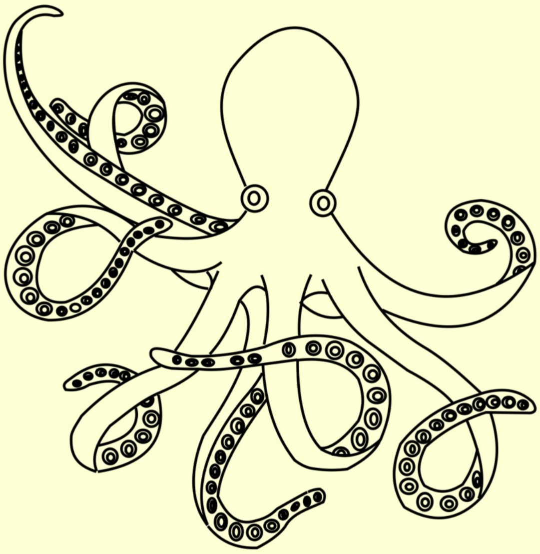

Diving & ROV specialists

Surface-Supplied Diving Handbook Series

Book #4

Description and maintenance of surface-supplied diving systems

June 2025

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This document is the fourth of eight books in the "Surface-Supplied Diving Handbooks Series", described below.

Book 1: Overview of surface-supplied diving operations and scope of this series
Book 2: Description and prevention of accidents associated to diving operations
Book 3: Legal aspects of project preparation
Book 4: Description and maintenance of surface supplied diving systems
Book 5: Managing Weather, Communications, Surface Supports & Underwater Vehicles
Book 6: Prepare and manage the dives
Book 7: Implement the MT 92 tables
Book 8: Implement the DCIEM tables

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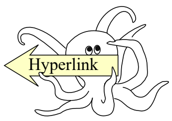

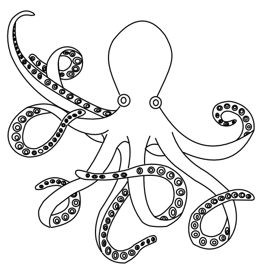

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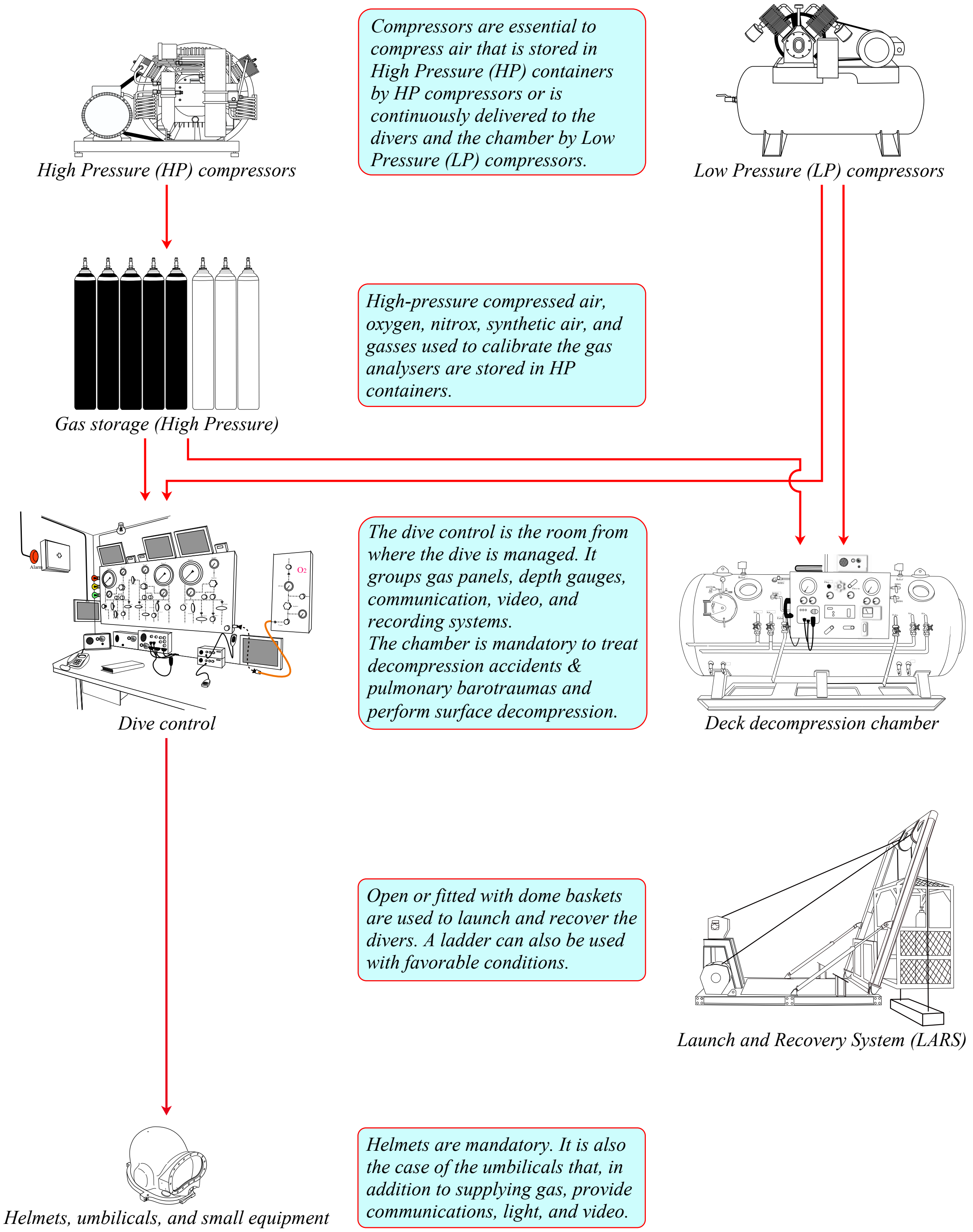
Table of contents

1 - Purpose

This document explains the various designs and maintenance processes of conventional surface-supplied air and nitrox diving systems. Please note that the procedures for systems using wet bells are not covered in this document. The same applies to dives with light transportable systems, commonly called “scuba replacement” or “Lightweight Dive Systems,” which are explained in separate documents.

The dive systems used for “conventional air & nitrox diving” are integrated into diving support vessels (DSV) or designed to be transportable and installed on ships of opportunity. Regardless of their design, they consist of the following elements:



It is worth noting that dive system manufacturers consider guidelines from organizations that influence the diving industry. These organizations include, but are not limited to, those listed below, also mentioned in Book #3 regarding the legal aspects of the preparation of a diving project, as well as those from classification societies and national bodies.

- IMO (International Maritime organization)

- NORSOK (Norsk Sokkels Konkuranseposisjon - Norway)
- IMCA (International Marine Contractor association)
- DMAC (Diving Medical Advisory Committee)
- ADCI (Association of Diving Contractors International)
- Dynamic Positioning Committee
- National safety organizations and ministries of labour
- European Standards – European committee for standardization
- ISO (International Organization for Standardization)
- ANSI (American National Standards Institute)
- ASME (American Society of Mechanical Engineers)
- ASTM international

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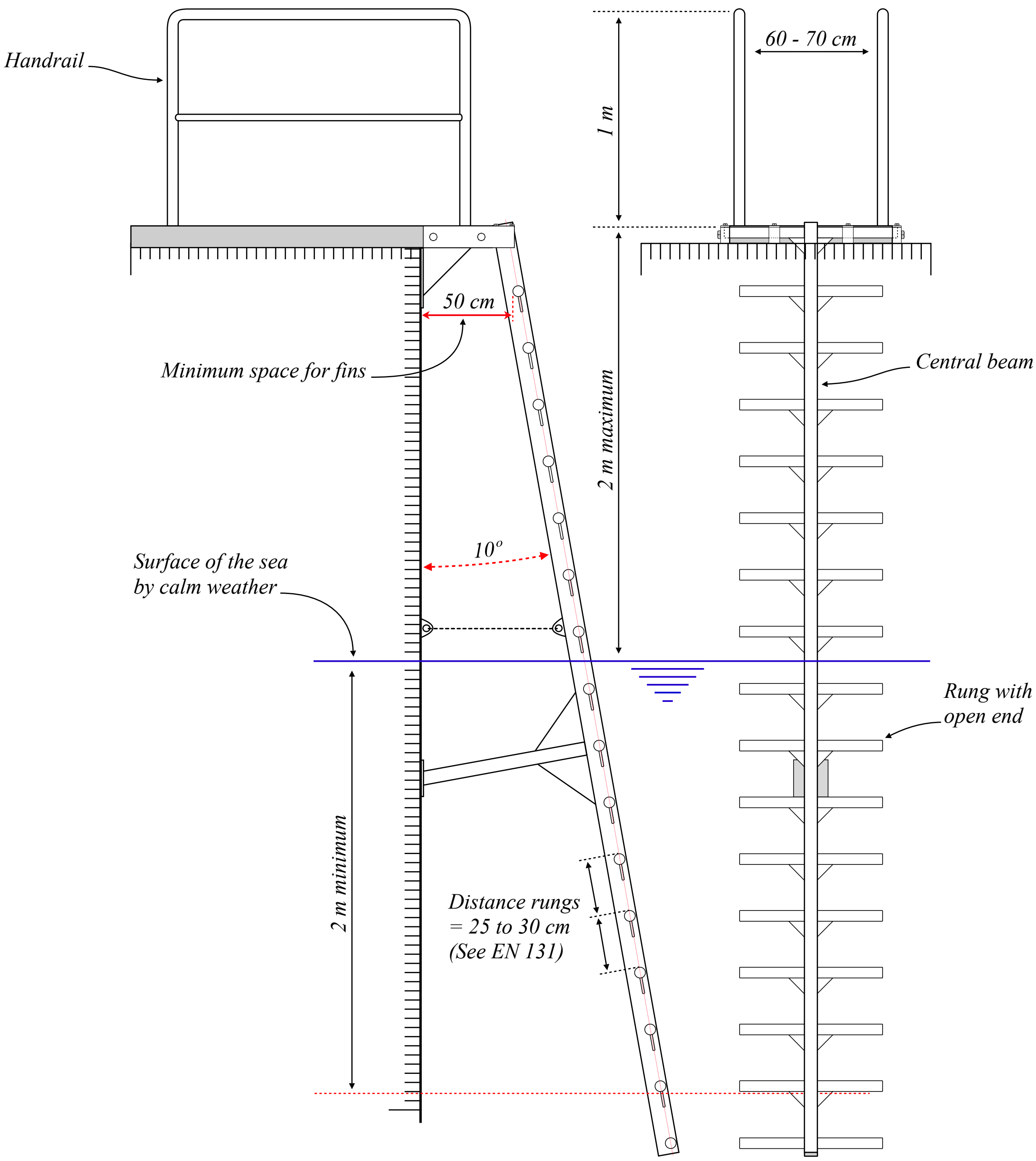
2 - Description of the various parts of a surface supplied diving system

2.1 - Ladders

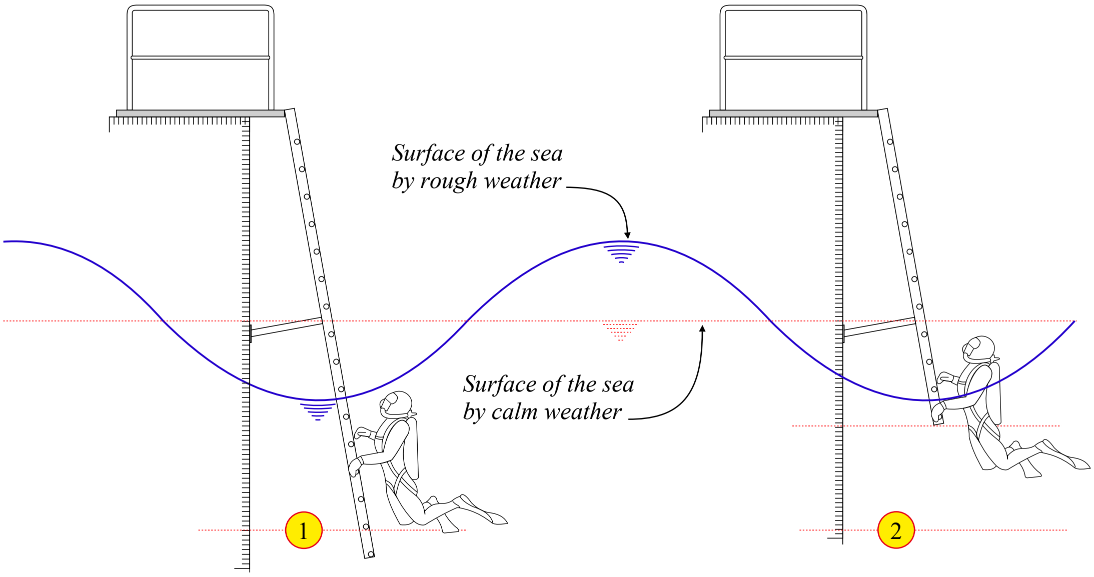
2.1.1 - Description

Ladders are the most simple means of deployment. For this reason, they are often used for surface-orientated diving. They should be designed as follow:

- They should allow the diver to step easily onto the deck without removing his fins:
  - A slight angle is recommended for this purpose and to compensate for the effects of rolling or pitching.
  - Handrails must be provided to facilitate the transfer to and from the deck.
  - The rungs are usually welded on a central beam so the diver can easily insert his fins. The inter rung distance is generally between 25 and 30 cm. There should be an interval of approximately 50 cm with the hull at the top of the device to allow the diver to climb onto the deck without removing the fins.
- Climbing a too elevated height to reach the deck at the end of the dive may oblige the diver to make efforts, which can trigger a decompression accident. For this reason, the distance between the surface of the sea and the deck must be minimized. The IMCA guideline limiting it to 2 metres maximum is thus relevant.
- The diver must be at the surface of the sea to access the ladder or be very close to it. As a result, he can be exposed to the waves and sudden movements of the ship that may prevent grabbing it and cause injuries by rough weather conditions, particularly if its extremity is episodically heaved out of the water. For this reason, ladders must extend sufficiently deep to compensate for this problem partially. Thus, the IMCA rule that says they must extend at least 2 metres below the surface in calm water is relevant.



- In complement to the point above, the drawing below shows the reason a ladder must extend at least two metres below the surface of the sea:
  1. If the ladder is sufficiently long, the diver can grab and climb it under adverse weather conditions.
  2. If the ladder is too short, it will be difficult or impossible to step on it during bad weather conditions, and the diver may not see it if it is episodically heaved out of the water.



- The ladder must withstand the weight of an equipped diver during adverse weather conditions. Regarding this point, the European standard EN 131 says that a ladder should be able to hold 150 kg, and the American Ladder Institute says that an "extra heavy-duty" ladder (Type IAA) should have a weight capacity of 375 pounds (170 kg). However, these standards refer to ladders used on static supports, not those deployed from vessels at sea and thus submitted to accelerations. In the absence of official legislation, the recommendation from the Lloyds Register's "Rules and regulations for the construction & classification of submersibles & diving systems" that says that the vertical acceleration of a submersible unit, including those during launch and recovery, should be assumed to be not less than 2g should be taken into consideration.
- In addition to the above, the ladder must be sufficiently strong to withstand the effects of the underwater currents and the navigation of the surface support at reduced speed. The purpose of this guideline is to be able to recover the diver if strong currents have established or sail if the worksite has to be abandoned in an emergency, and there is no time to recover the ladder (It can be recovered when the vessel is in safe waters). Also, the fastening points of the ladder must be sufficiently rigid to have it perfectly secured during the conditions indicated above. They should be checked during the mobilization and before starting the dives.
- Except for those installed on static surface supports, the ladder should be designed to be quickly installed and removed to allow for the vessel to sail. Davit or cranes are often used for this purpose on barges and ships requiring long and heavy units. However, this task can be done by hand with small ladders. Articulations may be provided to fold the ladder. In this case, they must be designed not to create pinch points. Also, materials such as aluminium allow fabricating lighter units.
- The materials used to build the ladder must be protected from corrosion. Also, the welds and other junctions must be checked before committing it to service.
- Lighting should be provided above the ladder in case of operations performed at night.

2.1.2 - Advantages and limitations

2.1.2.1 - Advantages

The advantages of these means of deployment are linked to their simplicity:

- They are easy to install and need a reduced space on deck.
- They do not involve any mechanical system, so no power source is necessary to implement them.
- Their maintenance is reduced.

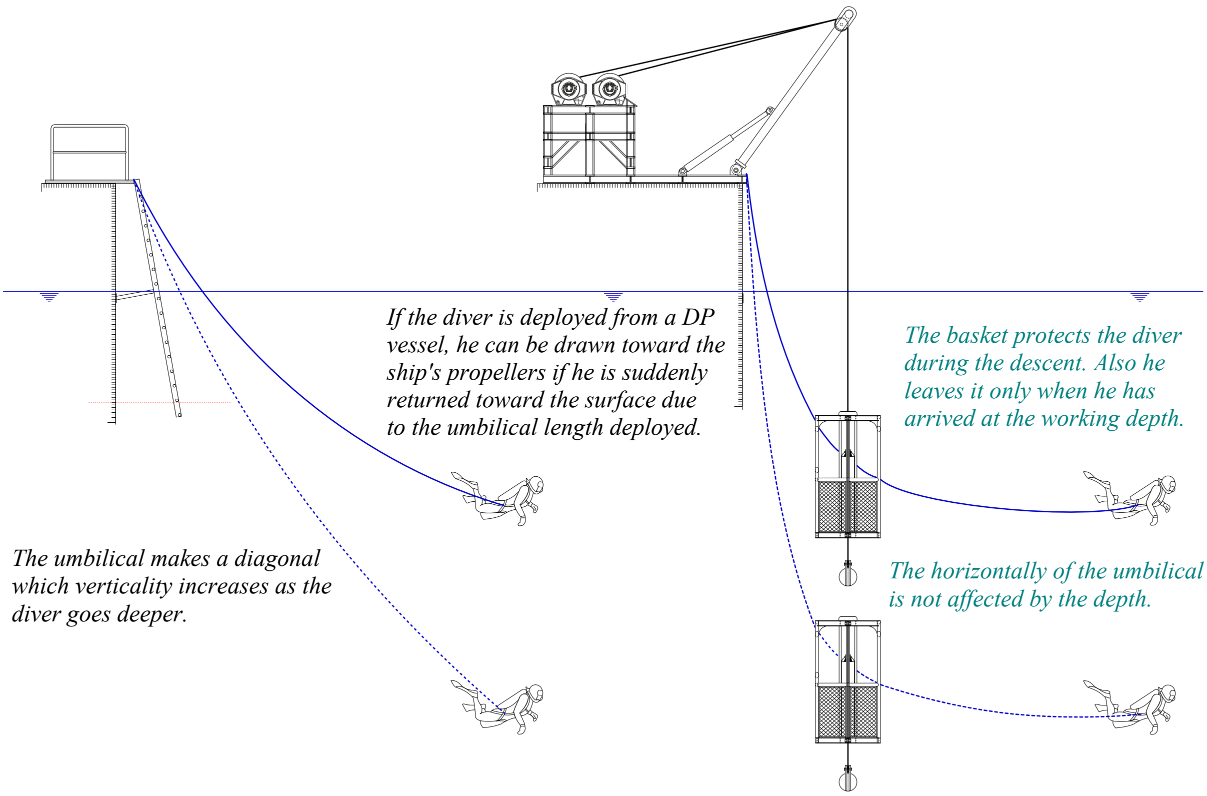
2.1.2.2 - Limitations

Diving ladders limitations are also linked to their simplicity:

- Because they are deployed in the splash zone of the vessel or the facility, they do not provide any protection against the waves and sudden movements of the ship that may prevent the divers from grabbing them and may cause injuries for the reasons explained previously, even they are designed according to the guidelines promoted above. For this reason, their use is commonly limited to sea conditions with wave heights of less than one metre.
- Opposite to diving using a basket or a wet bell, the umbilical of the diver is not enclosed in the deployment device but directly tended from the surface. For this reason, the diver may have difficulties reaching the ladder if the underwater current is too strong and pushes him away. For this reason, the underwater conditions must be c

calm, with currents strictly below 0.8 knots. A swimming line connected to the worksite and the direct proximity of the ladder is a suitable means to access it.

- Decompression stops are usually performed using a stop line installed at the direct proximity of the ladder. The stop line is generally a graduated rope terminated by a weight, where the depths of the stops are highlighted, in addition to D rings where the diver can secure his lanyard. In-water stops performed in such conditions are comfortable in calm weather conditions. Still, the opposite in agitated waters as the diver may have to make efforts to adjust his depth or fight the underwater current. For this reason, decompression dives with such means of recovery must be undertaken only by favorable conditions.
- In addition to the above, the ascent speed to the surface and the deck cannot be fully controlled by the support team, and the diver may have to make efforts to climb the ladder to the deck. For these reasons, this means of deployment should not be used with procedures such as "surface decompression", as this procedure which consists of interrupting the decompression after the stop at 9 m and transferring the diver to the chamber where the decompression is completed, requires that this transfer phase is under complete control not to trigger a decompression accident.
- Diving using a ladder does not offer the possibility to restrict the diver's umbilical horizontally as precisely as using a basket because it is not enclosed in the deployment device. For this reason, the umbilical makes a diagonal which verticality increases as the diver goes deeper. Due to this angle, restricting him can make him uncomfortable: Adjusting his umbilical to the minimum length tends to bring him toward the surface, and the action of the underwater current on the umbilical also draws him toward the surface. Many divers deploy more umbilical length than the minimum to counter these phenomena and be more comfortable. However, such a practice results in the exact required umbilical length being challenging to evaluate, resulting in the tender's inability to precisely limit the diver's distance from a hazard, particularly during the descent to the worksite. Also, suppose that a diver deployed from a Dynamic Positioning (DP) vessel is suddenly returned toward the surface for any reason. In that case, the umbilical length deployed during the descent or at depth is too long to prevent him from being drawn toward the active propellers and thrusters of the surface support, resulting in a high probability of fatality. On the opposite, the horizontality of the umbilical deployed through a basket is not affected by the depth, and the horizontal length deployed is more straightforward to manage. Also, the diver leaves the deployment device that protects him during the descent only when he has arrived at the working depth. Based on these considerations, all commercial diving organizations state that using ladders for diving from Dynamic Positioning (DP) vessels is highly hazardous and must be strictly forbidden.



2.2 - Launch and Recovery Systems using baskets

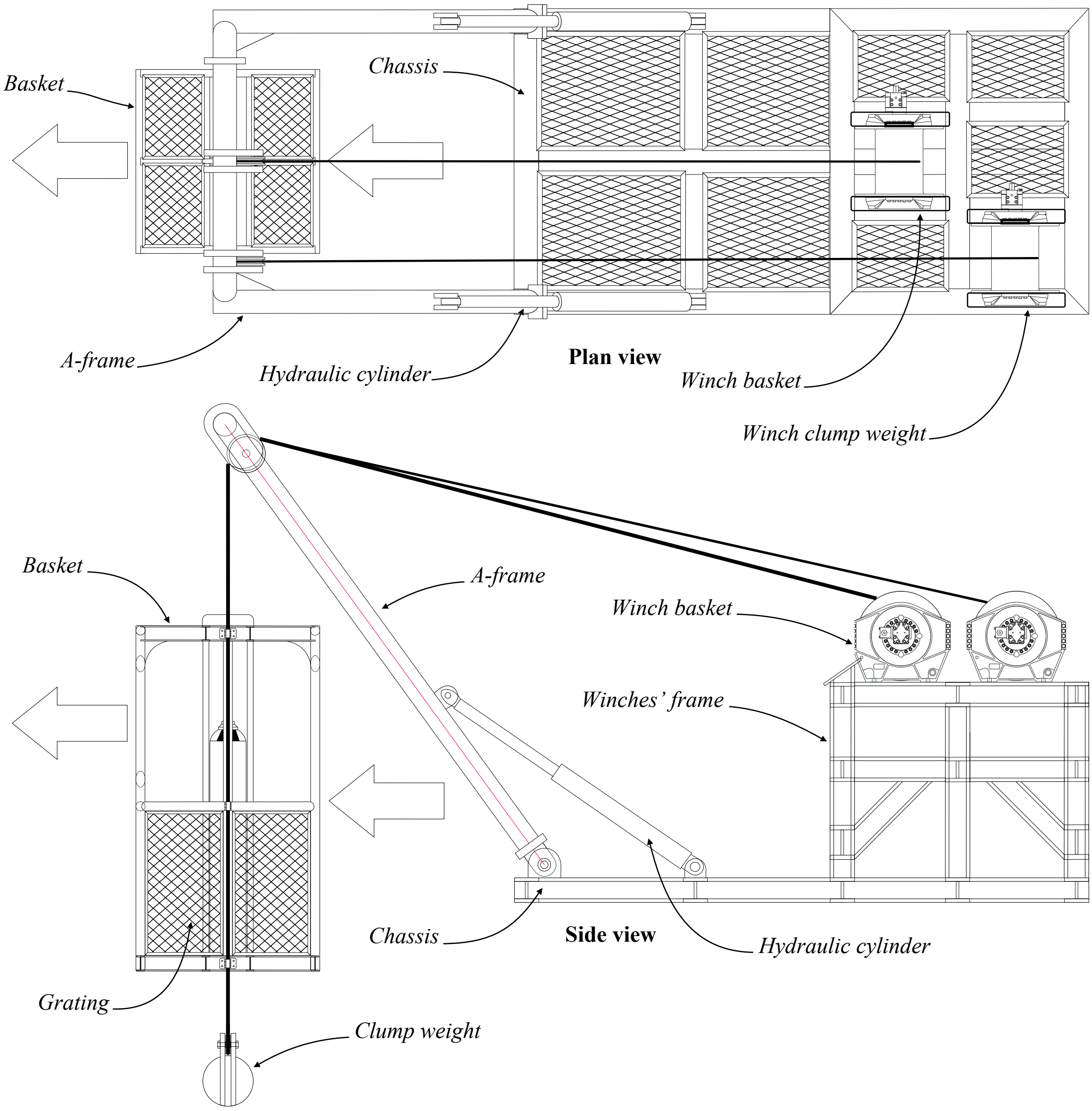
Baskets are cages used to deploy the divers to the bottom and recover them to the deck in a controlled manner and protect them during these phases or emergencies. They (or wet bells) must be used for diving operations where the freeboard exceeds two metres and for operations from a dynamic positioning vessel. They allow for deployments at roughest weather conditions than ladders and provide extra gas reserves to the divers. Please, note that there must be at least two baskets (one for the divers + one for the standby diver) to launch a dive when the weather conditions are not suitable for diving using a ladder. Also, the number of baskets should be increased in the case of continuous diving with in water decompression. Most diving regulations and companies restrict their use to 50 metres maximum.

