maritime Organization (IMO) says in the International Safety Management Code (ISM) that the examination, testing, and maintenance of systems used at sea is mandatory *(see in* *point 3.4.1**)*.
IMCA *(International Marine Contractor Association)* has developed the Diving Equipment Systems Inspection Guidance Note (DESIGN) that must be followed by IMCA members, and the companies working for IOGP *(International association of Oil and Gas Producers)* members and a lot of independent clients. Also, a lot of competent bodies have adopted these documents that are among the most accurate guidelines for the audit and maintenance of a diving system and can be downloaded at this address: https://www.imca-int.com/divisions/diving/publications/guidance/

3.5.1.1 - Aim and legal status of IMCA DESIGN documents

DESIGN documents aim to provide comprehensive reference sources regarding the equipment and layout that are required for a safe diving operation, plus the examination, test, and certification requirements necessary to at least meet acceptable industry practices. They also identify how inspection and testing should be carried out safely and efficiently. Note that recommendations in areas where there is a delicate balance between commercial considerations and safety implications are included. However, safety must never be compromised for any reason.

DESIGN documents are intended to assist the following people:

- Manufacturers and suppliers of diving plant and equipment.
- Diving contractors commissioning new build diving systems.
- Personnel involved in diving operations.
- Vessel owners and marine crews involved with diving operations.
- Staff involved in the maintenance, repair, test or certification of plant and equipment.
- Client and contractor representatives.
- Diving system auditors.
- All personnel involved in quality assurance (QA) and safety.

DESIGN documents apply anywhere in the world being:

- Outside the territorial waters of most countries (normally 12 miles or 19.25 kilometres from shore).
- Inside territorial waters where offshore diving, normally in support of the oil & gas or renewable/alternative energy industries, is being carried out.

Five IMCA DESIGN documents have been published:

- IMCA D 023: DESIGN for surface orientated (air) diving systems.
- IMCA D 024: DESIGN for saturation (bell) diving systems.
- IMCA D 037: DESIGN for surface supplied mixed gas diving systems.
- IMCA D 040: DESIGN for mobile/portable surface supplied systems.
- IMCA D 053: DESIGN for the Hyperbaric Reception Facility (HRF) forming part of a Hyperbaric Evacuation System (HES).

IMCA DESIGN documents have no direct legal status but many courts, in the absence of specific local regulations, would accept that a company carrying out diving operations in line with the recommendations of these documents was using safe and accepted practices.
Note that valid DESIGN documents are required by most clients to start the diving operations.

IMCA says: *"Any company which wishes to do so is free to carry out its operations in ways which do not comply with the recommendations in this document but in the event of an accident or incident it may be asked to demonstrate that the methods or practices that it used were at least as safe as if it had followed the advice of this document"*.
For this reason, audits using DESIGN documents must be regularly performed, and that the equipment audited must comply with the recommendations that are explained in these documents.

DESIGN documents should be used in conjunction with IMCA D 018 *"Code of practice on the initial and periodic examination, testing and certification of diving plant and equipment"*. Cross-references to this code are provided where appropriate.

IMCA says: *"A number of countries in the world have national regulations that apply to offshore diving operations taking place within waters controlled by that country. In such cases, national regulations must take precedence over this document, and the contents of this document should be used only where they do not conflict with the relevant national regulations"*. For this reason, when other codes or standards are required by the client or the administration, evaluation to make sure that the system complies with these codes and standards must be performed. If the system is not compliant, actions must be undertaken to meet the laws and rules requested.
Nevertheless, a lot of companies use IMCA DESIGN documents as the basis for their audit activities. For this reason, audits using the IMCA DESIGN document must also be performed. The result of these audits should be kept for the internal purpose, or published in a separate report if the client or the administration does not recognize it.

3.5.1.2 - Competent persons

The dive system must be audited by a recognised Diving System Assurance Auditor. Details regarding the competency of the auditor are indicated in the information note IMCA D 07/13 and the guidance IMCA D 011 “Annual audit of diving systems” issued in December 2010 and reviewed in January 2017 that sets up the rules for diving systems auditors that are explained more in the next point. This competent person must have a high level of diving expertise with a detailed knowledge of diving techniques and practices and the environment in which the plant will be used.

Except for those who are qualified auditors, the diving supervisor and the dive technicians are not supposed to carry out “official” audits. However, they have to ensure that the dive system is in good condition and that all the certifications are updated. For this reason, they should be familiar with these processes. These checks have to be performed regularly in accordance with the Planned Maintenance System (PMS) plan and using the relevant DESIGN documents and IMCA D 018 as supports.

IMCA D 018 gives advice on a way in which inspection and testing of diving plant and equipment can be carried out safely and efficiently, and it details that all the examinations must be documented in order to demonstrate when they have been carried out and by whom. As already indicated in point 3.4.3.1, the competent persons in charge of the maintenance of the diving system are defined in four categories depending of the inspection and test to be carried out:

- Category 1: An IMCA or equivalent level diving or life support supervisor duly appointed by the diving contractor: His competency should be limited to external visual examinations and function tests of the equipment he is familiar with, unless he has additional specific training.
- Category 2: A technician, certificated Class I Chief Engineer, or other person, all specialising in such work who may be an employee of an independent company, or an employee of the owner of the equipment (unless specific legal restrictions apply), in which case his/her responsibilities should enable him/her to act independently and in a professional manner.
- Category 3: A classification society or insurance company surveyor, or chief engineer certificated in accordance with IMCA C 002 guidelines and competence tables: Marine Division (Job Category A06) but who may also be an “in- house” chartered engineer or equivalent (unless specific legal restrictions apply), or person of similar standing.
- Category 4: The manufacturer or supplier of the equipment, or a company specialising in such work which has, or has access to, all the necessary testing facilities. That may also be a technician employed by the owner of the equipment provided that he has been fully trained and certified for the specific operation and has access to all necessary equipment and facilities.

3.5.1.3 - Organisation of DESIGN documents

The DESIGN documents are organized to perform a breakdown analysis of the diving system.

- Sections

Each document is divided in “sections” that are the important parts of the system.

- The DESIGN document IMCA D 023 is composed of the following sections:
  - 1 General Safety
  - 2 Dive Control
  - 3 Twinlock Air Chamber
  - 4 Diver Launch and Recovery System
  - 5 Diving Basket
  - 6 Wet Bell
  - 7 Wet Bell Main Umbilical
  - 8 Diver Heating System
  - 9 Divers’ Umbilicals
  - 10 Divers’ Personal Equipment
  - 11 Compressors
  - 12 HP Air and Gas Storage
- The DESIGN document IMCA D 024 is composed of the following sections:
  - 1 General System Safety
  - 2 Dive Control
  - 3 Surface Compression Chamber
  - 4 Bell Launch and Recovery System
  - 5 Diving Bell
  - 6 Life Support Control
  - 7 Main Bell Umbilical
  - 8 Diver Heating System
  - 9 Divers’ Umbilicals

- 10 Divers' Personal Equipment
- 11 Compressors, Pumps, etc.
- 12 High Pressure Gas Storage
- 13 Diver Gas Reclaim
- 14 Chamber Gas Reclaim and Purification
- 15 Hyperbaric Rescue Unit
  - 15.1 General – HES System
  - 15.2 HRU Interface with Dive System
  - 15.3 Hyperbaric Rescue Unit (HRU)
  - 15.4 HRU Launch and Recovery System
- 16 Life Support Package

- The DESIGN document IMCA D 037 is composed of the following sections:
  - 1 General Safety
  - 2 Dive Control
  - 3 Twinlock Chamber
  - 4 Diver Launch and Recovery System
  - 5 Wet Bell
  - 6 Wet Bell Main Umbilical
  - 7 Diver Heating System
  - 8 Divers' Umbilicals
  - 9 Divers' Personal Equipment
  - 10 Compressors
  - 11 HP Air and Gas Storage
- The DESIGN document IMCA D 040 is composed of the following sections:
  - 1 General Safety
  - 2 Small Vessel
  - 3 Control Position
  - 4 Divers' Umbilicals
  - 5 Divers' Personal Equipment
  - 6 High Pressure Air and Gas Storage
- The DESIGN document IMCA D 053 is composed of the following sections:
  - 1 General System Safety
  - 2 HRF Compression Chamber
  - 3 HRU Handling Arrangements and Interfaces
  - 4 HRF Life Support Control
  - 5 Compressors, Pumps, etc.
  - 6 High Pressure Gas Storage

- Items

Each section is divided in "Items" that are the important parts of the section. As an example, the section #2 "dive control" in the DESIGN document IMCA D 024 is composed of twelve items:

- 1 General
- 2 Communications
- 3 Surveillance
- 4 Alarms
- 5 Gas Supplies
- 6 Monitoring
- 7 Gauges
- 8 Pipework and Valves
- 9 Electrics
- 10 Firefighting
- 11 Hot Water Temperature
- 12 Breathing Apparatus

- Description

Each Item is described using "sub-items" that are the important parts of the main item. As an example, the item # 7 "gauges" in the section #2 "dive control" in the DESIGN document IMCA D 024 is composed of twelve sub-items:

- 7.1 General

- 7.2 Gauge Protection
- 7.3 Depth
- 7.4 Unit Marking
- 7.5 Contractor's Tables
- 7.6 Digital Gauges
- 7.7 Gas Supply
- 7.8 Scale Divisions
- 7.9 Unit Marking
- 7.10 Cross-over Valves
- 7.11 Supply Gauge Isolation
- 7.12 Gauge Calibration

- Requirement column

For each sub-item there is a description of what must be checked.

As an example the requirement for the sub-item # 7.1 "general" of the item # 7 "gauges" in the section #2 "dive control" in the DESIGN document IMCA D 024 is as follows:

7	Gauges	
7.1	General	The diving supervisor must have available to him enough suitable gauges so that he is aware of the depth of each diver and of the supply pressures of each main and secondary breathing supply

- Need column

This column identifies the importance given to each requirement. Three letters are used:

A. Signifies that the requirement is necessary and must be met. Only in the most unusual circumstances would a diving system be considered safe to use if a requirement with an A need had not been met.

B. Signifies a requirement which is considered as necessary but there may be other ways of meeting the requirement than the method identified in the 'Requirement' column. It is left up to the discretion of the person completing this document as to whether the requirement is being suitably met.

C. Refers to a requirement which is optional and the absence of which would still allow the diving equipment to be used safely

- Response column

This column is where the person completing the DESIGN document write the comments and observations. It is used to answer any questions asked in the 'Requirement' column.

NOTE: Single words or short phrases such as "acceptable", "suitable", "adequate", "yes", "meets the requirement" or similar should not be used as these provide no useful information to anyone reading the completed document. As a minimum, enough information should be given to allow a person reading the document to understand why the person completing it considers the 'Requirement' for a particular item to have been met.

Equally, where items of plant or equipment have unique serial numbers then these should be inserted in the 'Response' column.

Photographs embedded electronically in the document may assist in cutting down long explanations or clearly illustrating a variation, deviation, non-compliance or non-conformance.

- Certificate Issue Date Column

Where a certificate is required, the date of its issue should be entered in this column. The relevant part of the column is shaded if no certificate is required.

- Additional items and items not required for a system

If there is more than one of the same item on a particular dive system then the section or part of a section should be duplicated and repeated.

This means, for example, that if there are two surface compression chambers then that section would be completed twice, once for each chamber. Similarly if there were, for example, six diving helmets, then the part on diving helmets would be completed six times within the overall section.

This imposes the use of a system for references.

It is recommended that items not required for a particular system are not deleted but rather are marked as "not applicable". This will ensure that the tables in the various sections look similar to a master copy of the blank document, which may make it easier for a subsequent person to check.

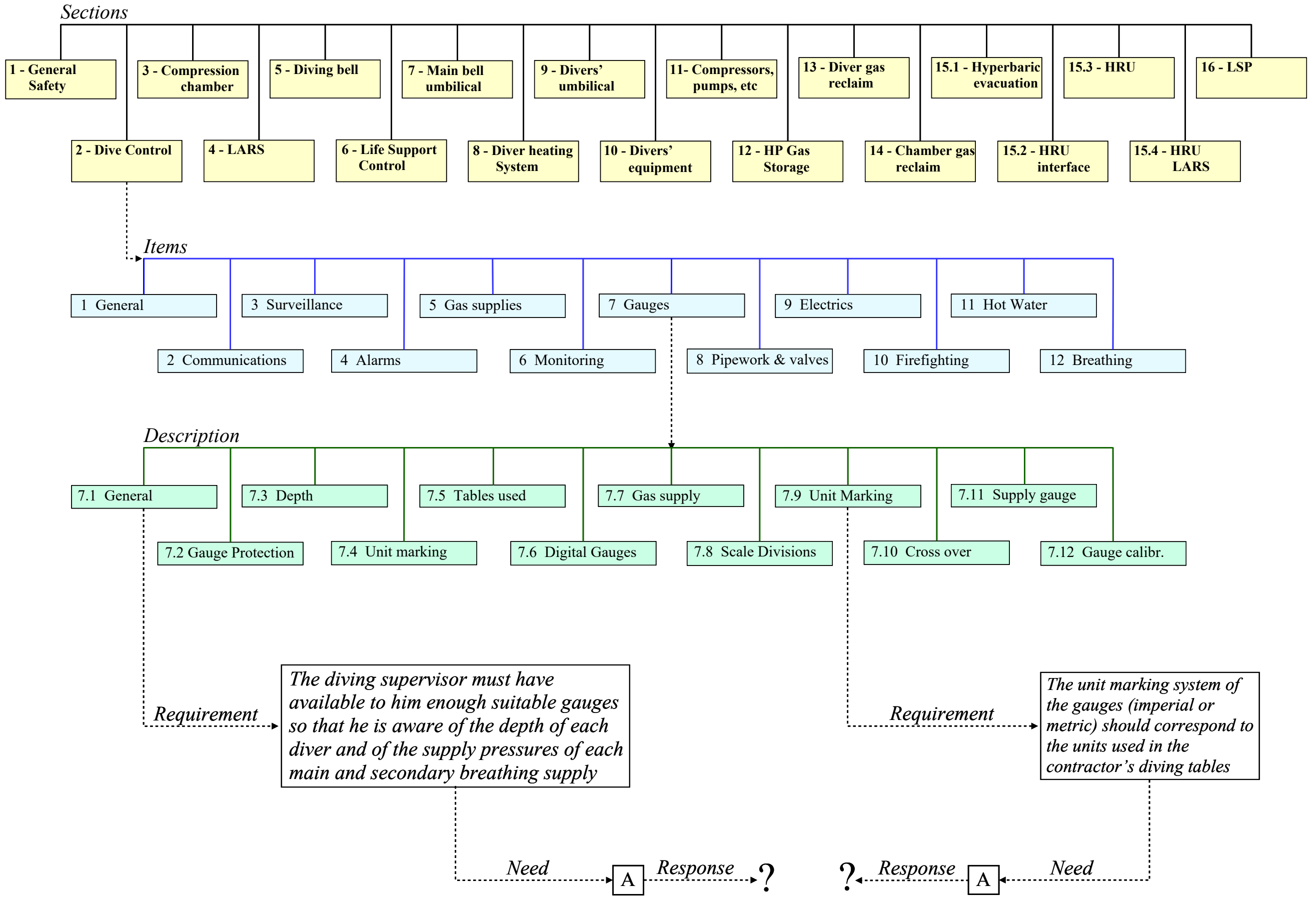
- Variation/deviations from requirement

The person completing the DESIGN document should prepare a list identifying any items which do not fully meet the requirements of this document. This will assist in making sure these items are dealt with speedily.

If the item in question has a C in the 'Need' column then variation/deviation does not signify a non-conformance. However if the item is present but is not correct then it should be placed on the variation/deviation list.

Hyperlink Tables of contents

The scheme below summarizes the organization of the DESIGN documents as explained on the previous page:



- Publication formats

The DESIGN documents are published in PDF *(Portable Document Format)* that can be printed and filled by hand or electronically using an appropriate software. Also, Microsoft Word, and Microsoft Excel formats are available. Note that Microsoft documents can be opened and filled using a compatible office suite.

Important point:
The final report should be published in a protected PDF format that is filled electronically and signed by the auditor.

- Close Out

The system cannot be considered in conformance and put in service as long deviations or non-conformances exist.
To assist in subsequent checking of the DESIGN document a list should be available detailing how and when any variations, deviations or non-conformances have been closed out and completed. This list should be part of the document available to any client or other interested parties for checking.
Note that diving companies, and also most clients consider that all non-conformance and deviation that are closed out and completed must be accepted by the auditor who has carried out the audit. This acceptance must be signed and attached to the final report.

- Records

The reports must be classified chronologically in a dedicated file and be available:

- They are the history of the diving system and they will be used by the auditor carrying out the next audit to fill the page "Record of inspection" at the beginning of the DESIGN document.
- The records can be used to identify the weaknesses of a system and initiate corrective actions

The DESIGN documents are part of the safety and quality system of the company using them, and can be used to prove that the diving systems and other equipment are safe and maintained appropriately.