2.2.1 - Description of a Launch and Recovery System using a basket deployed by an “A-frame”

2.2.1.1 - General design

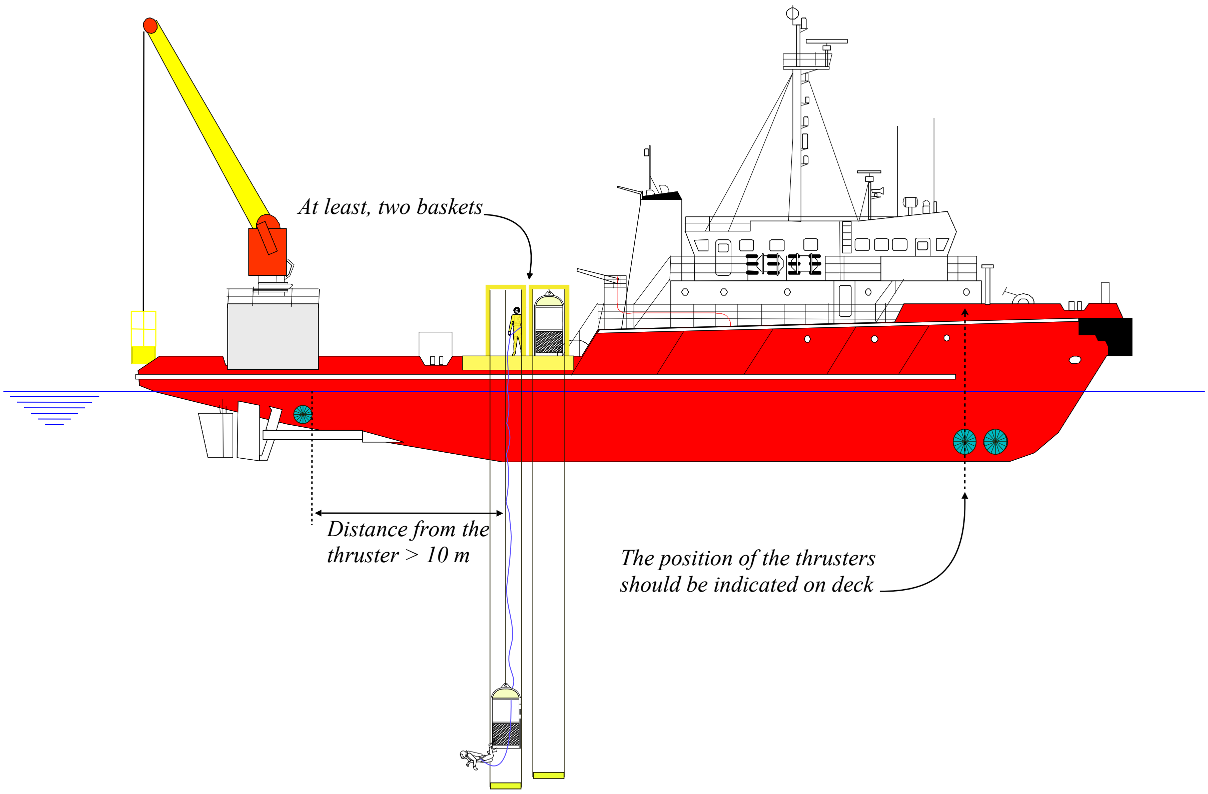
These models are usually designed to be transportable and are composed of the following main elements:

- A cage (the basket) provides divers' protections using top, lateral, and bottom grids. The divers enter this cage through the gate. When at depth, they go to the job site through the window on the opposite side of the gate, so the umbilicals are enclosed in it. Other means for securing the umbilicals to the basket are specific guides where the umbilicals are encased before starting the dive.
- The basket is over boarded and deployed to the bottom by an A-frame and a winch. Modern A-frames are deployed by hydraulic cylinders. Nevertheless, some old models were deployed by cables and pulleys. The winch can be pneumatic, hydraulic, or electric.
- A clump weight is provided to avoid the basket rotating on its deployment cable. It is also deployed by a winch and usually designed to be used as a 2nd means of recovery of the basket in case of failure of the primary system.
- This A-frame and the winches are installed on a solid chassis usually made of I beams. This chassis is fastened to the surface support. Note that, depending on the conception, the winches can be directly bolted to the chassis or installed on an additional frame to be higher and allow for a passage below the lifting cables.



- The basket must be located such that it is easy for fully equipped divers to board in and from it. It must also be organized such that an unconscious diver can be easily removed and transferred to a stretcher.
- When for operational reasons, the launch and recovery systems need to be installed on additional platforms, guards and handrails must be in place to prevent the operators from falling down on deck or at sea during the operations or when accessing or leaving the working platform.
  Note that these additional platforms must be designed and fabricated by competent engineers and technicians. Also note that the welds of the structure should be checked by recognized 3rd party inspectors during its construction. Their sea fastenings should also be inspected by competent persons during the mobilization.

- A lifting device and other suitable arrangements must be ready to recover from the water to the deck an injured or unconscious diver or someone who has fallen overboard.
- When the dive has to be organized from a dynamic positioning vessel, ladders are forbidden, and only basket and bells can be used. At least 2 baskets are mandatory, and one of the baskets must be dedicated for the standby diver only. In this case, the divers access to the water must be in an area which is at a suitable distance away from any thruster or other object likely to cause problems (at least 10 m from the outer edge of the thruster to the centre of the deployment device).



- During the installation, some precautions must be taken to be sure that the basket will not hit the hull of the surface support during the launch and the recovery, even in adverse weather conditions. Also, function tests must be performed with the “A frame” fully deployed.
- Suitable lighting should be installed if operations are carried out at night. This lighting should be sufficient to read gauges, perform maintenance tasks accurately, and avoid tripping hazards.
- IMCA D 023 says that the safe working load (SWL) must be clearly visible on every winch and on the A frame, guide wire weight or similar devices. Regarding this point, please note the following definitions:
  - The Safe Working Load (SWL) of a lifting appliance is the load it is approved to lift, excluding the weight of its lifting gears (hook, block, wire, etc.).
  - The “gross weight” of a basket is its total weight along with all its contents (fully equipped divers + emergency gas cylinders, etc.).
  - The “tare” is the weight of the basket when it is empty.

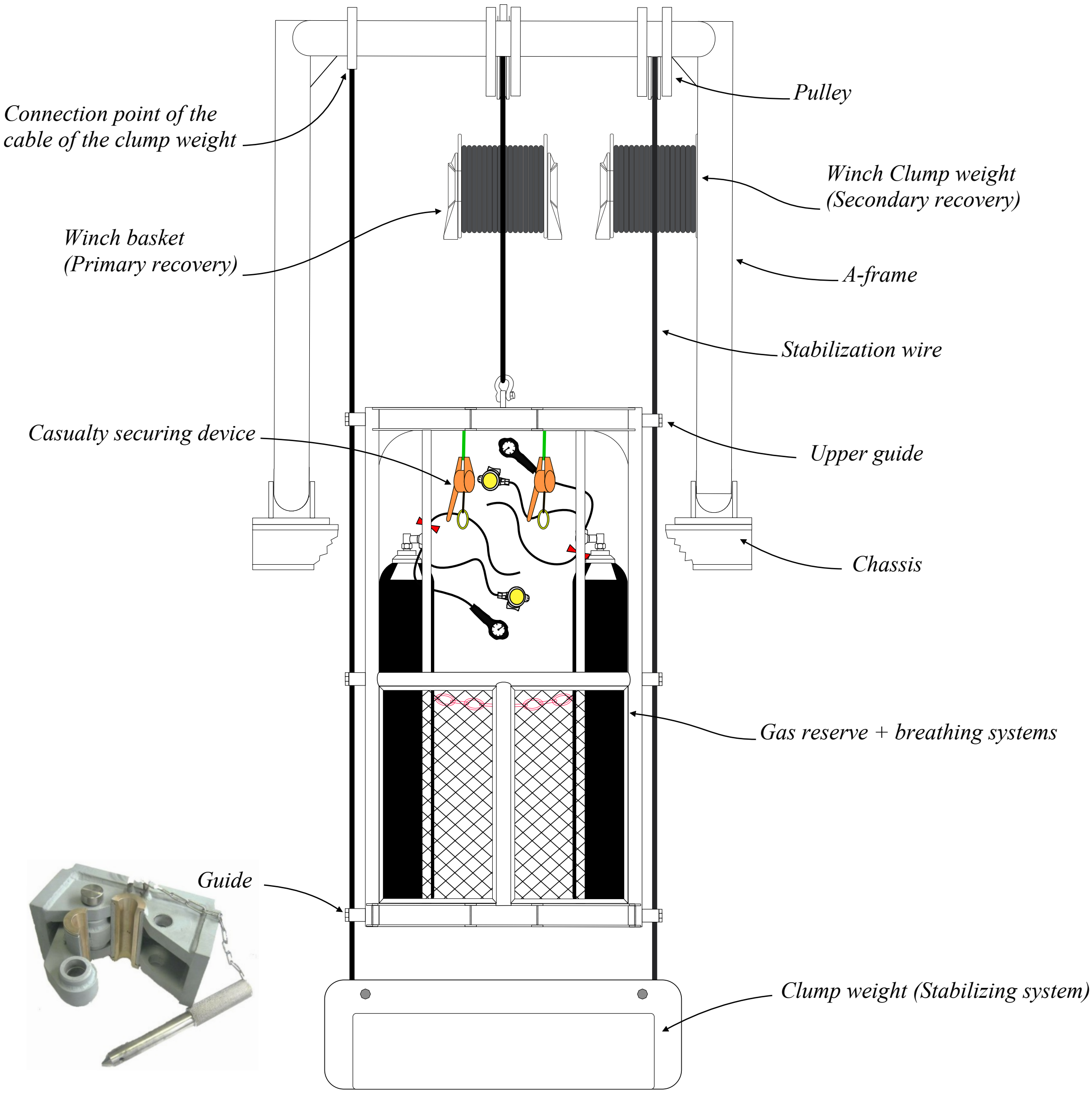
2.2.1.2 - Basket and clump weight

As previously said, baskets are cages used to safely transfer the divers from the deck to the worksite and vice versa. For this reason, they must be designed to protect them from shocks and be a refuge where they can find extra gas reserves in case of an emergency.

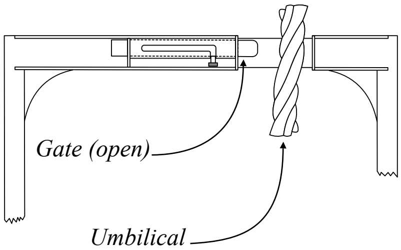
- Baskets are usually made of steel profiles and grids. This structure must be protected against corrosion, and only slight rust is acceptable. When square or round tubes are used, it is essential to ensure that they are fully closed as saltwater intrusion will result in uncontrolled internal corrosion. For this reason, rust pittings should be eliminated and closely inspected. The integrity of welds should also be regularly controlled. Note that water oozing indicates that a profile is flooded. The presence of water can also be confirmed by slightly knocking it (different sound than those that are empty).
- The Lloyd’s register says that diving baskets are to be provided with adequate mechanical protection to keep the divers safe and to prevent damage to the critical components of the basket during handling operations and other normal or emergency operations. The lower section of the basket is to be provided with a platform enabling the divers to stand safely.
- In addition to the rule above, Bureau Veritas NR 610 DT says that the basket must be fitted with protection at the top to prevent injury to the divers from dropped objects. The document IMCA D 023 confirms this point.
- The Lloyd’s register and Bureau Veritas also say that baskets must be provided with internal handholds to support the divers and gates or chains to prevent the divers from falling out. This safety point is also confirmed by ABS and in IMCA D 023.
- ABS says that baskets are to be designed for the carriage of at least two divers, including their equipment, and must have suitable dimensions to carry the divers in an uncramped position. Regarding this point, note that it may happen in exceptional conditions that two divers deployed simultaneously have to be recovered with the rescue diver (So, three divers). Documents from other classification societies and IMCA D 023 confirm the rule for two divers but do not consider a scenario with three people.
- Bureau Veritas NR 610 DT also says that the safe working load should be marked on the basket. In addition, IMCA says that the gross weight of the basket, fully equipped with divers and equipment (1 diver = 150 kg), should be marked on it with its tare weight. IMCA also states that for any basket manufactured after 1 January 2014, documentation showing the designed Safe Working Load (SWL), which should be equal to or greater than the gross weight marked on it, should be available. These markings are usually painted on the posts or upper beams of the device. Note that these elements should also be indicated on an identification plate with the date of fabrication of the device, the serial number, and the name of the manufacturer.
- A lifting point must be provided to attach the lift wire to the top of the basket. IMCA and Bureau Veritas say it can be a pad eye, a shackle point, or a captive ring. In addition, the Lloyds register says that it must be designed and arranged to be capable of withstanding the forces associated with launching and recovering the basket and that due regard should be paid to the worst operating conditions. Suitable tests should be applied to this attachment point to simulate dynamic forces.
- A secondary lifting point must be available and designed according to the same requirements as the primary one. ABS says that this lifting point is to be in-line with the centre of gravity of the diving basket.
- The connection of the wire to the basket must be also designed to withstand the forces associated with launching and recovering the basket during the worst operating conditions. In addition, IMCA D 023 says that it should have two retaining means (such as castellated nut locked with split pin) for the removable pin.
- Classification societies and most diving regulations say there must be a system to secure an unconscious diver. That can be a lanyard with carabiners or a small lever hoist attached to the top of the basket and connected to the harness. This system must be positioned to allow the rescue diver to manage the airways of the casualty during the ascent. Note that IMCA D 023 recommends such an arrangement for each of the working divers. In addition, a knife must be available in the basket to cut this arrangement in case detaching the victim takes too long time.
- IMCA and some classification societies say that at least one emergency cylinder must be fitted in the basket and securely mounted. Regarding this point, ABS says that the on-board emergency life support system is to be capable of supplying breathing gases to the divers at all depths up to the maximum operating depth, with a sufficient capacity to supply the divers while the basket is being recovered including decompression.
  ABS also say that a respiratory minute volume of not less than 12 litres/minute or 0.42 actual cubic feet/minute

(acfm) per diver for average rest conditions and 22.5 liters/minute or 0.8 acfm per diver for light work conditions at ambient pressure is to be used for determining the capacity. However, considering that the divers may be stressed, and submitted to the effects of cold water on the face, we recommend a calculation based on a consumption between 35 and 62.5 litres per minute, depending on the temperature of the water.
These cylinders should be colour coded, and the percentage of the mix indicated. Their last test date stamps should be highlighted using a specific colour. Gauges must be provided to monitor their pressure at all times. The cylinders must be fitted with a first-stage regulator supplying a mouthpiece with a separate mask or a full face mask. An open-end flexible hose equipped with a valve must also be provided. This flexible hose must be sufficiently long and rigid to be pushed up inside the helmet through the neck dam. There should be at least one set (mouthpiece or mask + open-end hose) per working diver. It is also recommended to install pressure relief valves on each first-stage regulator.
Note that the valves, mouthpieces, and hoses must be easily accessible but located where they are protected from shocks or an accidental opening. Other systems may be acceptable, subject to a risk assessment.

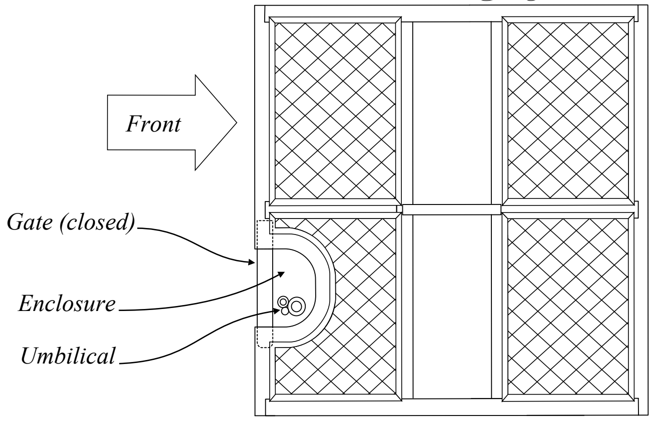
- A wire must be installed on each side of the basket to stabilize it and avoid gyration. They are usually employed as a secondary means of recovery. For this reason, guides are fitted to the basket to enclose them and must be organized so that the basket cannot capsize if the primary wire fails. Also, they must be designed not to open inadvertently and be in good condition and free of corrosion.
In addition, particularly when used with Dynamic Positioning vessels, the "clump weight" (guide weight) must be sufficiently heavy to minimize the swinging of the basket in case of a sudden loss of position or if a violent underwater current is established. It is usually a heavy beam or a closed pipe filled with high-density materials, which is deployed by a 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. Note that in case the anti gyration system is not designed as a secondary means of recovery, another arrangement must be in place for this purpose.



- Many baskets have a seat installed below the exit window. In addition to the fact that the diver can rest on it, it is used as a coffer where tools can be safely stored.
- Umbilical guides are also provided with modern baskets. They consist of an enclosure installed on the top of the cage, closed by a sliding gate *(see on the next page)*.



Front view (top of the basket)

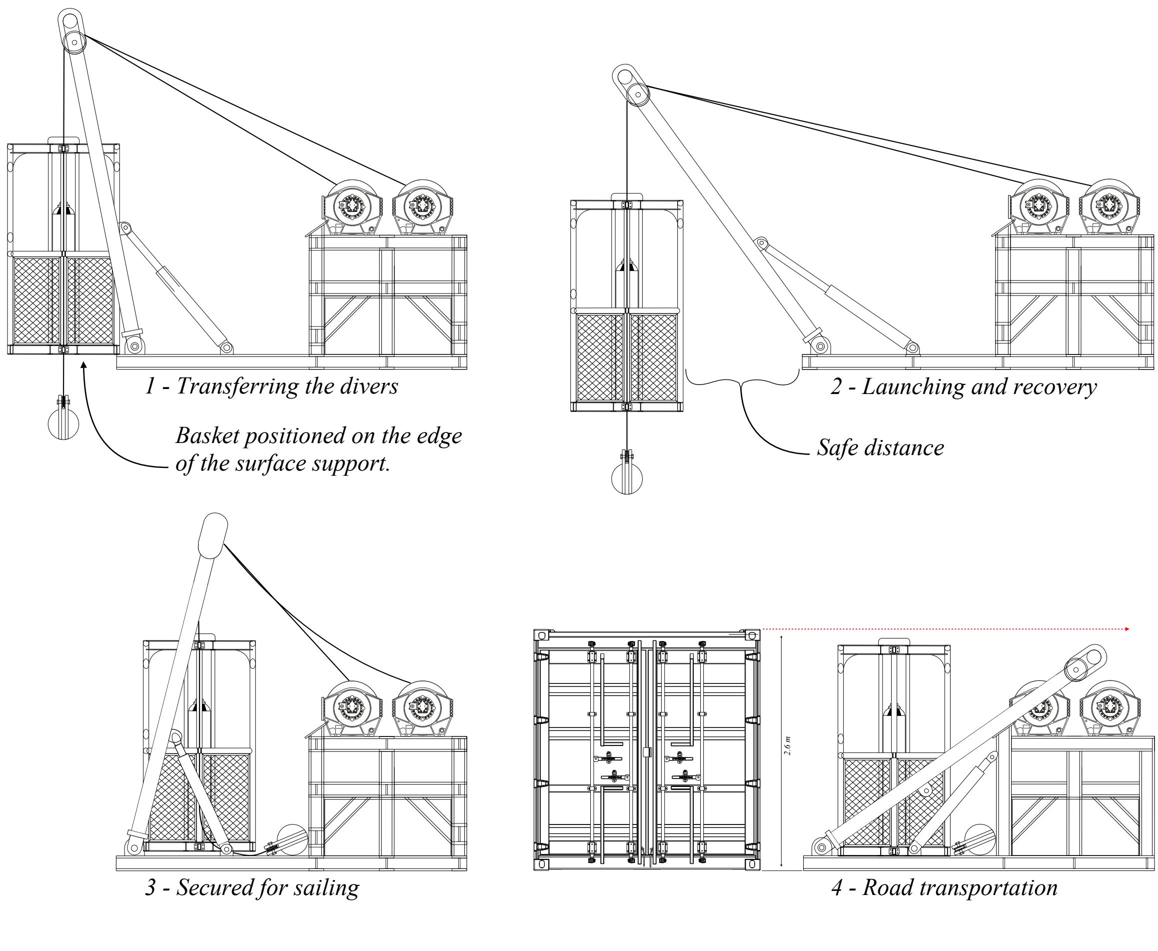


Plan view (top of the basket)

2.2.1.3 - A-frame and chassis

A-frames are lifting structures shaped in "A", which are fitted with a pulley at the top of the "A". They are erected on their two legs and are kept at a slight angle (approximately 20º) using ropes or cables fastened to various anchor points. They have been used for construction since antiquity and perhaps before and allow for the transfer of heavy loads. Those employed in the diving industry are based on this principle, although they are usually shaped like an inverted U to allow the basket to transfer between the two legs. They are designed as follows:

- A-frames are usually made of large square or round pipes and also “I “ profiles. They are typically fitted to the chassis by two bearing blocks on which they pivot. Pulleys through which the cables of the basket pass are fastened to the top beam. As said above, they are oriented and maintained in the working position by means of hydraulic pistons. However, cables were used to deploy and keep in working position the first models, and it is still common to encounter such arrangements.
- The A-frame should be designed to:
  1. Allows for an easy transfer of the divers to and from the basket.
  2. Extend sufficiently far from the hull of the surface support to protect the basket and the divers in it from shocks during the launching and the recovery.
  3. Secure the basket inside the Launch and Recovery System (LARS) for sailing.
  4. Be laid on the chassis without detaching its legs for easy transportation and implementation. Note that engineers usually design them so that the LARS is less high than a shipping container and thus can be shipped by normal means of transportation. This point is essential for the organization of the mobilization.



1 - Transferring the divers

2 - Launching and recovery

3 - Secured for sailing

4 - Road transportation

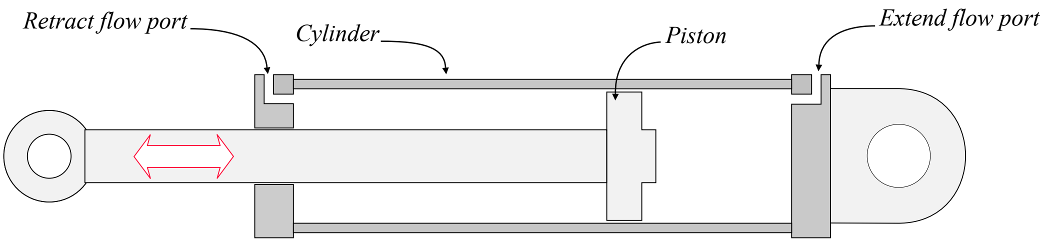
- The Lloyds Registers says that diver handling systems are subjected to extremely harsh and marine environmental factors that significantly impact the operational and maintenance characteristics of the system. Environmental factors which should be considered in the system design parameters are sea state, air temperature, water temperature, precipitation (rain and snow), ice, wind velocity, currents, and the corrosive effects of the saltwater environment. For this reason, the design analyses of the A-frame and the chassis must indicate forces, loads, shears, and moments for all structural members, welds, and connections, including interaction forces. Components should be analyzed considering tensile, compressive, bending, shear, and torsional loadings. Relatively high safety factors are necessary, even though the materials and their properties are well known. These evaluations should be approved by a classification society or an official organization of the same technical level, and the documents kept for reference.
- As shown previously, the pulleys of the primary and secondary lifting cables are connected to the upper beam of the A-frame. They must be, calculated according to the parameters indicated above and be at least of the same working load of the winches. Note that the safe working load must be visibly written on the A-frame. It is usually done on the external side of each leg. IMCA says that this SWL must be greater than or equal to the weight of the fully manned and equipped diving basket in air.
- The Launch And Recovery System (LARS) must be designed to be safely handled by the crane. For this reason, lifting points are installed on the chassis (see in the pictures below), and the weight of the LARS must be indicated on a visible part. Multi-leg slings are commonly used for the transfer, and for this reason, the lifting points are usually arranged so that they are equidistant to the centre of gravity of the LARS that should be transferred flat. If conditions other than these apply, a qualified person must determine the specific requirements and select a sling assembly with suitable characteristics. It is common to assign slings to a LARS, so the mobilization team does not need to look for them. These slings should be built according to a recognized standard and provided with their identification label.
- The fastening of the chassis to the deck must not be done by direct welding to the structure because welds done too often on the same point can affect the metal and reduce its strength. Chassis are generally designed with holes allowing the bolting of plates on which the welds are performed to avoid it. Other arrangements are wedges welded on the floor but not on the frame and arranged to imprison the chassis *(see in the pictures below)*. Fastenings are often solicited during the dive, particularly when launching and recovering. They must be designed by competent engineers and inspected by a qualified third-party auditor using Non-Destructive Techniques (NDT) after being welded. Also, they should be visually inspected every working day.


Wedges welded to the deck, but not the chassis


Fastening wedges and lifting points (in yellow)

2.2.1.4 - Hydraulic cylinders

Double acting cylinders are used to pivot the A-frame on its bearing point. They are composed of a piston that moves out and retracts in a cylinder as a result of the injection of oil in one side or the other, which creates motion in a straight line. These devices are also used to keep the A-frame in the desired intermediate position.
Note that pneumatic cylinders work on the same principle and could be used. However, it is said that hydraulic units are softer and handle greater force than pneumatics and seem preferred for these reasons.

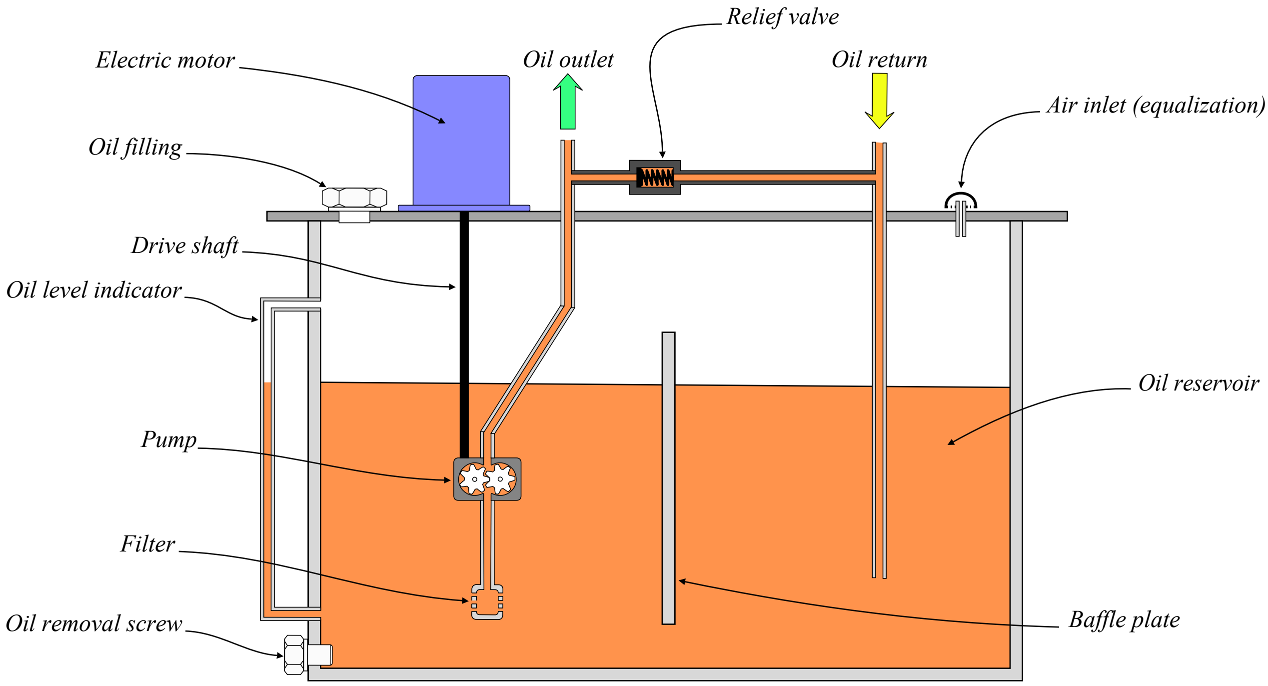


- Hydraulic cylinders must be designed to withstand the environmental factors described previously, and to keep the A-frame in position without failure. Note that safety cables adjusted to the maximum extension of the A-frame were in place as a backup on the previous generations of Launch And Recovery Systems (LARS).

- These cylinders must also be provided with a hydraulic shutoff valve. In addition, each cylinder must be capable of holding the rated capacity of the LARS.

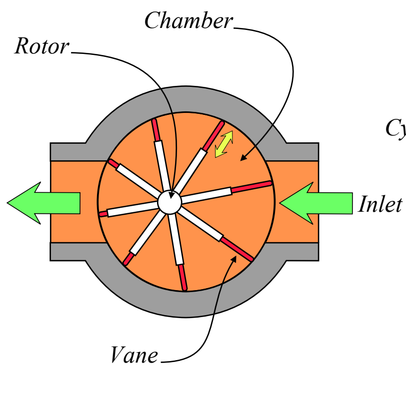
2.2.1.5 - Hydraulic Power Unit (HPU) & direction control valve

Hydraulic cylinders and motors cannot be operated if there is no pressure in the circuit that feed them 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.

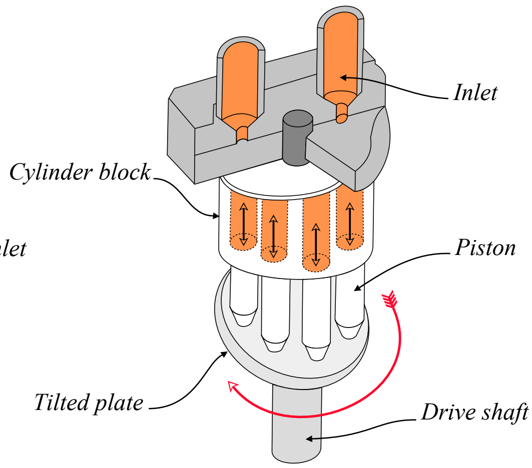


The pumps usually used are positive displacement pumps that are sufficiently powerful to power the tools they supply. Three types of pumps are commonly found:

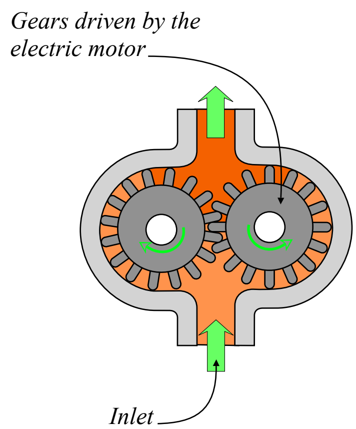
- Gear pumps produce a flow of oil by using the teeth of two meshing gears to move the fluid. They are reputed robust and can transmit high amounts of hydraulic fluid.
- Piston pumps are also used for this purpose. They contain one or more pistons that convert the rotary shaft motion into an axial reciprocating 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.

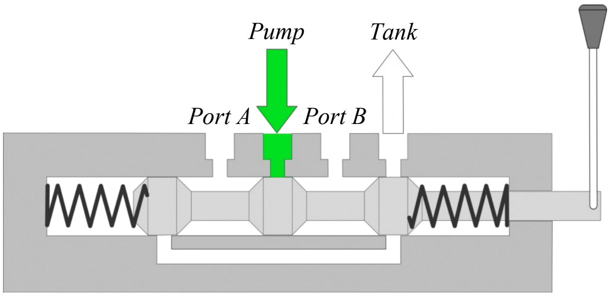
- Provide communication to the external atmosphere, and sufficient space above the fluid to let the air compressed when it is hot to escape to the atmosphere and vice versa.
- Provide a surface that is large enough to transfer the heat from the fluid to the ambient environment by radiation and convection.
- 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 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

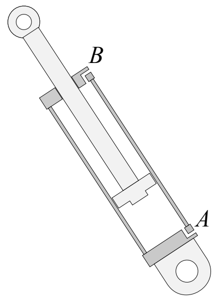
Important note:
The hydraulic power unit of the Launch And Recovery System (LARS) must not be for any other purpose than the supply of the elements of the LARS, and this according to the original design indicated by the manufacturer and agreed by the certification body. So, a separate Hydraulic Power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

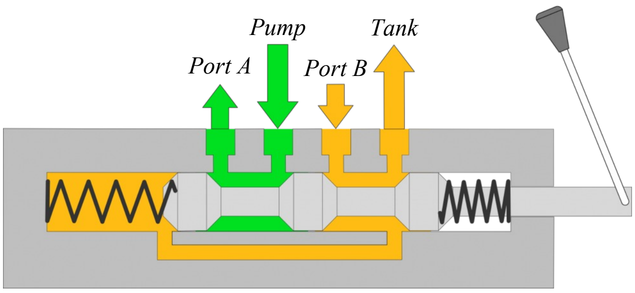
Examples of Hydraulic Power Units designed by Comanex (http://www.comanex.fr)

Linear hydraulic directional control valves are usually employed to operate the double-acting cylinders extending or retracting the A-frame because they combine ergonomic and ease of maintenance. They are made of a rod with lands and grooves which slides inside a cylinder with the help of a lever acting as a directional command. Lands (large diameters sections) close inlets and outlets, that are opened by the grooves (small diameter areas). The distribution of the ports according to the diameters of the rod allows obtaining various open and closed combinations, as in the example below:

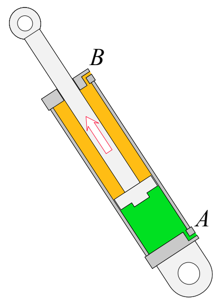


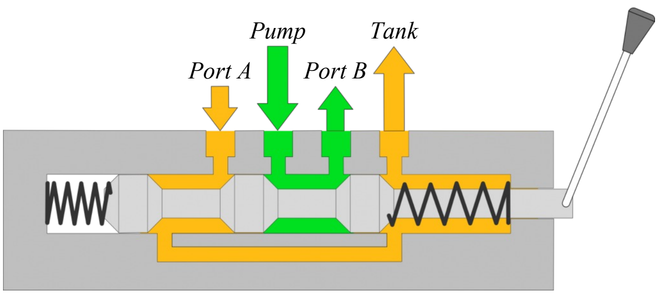
Standby position:
The inlet from the pump and the outlet to the tank are closed as well as the ports to the hydraulic cylinder. As a result, the hydraulic cylinder is not activated. Note that the overpressure valve of the oil inlet (not figured) is activated, so the oil returns to the tank. The springs are of the same force and maintain the arrangement in this neutral position.



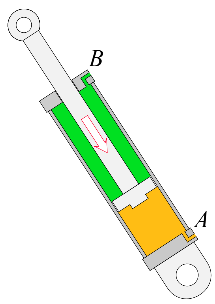


Extending the A-frame:
When the lever is pushed, the inlet flux from the pump goes to port A, and port B communicates with the tank. As a result, pressured oil is injected into the cylinder through port A, so the piston is pushed from A to B and expels the oil from the other side of the cylinder through port B. The rod of the cylinder, and thus the A-frame, extends.





Retracting the A-frame:
When the lever is pulled, the inlet flux from the pump goes to port B, and port A communicates with the tank. As a result, pressured oil is injected into the cylinder through port B, so the piston is pushed from B to A and expels the oil from the other side of the cylinder through port A. The rod of the cylinder, and thus the A-frame, retracts



Note that a single valve controls both hydraulic cylinders

Hydraulic directional control valves are arranged alone or in blocks depending on the number of elements to control. They should be installed such that the operator has a good view of the A-frame and the basket and that they are protected from shocks and undesired maneuvering. Also, highlighted labels indicating to the operator whether the position of the command extends or retracts the A-frame should be in place so that the operator knows it before operating it. Regarding this point, it is a good practice to organize the system such that the A-frame is deployed when the stick is pushed and retracted when it is pulled. The operating instructions must also be available near the hydraulic block and the HPU.

Block 3 valves
(https://www.comeo-france.fr)

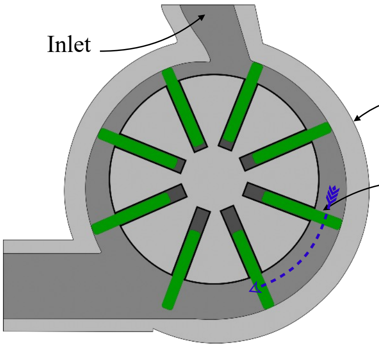
Block 2 valves
(https://www.ubuy.co.th/en/)

Single valve
(https://www.indiamart.com)

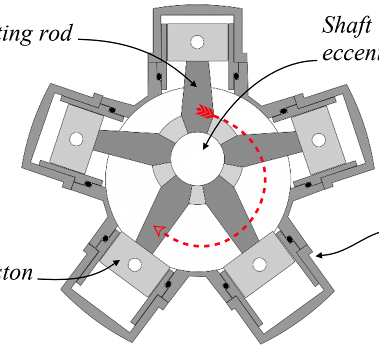
2.2.1.5 - Winches

Pneumatic, electrical, and hydraulic winches can be used to deploy and recover the basket. They are composed of a motor, gears providing reduction, a drum, brakes to stop and secure the drum, and a clutch system.

- Hydraulic and pneumatic motors are designed like the hydraulic pumps discussed in point 2.1.1.5, except they receive the hydraulic or air flux instead of producing it. Note that vane and radial pistons motors are often used with pneumatic winches. Radial pistons motors convert the reciprocating motion of pistons arranged radially into the rotary shaft motion: Compressed air is fed to the top of the cylinders, pushing the pistons one by one, which produces the rotation of the shaft, which incorporates an offset from the centre of rotation. This turning motion creates the mechanical power which drives the winch. Note that the principle of radial piston motors is also commonly used with hydraulic systems.

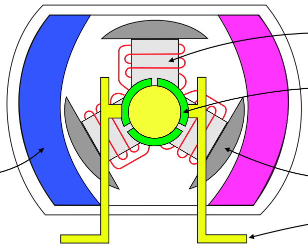


Vane motor

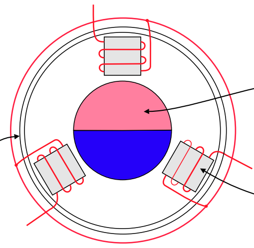


Radial pistons motor

Electric winches with heave compensation have become usual with Launch And Recovery Systems (LARS) designed for ROV and closed bells. These winches are usually powered with 440 volts Alternative Current (AC), and brushed or brushless electric motors are used. However, an investigation through most manufacturers' catalogs shows that electric motors are not yet commonly used with surface-supplied diving LARS.
As a reminder, the difference between brushed and brushless motors is that the current passes through coils mounted on the rotor with brushed motors. This assembly rotates because each coil generates a magnetic field that is pushed away from the pole of the stator of the same polarity and is pulled toward the one of opposite polarity. The power to these coils is supplied through fixed conductive brushes that make contact with a rotating commutator. With brushless motors, the coils are located on the stator instead of the rotor that is made of two separate polarities permanent magnets. As a result, the coils do not rotate, and there is no need for brushes and a commutator.

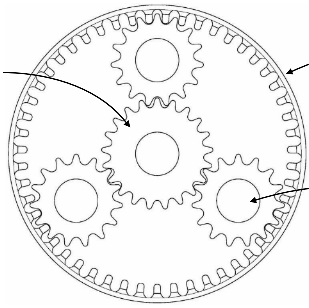


Brushed Motor

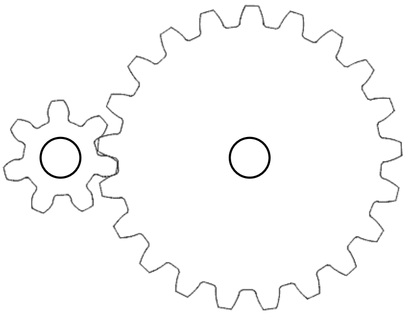


Brushless motor

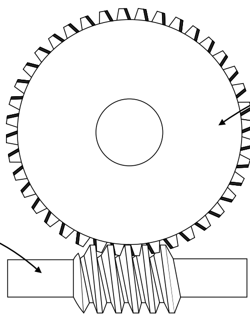
- Gears are used to transmit the motion of the motor to the drum. Among the numerous arrangements available, the solutions below are frequently used:
  - "Planetary gears transmission", also called "epicyclic system", is the most commonly used system with winches installed on surface supplied diving LARS.
    An advantage of this system, which is also used in automatic gearboxes of cars, is that it allows for numerous combinations and, according to manufacturers, transmits approximately 95% of the motor's energy. In addition to its excellent efficiency, this technical solution is reputed to be strong, smooth to operate, and compact. However, this type of transmission does not immobilize the drum when the motor is stopped; therefore, a braking mechanism that automatically does is to be added.



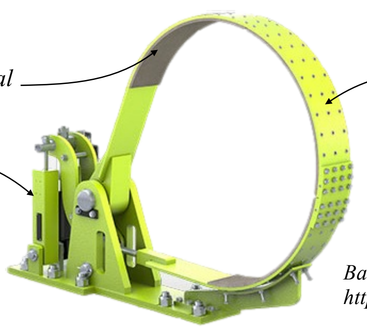
  - Spur gear systems are transmission systems used in various industries for a very long time. They are more simple, but less compact as planetary gear systems, and have an efficiency that, again, according to manufacturers, is comparable. However, it is said that a planetary gear system is more effective to transmit high speed and high torque. Like planetary gears systems, this type of transmission does not immobilize the drum when the motor is stopped; Therefore, an automatic brake is to be added.



  - Worm gear transmissions consist of a spiraled shaft that drives a toothed wheel. They offer high reduction, good reliability, and a built-in braking mechanism associated with their design, as the gear cannot move if the worm does not rotate. However, it is said that they transmit less energy than the planetary and spur gear solutions and provide a slower winching speed.

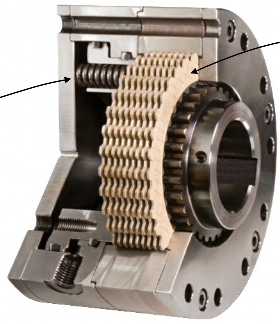


- Many systems of braking can be used. Their work principle is based on friction, which slows down or stops the winch and converts kinetic energy into heat energy. Thus, the effectiveness of a brake depends on the surface of friction and the force applied to this surface. Two types of brakes are commonly found on winches:
  - “Band brakes” consist of a band of friction material that tightens concentrically around a large cylindrical piece. The system can be operated through a lever, a clamping screw, or a pneumatic or hydraulic cylinder.



Band brake designed by Dellner Bubenzer
https://www.dellnerbubenzer.com/

- Multi-Disc Brakes are fully enclosed units that use coil springs and multiple friction discs to slow down or stop the winch's drum. The pressure on the discs is applied by the coil springs and released using hydraulic pressure, with a maximum braking torque when hydraulic release pressure is zero. As a result, the brake is automatically activated when the winch is not supplied with fluid. For this reason, these brakes are often associated with planetary and spur gear transmission systems. Note that the surface of friction can be increased by multiplying the number of discs.

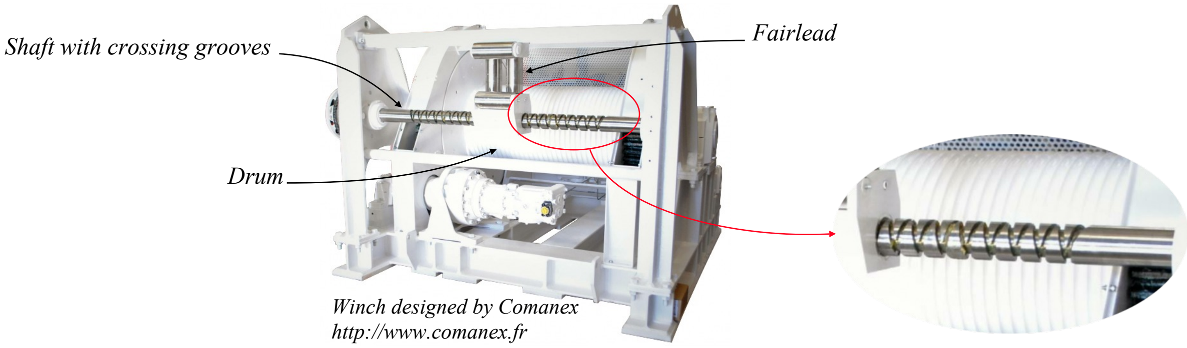


Multi-discs brake designed by Altra Motion
https://www.altramotion.com/

- There is a clutch between the motor and the reducer that can be switched on and off by a handle. It allows the input shaft to turn freely in the direction required to spool cable onto the drum.

Whatever the model of winches used, the Launch And Recovery System must be capable of safely transferring the divers in all conditions and thus even though unforeseeable undesirable events have occurred. For these reasons, winches must be designed to meet the requirements below from classification societies and diving organizations:

- They must be certified "suitable for man riding" by the manufacturer or a competent person.
- The lowering of the basket is to be controlled by power drives independent of braking mechanisms. Also, they must be provided with a brake that is automatically activated when the operating lever returns to the neutral position or in case of loss of power. This braking mechanism must be designed to hold 100% of the design load with the outermost layer of rope on the drum. In addition, the operating lever must be designed to automatically return to the neutral position when the operator releases it.
- Classification bodies say that an alternative independent braking system must be ready for use in case of failure of the primary automatic braking system (it is also said by IMCA).
- A secondary source of power must be available in case of failure of the primary one.
- As explained in the previous points, there must be an independent secondary means of recovering the basket to the surface and bringing it on board in case the primary handling system fails. This system must have a certified SWL, which is equal to the weight of the fully-loaded diving device in air and water. In addition, and as already indicated above, it must be designed for transferring people like the primary lifting system. Note that, as said previously, this secondary recovery system is usually the clump weight system.
- As for the A-frame, highlighted labels that indicate the function of each command and the effect of its activation on the device it controls must be in place. Regarding this point, it is a good practice to organize the system such that the devices are lowered when the commands are pushed forward and retracted when they are pulled. It is also desirable to arrange all the controls in the same manner.
- IMCA says that if a clutch mechanism is fitted to the winch, a system preventing it from becoming disengaged during operation must be in place.
- ABS says that winch drums must be capable of accepting the full length of rope being used. Not less than 5 full wraps of rope is to remain on the drum under any operating condition. The drum flange is to extend a minimum distance of 2.5 times the diameter of the rope over the outermost layer, unless additional means of keeping the rope on the drum are provided (keeper plates, rope guards, etc.). This point is confirmed by other classification bodies and IMCA.
- There must be an appropriate system to spool the rope being recovered on the winch drum correctly. Regarding this last point, systems using a shaft with helicoidal crossing grooves that guides the rope within two directions are commonly used (see the picture below): The design of this shaft makes the fairlead travel across to one direction when the drum rotates. When the filling of the first layer is completed, the shape of the shaft makes the fairlead automatically move back for laying the second layer, etc. The same movement is done when unspooling the drum, so the wire is always perfectly arranged on the drum.



Winch designed by Comanex
http://www.comanex.fr

- 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.
- Winches designed to work at the direct proximity of personnel must be provided with guards to ensure nothing can be drawn into the machinery. IMCA suggests that such protection can be removed for winches installed in places in which access is physically restricted.

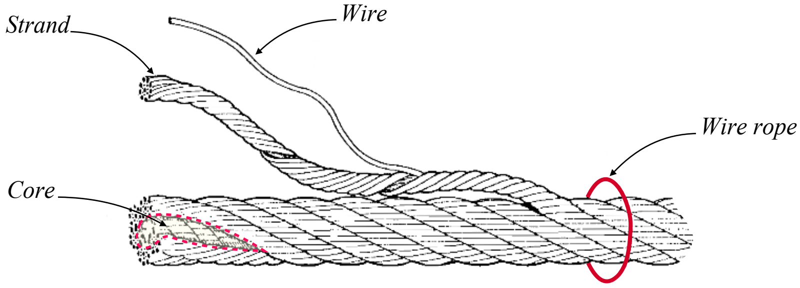
Example of winches with protections provided by Ingersoll Rand https://www.ingersollrand.com/

Regarding the controls, those of hydraulic and pneumatic winches are similar to those used for hydraulic cylinders. The only difference between hydraulic and pneumatic systems is the size of the pipes and valves. For electrically driven winches, control systems can range from simple up and down and emergency buttons in a control box to a multi inverter with variable speed that can be associated with multi Human Machine Interface (HMI) display control system. Inverters with variable rates are preferable and the most used as they allow to adjust the ascent and descent speeds. The control panel can be in a cabinet or be a mobile console connected to the machines by wires or Wifi.

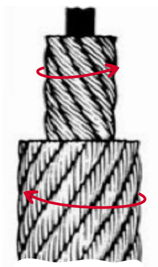
2.2.1.6 - Lifting cables

Wire ropes are used to lift and control the rotation of the basket. They consist of several strands of metal wire laid (or 'twisted') into a helix. Steel is the main material used for wire ropes that consists of the three essential components listed underneath. These, while few in number, vary in both complexity and configuration to produce ropes for specific purposes or characteristics.

1) The core, which is made of materials that will provide proper support for the strands under normal bending and loading conditions. Its materials include fibres (natural or synthetic) or steel.
2) The wires used to form the strands.
3) The multi-wire strands laid helically around the core. They are made up of two or more wires, laid in one of many specific geometric arrangements, or a combination of steel wires with some other materials such as natural or synthetic fibres.



A load creates a force that tries to untwist the rope and thus rotates the load with a conventional rope. For this reason, “non-rotating lifting cables”, also called “Rotation Resistant wire ropes” are mandatory to lift diving baskets and bells. They have a steel core which is an independent rope, closed in the opposite direction to the outer strands. Under load, the core tries to twist the rope in the one direction, the outer strands try to twist it in the opposite direction. The geometrical design of a rotation-resistant wire rope is such that the forces in the core and the outer strands compensate each other over a wide load spectrum, so that even with great lifting heights no rope twist occurs.
Note that “non-rotating “ wire ropes are unnecessary for clump weights, as they do not untwist and rotate due to the configuration of such systems.



The cables used to deploy and recover the basket must be certified “man riding” and be designed to withstand the arduous conditions they are submitted during the dives, such as accelerations during the deployment and the recovery of the basket resulting in internal wire breaks, and accelerated corrosion.

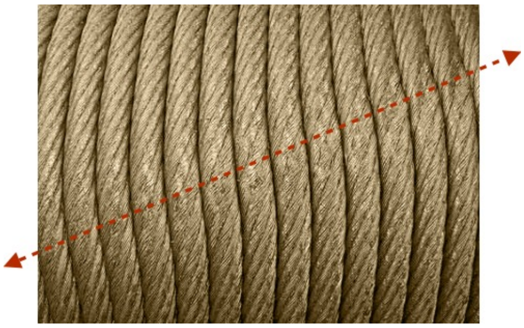
- IMCA says that non rotating ropes develop large numbers of internal wire breaks that happen before external signs of deterioration become apparent. Manufacturers say that this is due to the friction on the inner wires caused by the strand crossover’s.
- Regarding corrosion IMCA M 194 and manufacturers say that the performance of galvanized ropes is superior to that of ropes manufactured from ungalvanized wires. Galvanized steel is steel that has been dipped in a zinc coating, which gives it good corrosion-resistant qualities. The reason is that zinc provides sacrificial protection (sacrificial anodes are made of zinc) and counteracts the effects of fretting. For this reason, IMCA recommends using such cables. Manufacturers say that even with the addition of zinc, galvanized steel will rust, which is not

the case with stainless steel cables. However, galvanized steel cables will not weld together if in contact with one another, which can happen with stainless steel cables. In addition, they are less expensive than stainless steel cables. IMCA recommends pressure lubricating the cables every. Note that lubricating the cable at intervals less than 6 month and after the diving operations is another means for fighting corrosion. Such a procedure is recommended by IMCA.

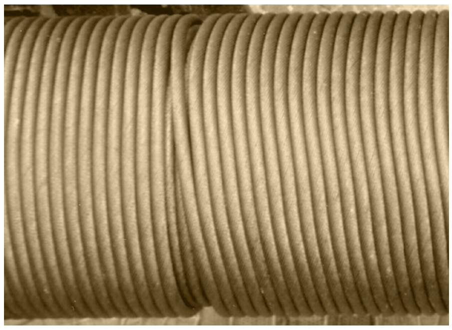
- Lifting cables must be appropriately lubricated not only to fight the effects of corrosion but also to counteract the effects of accelerations during harsh weather conditions. The reason is that each wire that composes the wire rope must remain as free as possible from adjacent wires so it can move to accommodate its allocated share of the varying rope tension it is planned to endure. Wire ropes' design usually minimizes inter wire frictional contact. Nevertheless, that can be fully accomplished only if relevant lubricating practices are in place.
  IMCA D 023 says that unless the wire is to be renewed every 2 years, it should be pressure-lubricated every six months. Also, manufacturers recommend lubricating and regularly verifying the surface wears of the elements in contact with the cable to make sure that it runs freely. These elements are sheaves, rollers, fairleads, etc. IMCA M 194 confirms this point and recommends doing this at least every week during the diving operations. IMCA recommends a marine grade lubricant for this purpose. Manufacturers say that petroleum and vegetable oils penetrate better than greases and are easier to apply because their fluidity allows for better penetration. In addition, their additives give them excellent wear and corrosion resistance, and the fluid property of oil lubricants helps to wash the rope to remove abrasive external contaminants.
  To complete this point, IMCA also says that when damages reach a level that indicates that the operations mentioned above must be done more frequently than every six months, a more suitable wire rope should be installed. A recognized competent technician should be in charge of this operation.
- Most certification bodies say that a destruction test should be carried out when any high tensile wire rope is first put into service to establish the actual minimum breaking force of the wire at that time. The most common reason for this test is to make sure the lifting components meet their specific equipment standards. The benefit of destruction testing are that:
  - The test outcome is directly observable.
  - It makes it possible to determine the outcome of interactions between components and materials of lifting cables.
  - It can reveal the presence of defects that might result from the manufacturing process.