3.5.2 - Organize an audit based on IMCA Diving Equipment Systems Inspection Guidance Notes (DESIGN)

IMCA recommends undergoing a comprehensive audit annually and at each mobilization for each diving system. These audits are asked by most clients, which some of them require that some systems are checked by 3rd party auditors. Regarding this point, wise company managers should organize the yearly survey of all diving systems of their company by a competent external body. The advantage of this process is that it removes suspicion against the system owner regarding the sincerity of the inspection performed.

Note that the following issues play critical roles in the quality of DESIGN audit reports:

- Selection and competence of diving system auditors.
- Accuracy, completeness and traceability of information.

- Management and quality control of the DESIGN process.
- Time allowed for auditors to undertake the audit.

The document IMCA D 011 “Annual Auditing of Diving Systems” intends to set out guidance on how the DESIGN process is carried out. It can be downloaded at this address: https://www.imca-int.com/publications/112/guidance-on-auditing-of-diving-systems/

3.5.2.1 - Training of company personnel

As indicated in point 3.5.1.2, diving supervisors and diving technicians are not supposed to carry out “official” audits, but they must ensure that the dive system is in good condition and that all the certifications are updated. Also, because audits are common, it is the duty of the company to ensure that some technicians are certified Diving Systems Auditors. As a result, the training of company personnel involved in IMCA DESIGN audits should be organized as follows:

- Initial and refresher training of personnel must be in place.
- The personnel in charge of the system must be technically competent. Their responsibility is to ensure that the diving system is maintained and certified in compliance with regulations, standards, codes, guidelines and industry good practices using the company’s maintenance system. The qualification requested for diving technicians are indicated in IMCA C 003 and IMCA D 001. In addition to the requirement from IMCA, some clients require additional formations.
- IMCA D 011 says that in addition to their technical qualifications, company personnel should receive formal inductions on the diving system, which should include an explanation of their specific roles and responsibilities:
    - Chief engineers, mechanical and electrical dive system technicians.
    - Offshore construction manager, diving supervisors, divers and tenders.
    - Life support supervisors and technicians.
    - Company assurance auditors.
- DESIGN auditors should:
    - have appropriate operational knowledge of the type of diving system to be audited;
    - be familiar with DESIGN document requirements for the type of system being audited;
    - be familiar with IMCA D 018 – Code of practice on the initial and periodic examination, testing and certification of diving plant and equipment;
    - be familiar with IMCA D 014 – IMCA International code of practice for offshore diving;
    - be familiar with Diving information note IMCA D 10/10 – Competence of auditors, and IMCA D 011 “Annual Auditing of Diving Systems”;
    - be familiar with the company’s quality assurance/control process;
    - comply with the audit terms of reference;
    - recognise the limitations of their competence and when to request specialist assistance as needed;
    - ensure that the DESIGN report is accurate, meaningful and comprehensive;
    - Raise concerns when observing or identifying non-compliance that may affect safety of personnel or the environment;
    - identify and communicate early any potential conflict of interest situations;
    - have undergone formal training in auditing techniques, e.g. certification as recognised by IMCA or similar;
    - have good report writing and communication skills;
    - have the ability to communicate audit findings;
    - be able to take into account/be aware of broader issues, e.g. HSE concerns during the audit;
    - keep a record of all the diving system assurance audits he has been involved in;
    - have undertaken two audits in tandem with a competent auditor before being eligible to carry out an audit unaccompanied;
    - have undertaken three similar diving systems audits before becoming a lead auditor;

The selection of the auditors should be performed using the IMCA document P01 “Dive system auditor”, that can be downloaded at this address: https://www.imca-int.com/core/competence-training/competence/offshore-project-roles/

3.5.2.2 - Training and selection of external personnel intervening on a diving system

The personnel from an external service provider intervening on a diving system has the same responsibilities as the company employees to ensure that the diving system is maintained and certified in compliance with regulations, standards, codes, guidelines and industry good practice.

- They must be technically competent. The qualifications requested are indicated in IMCA C 003 and P 01.
- In addition to their technical qualifications, the diving contractor and their management should make sure that the personnel proposed has received formal inductions on the diving system which should include an explanation of their specific roles and responsibilities. People concerned are:
    - Suppliers of diving system, plant, equipment and components.
    - Certifying authorities, inspection and test houses.
    - Independent third party assurance auditors.

- The Design auditors working for a 3rd party company should be in possession of a Diving Systems Auditing and Assurance (DSAA) certificate and have experience of the systems they audit. Their minimum experience should conform to what is indicated in the previous point.

The process of selection of external auditors should be as those used for choosing a classification society or external members of an FMEA team. Note that there are a lot of service providers that propose diving system auditing, and it is often difficult to see whether they are competent. Also, some clients may not accept some of them. For this reason, it is of utmost importance to ensure that all parties agree to use the services of the selected diving system auditing company. Some classification companies also provide such services, but it is not the case of all of them.
Note that the guidelines indicated in point 3.1.2.3 indicate the process for selecting a service provider. Also, this selection must not be linked to only the reputation of companies, but their ability to provide competent people in the area the diving contractor operates. For this reason, it is important to have the name and experience of the people proposed for an audit job.

3.5.2.3 - Types of audits

- Baseline Audit
The intent of a baseline DESIGN audit is to establish a datum for future reference and should be performed as soon as practicable:
    - After taking delivery of a newly built diving system;
    - Before/after the purchase of an existing diving system;
    - After significant changes to a system;
    - Following mobilisation of a temporary diving system;
    - When contracting a diving system without a baseline system audit;
    - Five years after the previous baseline audit.

Diving contractors with a large inventory of diving systems may find value in identifying a team of auditors to perform baseline audits to ensure continuity of standards across all systems within the company.

- Annual Audit
Annual audit is part of the company process to maintain the DESIGN report as a living document that can be presented at any time for audit and inspection. IMCA D 011 considers that this audit can be made in house. Nevertheless, a lot of clients want this audit performed by an independent 3rd party auditor, which is the safest solution and should always be the rule for the reasons explained previously.

Diving plants and equipment are often operated in remote locations where it is difficult to carry out the required auditing in the appropriate time scales. This may also be the case because of operational reasons where the equipment is in constant use. The audit report would typically be valid for a year, starting from the final day of the audit. However, IMCA says that a diving system with a valid annual audit would not become unsafe at 12 months and 1 day on expiry of the valid audit report.
However, a date of audit has to be decided to ensure that the client does not reject the system, as whether a few weeks can be considered acceptable, several months are not. IMCA D 011 says that if, due to operational circumstances, an annual audit cannot be renewed within the prescribed period then an extension of up to a maximum of 30 days can be issued if the diving or life support supervisor operating the system confirms, in writing, that it is operating satisfactorily and appears in good condition. Where there is one or more qualified equipment technician whose duties include maintaining the system, then they should also all confirm the system is satisfactory before such an extension is issued.

- Six month audit
Six month audits are performed internally by the maintenance and the diving teams. They are based on the fact that visual and function tests are to be made every six month.

- Verification Audit
Prior to accepting a diving system, clients and others assure themselves that the system is fit for purpose. This may be achieved by performing a verification audit.
This form of audit may be achieved by verifying the diving system certification is valid and observing diving system equipment function checks, especially on the winches. DESIGN verification audits may, at the client's discretion, be undertaken by independent third party auditors.

- Theme Audit
Theme audits may be undertaken in response to a diving industry related incident or other concern. These audits will generally have specific terms of reference outlining scope, lines of communication and reporting.

- Every day audit
Pre-dive checks must be performed every shift change during the diving operations. It is not a DESIGN audit, nevertheless, the check list should be built according to the recommendations from the auditing documents. Diving company manuals should explain how the check lists must be performed and any defect reported.

3.5.2.4 - Audit team

IMCA D 011 says:
A risk assessment should be carried out to identify the number of personnel and specialist disciplines required to undertake the full DESIGN audit or to verify the final report.

IMCA D 011 gives the following options:
- depending on the complexity of the system, the following appropriately qualified personnel may be involved:
  - lead auditor
  - lifting and winch specialist
  - hydraulic specialist
  - mechanical and/or electrical diving system technicians
  - classification and flag state experts
  - dive supervisors
  - life support supervisors;
- An appropriately qualified auditor, experienced and knowledgeable in the diving technique and diving system being assessed, may review and comment on the DESIGN report.
- An appropriately qualified internal or external independent third party auditor/s.

Note that when a 3rd party auditor performs the audit, the people carrying on the inspection are from the company of the auditor. However, the diving operator should give them support, and technicians should be ready to assist the auditors when required.