  The destructive tests must be performed by an establishment recognized competent by the government. They must be documented and signed by the person in charge.
  IMCA says that, provided the test result does not fall below the manufacturer's minimum breaking force, 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.
  IMCA also says that if the test to destruction when the wire is first put into service does indicate a minimum breaking force below that of the manufacturer, then the manufacturer's minimum breaking force 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 minimum breaking force, the rope should be discarded. The sample tested to destruction should prove an adequate safety factor exists, which is usually eight times the safe working load.
  All certifications, including the original manufacturer's certificate, initial test certificate, and annual test certificates, should be available for further inspection.
- As said above, destructive tests of the lifting cable in service must be organized to verify its integrity and maintain the required safety factor. The samples used for these tests are at the discretion of the inspector. They usually consist of cable lengths starting from the connection to the basket to a few metres above it because this area is considered the most exposed to stresses, and it is easy to remove samples from an extremity. Regarding this point, IMCA D 023 says that the length of wire should be removed from just beyond the first sheave from the basket termination with the basket below the surface and should be sufficient to provide samples for two tensile tests, but that the competent person may recommend cutting all the way back to the first sheave. Also, for systems with a vertical fall directly from the winch to the basket, IMCA says that it is necessary to cut the part of the cable used as a sample right back to the winch.
  Note that these tests must be performed every year by an establishment recognized competent by the government, and documented. IMCA says that in case of an unsatisfactory test due to problems with procedures or if the wire fails within a length equal to six wire rope diameters from the base of the socket or cone, a second test may be carried out. This alternative test should not be used to avoid discarding the cable when a valid test, which indicates low strength is performed.
  To finish with this point, the strength test to be carried out on a sample from the part subject to the most severe dynamic loading should be used to verify that a factor of safety of 8:1 is still being maintained. If this safety factor cannot be obtained, the wire rope should be discarded. Also, if 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 even though the safety factor is kept. Also, the internal parts of at least one of the samples should be dismantled and examined.
- Some damaged parts of the cable may be hidden while spooled on the drum. For this reason, the winch operator must watch the lifting cable during its deployment and recovery. In case damaged parts are seen during the deployment of the basket, the operation must be canceled, and the defect must be analyzed. This investigation may result that the cable having to be discarded.

- When a new cable is installed, it must be compliant with the winch's manufacturer's recommendations as changing the cable's characteristics may result in imperfect spooling and then damages to the lifting cable. Regarding this point, the observation of the drum can give indications of incorrect wire rope size and prevent future damages:
  - An inclined pattern in multi layer spooling indicates an incorrect rope diameter.
  - The rope crossing over one wrap also indicates an incorrect diameter, but also a damaged cable or a problem with the spooler.



Inclined pattern

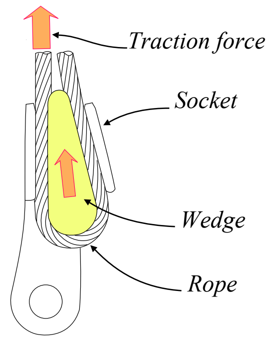


Rope crossing over one wrap

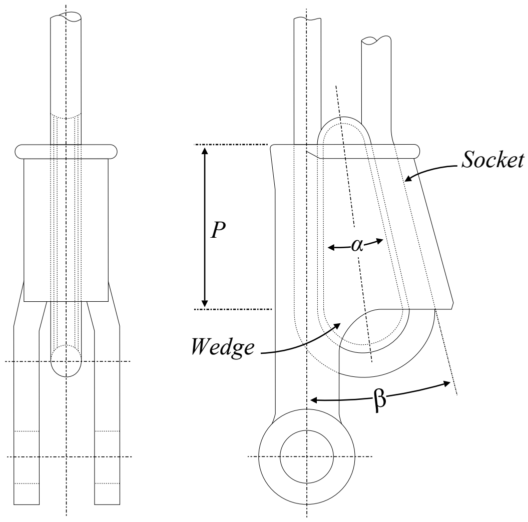
2.2.1.7 - Wire rope end sockets

End fitting connections must be able to withstand the static and dynamic forces the basket is submitted to, and must also be compact and light.
There are a lot of models of efficient end connections on the market, and the purpose of this point is to describe only "asymmetric wedge sockets", and "metal and resin sockets" (Also called Spelter sockets), which are today the most employed for connecting diving baskets and bells.

Asymmetrical wedge sockets are highly popular because they can easily be fitted on site, which is a great advantage. The model described below is based on the European standard EN 13411- 6.
There is a wide variety of designs which can be slightly different than those indicated in the document EN 13411-6 on the market. Nevertheless the operating mechanism is the same for all models.
The principle of work of such systems is that the rope end is jammed into the tapered socket. When the load is applied, the wedge is pulled deeper and deeper into the socket and exercises normal clamping force on the rope.
The traction force in the wire rope is transferred by the friction between the rope and the wedge and by the friction between the rope and the socket.

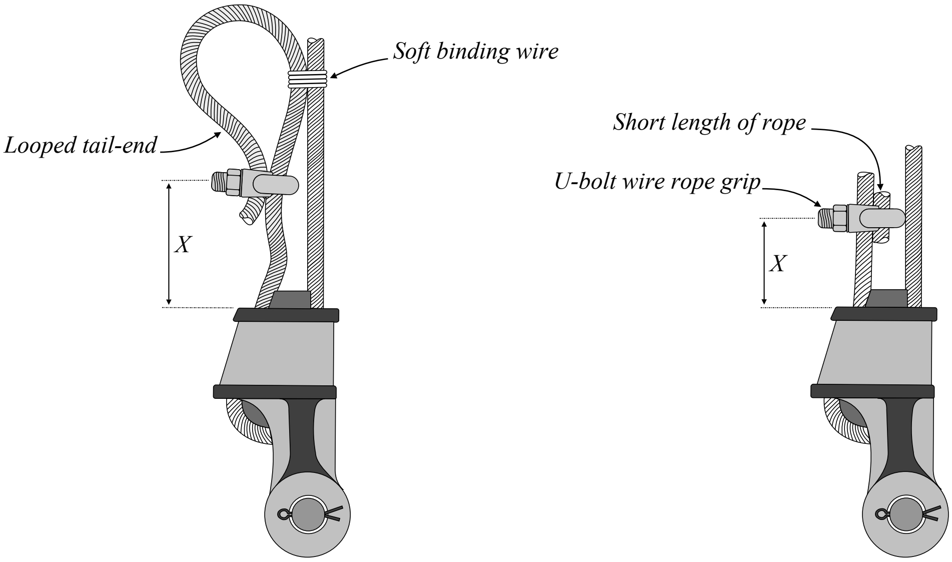


- Asymmetric wedge sockets should conform to the following geometrical criteria:
  - The longitudinal axis of the live portion of the rope should be perpendicular to the longitudinal axis of the pin.
  - The difference between the wedge angle (α) and the socket angle (β) should be not greater than 2°.
  - The internal side surfaces of the socket body and the wedge in contact with the rope should be straight.
  - The clamping length between socket body and the wedge in contact with the live portion of the rope should be a minimum length (P) equal to 4.3 times the nominal rope diameter.
  - The rope groove in the socket body and the wedge should no exhibit protrusions, marks, or casting joints that would affect the intimate contact with the rope.
  - The pin should be provided with a means for securing it in position when in operation. It should have at least 80% of the minimum breaking force of the rope used.
  - The socket body and the pin must be designed to ensure that there will be no movement between the rope and the termination. That can be noticed by a reduction of the tail's length or a movement between the rope and the wedge after a short settlement period.



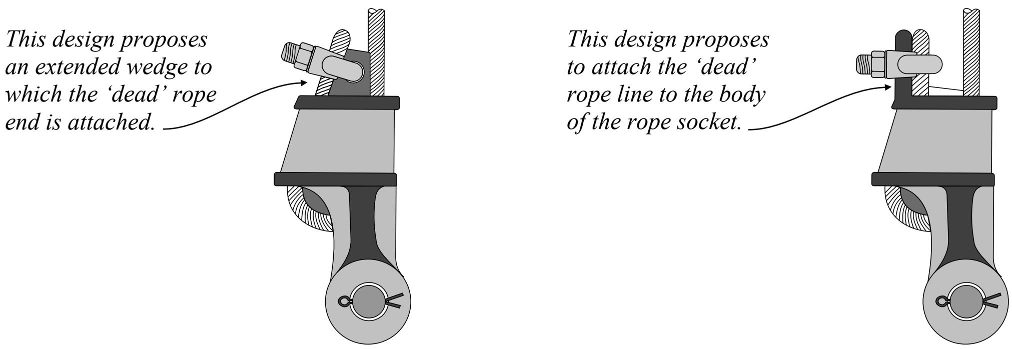
- The following indications should be visible on each asymmetric wedge socket:
  - The manufacturer's name, symbol, trade mark or other unambiguous identification.
  - The traceability code.
  - The standard applied.
  - The reference of the model allowing to find the rope grade, class and type for which the termination is suitable.

- The certificate should include at least the following information:
    - The name and address of the manufacturer or authorized representative, including the date of issue of the certificate and authentication.
    - The standard applied.
    - The traceability code.
    - The manufacturing tolerances.
    - The reference of the termination.
    - Details of the rope grade, class and type for which the termination is suitable.
- Different methods are recommended for dealing with the tail-end length of rope protruding from the socket. Their objective is to prevent the rope being pulled through when making the rope termination or in the event of accidental loosening of the wedge during operation. European standards recommend the following methods:
    - The tail-end is looped back on itself and secured by a U-bolt wire rope grip. The loop should then be lashed to the standing part of the rope by suitable means, such as soft binding wire, to prevent flexing of the rope in service.
    - Where the looped back tail-end described above interferes with an obstruction which might cause the wedge to loosen and the rope runs free, the tail-end length of the rope should not be looped back but should be laid parallel to the standing part of the rope. A distance piece or short length of rope of the same diameter and a U-bolt wire rope grip will be necessary to ensure that the tail-end is adequately secured. If necessary, the tail-end may be attached to the standing part with soft binding (serving) wire.



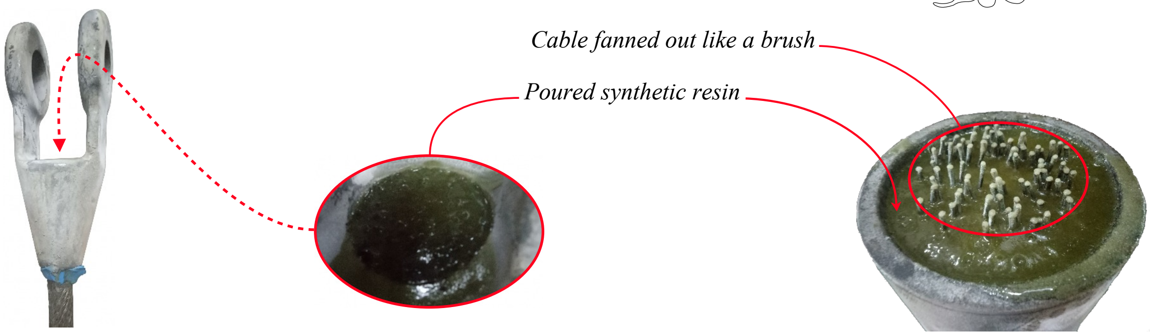
The wire rope grip is used to ensure that the rope cannot slip through the socket body before the wedge has had a chance to seat adequately. The clamp or wire rope grip should not be allowed to encroach on the fused end of the rope. The distance X of the grip from the nearest part of the socket body should be no more than 75% of the overall length of the wedge to avoid deforming the rope.

Some other designs than those above are proposed by manufacturers that are similar, but not limited to the examples below:



"Metallic spelter sockets" are very reliable and efficient rope end connections. They withstand to the full breaking strength of the wire ropes used, and they achieve the highest number of tension cycles of all rope end connections in tension fatigue test. Their installation requires trained personnel and specific material, and for this reason, they are less employed with baskets. They are fabricated as follows:

- At its end, the wire rope is fanned out like a brush which is then pulled into the conical socket.
- Once in position, a metallic or a synthetic resin cone is cast securing the brush of the rope into the rope socket.
- With increasing line pull, the metallic cone is pulled deeper and deeper into the socket, generating increasing transverse clamping forces. The transfer of force between the metallic cone and the rope socket is achieved purely by force closure.



The European standard for "Metal and resin sockets" is EN 13411-4. However, other criteria such as standard ISO 17558 or national standards exist. In addition to the standard used, sockets must be provided with their manufacturer's trademark or symbol legibly and durably marked at the large end of the device. Note that the marking should not impair the mechanical properties of the socketed portion of the termination.
Socketed assemblies should be visually inspected to confirm that:

- The socket and the rope axes are coincident.
- The gap between the rope and the socket at the entry of the rope into the socket is even and filled with socketing medium, unless stated otherwise by the socket manufacturer in the instructions.
- The socket basket is filled with the socketing medium.

The inconveniences of these terminations are that, in addition to the fact that their installation requires trained personnel and the necessary time to solidify the poured resin, it is not possible to remove the hardened resin only by means of heat. Therefore, this resin cone must be removed mechanically. For this reason, many users have built hydraulic devices which enable them to push it out of its socket.

2.2.2 - Other basket systems

2.2.2.1 - Launch and recovery systems using trolleys

These systems use trolleys installed on the top of the structure to lift and deploy the baskets overboard, similarly to the systems used to deploy closed bells through moonpools. This deployment is made by hydraulic cylinders or cabling arrangement. The main advantages of these systems are that the space around the baskets is not disturbed by cables from winches and the fixations and the hydraulic cylinders of the A-frame. Thus, they usually allow for more comfortable and safer access to and from the baskets. Also, the baskets recovering is faster as their transfer outside and inside the diving support is made horizontally and not by pivoting around an ax. As a result, the operator has not to readjust the height of the basket several times when retrieving it toward the edge of the vessel, which is often the case with A-frame systems. They are ideal for built-in diving systems.
The main inconvenience of these systems is their height, which may make their transfer more difficult by roads where low bridges and tunnels are on the way. Also, the beams sliding out the baskets work cantilever and are submitted to high forces. For this reason, this part of the system must be adequately monitored to avoid excessive wear.

System designed by Comanex
http://www.comanex.fr

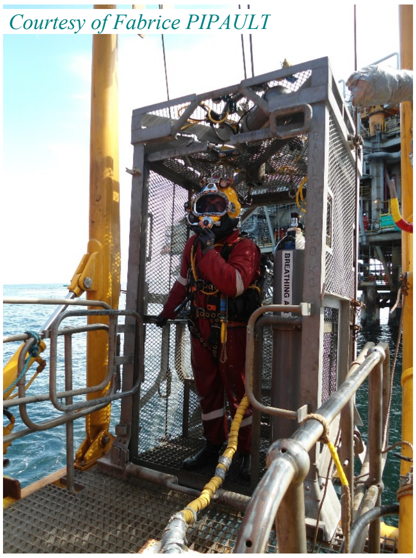
2.2.2.2 - Twin basket launch and recovery systems with a single A-frame

These systems have been designed for diving with two baskets on surface supports with reduced deck space and where the installation of only one standard basket is possible. They allow avoiding using a ladder for the standby diver and thus increase the weather conditions in which the dive can be launched and also allow diving from a Dynamic Positioning (DP) vessel. However, even though their compactness provides them some advantages, they must not be regarded as the magic solution as they also have some inconveniences that must be considered. That can be done by studying the two following designs currently found on worksites:

A solution proposed is to reduce the width of the standby diver basket and position it very close to the divers' basket to reduce the footprint of the launch and recovery system. As for the system in the picture, aside, that was built by SMP (https://www.smp-ltd.com). The standby diver basket is limited to only one diver. That is based on the IMCA guideline that says that the capacity of a standby diving basket can be reduced to a single diver.
Despite its advantages, this system has some inconveniences that may prevent from using it for operations from dynamic positioning vessels:

- A single A-frame is used to deploy the baskets. In case of a breakdown of its deployment system, both baskets cannot be approached to transfer the divers back to the deck. That may create tricky situations if the vessel has to sail as it may take time to do it manually. Such a problem is more under control with launch and recovery systems provided with two separate A-frames.
- The standby diver's basket is designed for only one diver. In case of a breakdown of the recovery of the main basket and two divers are in it, It may be outside its capacity to recover two divers.
- Depending on which side of the DP vessel, the baskets are installed, their configuration may oblige to reduce the working divers umbilical lengths (see the configuration of diving baskets in point 8.4.1.2 of book #2).

Another design consists of two baskets arranged like Russian dolls, with the divers' basket inside the standby diver's basket while on deck. This system, made by Unique Group (https://www.uniquegroup.com/), seems no longer described in the catalog of this manufacturer.



On deck: The basket of the working divers is in the basket of the standby diver

Deployment: The basket slides down in the standby diver's unit

Deployment: The basket quits the standby diver's unit which floor goes in place (see #1).

The advantage of this system is its extreme compactness. Its inconveniences are that:

- The standby diver is obliged to go through the divers' basket to intervene as his umbilical cannot pass through his basket because the main basket is recovered in it. If diving from a dynamic positioning vessel, that obliges him to secure his umbilical to the divers' basket before transferring, as he cannot be unsecured in the water, resulting in loss of time. Note that the standby diver basket must be stopped above the working divers' unit.
- The cable of the main basket pass through the standby diver basket (see #2).
- Similarly to above, a single A-frame is used to deploy the baskets. In case of a breakdown of its deployment system, both baskets cannot be approached to transfer the divers back to the deck.

2.2.2.3 - Baskets with dome

These systems were used by some companies in the past and maybe still used by a few of them. They consist of a traditional open basket fitted with a dome that can be filled with air if necessary. Their advantage is that they provide a refuge where the helmet can be removed. As a result, a casualty vomiting in his helmet can be protected from vomit intrusion in his airways, and the diver who is obliged to remove his helmet has not his face exposed to cold water, preventing him the effects of a "cold shock" (see in book #1 “Description and prevention of diving accidents”).
However, they must not be confused with wet bells as they are not supplied and controlled from the surface. Thus, their usage is limited to 50 metres maximum, the dome is to be used only in an emergency (a tender in the basket must remain helmeted), and thus, they must be equipped in the same manner as an open basket:

- Dedicated gas cylinders should be provided to deliver breathing gases to the divers at all depths up to the maximum operating depth, with a sufficient capacity to supply the divers while the basket is being recovered, including decompression. These gas cylinders must be fitted with gauges, mouthpieces, and semi-rigid hoses that can be introduced in the helmet through the neck-dam.
- The gas for filling the dome must be from an independent reserve of the standard breathing gas cylinders and thus not be considered in the calculation of the minimum gas reserve of the divers. However, because these reserves may replace the standard backup breathing system, they should provide the same breathing duration.

With the domed basket designed this way, the divers can safely use the two independent systems in case of a problem, which provides a plus compared with traditional open baskets.
The model in the picture was used by Mermaid Offshore Services in 2006.

2.2.3 - Lighting

When operations are to be performed at night, there must be sufficient lighting on the launching station to be able to dress and undress the divers, read gauges and documents, perform some maintenance tasks, and allow the winch operator to have a view of all parts of the system during the launching and the recovery of the baskets.
This point must be checked during the mobilization, and additional lights must be added if necessary. Note that these lights must be at least waterproof, and be explosion proof (certified ATEX) if operations are performed at the proximity of installations were gas leaks are likely. Note that such lights are today easy to find (see below).

Light designed by Sinozoc
http://en.sinozoc-ex.com/

Light designed by Locquet
https://www.locquet.com/

Light designed by Nemalux
https://nemalux.com/

Note that lighting systems must be provided on the entire installation and not limited to the diving launching station. For this reason, they are more detailed in other chapters.

2.2.4 - Fire fighting systems

Fire fighting systems such as portable extinguishers should be provided at the direct proximity of the Launch and Recovery System (LARS). They should allow for sufficient reserves, be positioned close to the installation but not at the direct proximity of elements that can trigger a fire, such as motors, hydraulic power packs, and similar devices. Other fire fighting systems such as water lances should be provided on deck and be ready for use.

Fixed installations are typical with built-in systems. In this case, this installation is integrated into the boat’s fire fighting system and usually consists of deluge systems. According to NFPA 99: Health Care Facilities Code (National Fire Protection Association), these systems should deliver water from sprinkler heads 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 for 1 minute. The system should have stored pressure to operate for at least 15 seconds without electrical branch power.
Fire detectors can be installed. They consist of heat detectors, flame detectors, and smoke detectors.

Breathing apparatus for at least the winchman, and tenders must be provided. They are described in the next chapters.

Note that fire fighting systems should protect the entire diving system, and are more detailed in the next chapters.

2.2.5 - Arrangement of supply hoses and electric wires

The hoses and wires supplying the launch and recovery system must be positioned to protect them from shocks, cannot injure people, and can be easily identified.

- They can be routed along ropes, walls, and through cable trays specifically installed.
- IMCA says that hoses must be supported and secured at intervals not exceeding 2 metres. However, this interval is definitively too long, and 50 centimetres is safer and more realistic to protect the hoses and cables from gravity stresses, vibrations, and avoid uncontrolled whipping of ruptured pneumatic hoses.
- Cable trays installed on the floor must not create tripping hazards and protect hoses and cables from shocks.
- The hoses and cables should be positioned to be easily identified, accessed, and changed. Also, it is essential to be able to verify the test dates of hoses and organize tests.

2.2.6 - Maintenance

2.2.6.1 - pre-operation checks

Pre-operation checks must be performed at least daily during the diving operations. The checks should be carried out with the system isolated from any supply:

- Visual inspection of the basket and guidewire winches is to be performed. The operator should ensure that no debris is present in gear trains. He also should check that cables and all terminations are sound and that the lifting wire is secured to the basket. Also, all guards should be adequately fitted.
- The chassis and the A-frame must be visually inspected for cracks, particularly the fixations of the A-frame. If the launch and recovery system uses trolleys, they must be thoughtfully inspected.
- The fastenings of the chassis to the deck must be inspected for cracks and weld failures.

The structure of the basket should also be thoughtfully inspected. As already said, water oozing indicates that a hollow profile is flooded.

- Hydraulic hoses and pipework should be inspected for damages and leaks. The same operation is to be done with pneumatic hoses if used.
- Electrical wires must also be checked for damages.
- Gas cylinders in the basket must be full and the regulator tested
- Casualty securing devices must be present in the basket and in good condition.

When the visual inspection of the system is completed, the Launch and recovery system is energized and function tested.

2.2.6.2 - Planned maintenance

IMCA Diving Equipment Systems Inspection Guidance Note (DESIGN) D 023 remains one of the more accurate guides for the inspection of air and nitrox diving systems. Note that the frequencies of maintenance interventions are based on IMCA D 018.

Items	*Visual examination + function test + Load test 1.25 SWL*	*Wire destruction test*	*Load test 1.5 SWL*	*Other*
Main winch testing	6 months		12 months (+ dynamic 1.25 SWL)	12 months (NDE critical areas)
Lubrication main wire (by pressure)				6 months
Main wire testing	6 months	12 months	12 months	
2nd lifting system: Basket/bell recovery demo.				12 months
2nd recovery winch testing	6 months		12 months (+ dynamic 1.25 SWL)	12 months (NDE critical areas)
Lubrication secondary wire (by pressure)				6 months
Secondary wire testing	6 months	12 months	12 months	
Hydraulic system testing	6 months			
Intercooler (if in place)	6 months			
Hydraulic oil analysis or replacement				12 months
Relief valve (hydraulic)	6 months			30 months (1.5 x working press)

Items	*Visual examination + function test + Load test 1.25 SWL*	*Wire destruction test*	*Load test 1.5 SWL*	*Other*
Pneumatic hose	6 months			24 months ((1.5 x working press)
Electric winch: Electrical testing	6 months			
Communication	6 months			
Overall testing of LARS	6 months	12 months (+ dynamic 1.25 SWL)		12 months (NDE critical areas)
Portable fire fighting system	6 months			Manufacturer specifications
fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
Automatic fire detection	12 months			
Breathing apparatus	6 months			2 ½ years (max press) 5 years (max press x 1.5)
Documentation showing the designed SWL	Note: Only for basket manufactured after 1 January 2014			Permanent
Load test	6 months		6 months	
Emergency cylinder	6 months			2 years (max press) 4 years (max press x 1.5)
Pressure gauge emergency cylinder	6 months			
Pipework	6 months			
Hoses	6 months			2 years (max working pressure)
Relief valve regulator	6 months			

2.3 - Divers' excursion umbilicals

2.3.1 - Function

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

- Gas supplies
  - Gas supply hose
  - The breathing systems used are open circuits; thus, a gas exhaust hose is unnecessary. However, it may be provided for systems designed for intervention in unhealthy surroundings, such as Divex's "Dirty Harry".
- Temperature & depth control
  - Hot water supply (used only in cold waters)
  - 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.

2.3.2 - 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.

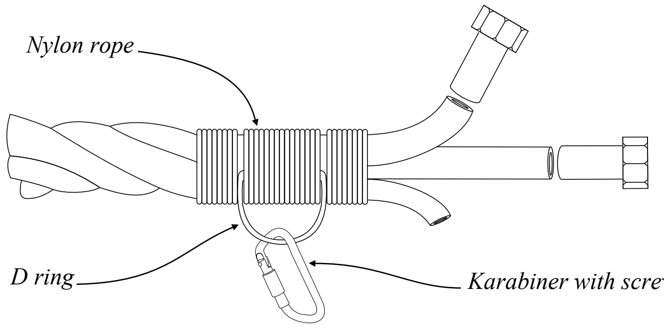
- Spiral-wound umbilicals are manufactured industrially as only machines allow producing this type of equipment with perfect twisting. Their strength comes from their spiral construction where hoses and cables are supporting each other. They resist kinking and abrasion and provide good flexibility, which 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 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 - Installation

IMCA D 023 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 standby diver 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 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 on deck 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."*

2.3.4 - Backup umbilicals and their storage

Note that backup excursion umbilicals are not mandatory with diving organizations such as NORSOK, IMCA and others. 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 most projects. For this reason, replacement umbilicals are often required by the clients. They should be ready for immediate use and stored so 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.

2.3.5 - Maintenance

Umbilicals must be checked and function tested before every dive. Also, IMCA D 023 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.

2.4 - Helmets And bandmasks

2.4.1 - Helmets

Helmets must be designed and built according to a recognized standard such as EN 15333-1 & EN 15333-2.

- They must be designed with a double locking system so they cannot be torn off from their clamp during the dive. Also, they must be able to be removed by the diver unaided.
- Their shells are made of composite materials or metal. Each unit must be engraved with a dedicated serial number.
- Their weight should be close to neutral in the water so that the divers are not incommoded by their mass and can move the head freely. They must offer sufficient vision to reduce head movements.
- Their viewport is usually made of polycarbonate plastic. In addition to its high resistance to pressure and shocks, the advantage of this material is that it is more transparent than glass.
- They must be fitted with communications. Lighting should also be provided for operations at night.

Helmets protect the head of the diver. For this reason, they are mandatory on most diving projects. They can be divided into two categories: The units equipped with demand regulators and those using a continuously gas flowing system.

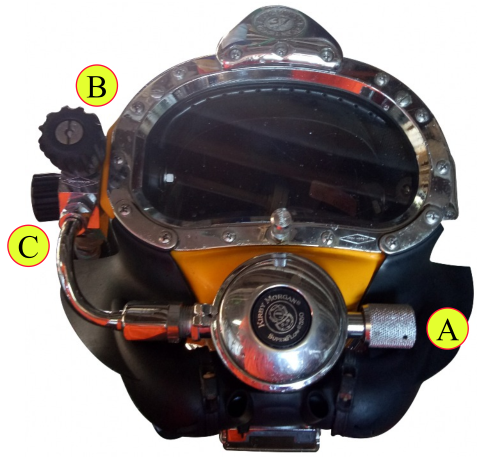
2.4.1.1 - Helmets using demand regulators.

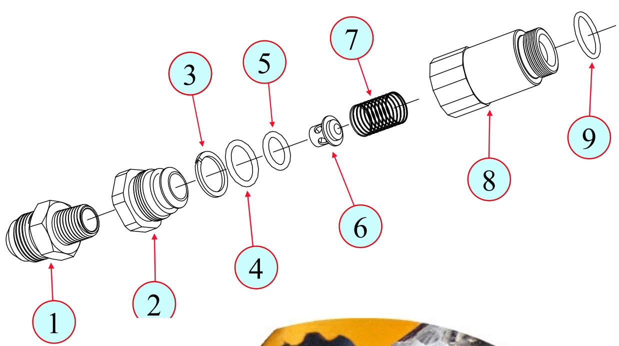
Demand regulators are also used with SCUBA (Self Contained Underwater Breathing Apparatus). Thus, the regulators fitted to these helmets are merely like the second stages of regulators designed for SCUBA. They are usually provided with a knob allowing to adjust the softness of the inlet valve (see #A in the picture below). Note that most of them are designed for the use of oxygen. However, the manufacturer must indicate the gas they are designed for.

A block that provides a free-flow supply system (see #B), operated by the front knob, and a valve isolating the supply from the bailout bottle whose command knob is situated on its side (see #C) is usually fitted to the right side of these models of helmets.

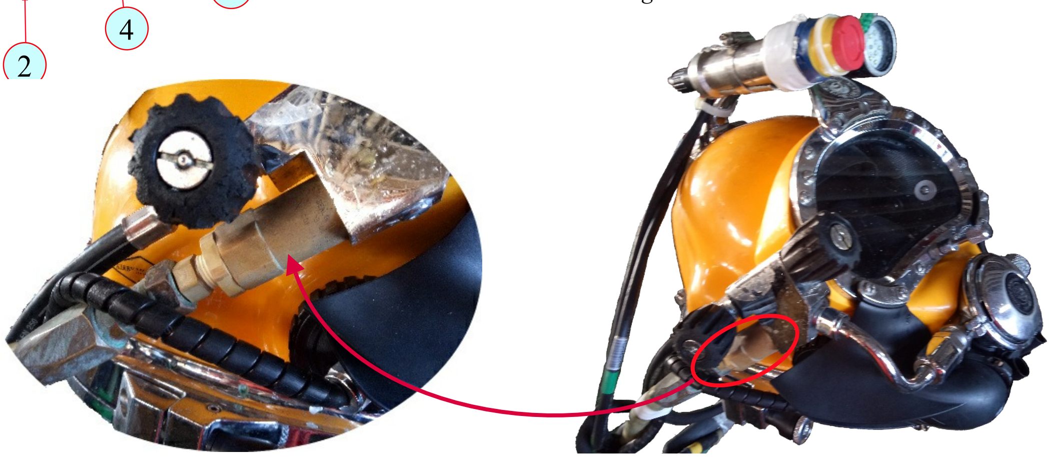
A supply hose severed or suddenly depressurized may expose the diver to a depression that can be fatal. For this reason, a non-return valve must be fitted between the inlet block and the gas supply hose of the umbilical. Non- return valves are composed of a poppet valve (see #6 in the scheme below), 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.

Note that this valve must be function tested before each dive.





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

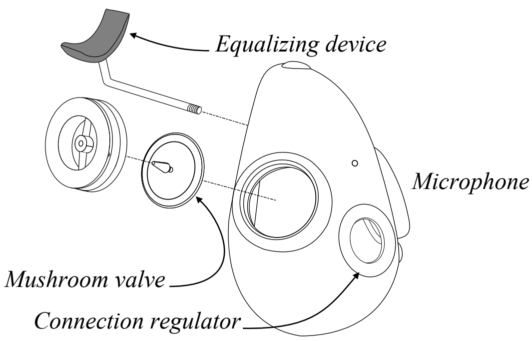


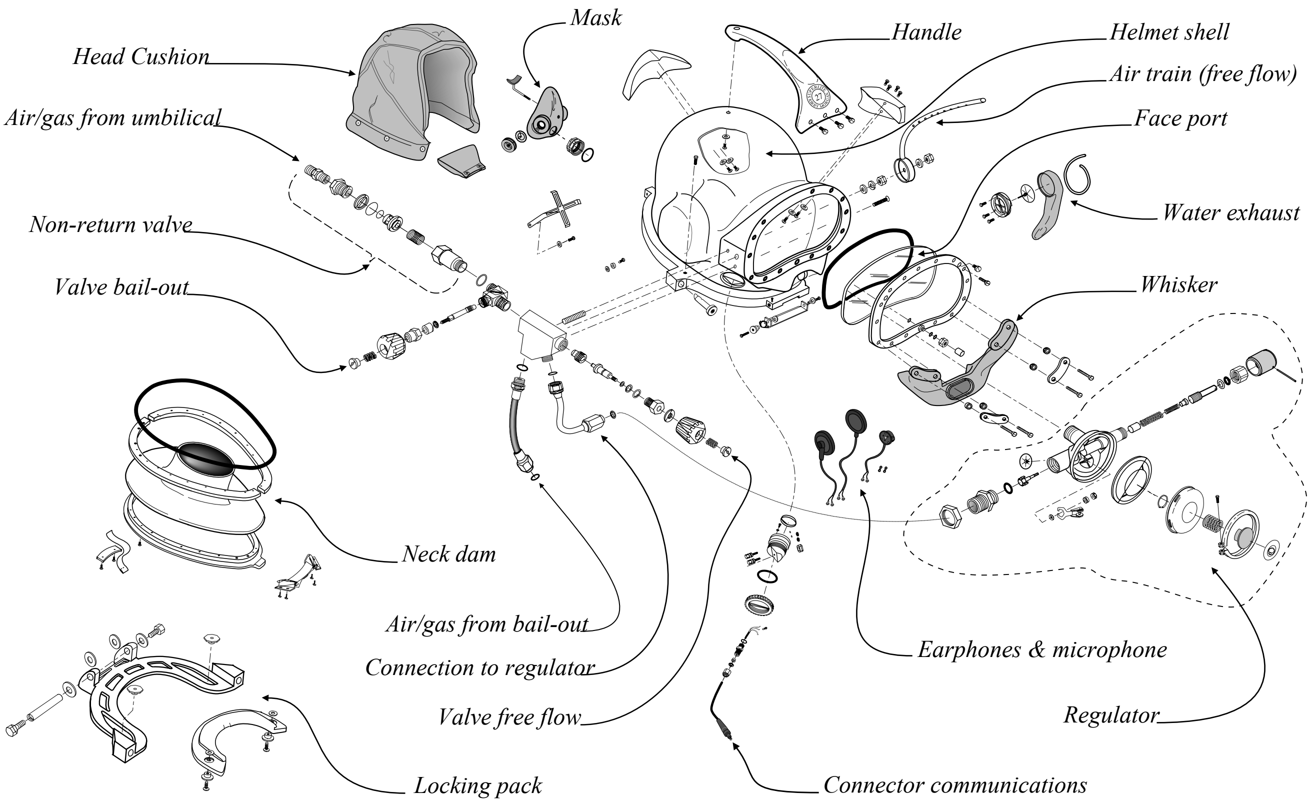
These helmets are secured on a "neck ring assembly" composed of a rigid circle with an O-ring and a "neck dam", which is an open neoprene sock that is perfectly adjusted to the neck of the diver and fitted to the circle. It isolates the helmet from water intrusions, even though the diver has the head pointed toward the bottom.
A locking pack allows to perfectly secure the helmet, so the diver cannot lose it. As already said, the clamping system of the helmet should be designed such that the diver can don and secure his helmet alone

In addition to their clamping system, these models of helmets are adjusted to the head of the diver with the help of a head cushion. This element is made of foam enclosed in synthetic and cotton textiles. It is of primary importance for the diver's comfort as its function is to ensure that the helmet perfectly fits the head of the diver and becomes like a second skin. Small connectors allow for securing it to the shell. Note that it is usually designed such that it can be cleaned after the dive, and the foam can be replaced if necessary.

The helmet must be designed such that any water intrusion can be removed. For this reason, a water exhaust valve is fitted to the lowest parts of the shell, so the water is pushed out of the helmet when the free flow system is activated.

An oral/nasal mask is connected to the regulator to allow the diver to breathe efficiently. It consists of a rubber enclosure that, in addition to the connection to the regulator, is fitted with the microphone on one side and a mushroom valve on the other side. The purpose of this mushroom valve is to supply gas to the diver when the free flow system is used and ensure that the exhaled gas is not sent into the helmet. For this reason, the valve is oriented to open when a flow from the external of the oral/nasal mask is applied to it.
An adjustable equalizing device is in the oral/nasal valve. It consists of a neoprene piece shaped in v mounted on a rod that can be adjusted to perform ears equilibration.

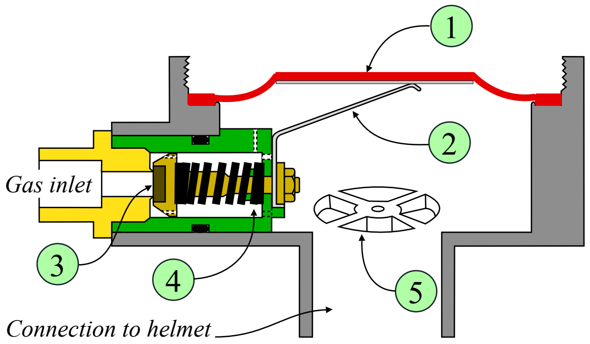




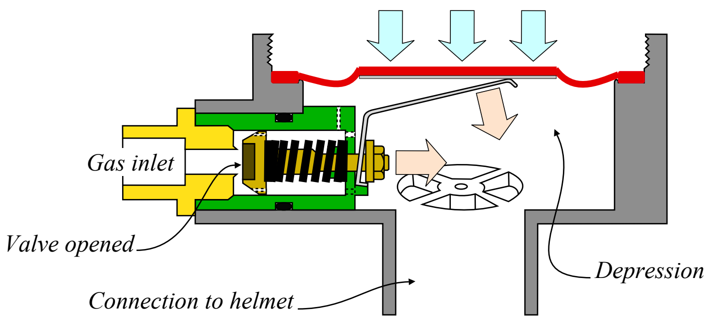
The scheme above is the representation of a Kirby Morgan 37.
Kirby Morgan is based 1430 Jason Way, Santa Maria, CA 93455 - USA Phone: (805) 928-7772
e-mail: kmdsi@KirbyMorgan.com Website: https://www.kirbymorgan.com/

The demand regulators used on these helmets are installed at mouth level like scuba 2nd stage regulators. Also, they use the same principle of work and working pressures, which, depending on the model, usually vary between 10 and 14 bar above the ambient pressure. They may be balanced or not.

Non-balanced regulators are usually composed of a membrane (see #1 below), which activate a lever (see #2) when the diver inhales, and thus creates a depression in the regulator. This lever opens the inlet valve (see #3), which is closed by a spring (see # 4) when the diver exhales or does not breathe. The breathed gas is expelled through the exhaust valve (see # 5), situated at the bottom of the regulator shell. It is composed of one or two mushroom valves.

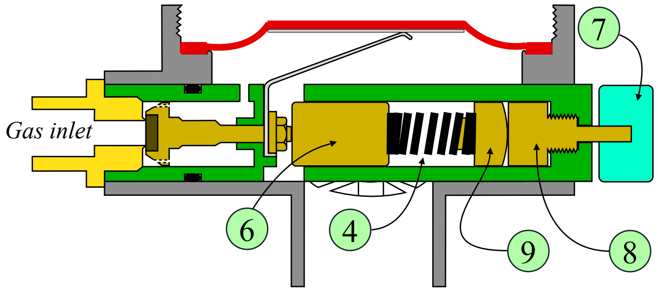


Expiration or no breathe



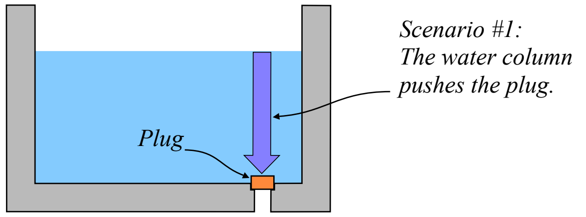
Inspiration (breathing)

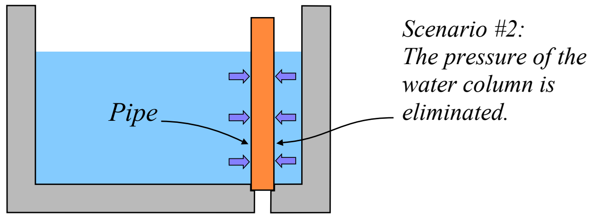
Engineers provide several refinements to improve diving regulators' efficiency and breathing comfort. One of these, which is commonly used with regulators used on helmets, is the adjustable gas inlet.
This system allows adjusting the hardness of the spring closing the gas inlet valve. It consists of a piston (see # 6) that is pressed toward the valve/lever assembly by the spring, which hardness is adjusted by a knob (see #7) through a shaft (see #8), and a spacer (see # 9).



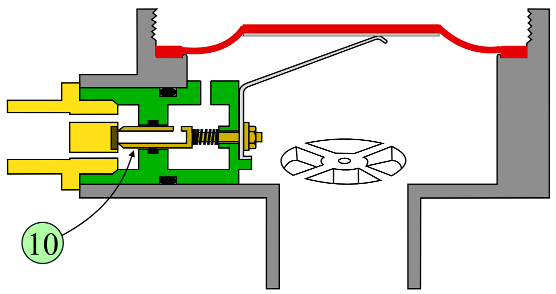
Even though some regulators are equipped with an adjustable gas inlet, the supply system described above has the inconvenience that if the supply pressure or the ambient pressure varies, the force necessary to open the valve differs as well. Consequently, breathing effort may become more demanding if the balance between the strength of the spring and the inlet pressure is ruptured due to the inlet pressure diminishing, or at the opposite, the gas may start to free-flow if the unbalance is in favor of the gas supply because the spring is too released.
As a result, if the diver has frequent balance variations between supply pressure and depth, he is obliged to continuously readjust the hardness of the spring closing the inlet valve, if possible, and adapt his breathing effort. To eliminate this inconvenience and make the breath smoother, engineers had the idea to balance the gas supply valve of the regulators. This results in the change of breathing effort being minimal for small pressure changes compared to a standard regulator. However, a radical change of supply pressure or depth will require resetting the regulator.

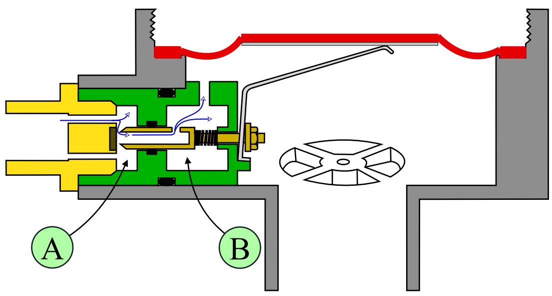
The principle of balanced regulators is commonly explained by comparing a sink whose discharge is closed by a classical plug with a sink whose discharge is closed by a pipe as done by laundresses in the old time. In the 1st scenario, the water column pushes the plug. As a result, removing the plug will require more effort if this water column increases. In the 2nd scenario, the forces resulting from the water column are applied to the circumference of the pipe, so they counterbalance. Thus, the necessary strength to open the discharge is the same, whatever the water level in the sink.



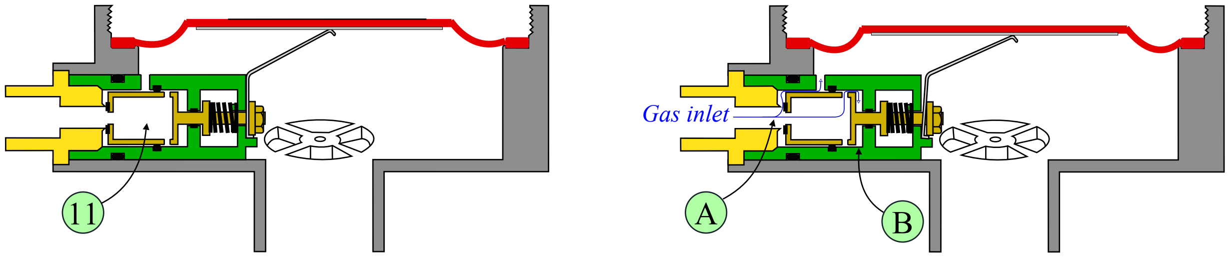


Balanced regulators using hollow tubes (see # 10 below) are based on the principle of equilibration explained above. This system is organized so that the gas expands in the chamber "A" and "B", so the effect of the inlet pressure is neutralized.



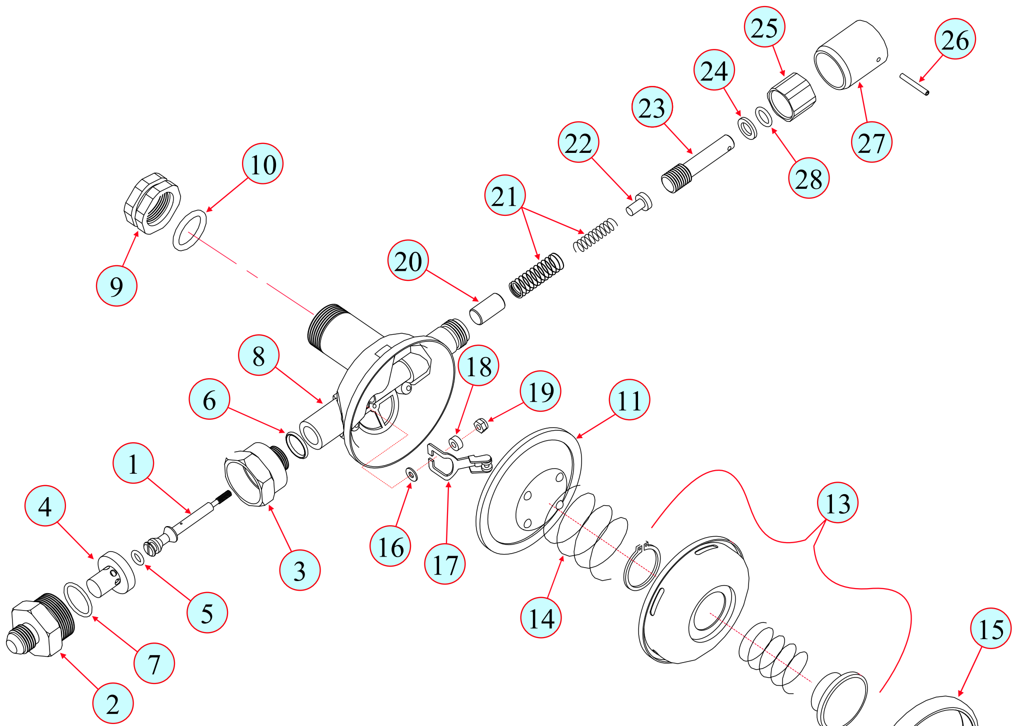
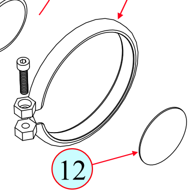


Auto compensated valves (see #11 below) are a variation of the system discussed above. With this system, the forces in chamber A are counterbalanced by those in chamber B.

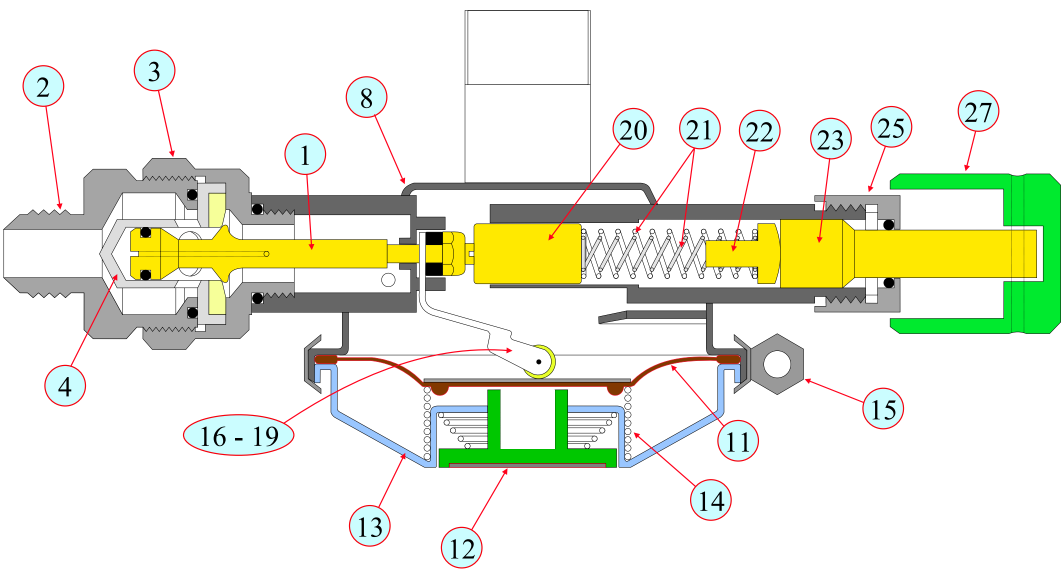


Another system commonly employed is the reinforcement of the spring by a smaller unit inside it.
This arrangement is not to increase the pressure applied to the valve but because when it is highly solicited, the spring can vibrate at higher frequencies than those it can withstand, which may result in a rupture. Thus, the function of the smaller spring is to counterbalance the harmonics that can destroy the larger spring that, in return, counteracts the harmonics that can damage the small spring.

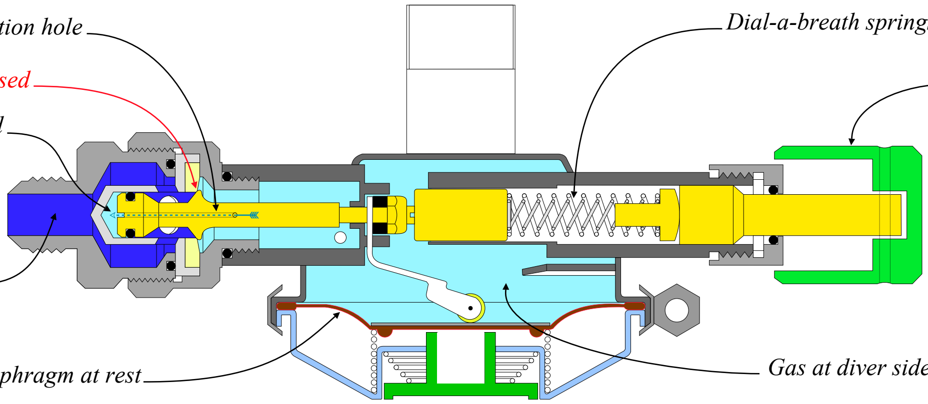
Examples of balanced regulators that cumulate the refinements indicated above are the “Ultraflow 501 & 601” from Divex (https://www.jfdglobal.com/) which scheme and principle of work are displayed below:

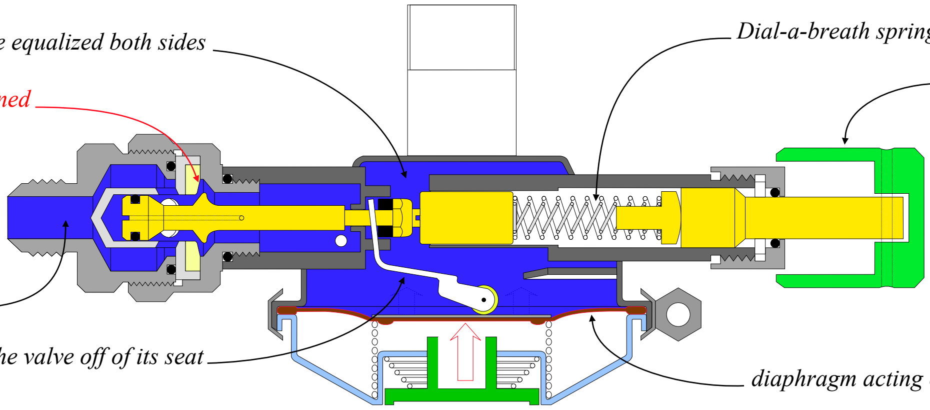
1 - Valve stem
2 - Inlet cap
3 - adapter
4 - Valve seat retainer
5 - O-ring
6 - O-ring
7 - O-ring
8 - Ultraflow body
9 - Nut
10 - O-ring
11 - Diaphragm
12 - Decal
13 - Cover assembly
14 - spring diaphragm
15 - Clamp
16 - washer
17 - Roller lever
18 - Spacer
18 - Spacer
19 - Nut
20 - Piston
21 - Spring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



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.



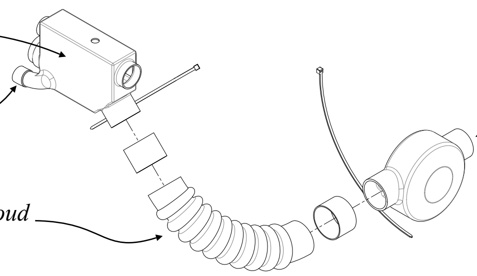
As the diver inhales, this reduces the pressure in the regulator body, which reduces the closing balance force enabling the diaphragm acting on the roller lever to lift the valve off of its seat easily (see below).