3.5.2.5 - Planning and Assumptions

IMCA says that the estimated audit durations are based upon the assumption that:
- All documentation relevant to the diving system is immediately available and is clear, concise, accurate and legible. For this reason, documents are presented in an appropriate auditable sequence with current in-date documents separate from historical documents.
- There is immediate access to personnel responsible for maintaining the DESIGN documentation to address queries.
- In addition to what IMCA says, the system must be organized for inspection, so the auditors can easily access it and do not lose time waiting for someone to open some areas they need to check. For this reason a technician should be nominated to accompany the auditors and facilitate their inspection.
- A drawing showing where the elements referenced are situated must be ready for use. As built diving schematic diagrams should be kept updated to reflect any significant changes to the diving system and, where appropriate, should be approved by the relevant certifying authority.
  This point is not indicated by IMCA, but it is important for the planning of the job.

The table below indicates the minimum durations given by IMCA. However, it is common that auditing teams need more time, and that these given timings are multiplied by two.

Guidance	Assumptions	Estimated audit duration
IMCA D 023 – DESIGN for surface orientated (air) diving systems	- Containerised twin lock decompression chamber and three diver panel. - Two diver deployment baskets/wet bells, clump weights, man-riding winches. - Main umbilicals. - Compressors. - Gas storage. - Hot water system. - Diving equipment. - Comprehensive, clear and concise diving system documentation portfolio.	2 - 4 man days including report
IMCA D 024 – DESIGN for saturation (bell) diving systems	- Single bell. Single chamber plus transfer lock. - Bell deployment and recovery system. - Main bell umbilical. - Hyperbaric rescue system. - Dive and saturation control rooms/panels. - Diver’s heating system. - Compressors. - Gas storage. - Gas reclaim. - Diving equipment. - Comprehensive, clear and concise diving system documentation portfolio. - Emergency exercise information.	3 - 6 man days including report

Guidance	Assumptions	Estimated audit duration
IMCA D 037 – DESIGN for surface supplied mixed gas diving systems	- Containerised twin lock decompression chamber and three diver panel. - Two diver deployment baskets/wet bells, clump weights, man-riding winches. - Main umbilicals. - Compressors. - Gas storage. - Hot water system. - Diving equipment. - Comprehensive, clear and concise diving system documentation portfolio.	2 - 4 man days including report
IMCA D 040 – DESIGN for mobile/portable surface supplied diving systems	- Mobile/portable two diver panel with HP air cylinders. - Surface crafts. - Control position. - Deployment davit/s. - Deck decompression chamber (DDC). - Compressors. - Gas storage. - Diving equipment. - Comprehensive, clear and concise diving system documentation portfolio.	1 - 2 man days including report
IMCA D 053 – DESIGN for the hyperbaric reception facility (HRF) forming part of a hyperbaric evacuation system (HES)	- Single chamber plus transfer lock. - Hyperbaric rescue unit (HRU) handling system. - Saturation control room/panels. - Compressors. - Gas storage. - Gas reclaim. - Comprehensive, clear and concise diving system documentation portfolio. - Emergency exercise information.	2-3 man days including report

- In complement to what is said on the previous page, IMCA D 011 also says that the following variations may extend or reduce estimated audit durations include:
    - size and complexity of the diving system;
    - use of audit team size and disciplines to spread the audit workload;
    - access to diving system documentation onshore which may reduce audit duration at site;
    - whether it is the diving system's baseline DESIGN audit;
    - whether the diving system has arrived from working in a different global region;
    - if the diving system has a DESIGN report from another global region applying different engineering/test criteria;
    - if the diving system has been inoperable for an extended period of time;
    - if the diving system has been assembled from several other diving systems;
    - the audit may be being carried out at the same time as the diving system is coming out of dry-dock, being mobilised or undergoing certification or commissioning tests;
    - any limitations or restrictions to access to key personnel to assist sourcing information or deal with concerns;
    - the diving system may be working offshore and access restricted, delayed or protracted;
    - chambers, hyperbaric chamber and/or bell may be under pressure and inaccessible to auditor;
    - diving system or parts may not be equipped ready for audit;
    - diving system documentation portfolio may not be readily available for review onshore or at site;
    - previous annual DESIGN documentation may not be completed correctly;
    - certificates may be missing, incorrectly filed or incorrectly completed;
    - circumstances may not allow function testing or exercising plant, e.g. planned maintenance, hyperbaric rescue system deployment, etc;

3.5.2.6 - Non-conformances reports

IMCA D 011 says that non-conformances identified during audits should be reported to the on-site contractor's management as soon as reasonably practicable to allow close out actions to commence.
Non-conformity points are usually logged and highlighted at the beginning of the report or on a non-conformances report tracking register with suggested corrective actions. The date, name, signature of the auditor, and the stamp of the company in charge of the audit should be visible on the final document sent to the diving contractor.
Non-conformities must be closed up to authorize the diving system to operate. It is recommended that the acceptance of the resolution of the non-conformances is made by the auditor who made the report.

It is also said that a risk assessment should be carried out to evaluate and rank the non-conformances. From this risk assessment, a “common sense” approach may be used to allow a diving system to operate with some non-conformity points category A or B if relevant control measures can be implemented. However, the decision to allow a diving system to work on his oilfield comes only from the senior client representative, who is the only person who can decide whether the contractor can start the operations or not. Note that the risk assessment and decisions taken must be recorded.

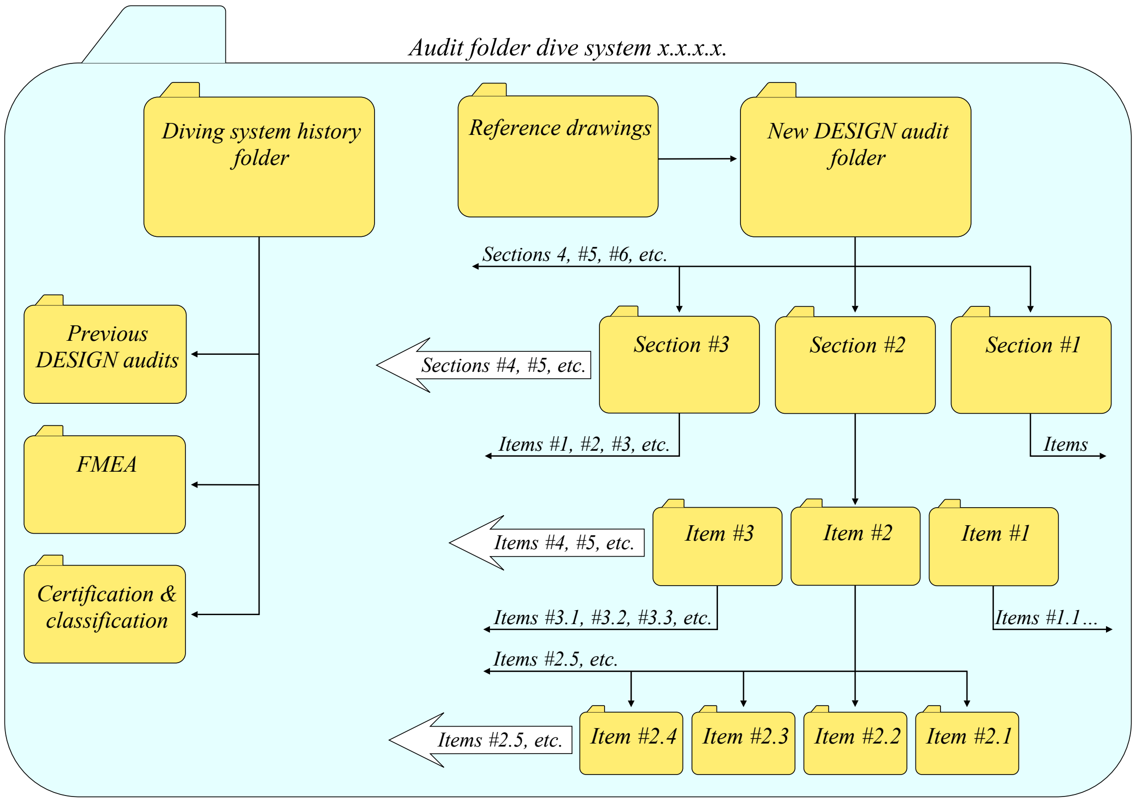
IMCA also indicates that when a disagreement occurs on the audit findings between the auditors and the diving contractor that cannot be resolved on-site, such problems are usually addressed internally by senior management within the organizations with further dialogue and resolution. However, such a discussion has its limits and must never go to a point where the safety of the divers is degraded. Also, as above, the decision to accept an audit with some litigious points is from the senior client representative who can reject the report if he considers that there are unacceptable non-conformities, and may ask for another inspection by a different auditor. In this case, the contractor or the auditing company may lose their reputation.