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

In addition to the refinements above, the orientation of the gas jet inside the body of the regulator is essential to avoid the device being in depression and thus in continuous free-flowing: This is linked to the fact that the friction of the molecules of the primary gas flux against static gas molecules progressively results in heating and slowing down of this primary flux, and thus create a depression inside the regulator. As a result, the membrane tends to be sucked and maintains the inlet valve continuously open. To counter this phenomenon, the gas inlet flow is partially oriented toward the membrane.

Another problem of demand regulators is the freezing:
It is linked to the fact that the Venturi effect is used by the gas supply system of the regulator. The Italian scientist Giovanni Battista Venturi demonstrated in 1797 that if a fluid arrives in a convergent that consists of a pipe section that gradually restricts, its speed increases, and its pressure and temperature diminish as it progresses in this pipe section. As a result, the jet has more velocity than in a not-restricted pipe. An application of this principle is the extremity of a fire lance. Of course, when the accelerated fluid arrives in a divergent, its speed diminishes, and its temperature increases again. The problem resulting from the Venturi effect is that the moisture present in the gas can freeze and result in the regulator not responding or free-flowing without the possibility to stop it.
To avoid this phenomenon, in addition to minimizing the presence of humidity in the gas, manufacturers increase the surface of contact of the supply hose and the jet with the ambient water. However, that may be insufficient in cold waters in addition to the fact that breathing a cold gas favours hypothermia. For this reason, the regulator may have to be heated. 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 provide efficient gas heating. It is connected to the hot water supply of the diver by a splitter block assembly



The free-flow system can be used as a secondary gas supply when the regulator does not provide enough gas or flush the helmet. Also, some mist can be present on the viewport due to a difference in temperature inside and outside the helmet. For this reason, the gas from the free flow system is distributed on it through a pipe pierced of multiple small holes. EN 15333 says that the means for reducing misting must not irritate eyes or skin or damage helmet components.

Some surface-supplied helmets designed to work in unhealthy surroundings are equipped with a reclaim system to avoid any contaminated water intrusion. It is the case of the Divex “Dirty Harry”. With this system, the breathed gas is expelled to the surface by a hose, like helmets used for saturation. The “Jewel 601” exhaust regulator is installed for this purpose just below the “Ultraflow 601” demand regulator, in place of the classical exhaust whiskers of an air helmet.
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 an “open circuit valve” also prevents excess pressure in the helmet. That is achieved through 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 seawater above the 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 the closed-circuit mode. 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

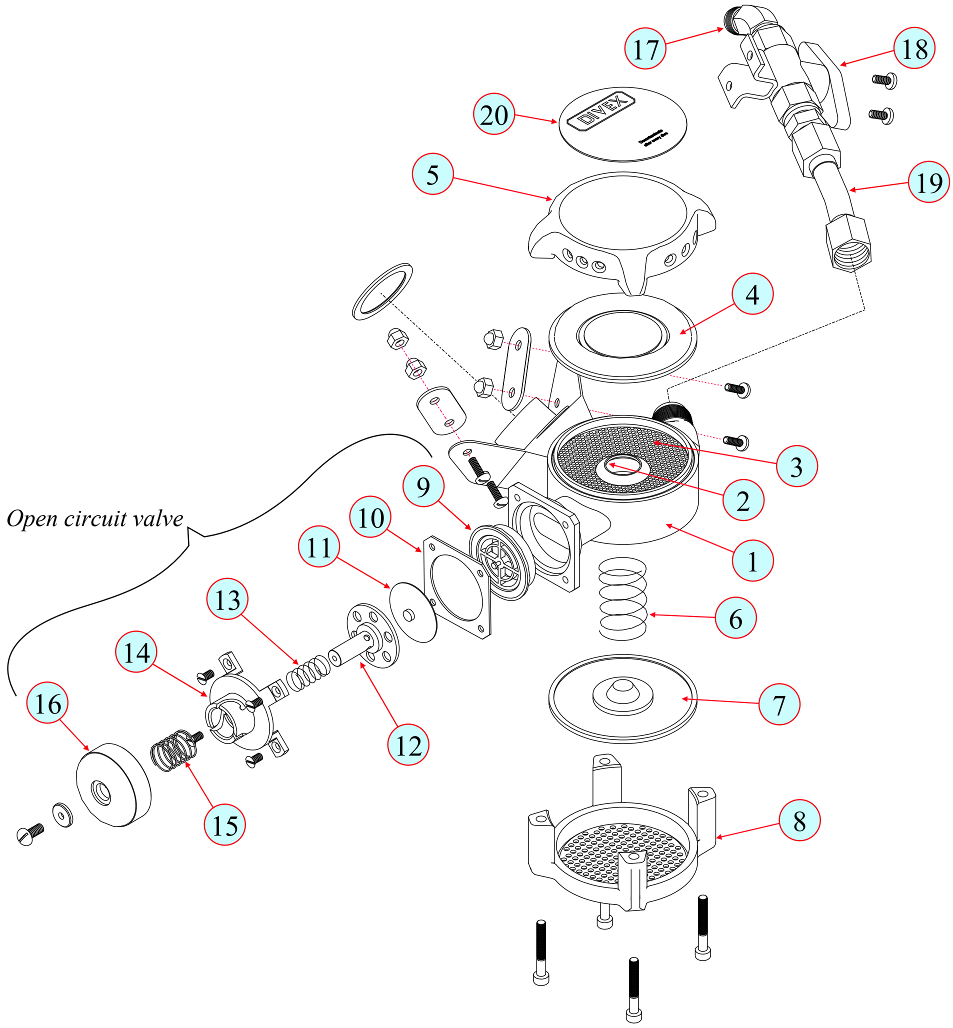
16 - Cover

17 - Elbow tube

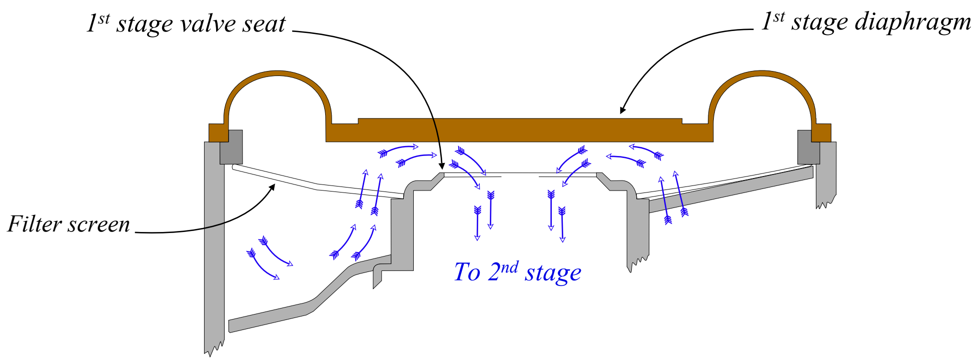
18 - Shutoff valve

19 - tube

20 - Brand & model sticker

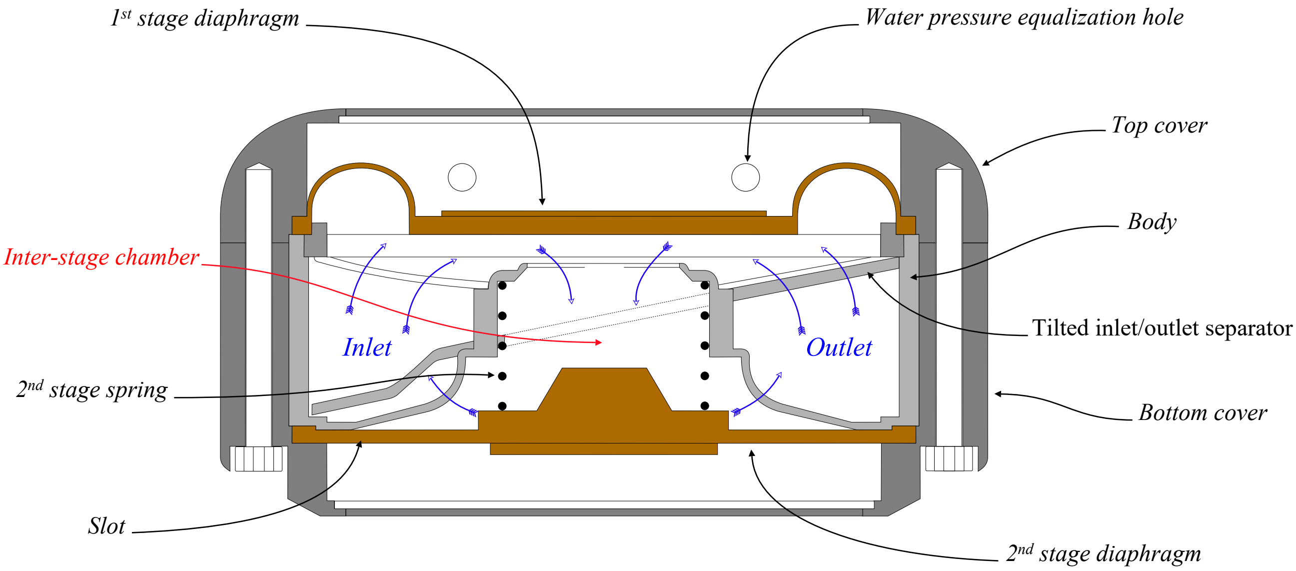


The first stage diaphragm controls the opening pressure of the regulator. It is situated as close as possible to the “Ultraflow 601” diaphragm to minimize the hydrostatic imbalance when the diver changes orientation.
When the diver exhales, the helmet pressure increases slightly, and this lifts the first 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 favor very high flows into the second stage.

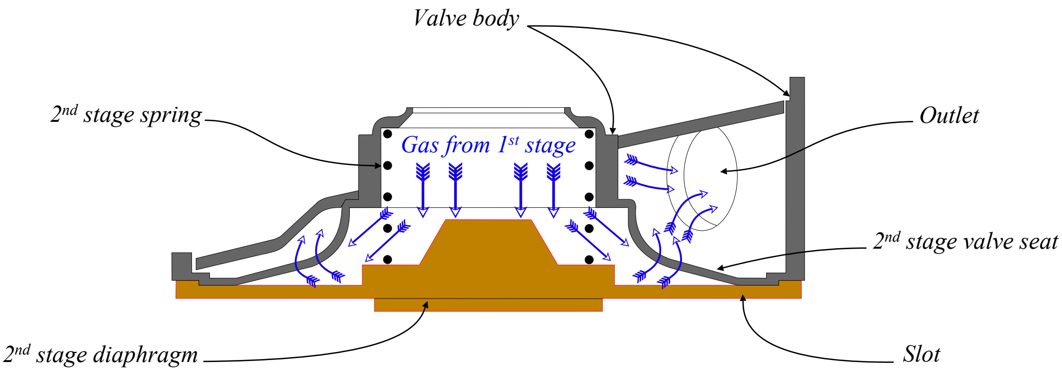


When the diver stops exhaling, the helmet pressure drops slightly below ambient water pressure and the diaphragm is drawn back onto its seat.

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



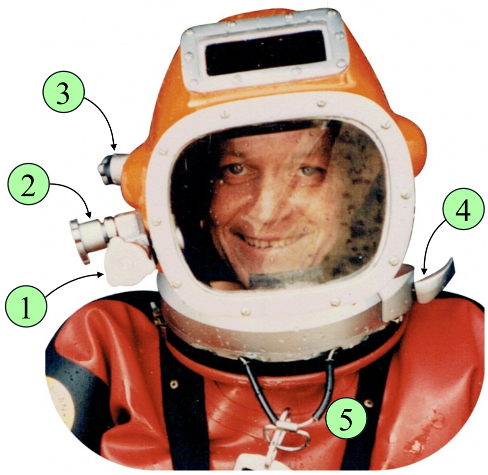
This increase in pressure, together with the second stage spring, lift the second stage diaphragm off twelve tapered radial slots and allows the exhaled gas flowing into the return line.
The second stage spring regulates the inter-stage pressure to between 30 and 60 cm of seawater below the ambient pressure.



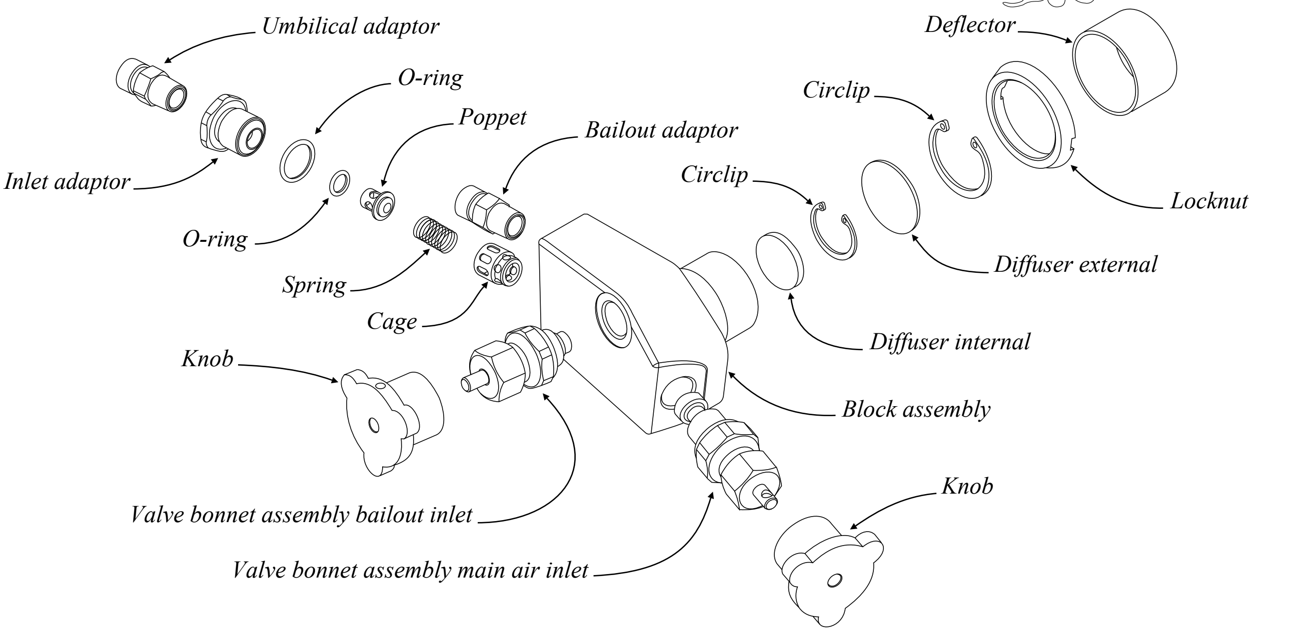
This low suction means that there is only a small force holding the first stage diaphragm on its seat and provides no hazard to the diver in the unlikely event that the first stage fails to open and the Ultraflow demand regulator fails to shut.
The slots in the second stage are tapered so that only a 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.

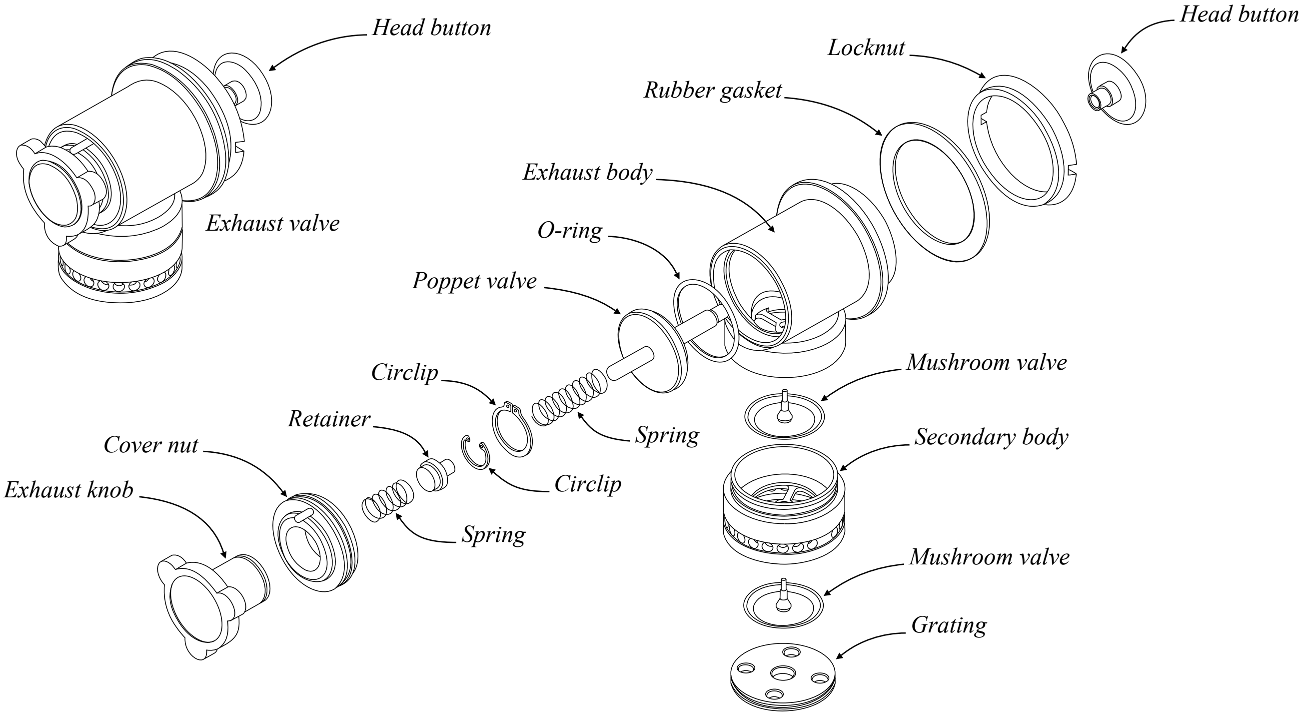
2.4.1.2 - Continuous flow helmets

These helmets use the same working principle as those designed during the early times of the diving industry. However, they are made of the same materials as the helmets equipped with demand regulators.
These helmets are usually clamped to the dry diving suit, which prevents water intrusion by the neck dam. In addition, water intrusion is prevented by the continuous gas flow and a series of exhaust valves.
For these reasons, they are often used to dive into unhealthy surroundings such as nuclear pools, sewers, and all sorts of polluted waters.
The model in the photo is an AH4 initially designed by Dive Dynamics and replaced by the AH5 today sold by Divex. These helmets are composed of:



- A free flow valve (see #1 in the photo)
- A bailout valve (see #2),
- An adjustable exhaust valve (see #3) that can also be operated by pressing a dedicated button with the head (head button)
- A waterproof clamping system (see 4)
- Two cables that maintain the helmet on the shoulders with the help of a harness (see #5)



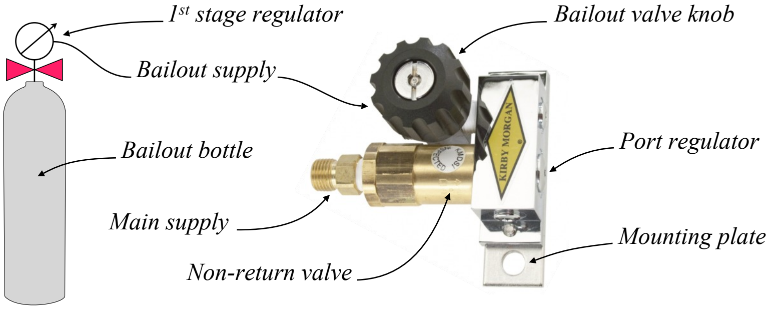


Note that some of these helmets communicate with the suit, which can be easily overinflated if the diver is not sufficiently vigilant to control the gas flow adequately. This overinflation can result in an uncontrolled ascent (blowup) and its associated injuries to the diver. For better control, manufacturers have fitted their last models with neck-dams, which function is to isolate the helmet from the drysuit that, in return, can be inflated separately. However, even though the neck dam theoretically provides efficient isolation, air may pass into the suit if it is incorrectly donned or adjusted. The flowing of the exhaust valve can be adjusted by activating the exhaust knob. Also, the head button (see in the scheme above) allows opening the exhaust valve when pressed by the head. This system avoids overinflation when the diver changes depth or the gas flow is inadequately adjusted. To prevent overinflation of the helmet, so as not to be obliged to operate the head button too often, the diver must adjust the exhaust valve accordingly to the gas inlet or vice versa to obtain a balanced flow. Note that the gas flow must be sufficiently high to allow good flushing of the helmet. If the flushing is insufficient, CO2 quickly builds up and may result in hypercapnia. The presence of mist on the viewport is an indicator of inadequate flushing. On the opposite, too elevated gas flowing may result in cool of the head of the diver. For this reason, tightened wool bonnets were used by the divers of early time to control this problem and are still used nowadays.
Based on the characteristics of these helmets, only adequately trained personnel should be allowed to use such a type of equipment.

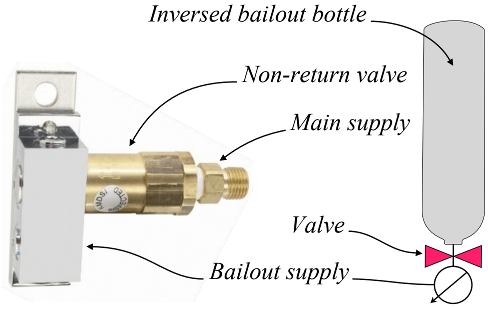
2.4.1.3 - Note regarding supply blocks

Even though helmets equipped with a side supply block are today the norm adopted by most manufacturers, a few models still in service are not provided with such a system and have their gas inlet connected to the back of the helmet instead of the side. In this case, the side block can be replaced by a manifold block, such as the model from Kirby Morgan on the next page, that can be installed on the diver's harness.

Also, it may happen that the manifold block is not provided with the bailout supply valve. In this case, the bailout bottle is inverted (valve and regulator at the bottom side), so the diver can easily access the cylinder's valve to open and close it.



Manifold block provided with bailout valve



Manifold block without bailout valve

2.4.1.4 - Note regarding EN 15333 requirements

The European Committee for Standardization has published two standards that specify the minimum requirements for surface supplied and demand surface-oriented diving apparatus:

- EN 15333-1 "Respiratory equipment - Open-circuit umbilical supplied compressed gas diving apparatus - Part 1: Demand apparatus", and
- EN 15333-2 "Respiratory equipment - Open-circuit umbilical supplied compressed gas diving apparatus - Part 2: Free flow apparatus".

They apply to the depths and temperatures listed below:

- Depths between 0 m and 50 m for apparatus using air, oxygen, or oxygen in nitrogen mixtures;
- Depths between 0 m and 60 m for apparatus using oxygen, oxygen, and helium or oxygen, nitrogen, and helium gas mixtures;
- Water temperatures between 4 °C and 34°C or outside these temperatures, as specified by the manufacturer.

Helmets used on worksites should conform with these standards or a similar one. It must be noted that they are based on practices previously implemented by manufacturers. It must also be said that navies such as the US Navy have once put similar criteria for the equipment they select in place. Among the numerous requirements, note the following that are not specified above:

Regarding materials:

- The parts used must have suitable mechanical strength, durability, and resistance to wear. Also, they must have adequate resistance to change caused by the effect of temperature individually and when assembled.
- Materials that may come into contact with pressurized gas above 25 bar, other than air that conforms with EN 12021 and with an oxygen content greater than 21%, must be compatible for use with high-pressure oxygen. All components and assemblies must be supplied "clean" to meet the intended service.
- Materials into direct contact with the wearer's skin and the breathing gas must not be known to be likely to cause irritation or any other adverse effect to health.
- Any material that may come into contact with seawater must be sea water-resistant. The test to control this point consists of checking the condition of the device after four cycles where it is submerged for more than 8 hours in saltwater between 15 and 25 ºC, then dried in air at the same temperature and no more than 75% moisture.

Regarding valves

- The valves must open progressively with more than one rotation to be fully open. Other means must be provided to delay full gas flow of units in which it is technically difficult to limit the opening in this way (e.g., diaphragm valves). Valves must be designed and located so that they cannot be closed inadvertently.
- Water ingress must not impair the function of valves that must also be protected against the entrainment of dirt, solid particles from inside the pressure vessel.
- The design and configuration of the exhalation valves must prevent the ingress of water in all positions. Also, the bubbles emerging must not impede the diver's vision when swimming or in vertical position.

Regarding breathing performances:

- Standard Respiratory Minute Volumes (RMV) of devices are measured using sinusoidal waveforms from a breathing simulator with simulated RMV (Respiratory Minute Volume) up to 62,5 I min. The performances of the system must be determined using air or an oxygen in nitrogen gas mixture at an ambient pressure of 6 bar and where appropriate using an oxygen in helium based mixture at an ambient pressure of 7 bar or a reduced pressure specified by the manufacturer.
  Based on a Respiratory Minute Volume (RMV) from 10 I min to 70 I min, the breathing system must meet the following requirements:
    - The “Work Of Breathing” (WOB) is the energy necessary to inhale and exhale a breathing gas. It is usually expressed in joules/litre. EN 15333 says that it must not exceed a value of 0,5 + 0,03 x RMV [Jxl^{-1}]
    - The inspired and expired respiratory pressures must not exceed 25 mbar each
    - The positive work of breathing during inhalation must not exceed 0,3 Jxr1

- Pressure spikes with no measurable positive work of breathing must not exceed 25 mbar
- Pressure peaks with measurable positive work of breathing must not exceed 5 mbar

- High Respiratory Minute Volumes (RMV) are also measured using sinusoidal waveforms from a breathing simulator. However, the simulated RMV (Respiratory Minute Volume) is raised up to 75 I min.
The performances of the system must also be determined using air or an oxygen in nitrogen gas mixture at an ambient pressure of 6 bar and where appropriate using an oxygen in helium based mixture at an ambient pressure of 7 bar or a reduced pressure specified by the manufacturer.
Based on a Respiratory Minute Volume (RMV) from 70 I min to 85 I min, the breathing system must meet the following requirements:
  - The “Work Of Breathing” (WOB) is the energy necessary to inhale and exhale a breathing gas. It is usually expressed in joules/litre. EN 15333 says that it must not exceed a value of 0,5 + 0,04 x RMV [Jxl-¹]
  - The inspired and expired respiratory pressures must not exceed 35 mbar each
  - The positive work of breathing during inhalation must not exceed 0,5 Jxr1
  - Pressure spikes with no measurable positive work of breathing must not exceed 25 mbar
  - Pressure peaks with measurable positive work of breathing must not exceed 12 mbar
- Breathing performance in cold water must be also measured using a sinusoidal waveform from a breathing simulator with simulated RMV of 62,5 I min. The air exhaled by the breathing simulator must be heated to a temperature of 28 ± 2 °C, and a relative humidity greater than 90% when measured at the interface with the demand valve. The performance of the apparatus must be determined using air at an ambient pressure of 6 bar.
  - The work of breathing (WaS) must not exceed a value of: waB = 0,5 + 0,03 RMV
  - The inspired and expired respiratory pressures must not exceed 25 mbar each
  - The positive work of breathing during inhalation must not exceed 0,3 Jxr1
  - Pressure spikes with no measurable positive work of breathing must not exceed 25 mbar
  - Pressure peaks with measurable positive work of breathing must not exceed 5 mbar

Noise:
The measured noise levels at 40 I/min must be compared to the exposure limit value noise dose of L(ep,d) 85 dB(A) re 20 цPa or a modified weighting of the sound spectrum, taking into consideration the effects of different ambient conditions (gas composition, pressure, water). Using current national occupational health 24 time-weighted exposures and the principle of 3 dB halving of noise dose, the manufacturer must state the maximum permissible noise exposure time, taking into consideration the time the diver will spend at each RMV. Noise levels must be less than the peak sound pressure level (135 dB).

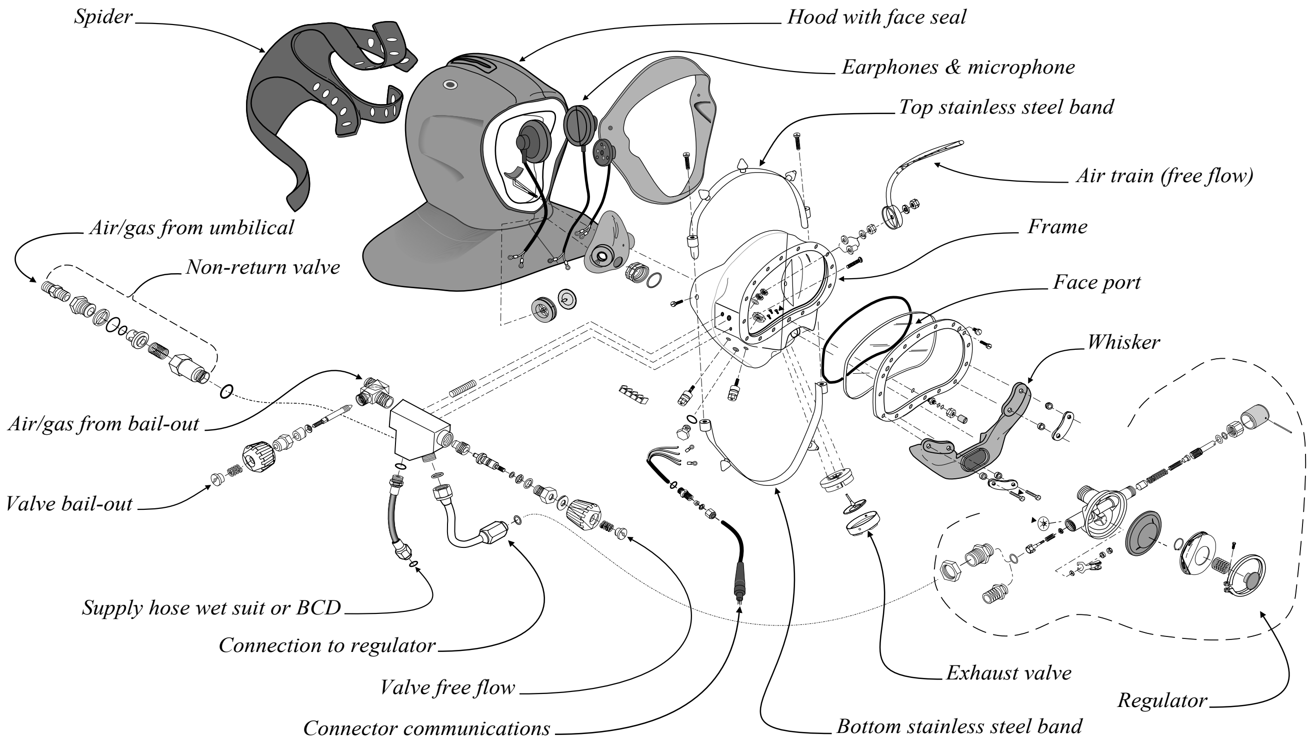
2.4.2 - Full-face masks

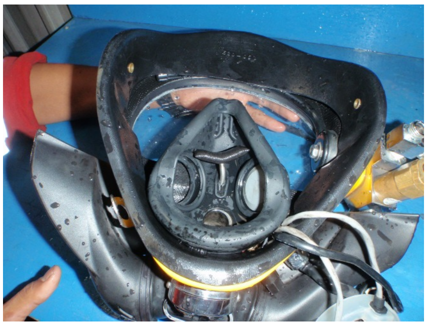
A full-face mask consists of an envelope that encloses the face of the diver and is maintained in place by an arrangement of rubber straps usually called "spider". They are made of rubber and composite materials and are commonly used by rescue divers on many diving projects because they can be easily and quickly donned.
Some companies also utilize them to work daily because they are cheaper than helmets. However, they do not offer head protection, and for this reason, they are not recommended for jobs where there is a risk of head injury. Also, they are less comfortable than helmets, do not protect the head from contact with water, and their fixation system, based on rubber straps, does not guarantee that they cannot be torn off: It has happened that divers have been deprived of their masks in very strong currents despite these devices were made according to recognised standards.
In addition, many models like the one on the left side below do not provide elements such as a free flow system, the side supply block with the bailout supply valve and the main supply, and a viewport in polycarbonate plastic. Even though the supply block can be a manifold block installed on the harness, we can conclude that full-face masks do not provide the safety level of helmets, and many of them do not satisfy the requirements of the European standard EN 15333-1. For this reason, only models equipped similarly to helmets and with an integrated hood that prevents water intrusion due to strong current coming to the back of the head, like for example, the KMB 18 and 28, represented on the right side below, should be used by the standby diver or to perform works.

Not recommended full face mask

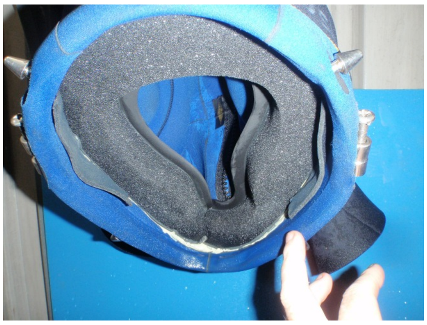
Full face mask conforming with EN 15333-1

The scheme of KMB 18 & 28 below show the elements that should be present in a full-face mask used for surface supplied diving operations. Note that these two models are exactly similar except the frame of KMB 28 that is made of injected plastic instead of composite materials.




Frame + Breathing mask + whiskers


Hood + face seal + Breathing mask


Hood + face seal (reversed side)

Note that the manufacturer of the full-face masks above provides the hard shell below to protect the diver's head partially. However, in addition to the fact that donning it takes more time than a helmet, it also does not provide the same level of protection. For this reason, many clients prefer their contractors to use standard helmets instead.


Head protection: Side view


Head protection: Rear view


Head protection: Front view

The requirements of the European standard EN 15333-1 for full face masks are the same as for helmets, except, of course, for the fastening to the head of the diver. Regarding this point, EN 15333-1 says that the spider must allow for donning and removing the full-face mask without difficulty and must be easily adjustable by the diver. Also, in addition to the fact that they must hold the full face mask firmly and comfortably in position, each strap and its dedicated buckle must be able to withstand a tensile force of 150 N applied for 10 seconds in the direction of pulling when the mask is donned, and the permanent linear deformation of each strap must not be greater than 5 % when tested at a tensile force of 30 N for 10 seconds. Consequently, it is highly recommended to use spiders sold by the device's manufacturer or units that comply with this standard. Homemade spiders should not be used if not approved by a competent body.

2.4.3 - Marking and attached documentation

2.4.3.1 - Marking

As for every piece of equipment used for diving activities, helmets and full-face masks must be marked to establish traceability and utilization limits. Markings should consist of at least:

- The name, trade mark, or other means of identification of the manufacturer.
- The unique serial number of the device.
- Another identifying marking if used (For example, a barcode)
- The standards to which the equipment refers must be marked on all components.
- The date (at least the year) of manufacture must be marked on components whose performance and reliability can be affected by aging or usage.
- Sub-assemblies and components with a considerable bearing on safety must be marked so that they can be easily identified. If sub-assemblies with significant bearing are too small to be marked or where it is impractical to mark them, the information must be included in the documents provided by the manufacturer.
- Pressure reducers and pressure indicators must be marked with the rated working pressure.
- EN 15333 says that helmets and - if applicable - full face masks must be marked with the following class of head protection:
    - Class A; "Head protection"
    - Class B; "Bump protection"
    - Class C; '"No protection"

2.4.3.2 - Attached documentation

The European standard EN 15333 says that on delivery of a device, its manufacturer must provide information in the official language of the country of destination that enables trained and qualified persons to assemble and use it. The information consist of:

- Application
- Maximum depth of equipment certification
- Gas mixtures to be employed and maximum depth for each mixture
- Limitations on use
- Assembly
    - Subassemblies
    - Components
    - Connections
    - Safety devices
    - Interface requirements
- Assessment of risk
    - Temperature conditions
    - Mass of apparatus
    - Work rates
    - Visibility
    - Use of high oxygen content gases
    - Noise exposure
    - Classification of head protection
- Apparatus checks
    - prior to use
    - post dive
- Donning and fitting of the apparatus on the diver and system use
- Maintenance (preferably separately printed instructions)
    - cleaning and disinfection
    - use of oxygen cleaning procedures
- Storage
    - Conditions
    - Shelf lives (where applicable)
    - Precautions
- Inspection intervals

EN 15333 also says that the instructions must be unambiguous with illustrations if helpful and include information on:

- The purity and tolerances of gases to be used.
- The compatibility of accessories and other personal protective equipment that have been added to the apparatus.
- The integration and performance of voice communications

2.4.4 - Maintenance

2.4.4.1 - Inspection and function test

The document IMCA (international Marine Contractor Association) D 023 says that helmets must be visually checked every 6 months and inspected and tested in line with manufacturer's recommendations every 12 months. However, most manufacturers say that preventive inspections must be performed every month and every year. The manufacturer should publish checklists and recommendations for this purpose.
The helmet or full face mask should also be inspected during the operations. This inspection is to be performed daily before starting the dives. Also, another checklist is to be completed before and after each dive. The purpose of these inspections is to ensure that the visible components of the helmet or full-face mask are in perfect condition. Defective parts should be replaced or, if too long to do it, the helmet or full face mask should be changed. The rule is that any device used for diving must be in perfect condition when launching the operations.
Sanitizing should be performed between each dive to minimize the spread of germs. The procedure regarding this point is explained in the diving procedures with the pre-dive and post-dive checks as they are considered parts of the diving procedures.

- The daily pre-job inspection usually consists of the following:
    - The external and the internal condition of the shell. The person in charge must ensure that no damage may affect the shell's integrity. Note that scratches, gouges or pittings may expose composite materials to the water and thus destroy them.
    - The condition of the viewport is also verified
    - The neck dam and clamping system (condition and adjustment) or, for full face masks, the condition of the hood and the spider.
    - The condition and the adjustment of the oral/nasal mask must be verified. That includes the condition of the valve allowing to breath with the free flowing system and the equalizing device. The water exhaust valve should also be checked.
    - The visible condition of the microphone and earphones, and whether they are correctly secure. The condition of the connector is also to be verified.
    - The condition of the light and whether is satisfactory secured, and the electrical connector is not damaged.
    - The visible condition of the regulator
    - The condition of the side block of the manifold to be installed on the harness (There should not be visible damages, and the valves must open or close smoothly)
    - The condition of the connections and the supply hoses (main and bailout). The supply from the bailout should be connected and the main supply hose should be disconnected.
    - The presence of the non-return valve and whether it works must be checked. The non-return valve should be sufficiently reactive to be orally tested: The air should pass freely if the technician blows air in it through the adaptor of the umbilical with the free flow open, and the air should not pass when he is sucking it through the same adaptor. The free flow should be closed at the end of the test, and the main supply hose must be kept disconnected.
    - The bailout and the 1st stage regulator should be inspected and the supply valve opened. Usually, the non-return valve should emit a characteristic "clack" that indicates it is working. Also, there should not be air passing through the adaptor of the umbilical.
    - The regulator must also be tested (the adjustment knob should easily rotate, the gas purge must work, and the breathing resistance and the gas delivery must be satisfactory). The bailout valve should be closed and the circuit's pressure fully purged. The main hose is reconnected to the non-return valve port.
    - The main air/gas supply must be checked for pressure delivery and leakage at the connection. The free flow and the regulator are operated for this purpose.
    - If a heating system is connected, the shrouds must be checked and the water flowing verified,
    - If a dry suit of a BCD (Buoyancy Control Device) is connected, its inflator should be tested.
    - The communications and the lights must be tested.
    - Then the air/gas supply to the helmet (or full-face mask) is closed and the supply system purged.
    - The straps and harness that may be used to adjust and keep the helmet in place should also be inspected and tested.
- The monthly inspection usually consists of a close examination and function tests of all device parts. Note that as indicated below, some technicians disassemble most components for better observation, but some others and some manufacturers do not clearly specify it:
    - The neck dam & clamping system or the hood should be removed, and a close visual inspection of all the components must be carried out. This inspection should include the function tests of hinges, mechanisms of clamping, or the spider of full-face masks.
    - Helmet liners / cushions should be opened and the foam replaced if necessary
    - The condition of the viewport is also verified
    - The microphone and earphones must be removed and verified. They must also be tested.
    - The equalizing device (also called "nose clearing device") and the "oral-nasal mask" assembly should be removed, cleaned, and closely inspected. That includes the inspection of the free flow inlet valve.

- Whiskers and water exhaust valves must also be closely verified.
- The helmet shell must be thoroughly verified for damages (scratches, cracks, gouges, and depressions), including loose and/ missing fasteners. "gelcoat" of shells made of composite materials must be repaired as soon as possible. Any gouge deeper than 1.5 millimetres should be inspected by the manufacturer.
- The "supply block" should be checked for external damages. Its valves should be tested. It is usual to disassemble, clean, inspect, and lubricate them if there is any doubt regarding their condition.
- The non-return valve must also be closely inspected, and tested.
- The regulator should be opened and checked for damages. That includes the diaphragm, the exhaust valve, the body, and the mobile parts of the device. Note that many regulators are supplied by an external bent tube that may be damaged and so affect the functioning of the regulator. When reassembled, the regulator must be adjusted according to the procedure and the values indicated by the manufacturer and tested.
- The same function test as those performed for the daily checks should be performed.

- The yearly inspection is similar to the monthly one, except it is more detailed. It should be performed on devices in service and also those not attributed to a project and kept in reserve.
  - The helmet components should be dismantled, cleaned, and inspected for corrosion and damage. Kirby Morgan says that the side block and the regulator do not need to be removed from the shell. However, the statement of their fixations and seals with the hull must be closely verified.
  - Gaskets and O' rings must be closely checked. Some technician systematically replace them.
  - Mushroom exhaust valves are critical and not expensive parts: They should be replaced for these reasons.
  - Some manufacturers say that umbilical and hoses adapters of helmets in service should also be replaced.
  - Damages of the "gelcoat" of shells made of composite materials must be repaired as soon as possible. Any gouge deeper than 1.5 millimetres should be inspected by the manufacturer. It often happens that slightly damaged "gelcoats" are integrally redone.
  - Some composite helmet manufacturers say that the viewport insert should be verified every year
  - The same function test as those performed for the daily and monthly checks should be performed.

2.4.4.2 - Failure mode effect analysis & troubleshooting

Standard EN 15333 requires that manufacturers provide an FMEA (Failure Mode Effect Analysis). This FMEA is often presented under a troubleshooting checklist, such as the one below, which is based on those published by manufacturers such as Aqualung and Kirby Morgan. It must be improved with problems arising from the model of helmet used.

Problem encountered	***Causes***	***Solution***
No gas supply (Gas supply can be checked by opening the free flow)	*Umbilical not supplied*	*Turn on the umbilical supply*
	Umbilical not connected or cut	*Connect the umbilical and open the supply. If it happens during the dive, the diver activates his bailout and returns the the deployment device*
Free flow valve difficult or impossible to open	*Valve damaged, corroded, or stuck by debris*	*Repair the valve*
Insufficient or no free flow (helmet supplied & valve working)	*Distribution hose plug*	*Remove and check*
Regulator not working or with an insufficient air flow	*Incorrect air supply pressure*	*Adjust it according to the specifications of the manufacturer*
	Regulator incorrectly adjusted	*Adjust the knob to obtain a correct flow*
	Regulator damaged	*Open the regulator, check the internal parts, and repair*
Regulator free flowing	*Incorrect gas supply pressure*	*Adjust it according to the specifications of the manufacturer*
	Regulator improperly adjusted	*Adjust the knob to obtain a correct flow*
	Regulator damaged	*Open the regulator, check the internal parts, and repair*
	Bent tube damaged causing a misalignment of the nipple tube (KMB)	*Check the inlet nipple and soft seat. Replace as necessary.*
No emergency supply	*Bailout empty, or not connected, or not open.*	*Check the bailout pressure, its connection, and whether it is open.*
Helmet emergency valve difficult or impossible to open	*Valve damaged, or corroded, or stuck by debris*	*Repair the valve*
Helmet emergency valve leaking	*Valve seat damaged or presence of debris*	*Clean or repair the valve*

Problem encountered	***Causes***	***Solution***
Insufficient bailout supply (Helmet valve correct)	*Bailout valve damaged*	*Check*
	1st stage regulator damaged or plugged	*Check and repair*
Non-return valve not working or stuck closed	*Foreign object in the circuit or component damaged*	*Open the valve, to clean and repair it - change it if it is not possible.*
Regulator free flowing while the emergency supply is open	*1st stage regulator incorrectly adjusted or damaged.*	*Check, repair, or replace.*
Regulator free flowing during the dive with water intrusion	*For helmets: Neck dam incorrectly adjusted or don.*	*Ensure that the neck dam fits the diver's neck and is correctly positioned.*
	For helmets: Damaged O' ring of the clamping system or foreign object in it.	*Ensure the condition of the Clamp's O' ring and its cleanliness.*
	For full-face masks: Spider insufficiently tightened, or face seal incorrectly adjusted,	*Ensure the tension of the spider and that the face seal fits the face of the diver.*
	For full-face masks: Face seal disassembled from the hood, or too old.	*Check the condition of the face seal, and replace it if necessary.*
	Wire penetrator incorrectly sealed	*Check the penetrators for incomplete tightening or damaged O' rings*
Complete or partial flooding	*Water or breathing exhaust valve damaged, or stuck open*	*Replace the valve (A valve stuck open is to be considered damaged)*
	Regulator's diaphragm damaged or not sealed	*Check the condition and whether foreign objects are present.*
No communications	*The communications are not turned on, or connected*	*Turn on the communications and make sure that the connectors are suitably secured.*
	Communication post not working	*Replace it with the backup post*
	Wire cut	*Check the continuity of the umbilical's wire*
	Connectors corroded or damaged	*Check the condition of the connectors, remove corrosion, check their continuity, and replace them if necessary*
No voice communication to the surface	*Microphone damaged*	*Check the microphone or replace it*
Intermittent communications	*Wire or connectors damaged*	*Check the continuity of the line*
No light	*Electrical supply not turned on, or connected*	*Turn on the electrical supply and make sure that the connectors are suitably secured.*
	Electrical supply block not working	*Repair or replace*
	Wire cut	*Check the continuity of the umbilical's wire*
	Connectors corroded or damaged	*Check the condition of the connectors, remove corrosion, check their continuity, and replace them if necessary*
Intermittent lighting	*Wire or connectors damaged*	*Check the continuity of the line*

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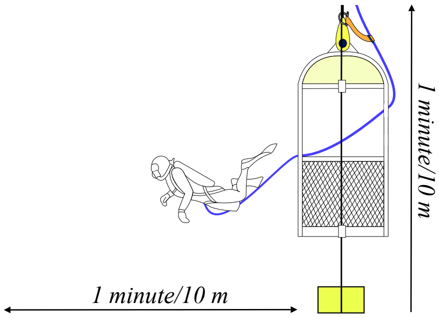
2.5 - Bailout systems

2.5.1 - Purpose

Most diving associations and states rules say that every diver must be provided with a reserve supply of breathing gas carried in a bailout system. Also, NORSOK U100 says that 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 air for 1 minute for every 10 metres horizontal excursion plus 1 minute for every 10 metres of depth.

Procedure to calculate the diving duration offered by a bailout:

1) *Find the pressure available:*
   Pressure bottle - absolute pressure bottom - working pressure regulator
2) *Find the volume of gas available:*
   Cylinder's floodable volume x Available pressure
3) *Find the breathing duration offered by the cylinder:*
   Available volume / (average consumption x absolute pressure)



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. It is also selected in the European standard EN 15333 *"Respiratory equipment - Open-circuit umbilical supplied compressed gas diving apparatus".*

The bailout systems used for surface-supplied diving operations are usually scuba diving cylinders. They should be selected depending on the depth and the distance from the deployment device to fulfill the requirements indicated above. Rebreather apparatus are used by militaries and experienced recreational divers for diving operations that cannot be organized with standard scuba sets. However, the systems they use are not adapted to the requirements of commercial diving. Nevertheless, systems of rebreather apparatus have been designed for bailout usage for saturation diving 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. These equipment that can be used for deep depth are expensive and complex. For these reasons, they are usually not used with surface-supplied diving operations and are not described in this document. However, a description is available in our document "Description of a saturation system".

2.5.2 - 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.
Most companies involved in surface-supplied diving operations use cylinders that provide only the minimum calculated range as they favor compacity and apparatus as light as possible.
Opposite such policy, it is desirable to provide more gas reserve than the minimum calculated, even though the gas containers are more voluminous and heavier. Regarding this point, 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 preferable to mono cylinders of 15, 18, or 20 litres that have a wider diameter and are less stable, and also 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

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 should be colour-coded according to the recommendations of 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.
Based on these regulations, cylinders used with air and nitrox should be organized as follows:

- The shoulder must be colour coded with white and black quarters.
- The floodable volume should be indicated on the body with the words “air” and “diving quality” if the bailout is filled with air. If it is filled with ”nitrox”, the word “nitrox” should be written in place of “air” with the gas percentage by volume, quoting percentage of oxygen first. It is also acceptable to put additional green and yellow bands (American colour code) with the mention “nitrox” or “enriched air nitrox“ on the body.
- 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 coloured paint to aid location. These identification marks must not be hidden by accumulated layers of paint.

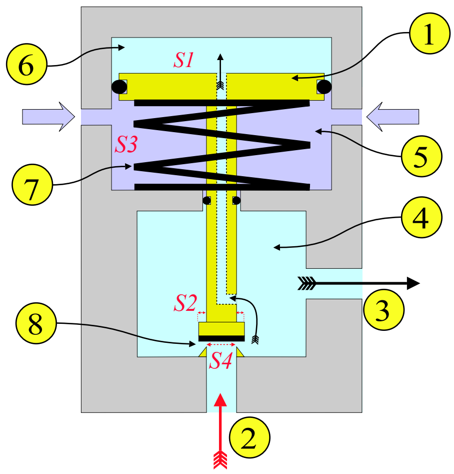
The high-pressure gas contained in the cylinder must be regulated to a pressure and a flow that are compatible with those of the 2nd stage regulator of the helmet. This is achieved by the 1st stage of a scuba diving regulator that is installed on the bottle and connected to the 2nd stage of the helmet 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

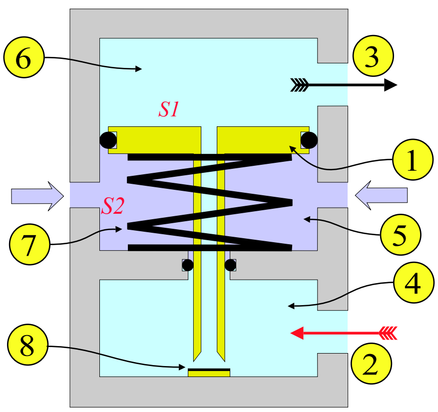


- A balanced piston regulator uses the same basic mechanism as above. However, the forces are organized in such a manner that there is no intervention of the high pressure in the opening of the regulator. As a result, the opening and closure depend only on the low pressure and the effort to inhale is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

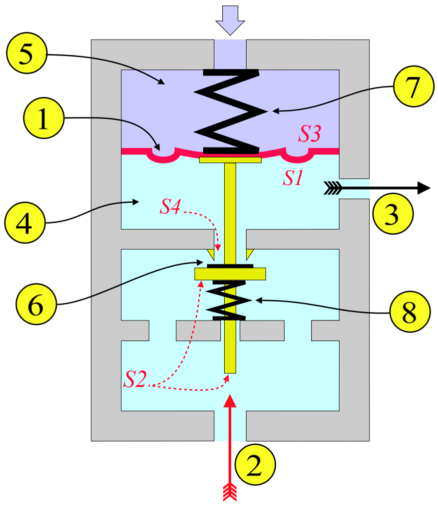
1 - Piston
2 - High Pressure inlet
3 - Low Pressure outlet
4 - Depression chamber HP - LP
5 - Hydrostatic pressure chamber
6 - Top-side LP chamber
7 - Spring
8 - Valve + seat



- 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*

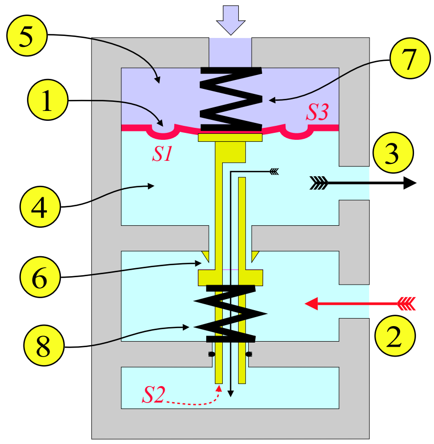


1 - Membrane
2 - High Pressure inlet
3 - Low Pressure outlet
4 - Depression chamber HP - LP
5 - Hydrostatic pressure chamber
6 - Tail + valve assembly
7 - Spring in wet chamber
8 - Return spring

- 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 inhale 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 is that when filled with nitrox, the cylinder, its pipework, and the 1st stage regulator must be designed to work with such mixes. Note that the IMO (International Maritime Organization) code of safety for diving systems says that oxygen and gases with an oxygen volume percentage higher than 25% should be stored in bottles or pressure vessels exclusively intended for such gases. NORSOK standards reduce this limit to 22%. IMO also says that piping systems containing gases with more than 25% oxygen should be treated as systems containing pure oxygen, and that materials used in oxygen systems should be compatible with oxygen at the working pressure and flow rate.
It must also be considered 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”.