3.5.2.7 - Complementary guidelines for the organization of audits

As indicated previously, a lot of clients want the IMCA audits performed by an independent auditor. Despite the recommendations from IMCA, a lot of companies still have difficulties organizing for such inspections, and numerous non-conformances that could be avoided are recorded, which result that the dive system cannot be returned to service immediately and gives a bad picture of the company to its client.
It must be highlighted that the quality system of the contractors is a criterion clients take into account for the selection of their contractors. So an audit with too many non-conformances is an indicator that there are breaches in the management system of the diving contractor, which may result that this contractor is rejected from the list of companies agreed by the client. For this reason, it is of utmost importance that the audit report indicates that the system is in peak condition and appropriately maintained.

1. A folder where all the documents are to be collected should be created with sub-folders:
   - A sub-folder that groups the documents that have been used for the certification and the classification of the diving system, the Failure Mode Effect Analysis (FMEA). The previous audits should also be classified in this sub-folder.
   - Another sub-folder that groups all the test and maintenance performed on the diving system should also be created. Note that as indicated in the DESIGN documents, the sea fastening calculation and inspections of portable systems must be included.
   - As the auditors usually require the original certificates, they must be classified the same way as electronic documents and kept ready for the audit.
2. The schemes/drawings of the elements constituting the dive system should be established, taking into account the following:
   - These schemes/drawings can be those made by the manufacturer or by a competent person category 2 or 3. However, the person in charge must ensure that the drawings/schemes are easy to read.
   - Modifications that have been made must be precisely indicated on the scheme.
3. The sections, items, and sub-items should be identified on the schemes/drawings.
   - Each item is precisely located to be easy to find. If necessary photos are added.
   - A reference number or code is given to each item.
   - Acronyms, symbols, or code that are used on the schemes/drawings should be listed in a glossary.
   - Items that are represented on the schemes/drawings should be listed with their identification code, and the path to follow to find them on the drawing.
4. Function tests and inspection certificates of the diving system must be appropriately classified. using the structure of the DESIGN document explained in point 3.5.1.3.
   - The sections are organised and listed, taking in account that the system may have several similar sections. As an example there may be several chambers and compressors.
   - A folder should be created for each section.
   - The items and sub-items that are in these sections should be classified, taking in account that the section is composed of many items and that each item has a function despite some of these items are similar.
   - A sub-folder should be created for each item and sub-item
     The “examination, testing, certification & maintenance” sheets (or equivalent) of the sub-items in the planned maintenance system should be collected with their certificates, and classified in a sub folder, making sure that they are in a chronological order and that the last certificates are on the top of the list.

- The same classification should be done with the original (paper) certificates. Specific office furniture should be used for this purpose. All the original documents should be in the same classier.
- Note that the file names should be as short as possible because Operating Systems such as Windows limit the paths to stored documents to 260 characters. As a result, a certificate with a too-long name and that is reachable through a cascade of too many folders may not be opened by the system.
- When they are several identical elements, each element must be classified in a dedicated sub-folder where its examination and test certificates are classified. As an example, there must be a folder for each gauge, each flexible hose, etc. Thus it is recommended to have dedicated certificates for each item. However, it often happens that organizations performing tests emit only one document for several pieces of the same nature that have been tested in the same period. Manufacturers also issue such “grouped” certificates. In this case, the serial number of the items tested must be listed in the document. To make the audit clear and comfortable, there should be a copy of the “grouped” certificate with the reference number of the item highlighted for each tested article.
- The drawing below shows the way the folders described above can be organized. Note that the most important is to create a classification system that groups all the information of the dive system, and that allows finding quickly every certificate.



5. Perform an internal audit
   This audit allows the technicians to be familiar with the system and the IMCA DESIGN procedures. Also, it will enable finding non-conformances that have not been seen, and whether the system of classification works satisfactorily. It can be done at the same time as updating the Planned Maintenance System.
   - The team audit the system using the appropriate DESIGN document to establish the first status and creating the first list of non-conformances. Also, the team evaluates the classification system in place and propose improvements.
   - Then, the team closes-out the non-conformances listed and update the Planned Maintenance system and ensure that the system is ready to be audited by the Diving System Auditor & Assurance (DSAA).
6. Organize the 3rd party audit and close-outs
   When the problems seen during the internal audit are closed out, the file indicated above can be sent to the 3rd party auditing company so that the inspectors can prepare for the inspection. Also, the team should organize to assist the Diving System Auditors. For this reason, the people involved should:
   - prepare the diving system for inspection, as previously indicated.
   - give explanations regarding the dive system and the Planned Maintenance System (PMS) in force.
   - supply the certificates when asked by the DSAA. Regarding this point, the team must always ensure that the auditor is not struggling to find them.
   - help the DSAA to find the elements indicated in the drawings, and to fill the DESIGN document if required.
   - note the remarks and recommendations of the auditor.
   - close-out the non-conformances as soon as possible (If possible during the audit).
   - ensure that the close-outs are accepted and signed by the Diving System Assurance Auditor (DSAA).

3.5.3 - Ensure of updated certifications

The Diving Equipment Systems Inspection Guidance Note (DESIGN) D 024 and D 053 must be used as support by the supervisors and the diving technicians to check the saturation system regularly with particular attention to the dates of certifications indicated in these documents and listed below.

Note:
The categories of competent persons are those listed in point 3.5.1.2.
The numbers in brackets (; ;) indicate the categories of competent persons and are specified only when only some categories are allowed to test an item … As an example : (2;4) = only n° 2 and 4 are allowed to undertake the test or examination indicated.

IMCA - Diving Equipment Systems Inspection Guidance Note (DESIGN) D 024 - Certifications list

Nb	Section	Reference number of items & Description	Visual external + function test , calibration or for lifting appliances: Load test 1.25 SWL	Visual internal + external + gas leak test at max. Working pressure or for lifting appliances: Wire destruction test	Internal + external+ leak test 1,5 max. working pressure or for lifting appliances: Load test 1.5 SWL	Other
1	General safety	1.1 - Classification				According to the class. society
2	General safety	4.4 - Sea fastening (Design)				At mobilisation
3	General safety	4.5 - Sea fastening (installation)				At mobilisation
4	General safety	7.6 - Emergency power testing	6 month			
5	Dive control	2.15 - Communications	6 months (1;2;4)			
6	Dive control	4.5 - Alarm testing	6 months			
7	Dive control	6.6 - Analysers	6 months (1;2;4)			
8	Dive control	7.12 - Gauges	6 months			
9	Dive control	8.8 & 8.9 - Valves and pipework	6 months	2 years		
10	Dive control	8.11 & 8.12 - Relief valves	6 months	2 ½ years (2;3;4)		
11	Dive control	9.5 - Electrical	6 months (2; 3; 4)			
12	Dive control	10.2 & 10.3 - Fire fighting portable system	6 months			Manufacturer specifications
13	Dive control	10.2 & 10.3 - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
14	Dive control	10.6 - Automatic detection	12 months			
15	Dive control	12.3 to 12.5 - Emergency breathing apparatus	6 months (1;2;4)	2 ½ years (3;4)	5 years (3;4)	
16	Dive control	Remote bell contamination control (hydrocarbons +H_2S)	6 months (1;2;4)			Note: Requested by OGP
17	Chambers	1.5 - to 1.7 - Chamber testing	6 months	2 ½ years	5 years (3;4)	
18	Chambers	2.5 to 2.9 - Viewports	6 months	2 ½ years	5 years (3;4)	10 years old max.
19	Chambers	3.3 & 3.4 - Fire fighting portable system	6 months			Manufacturer specifications

Nb	Section	Reference number of items & Description	Visual external + function test , calibration or for lifting appliances: Load test 1.25 SWL	Visual internal + external + gas leak test at max. Working pressure or for lifting appliances: Wire destruction test	Internal + external+ leak test 1,5 max. working pressure or for lifting appliances: Load test 1.5 SWL	Other
20	Chambers	3.3; 3.5; 3.6 - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
21	Chambers	3.7 - Automatic detection	12 months			
22	Chambers	4.3 - Medical equipment (DMAC 15)	6 months			
23	Chambers external	5.7 - Electrical penetrators	6 months (3;4)			
24	Chambers external	5.14 - Interlock pipework	6 months	2 years		
25	Chambers external	5.18 & 5.19 - Pressure relief valves	6 months (1;2;4)	2 ½ years (2;4)		
26	Chambers external	5.21 - Communication	6 months (1;2;4)			
27	Chambers external	5.23 - ECU Flow fuse test	6 months			
28	Chambers external	5.24 - Pipework	6 months	2 years		
29	Chambers external	5.27 - Electrical	6 months (2;3;4)			
30	Chambers internal	6.12 - Communication	6 months (1;2;3)			
31	Chambers internal	6.15 - BIBS	6 months (1;2;4)			
32	Chambers internal	6.26 - Sanitary system	6 months			
33	Chambers internal	6.28 & 6.29 - Fire fighting portable system	6 months			Manufacturer specifications
34	Chambers internal	6.28; 6.30; 6.31 - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
35	Chambers internal	6.32 - Automatic detection	12 months			
36	Chambers internal	6.34 - Gauge calibration	6 months (2;3;4)			
37	Chambers internal	6.38 - Environmental control unit (ECU)	6 months (2;3;4)			
38	Chambers internal	6.42 to 6.44 - Valves & pipework	6 months	2 years		
39	Chambers internal	6.45 - Electrical	6 months (2;3;4)			
40	Chambers internal	"VitalLink" or similar medical data transmission	6 months			Note: Requested by OGP
41	Bell LARS	1.2 - Weight of the bell	12 months			Test to be in air and in water
42	Bell LARS	2.14 - Main winches (function and load test)	6 months (2;3;4)		12 months (2;3;4)	NDT critical areas: 12 months
43	Bell LARS	3.4 to 3.7 - Main lift wire	6 months (3;4)	12 months (3;4)	12 months (3;4)	History of cert. available

Nb	Section	Reference number of items & Description	Visual external + function test , calibration or for lifting appliances: Load test 1.25 SWL	Visual internal + external + gas leak test at max. working pressure or for lifting appliances: Wire destruction test	Internal + external+ leak test 1,5 max. working pressure or for lifting appliances: Load test 1.5 SWL	Other
44	Bell LARS	4.17 - Secondary winch	6 months (2;3;4)		12 months (2;3;4)	NDT critical areas: 12 months
45	Bell LARS	4.22 to 4.25 - Secondary lift wire	6 months (3;4)	12 months (3;4)	12 months (3;4)	History of cert. available
46	Bell LARS	5.3 - Lift attachment points	6 months (2;3;4)		12 months (2;3;4)	NDT critical areas: 12 months
47	Bell LARS	8.1 - Cross haul system general			6 months (2;3;4) (test in water)	
48	Bell LARS	9.4 - Heave compensation (Visual exam. + test at max SWL)	Visual & dynamic test 1,25 SWL: 6 months (2;3;4)			
49	Bell LARS	10.8 to 10.11 - Hydraulic systems (general)	6 months (2;3;4)			
50	Bell LARS	10.9 - Hydraulic systems (Intercooler/heater)	6 months (2;3;4)			
51	Bell LARS	10.11 - Hydraulic oil analysis or replacement				12 months (2;3;4)
52	Bell LARS	10.13 - Relief valve	6 months	2 ½ years (2; 3; 4)		
53	Bell LARS	11.16 - Pneumatic hoses	6 months	2 years		
54	Bell LARS	12.8 - Electrical winch testing	6 months (2;3;4)			
55	Bell LARS	13.2 - Communication	6 months (1;2;4)			
56	Bell LARS	14.3 to 14.5 - Emergency breathing apparatus	6 months (1;2;4)	2 ½ years (3;4)	5 years (3;4)	
57	Bell LARS	15.2 - Bell clamp safety interlock	6 months	2 years	When installed (3;4)	
58	Bell LARS	17.3 & 17.4 - Fire fighting portable system	6 months			Manufacturer specifications
59	Bell LARS	17.3; 17.5; 17.6 - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
60	Bell LARS	17.7 - Automatic detection	12 months			
61	Bell LARS	18.2 LARS overall testing	Static: 6 months Dynamic: 1 year		12 months	1 year: NDE critical areas
62	Diving bell	1.1 Design and manufacturer				Date of issue
63	Diving bell	1.3 - Pressure vessel	6 months	2 ½ years	5 years (3;4)	
64	Diving bell	2.4 to 2.9 - Viewports	6 months	2 ½ years	5 years (3;4)	10 years old max.
65	Diving bell	4.2 - Buoyant ascent: Secure mechanism.	6 months			
66	Diving bell	4.3 - Buoyant ascent: Other components	6 months			
67	Diving bell	4.9 - Ballast release system				Dry function test: 1 year

Nb	Section	Reference number of items & Description	Visual external + function test , calibration Or for lifting appliances: Load test 1.25 SWL	Visual internal + external + gas leak test at max. Working pressure Or for lifting appliances: Wire destruction test	Internal + external+ leak test 1,5 max. working pressure Or for lifting appliances: Load test 1.5 SWL	Other
68	Diving bell	4.10 to 4.11 - Ballast release system			1 year (Overload static test)	NDE of critical items: 1 year
69	Diving bell	4.12 - test buoyancy				1 year
70	Diving bell	4.16 & 4.17 - Cutter/ release system	6 months			Dry function test : 1 year
71	Diving bell (external)	5.22 - Transponder	6 months			
72	Diving bell (external)	5.29 - External cylinders	6 months	2 years (3;4)	4 years (3;4)	
23	Diving bell (external)	5.32 - Interlock pipework	6 months	2 years		
74	Diving bell (external)	5.37 - Overpressure relief valve	6 months	2 ½ years (2;3;4)		
75	Diving bell (external)	5.45 - External battery pack : overpressure relief testing	6 months	2 ½ years (2;3;4)		Complete renewal bursting discs: 10 years
76	Diving bell (external)	5.52 - Pipework	6 months	2 years		1.5 max. working press: 1st install.
77	Diving bell (external)	5.55 - Electrical	6 months (2;3;4)			
78	Diving bell (internal)	6.16 - Gauges	6 months (2;3;4)			
79	Diving bell (internal)	6.21 - Emergency survival packs and passive scrubbers	6 months (Water ingress and integrity packaging)			Fully checked and repacked: 12 months
80	Diving bell (internal)	6.24 - Gas monitoring (O_2 and CO_2)	6 months (1;2;4)			
81	Diving bell (internal)	6.26 - Bell contamination control (included H_2S)	6 months (1;2;4)			
82	Diving bell (internal)	6.39 - Gas cylinder pressure gauges	6 months (1;2;4)			
83	Diving bell (internal)	6.43 - Communication (all systems)	6 months			
84	Diving bell (internal)	6.47 - Approval pulley attach. point inside the bell				Permanent
85	Diving bell (internal)	6.51 - Medical equipment (DMAC 15)	6 months			
86	Diving bell (internal)	6.58 - Pipework	6 months	2 years		1.5 max. working press: 1st install.
87	Diving bell (internal)	6.61 - Electrical	6 months (2;3;4)			
89	Diving bell (internal)	6.62 - Alarm	6 months			
90	Life support control	2.8 - Communications	6 months			
91	Life support control	3.12 - Gauges calibration	6 months (2;3;4)			
92	Life support control	4.7 - Pipework	6 months	2 years		1.5 max. working press: 1st install.

Nb	Section	Reference number of items & Description	Visual external + function test , calibration or for lifting appliances: Load test 1.25 SWL	Visual internal + external + gas leak test at max. working pressure or for lifting appliances: Wire destruction test	Internal + external+ leak test 1,5 max. working pressure or for lifting appliances: Load test 1.5 SWL	Other
93	Life support control	4.11 - Relief valve	6 months	2 ½ year (2,3,4)		
94	Life support control	5.4 - Electrical	6 months (2;3;4)			
95	Life support control	6.3 & 6.4 - Fire fighting portable system	6 months			Manufacturer specifications
96	Life support control	6.3; 6.5; 6;6 - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
97	Life support control	6.7 - Automatic detection	12 months			
98	Life support control	7.3 - Medical equipment (DMAC 15 & DMAC 28)	6 months			
99	Life support control	8.3 to 8.5 - Emergency breathing apparatus	6 months (1;2;4)	2 ½ years (3;4)	5 years (3;4)	
100	Life support control	10.6 - Oxygen analysers	6 months (1;2;4)			
101	Life support control	10.7 - Alarms	6 months (1;2;4)			
102	Life support control	11.8 - Gas monitoring (analysers)	6 months (1;2;4)			
103	Bell main umbilical	4.1 - Main bell umbilical: Electrical components	6 months			
104	Bell main umbilical	4.2 - Main bell umbilical: Hoses	6 months	2 years	1.5 max. working press: 1st install.	
105	Bell main umbilical (emergency)	5.5 - Emergency bell umbilical: Electrical components	6 months			
106	Bell main umbilical (emergency)	5.6 - Emergency bell umbilical: Hose	6 months	2 years	1.5 max. working press: 1st install.	
107	Bell main umbilical	Intention (if used as a secondary recovery)	6 months (3;4)	12 months (3;4)	12 months (3;4)	History of cert. available
108	Diver heating system	5.3 & 5.4 - Fire fighting portable system	6 months			Manufacturer specifications
109	Diver heating system	5.3; 5.5; 5;6 - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
110	Diver heating system	5.7 - Automatic detection	12 months			
111	Diver heating system	6.1 - Hot water system	6 months			
112	Diver heating system	6.2 to 6.4 Pipework and fittings	6 months	2 years		
113	Diver heating system	6.5 - Gauges (calibration and test)	6 months (2;3;4)			
114	Diver heating system	6.6 - Electrical	6 months (2;3;4)			
115	Diver heating system	6.7 to 6.10 - Pressure vessels	6 months	15 months (3;4)	5 years (3;4)	

Nb	Section	Reference number of items & Description	Visual external + function test , calibration or for lifting appliances: Load test 1.25 SWL	Visual internal + external + gas leak test at max. Working pressure or for lifting appliances: Wire destruction test	Internal + external+ leak test 1,5 max. working pressure or for lifting appliances: Load test 1.5 SWL	Other
116	Diver heating system	6.11 - Alarms	6 months (1;2;4)			
117	Diver heating system	6.13 - Relief valve	6 months	2 ½ year (2,3,4)		
118	Diver's umbilical	3.1 - Electrical components	6 months			
119	Diver's umbilical	3.2 to 3.4 - Hoses	6 months	2 years		1.5 max. working press: 1st install.
120	Divers' personal equipment	1.7 - Helmet (function tests in line with manufacturer's manual)	Visual: 6 months Test: 1 year (2;3;4)			
121	Divers' personal equipment	2.5 - Bail out (Steel)	6 months (2;4)	2 years (3;4)	4 years (3;4)	
122	Divers' personal equipment	2.8 - Bail out (Composite)	6 months (2;4)	1 year (3;4)	5 years (3;4) (or vol. expansion test)	
123	Divers' personal equipment	3.6 & 3.7 - Whips and connectors	6 months	2 years		
124	Divers' personal equipment	3.8 - Gauge	6 months			
125	Divers' personal equipment	3.9 to 3.11 - Pipework	6 months	2 years		
126	Divers' personal equipment	3.13 - Relief valve regulator	6 months	2 ½ years (2;3;4)		
127	Divers' personal equipment	4.3 & 4.4 - Diver harnesses	Any dive			discard criteria: 5 years after 1st use & if more than 10 year old
128	Compressors, pumps, etc.	3.3 & 3.4 - Fire fighting portable system	6 months			Manufacturer specifications
129	Compressors, pumps, etc.	3.3; 3.5; 3;6 - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
130	Compressors, pumps, etc.	3.7 - Automatic detection	12 months			
131	Compressors, pumps, etc.	4.3 - Cracked plate detector	6 months			
132	Compressors, pumps, etc.	4.5 - Automatic shut down device if more than 25% O_2	6 months			
133	Compressors, pumps, etc.	4.7 & 4.8 - Relief valves	6 months	2 ½ years (2;3;4)		
134	Compressors, pumps, etc.	5.7 to 5.9 - Pipework and fittings	6 months	2 years	1.5 max. working press: 1st install	
135	Compressors, pumps, etc.	6.2 & 6.3 - Air/gas receivers	6 months	2 ½ years OR internal/external inspection		
136	Compressors, pumps, etc.	7.2 - Electrical testing	6 months (2;3;4)			
137	Compressors, pumps, etc.	8.1 - Function test equipment	6 months			

Nb	Section	Reference number of items & Description	Visual external + function test , calibration or for lifting appliances: Load test 1.25 SWL	Visual internal + external + gas leak test at max. working pressure or for lifting appliances: Wire destruction test	Internal + external+ leak test 1,5 max. working pressure or for lifting appliances: Load test 1.5 SWL	Other
138	Compressors, pumps, etc.	8.2 - Delivery rate and pressure compressors	6 months			
139	Compressors, pumps, etc.	8.3 - Output gas purity compressors	6 months (1;2;4)			
140	High pressure gas storage	2.1 to 2.3 - Cylinders	6 months	2 ½ years (3;4)		Internal & Ext. examination. + test max working press: 5 years
141	High pressure gas storage	2.4 - Welded pressure vessels	6 months	2 ½ years (3;4) + internal & external examination		
142	High pressure gas storage	2.6 to 2.9 - Pipework	6 months	2 years		1.5 max. working press: 1st install
143	High pressure gas storage	2.10 & 2.11 - Lifting equipment	6 months (2;3;4)		12 months (2;3;4)	
144	High pressure gas storage	2.12 to 2.15 - Relief valves & bursting discs	Visual: 6 months Function: 2,5 years	2 ½ years (2;3;4)		Bursting discs renewal: 10 years
145	High pressure gas storage	2.16 to 2.17 - Analysers	6 months (1;2;4)			
146	High pressure gas storage	3.3 & 3.4 - Fire fighting portable system	6 months			Manufacturer specifications
147	High pressure gas storage	3.3; 3.5; 3;6 - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
148	High pressure gas storage	3.7 - Automatic detection	12 months			
149	Divers gas reclaim	1.1 - Suitability date cert.				Permanent
150	Divers gas reclaim	2.1 - Helmet Cert. for reclaim use				Permanent
151	Divers gas reclaim	6.8 & 6.9 - Gas bag: relief valve	6 months	2 ½ years (2;3;4)		
152	Divers gas reclaim	6:10 - 6:12 - Gas bag: bursting disc	6 months	2 ½ years (2;3;4)		Bursting discs renewal: 10 years
153	Divers gas reclaim	6.13 - Alarm testing - Gas bag	6 months			
154	Divers gas reclaim	7.3 - Alarm testing – Control panel	6 months			
155	Divers gas reclaim	8.3 - Power failure closure oxygen make up	6 months			
156	Diver gas reclaim	9.5 & 9.6 - Analysers	6 months (1;2;4)			
157	Diver gas reclaim	10.7 to 10.9 - Pipework	6 months	2 years	1.5 max. working press: 1st install	

Nb	Section	Reference number of items & Description	Visual external + function test , calibration or for lifting appliances: Load test 1.25 SWL	Visual internal + external + gas leak test at max. working pressure or for lifting appliances: Wire destruction test	Internal + external+ leak test 1,5 max. working pressure or for lifting appliances: Load test 1.5 SWL	Other
158	Chamber gas reclaim	1.9 - Gas bag: relief valve	6 months	2 ½ years (2;3;4)		
159	Chamber gas reclaim	1.11 - Gas bag: bursting disc	6 months	2 ½ years (2;3;4)		Bursting discs renewal: 10 years
160	Chamber gas reclaim	1.14 - Alarm testing	6 months			
161	Chamber gas reclaim	2.3 - Analysers	6 months (1;2;4)			
162	Chamber gas reclaim	4.7 to 4.9 - Pipework	6 months	2 years		1.5 max. working press: 1st install
163	Hyperbaric evacuation system (general)	Classification certificate				Classification society
164	Hyperbaric evacuation system (general)	4.4 - Sea fastening (Design) cert.				At mobilisation
165	Hyperbaric evacuation system (general)	4.5 - Sea fastening (installation) cert.				At mobilisation
166	Hyperbaric evacuation system (general)	7.5 - Emergency power testing	6 months			
167	Hyperbaric evacuation system (general)	10.1 - Interface compliance assessment				Permanent
168	Hyperbaric evacuation: Interface with dive system	1.2 to 1.4 - Testing	6 months	2 years	When new	
169	Hyperbaric evacuation: Interface with dive system	3.8 - Communication: test and statement batteries	6 months			
170	Hyperbaric evacuation: Interface with dive system	5.1 - Design trunking international certificate (units after 06/14)				Permanent
171	Hyperbaric evacuation: Interface with dive system	5,7 Trunk pressure testing	6 months	2 ½ year		Internal Overpressure: 5 years
172	Hyperbaric evacuation: Interface with dive system	5:11 Venting test				At work mobilization
173	Hyperbaric evacuation: Interface with dive system	5.17 to 5.19 Pipework	6 months	2 years		1.5 max. working press: 1st install
174	Hyperbaric evacuation: Interface with dive system	5.24 - Gauge calibration	6 months			1.25 times maximum rated working pressure when new
175	Hyperbaric evacuation: Interface with dive system	6.4 to 6.9 - Viewports	6 months	2 ½ years	5 years (pressure as for the chamber)	Complete renewal within the last 10 years

Nb	Section	Reference number of items & Description	Visual external + function test , calibration or for lifting appliances: Load test 1.25 SWL	Visual internal + external + gas leak test at max. working pressure or for lifting appliances: Wire destruction test	Internal + external+ leak test 1,5 max. working pressure or for lifting appliances: Load test 1.5 SWL	Other
176	Hyperbaric evacuation: Interface with dive system	7.6 to 7.10 - Pipework interfacel panel	6 months	2 years		1.5 max. working press: 1st install
177	Hyperbaric evacuation: Interface with dive system	7.10 Electrical testing interface panel	6 months			
178	Hyperbaric rescue unit	1.5 - Floating test				Before 1st use (Manufacturer)
179	Hyperbaric rescue unit	2.1 - Design Standard				Permanent
180	Hyperbaric rescue unit	2.5 to 2.7 - Pressure vessel testing	6 months	2 ½ years		5 years: Overpressure test + leak test (3: 4)
181	Hyperbaric rescue unit	3.4 to 3.9 - Viewports	6 months	2 ½ years	5 years (pressure as for the chamber)	Complete renewal within the last 10 years
182	Hyperbaric rescue unit	4.1 & 4.2 - Fire fighting portable system	6 months			Manufacturer specifications
183	Hyperbaric rescue unit	4.1; 4.3; 4.4; 4.5 - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
184	Hyperbaric rescue unit	3.6 - Automatic detection	12 months			
185	Hyperbaric rescue unit	5.5 Electrical penetrators certification				Permanent (3;4)
186	Hyperbaric rescue unit	5:14 - Interlock pipework	6 months	2 years (2;3 4)		
187	Hyperbaric rescue unit	5.17 Electrical testing	6 months			
188	HRU - Chamber internal	6.16 - Communication test.	6 months (Test batteries: 1; 2;4)			
189	HRU - Chamber internal	6.19 - BIBS testing	6 months			
190	HRU - Chamber internal	6.31 & 6.32 - Fire fighting portable system	6 months			Manufacturer specifications
191	HRU - Chamber internal	6.31; 6.33; 6.34 - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
192	HRU - Chamber internal	6.3.5 - Automatic detection	12 months			
193	HRU - Chamber internal	6.38 - Validity medical kit				6 months
194	HRU - Chamber internal	6.42 - Survival bag	6 months			Checked or returned to the suppliers for overhaul: 3 years
195	HRU - Chamber internal	6.49- Environmental control unit testing	6 months			
196	HRU - Chamber internal	6.50 to 6.52 - Pipework	6 months	2 years		1.5 max. working press: 1st install

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197	HRU - Chamber internal	6.53 - electrical	6 months			
198	HRU - Chamber internal	6.55 - gauge	6 months			
199	HRU without external life support control	7A.10 - Pipework	6 months	2 years		
200	HRU without external life support control	7A.13 - Electrical testing	6 months			
201	HRU without external life support control	7A.14 - Communication testing	6 months (2; 3; 4)			
202	HRU without external life support control	7A.15 - Gauge calibration	6 months			
203	HRU without external life support control	7A.16 - Analysis (pump) & Analyser	6 month			Note: check expiry date of tubes: 6 months
204	HRU with external life support control	7B.9 - Communication testing	6 months (2; 3; 4)			
205	HRU with external life support control	7B.21 - Gauge calibration	6 months			
206	HRU with external life support control	7B30 - Pipework	6 months	2 years		
207	HRU with external life support control	7B.34 - relief valves	6 months	2 ½ years (2; 3; 4)		
208	HRU with external life support control	7B.37 - Electrical testing	6 months			
209	HRU with external life support control	7B.39 & 7B.40 - Fire fighting portable system	6 months			Manufacturer specifications
210	HRU with external life support control	7B.39; 7B.41; 7B.42 - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
211	HRU with external life support control	7B.43 - Automatic detection	12 months			
212	HRU with external life support control	7B.46 - First aid	6 months			
213	HRU with external life support control	7B.56 - Analyser and alarm	6 months			
214	HRU with external life support control	10.7 - Cylinder testing	6 months	2 years	4 years	
215	HRU with external life support control	11.7 - Radio, GPS, Satellite phone	6 months			

Nb	Section	Reference number of items & Description	Visual external + function test , calibration or for lifting appliances: Load test 1.25 SWL	Visual internal + external + gas leak test at max. working pressure or for lifting appliances: Wire destruction test	Internal + external+ leak test 1,5 max. working pressure or for lifting appliances: Load test 1.5 SWL	Other
216	HRU with external life support control	13. - Towing test				Before 1st installation
217	HRU with external life support control	14.9 - Mating Trials IMCA D 052, section 5.6				Before or at mobilization
218	HRU Launch and Recovery System	2.1 - Dedicated launch system (SOLAS) fit for purpose certificate				During construction
219	HRU Launch and Recovery System	2.3 - Dedicated launch system: Release Hooks compliant with IMO				During construction
220	HRU Launch and Recovery System	2.4 to 2.8 - Dedicated launch system: Launch System Testing	Visual: 6 months Function test: 1 year			Falls replacement : 5 years. Practice deploy: 6 months
221	HRU Launch and Recovery System	3.1 - Non Dedicated Launch System: Fit for purpose cert				During construction
222	HRU Launch and Recovery System	3.3 - Non dedicated launch system: Launch System Testing	Visual : 6 months Function test: 6 months Static 1.25 SWL: 6 months		Static load test: 1 year	Practice deploy.: 6 months
223	HRU Launch and Recovery System	4.1 - Practice deployment				6 months
224	HRU Launch and Recovery System	4.4 - If test above require major components replacement				Evidence that a practice has taken place within the last 5 years
225	HRU Launch and Recovery System	5.1; 5.2 - Fire fighting portable system	6 months			Manufacturer specifications
226	HRU Launch and Recovery System	5.1; 5.3; 5.4; 5.5 - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
227	HRU Launch and Recovery System	5.6 - Automatic detection	12 months			
228	HRU Launch and Recovery System	6.6 - Communication	6 months			
229	Life support package	1.1 classification certs				During construction
230	Life support package	4.4 Sea Fastening (Design of)				During mobilisation
231	Life support package	4.5 Sea Fastening (Installation)				During mobilisation
232	Life support package	6.8 - Protection against electrical failure				At mobilisation
233	Life support package	6.9 - Electrical	6 months			

Nb	Section	Reference number of items & Description	Visual external + function test , calibration or for lifting appliances: Load test 1.25 SWL	Visual internal + external + gas leak test at max. working pressure or for lifting appliances: Wire destruction test	Internal + external+ leak test 1,5 max. working pressure or for lifting appliances: Load test 1.5 SWL	Other
234	Life support package	6.10 - Emergency Power Testing	6 months			
235	Life support package	8.5 - BA testing	External:6 months Internal + external: 5 years	2 ½ years 5 years		
236	Life support package	8.10 - communication	6 months			
237	Life support package	8.22 - Gauge calibration	6 months			
238	Life support package	8.31 - Pipework	6 months	2 years (2; 3; 4)		
239	Life support package	8.35 - Relief valves	6 months	2 ½ years (2; 3; 4)		
240	Life support package	8.38 - Electrical testing	6 months			
241	Life support package	8.48 - Analyser and alarm testing	6 months			
242	Life support package	8.55 - Communication systems function testing	6 months			
243	Life support package	9.3 - HRU Chamber Environment Heating and Cooling function test	6 months			
244	Life support package	11.5 - Supplies to the LSP - Hose component test	6 months	2 years	When new	
245	Life support package	12.6 - Electrical components umbilical HRU	6 months			
246	Life support package	12.7 to 12.9 - Hose components umbilical HRU	6 months	2 years	When new	
247	Life support package	14.2 & 14.3 - Fire fighting portable system	6 months			Manufacturer specifications
248	Life support package	14.2; 14.4; 14.5; - Fire fighting fixed system	Visual: 6 months Test: 12 months			Manufacturer specifications
249	Life support package	14.6 - Automatic detection	12 months			
250	Life support package	16.4 - Kit DMAC 15	6 month			

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- CCO Ltd - Diving study #2 - Organize the maintenance of diving cylinders
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- **CEN / CENELEC** *(European standards)* -
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- **American Society for Testing and Materials (ASTM),** *(headquarters)* -
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