2.5.3 - Maintenance

Note that the reference standards and procedures for inspecting diving cylinders are detailed in the diving study CCO Ltd

"Organize the maintenance of diving cylinders", which is available on our website. The inspection of cylinders is a complex task that requires more than a chapter to be described and must be performed by specialists. For this reason, they are explained in this specific document.
Regarding the frequencies of inspection, IMCA and a lot of classification societies recommend the following:

Seamless steel and aluminium gas cylinders

Examination / Test	***Frequency***	***Competent person***
External visual examination	*6 months*	*Diving supervisor, technician, classification societies or engineers, manufacturer or specialised societies.*
Internal visual examination	*6 months*	*Technician,and manufacturer or specialised societies.*
Thorough internal and external visual examination and gas leak test to maximum working pressure. If the competent person deems it necessary, a hydraulic overpressure test may be required	*2 years*	*Technician, classification societies or engineers.*
Hydraulic overpressure test to 1.5 times maximum working pressure (or the factor required by the design code or standard if different) plus the 2 yearly tests above	*4 years*	*Technician, classification societies or engineers.*

Composite gas cylinders

Examination / Test	***Frequency***	***Competent person***
External visual examination	*6 months*	*Technician, classification societies or engineers, manufacturer or specialised societies.*
Internal visual examination	*6 months*	*Technician,and manufacturer or specialised societies.*
Thorough internal and external visual examination and gas leak test to maximum working pressure. If the competent person deems it necessary, a hydraulic overpressure test may be required	*12 months*	*Technician, classification societies or engineers.*
Hydraulic overpressure test to 1.5 times maximum working pressure (or the factor required by the design code or standard if different) plus the 2 yearly tests above	*5 years*	*Technician, classification societies or engineers.*

The valve and the 1st stage regulator should be considered a part of the helmet and checked similarly with the same frequency:

- Daily external visual examination and function tests during operations.
- Monthly detailed visual inspection and function test.
- Yearly internal and external close visual inspection, with the preventive replacement of gaskets and parts submitted to wear.

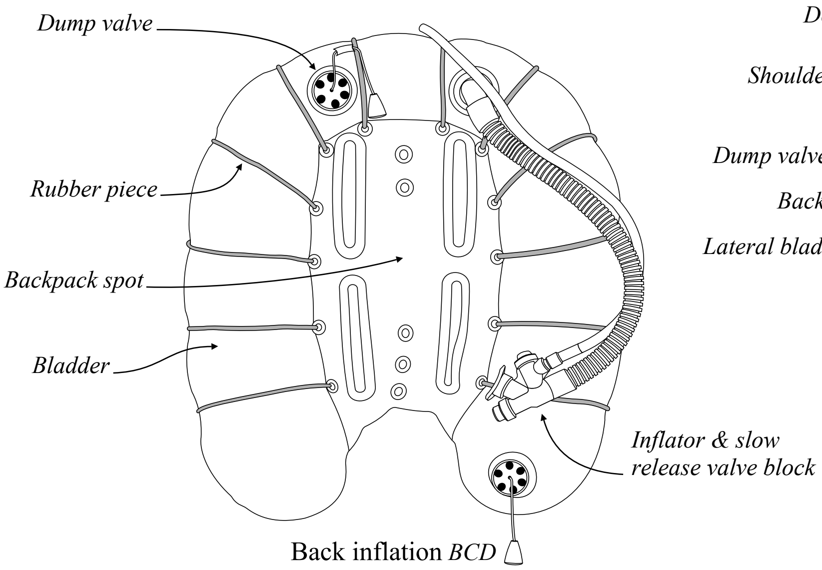
2.6 - Buoyancy Control Devices (BCDs)

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 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 surface or the deployment device is a difficult task, even though the rescue diver and the tender are active and experienced. Thus, 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.

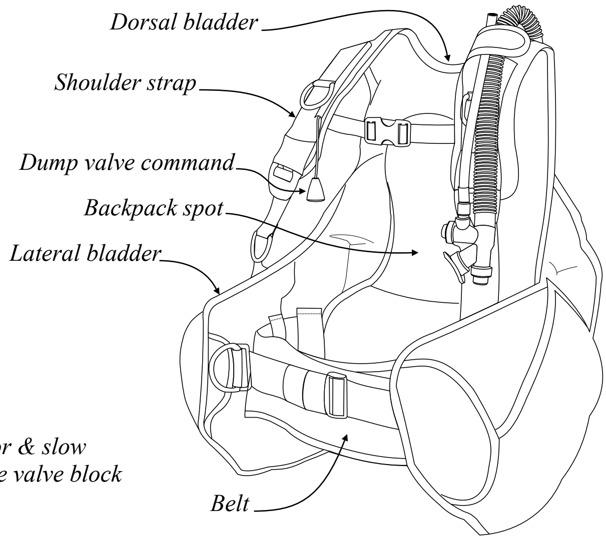
2.6.1 - Description

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.
- “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 surface supplied commercial divers as, due to the supply from the umbilical, they do not need to carry these cumbersome extra gas bottles.



Back inflation *BCD*



Stabilizing jacket

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

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 dives 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.

2.6.3 - Select the suitable 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 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.
- 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.

2.6.4 - Pre-dive checks and maintenance

BCDs are safety equipment that must be checked before each dive:

- 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.

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.
- 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.

2.7 - Diving suits and temperature control of divers

Diving suits are designed to protect the diver from wounds and irritations or burns. They are also designed to isolate his body from the cold water.
The temperature of the sea is quite hot in tropical waters, and thermal protection is often not used for surface supplied diving operations above 30 m. Nevertheless, even at shallow depths, cold currents can be encountered, which will oblige to wear appropriate diving suits.
Thermal protection is necessary for tempered waters and in the areas that are not far from the Arctic or the Antarctic circles. Also, the probability to be confronted with cold water is increased with the depth. Thus, efficient protection or heating systems may be necessary. Depending on the location and the temperature it is commonly achieved by the use of wetsuits, drysuits, and hot water suits which are also used for saturation diving operations.

2.7.1 - Coveralls

Coveralls are not originally designed to be used as diving suits. They do not offer any thermal protection and extra buoyancy. Nevertheless, they can protect against corals and shells if they are sufficiently robust. For this reason, they can be used for static jobs in hot waters. In addition to their low cost, they can easily be washed and disinfected.
Note that, opposite to wetsuits that are designed to follow the shapes of the body, coveralls are slack. As a result, they may act as small sails when the divers are confronted with underwater currents. Thus swimming with them is sometimes difficult.
Coveralls used underwater should be restricted as follows:

- A coverall needs to be modified to be used underwater:
  - It must be closed with a zip
  - The sleeves must be sealed around the wrists and ankles to avoid the intrusion of undesirable marine animals such as coral, small jellyfish, etc. The neck should be sealed as well. It can be achieved by the use of rubber or neoprene rings or a similar arrangement.
  - As indicated above it must be made of a strong and thick textile
- A coverall cannot be used in polluted waters. Specific suits are to be used in this case. Please refer to the chapters “Hydrocarbons” and “Water contamination other than Hydrocarbons” in document “diving accidents”.
- A coverall cannot be used if there is the risk of cold underwater currents. If the conditions at the location are unknown, a real diving suit should be used.
- Also real diving suits are preferable if there is the risk of strong currents.

2.7.2 - Wetsuits

2.7.2.1 - Description

A wetsuit is made of foamed neoprene that is protected from scratches and other damages by an external sheet of lycra or a similar textile. Due to its elasticity the wetsuit follows perfectly the shapes of the body and the quantity of water entering in it during the launching of the dive is reduced to a very minimum that is then trapped and heated by the body. The body is isolated from the cold water by the foamed neoprene.
The performance of a wetsuit depends on the number and the size of the bubbles in the neoprene foam. High-density neoprenes are more compressed and have more small bubbles. They are less subject to crushing and buoyancy change than low-density neoprenes. Thus, they are offering a better thermal protection and are often used to manufacture diving suits. Their inconvenience is that they are not as soft as low-density neoprenes that are preferred for surface sportive activities such as swimming, windsurf and others.
Thicknesses the most commonly used for diving suits are 3 mm, 5 mm, and 7 mm. The thickness is selected according the thermal protection desired. The suits can be composed of one piece or two pieces. It is recommended to reinforce some vulnerable areas such as knees and elbows. A coverall may be used to protect the wetsuit if the work is static.
These suits are usually used in tropical waters. They should be available onboard the vessel when dives are initially planned to be with coveralls. They can be used in colder latitudes during the hot season considering that a good wetsuit allows to dive at temperatures around 17°C or less if the dive time is short. They should not be used in cold waters.

2.7.2.2 - Precautions of use and maintenance

It is essential to implement appropriate procedures of selection, hygiene, and maintenance.

- A team of scientists composed of O. Castagna, J. E. Blatteau, N. Vallee, B. Schmid, and J. Regnard published in 2013 a documented study called “The Underestimated Compression Effect of Neoprene Wetsuit on Divers Hydromineral* Homeostasis**”, available on our website, that concludes that neoprene wetsuits commonly used

in diving activities produce a compression effect independent of ambient pressure and wetness that alters fluid balance to a lesser degree but in the same way as water immersion, so, an overall fluid loss through increased urine output and a lower scaled decrease in plasma volume. This study also concludes that this effect becomes minor with submersion and eventually merges with the effects of the hydrostatic pressure.
Based on the conclusion of this study, we can consider that a too-tight suit will increase the fluid loss discussed in this study, in addition to discomfort, as it also will limit the movements and the breathing of the diver. Thus the wet suit must be perfectly adjusted to limit water intrusions, but that must be done without compressing the body. This study also proves that a suit perfectly adjusted protects efficiently against the cold with an average loss of 2.7 degrees of the skin temperature in depths less and equal to 12 m in waters at 28 degrees and after 2 hours exposure using a 5 mm suit. Opposite, a suit that is too slack or has folds will favor water intrusion and expose the body to the effects of cold.

- Based on the elements discussed above, wetsuits and boots should not be shared between several divers. Another reason for not sharing them is the potential transmission of skin diseases. It has been noticed that people have been contaminated while borrowing improperly disinfected suits. Thus each diver should be provided with a dedicated suit he is responsible for.
- Wetsuits must be kept in good condition. It is the responsibility of the diver to maintain his suit. During diving operations, wetsuits should be soaked with fresh water not over 40° C for at least 20 minutes, then be dried in a ventilated space that is not under the sun. Onboard electrical driers that are used to dry the clothes after cleaning must not be used as they work with too hot of temperatures.
- When the project is completed, wetsuits must be thoroughly disinfected with an appropriate product that does not damage the neoprene and be cleaned using warm freshwater, not over 40° C. They should be stored flat in a cool and dry place protected from the sunlight, chemical emissions, and exhaust emissions from vehicles that may damage the neoprene. Note that zips are sometimes fragile. They need to be inspected and then slightly greased. Damaged wetsuits should be repaired before being stored.

Note: * "hydromineral" refers to the balance of water and minerals (electrolytes) in the body, and ** "homeostasis" refers to the self-regulating process by which the body tends to maintain an equilibrium between interdependent elements.

2.7.3 - Drysuits

2.7.3.1 - Description

Wetsuits are designed to keep the diver warm through millions of gas bubbles in the suit's material (neoprene) that provide insulation even though the suit is relatively thin. Unfortunately, this protection is decreased by the effect of the pressure that crushes the bubbles as the diver descends.
A drysuit is designed to keep water away from the diver's body and replace it with air or a low thermal conductivity gas. Hence it must be sealed at the neck and wrists, and the zip that provides entry must be totally waterproof. Dry suits have proved their ability to keep a diver warm for more extended periods than wetsuits.
Some drysuits are made of neoprene. They provide insulation in 2 ways: Using the millions of bubbles inside the neoprene and the gas trapped in the suit.
Other drysuits made of nylon or composite materials are pretty thin (< 1 mm). These materials do not provide insulation. As a result, the diver must wear hot undersuits. This undergarment should be capable of trapping a lot of air within it. Synthetic fibres, wool, etc., are materials with many gas spaces and do not weigh too much. The more underwear the diver wears, the warmer the dive will be. Nevertheless, there is a limit due to the size of the suit.
Also, note that underwears add gas spaces that need to be compensated by more weight to submerge.
Incidentally, most divers using neoprene drysuits also wear undergarments under them, especially if they are diving in very cold waters.

Drysuits should be used when wetsuits are insufficient to protect the divers from the cold. Also, the advantage of dry suits is that they can avoid the use of bulky heating systems. For this reason, they are often used for short-duration air dives in cold waters. But because the protection offered by this type of suit is passive (there is no heat production), the diver may become hypothermic if the dive is too long or unexpected cold currents are encountered. Such cold currents can sometimes happen suddenly.
Note that specific drysuits must be used for diving in unhealthy surroundings (See in "diving accidents")

2.7.3.2 - Precautions when using

Diving using a drysuit requires much more training than diving in a wetsuit. The diving superintendent and the project manager must consider this safety aspect when selecting the team, as the divers must be familiar with this type of suit. Numerous accidents have happened with untrained divers, and the job site is not the place to teach about such equipment. Among the accidents that may occur, the following are the most frequent:

- As the diver descends, the suit can compress around the body, making folds. The skin can then be trapped and pinched into these folds, causing blood blisters along the body. The diver can control this phenomenon by

adding measured amounts of gas into the suit.
- During the descent, the gas added into the suit expands as the diver ascends. It can result in an uncontrolled ascent (blow up), with possibly pulmonary barotrauma, decompression sickness, or both. The gas expansion during the ascent is controlled using a purge valve generally installed on one arm.

2.7.3.3 - Maintenance

The maintenance of dry suits is similar to wet suits except for the sealing devices, the inflator, and the exhaust valve.
- During diving operations, wetsuits should be soaked with fresh water not over 40° C for at least 20 minutes, then be dried in a ventilated space that is not under the sun. Onboard electrical driers that are used to dry clothes after cleaning must not be used as they work with too hot of temperatures.
- After the dive, the suit must be thoroughly checked for damages:
    - Cuts and scratches must be evaluated and repaired if needed and possible.
    - The waterproof zip must be inspected and greased
    - Neck seals and wrist seals must be inspected. Some are made of neoprene, and others are made of rubber, depending on the suit. Also, wrist seals may be glued or secured to a ring using a rubber piece. The models installed on rings can easily be changed. Those that are glued need a more complex intervention rarely possible on the worksite.
    - The inflator and the exhaust valve must be visually inspected and be function tested.
- Preventive maintenance should be organized every month or at the frequencies indicated by the manufacturer.
    - Damages of the suit that could not be repaired during the operations should be resolved.
    - Neck seals and wrist seals that become old or are damaged should be changed.
    - If damaged, the waterproof zip must be changed. Regarding this point, this operation may cost more than the residual value of the suit.
    - The inflator and the exhaust valve should be opened, and thoroughly inspected for damages and corrosion. The suspicious parts should be replaced.
- When the project is completed, drysuits must be thoroughly disinfected with an appropriate product that does not damage neoprene and rubber clothes and parts and cleaned using warm freshwater, not over 40° C. They should be stored flat in a cool and dry place protected from the sunlight, chemical emissions, and exhaust emissions from vehicles that may damage the neoprene or rubber. Zips must be inspected and then slightly greased.

2.7.4 - Hot water diving suits

The diving suits previously described are "passive protection suits", which materials 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. Based on the fact 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, active protections suits are the most appropriate to work in cold waters.
Hot water suits are designed to provide "active protection" through a hot water flow transferred to the diver's suit by a specific hose. The hot water machines supplying the diver are installed on the dive station and specifically designed to provide a comfortable temperature that is continuously monitored, allowing the diver to work a long time.

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.
The hose delivering the hot water 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 be 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 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.

- The manifold must be easy to open and close, and the small tubes must be all in place and connected.

2.3.4.2 - 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.

2.3.4.3 - 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 made of heavy linen cloth are usually preferred. They can be suits 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, as already said for coveralls, they do not offer any extra buoyancy and passive thermal protection, which limits their usage.
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 usually more robust than classical coveralls made of cotton or other non-flammable fabrics. Nevertheless, they have, of course, the same inconveniences. For these reasons, neoprene hot water suits should be preferred when the conditions at the location are doubtful.
Also, linen clothes used for hot water suits are often more aggressive to wet skin than standard coveralls, and it is recommended to use soft under-suits to protect it. It is also recommended that these undersuits are designed to follow the body's shapes 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 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.

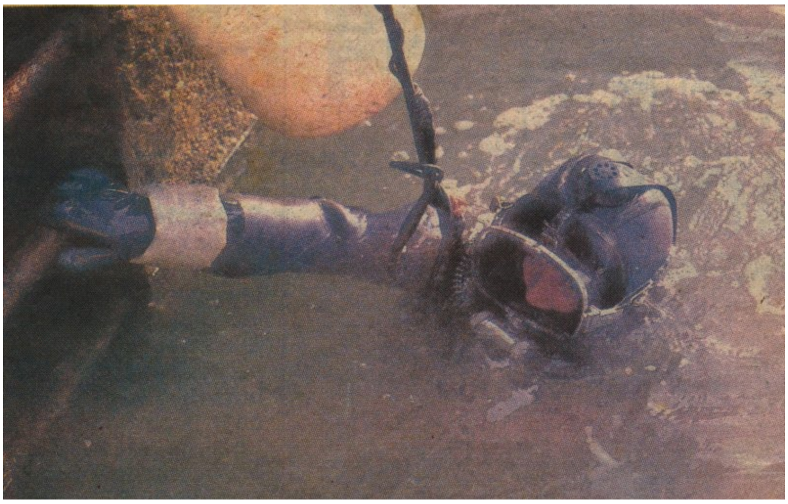
2.7.5 - Electrically heated diving suits

Another "active protection" system is based on insulated electric wire or heating elements that heat the diver when they are switched on. Thus using a similar principle as domestic heated blankets.

For a few years, several wetsuits manufacturers have increased their range of products by electrically heated underwear fed by batteries. However, far from some people's belief, this is not a new invention as such a system was already sold by the company “La Spirotechnique” under the brand “Chromex” in 1971 and used by many divers during the '70s and '80s. A description of this system allows understanding the models currently sold to scuba and rebreather divers.

2.7.5.1 - The Chromex system

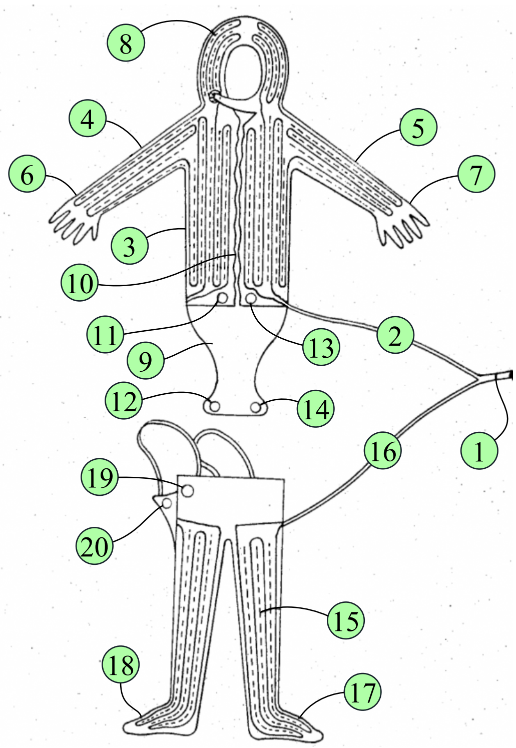
The Chromex heating system consisted of heating garments comprising conduits, each containing one or more heating elements. It was designed to be worn below the classical isolation underwear of wetsuits. These systems were often employed with integral drysuits designed by La Spirotechnique and known under the name “Phoque” (see the photo below), a version of which was also produced by Dragger company. Note that La Spirotechnique is today Aqualung.



The heating elements, which were flat to diminish the thickness, had an undulated configuration in a plane parallel to the fabrics between which they were disposed, so the developed length of a portion of a heating element was at least 1.5 times longer than the visible length of its support.
These heating elements were supported by the fabrics in between which they were laid, so they had a degree of freedom except at the points of connection to the feed source. This configuration prevented local stresses of the said elements when the suit was subjected to deformations, such as when it was donned on or removed and when the diver was swimming and working.
The 24 or 48 volts electric current was obtained from a generator or batteries. It was supplied inside the suit through the main cable, divided into two secondary lines with three conductors: One secondary line fed the jacket whereas the other one fed the trousers; one of the three conductors on each line connected the braids the heating elements to the earth.
Some batteries were designed to be arranged on the diver’s weight belt or harness.
The maximum power provided was 458 W. It was possible to diminish it by changing the fed voltage.

This underwear was presented as follows in the official patent document:

- The jacket was supplied with electricity by the cable #2 that was fed by the main cable #1.
- It comprised a jacket body # 3, sleeves # 4 & 5, gloves # 6 & 7, a hood or cowl # 8, and a flap #9.
- It was closed using a sliding clasp fastener #10, and the flap was closed by clasps #11, 12, 13, and 14.
- The pair of trousers #15 was fed with electricity by the secondary cable #16.
- It comprised shoes # 17 & 18. It was closed by plates having hooks and small loops #19 & 20.
- The upper portion of the trousers covering the jacket was not provided with heating elements, and the same applies to the flap of the jacket.



According to the divers who used it, this heating system was efficient. However, it had the inconvenience of generating unpleasant electric shocks during the dive when the garment started to become moistened due to the diver's sweating or water intrusions.
Due to these problems and the increasing comfort of heating systems using water, this product has been discontinued.
Patents related to similar heating systems have been published following the end of production of this product.

2.7.5.2 - New systems

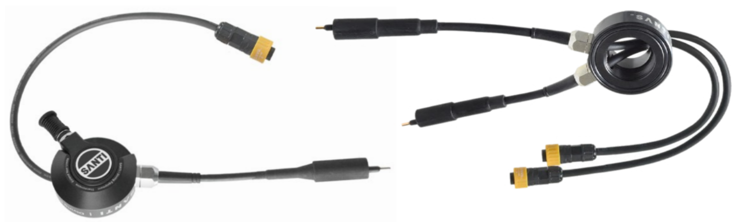
The systems currently offered by many manufacturers consist of undersuits composed of only a vest. However, some producers make integral heated undersuits like the one taken as an example in this presentation, which is fabricated by Santi, a company specialized in diving suits based in Poland (https://santidiving.com/).
Like the Chromex system, this undersuit is fed with electricity by an external battery canister. It is connected to the garment by a waterproof connector, which wire passes through a specific dry suit inflator.

The heating undersuit comprises an external abrasion and tear resistant polyester layer and a microfleece layer inside. It is designed to transfer the majority of the heat output to the diver's torso, back, and thighs.
The manufacturer recommends not wearing it on the naked body. Thus, this heating undersuit should be worn on the top of a thin form-fitting thermal wear.

The technical specifications indicated by the manufacturer are the following:

- A 12 volt / 24Ah battery provides electricity for 2:30 to 3 hrs heating
- A waterproof connector and flexible overheating resistant cables are used to connect the battery to the heating elements of the suit. The connector is integrated through the suit inflation valve (see the picture below).
- This battery is equipped with safeguards against excessive discharge, excessive charging, overload, and short circuit. The cord connector, piezo switch, and an overpressure valve are situated on the top section of the canister. A blue led indicates that the battery is activated. Also, a belt loop is provided on the side of the housing.
- The manufacturer indicates a maximum heating power of 110 W and a maximum temperature of 45°C. A safety switch prevents overheating and too elevated current.
- The manufacturer says that the heating wiring is arranged so that the diver's movements are not restricted. However, no more information is provided regarding this point.
- The heating undersuit provides sufficient isolation to keep the diver warm when the heating system is switched off.
- The manufacturer also provide heating gloves that can be connected to the system.

External lithium-ion battery



Inflators with one or two integrated 12 volts connectors

2.7.5.3 - Possible future utilizations

The systems currently on the market seem to have been developed for scuba and rebreather diving. However, although the system's electrical supply is presently done by battery, there should not be a problem adapting it to a supply bloc situated in the dive control room. Also, the battery of the system taken as a reference provides between 2 and 3 hours of dive time. Thus, nothing prevents using such a system for light operations in cold waters.
However, the fact that the manufacturer recommends not wearing this heating undersuit on the naked body suggests that the inconveniences reported with the Chromex system are not 100 % solved with these new products, which may limit their use to dives not requiring efforts.
There is, for the moment, no published data from commercial diving companies regarding the use of such systems for surface support diving operations to evaluate this last point.

2.8 - Diving harness

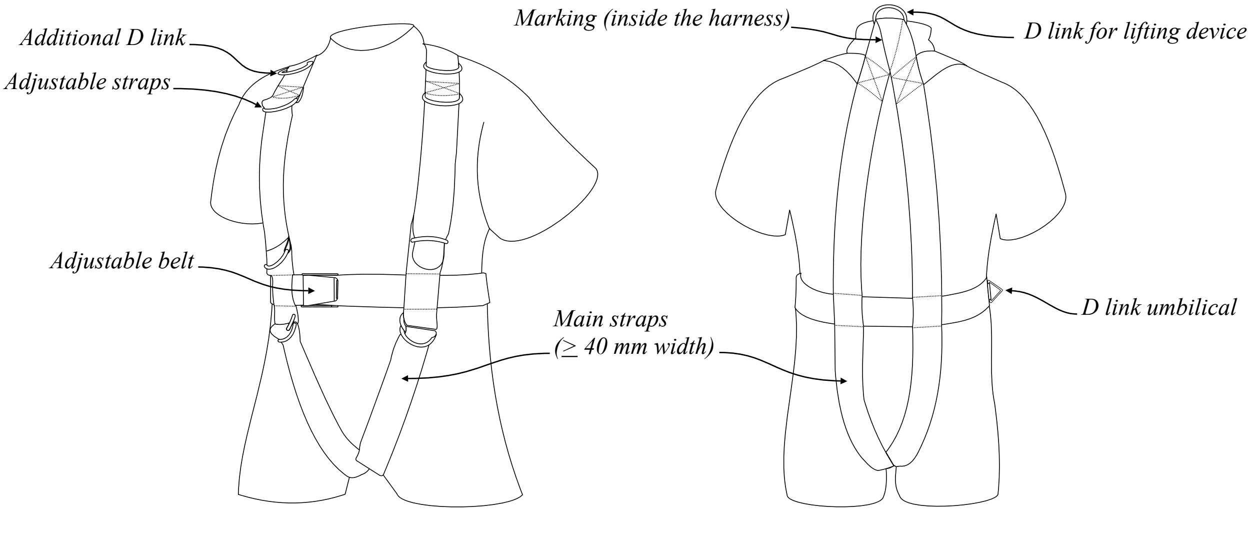
2.8.1 - Description

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 cm³).
- 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).

2.8.2 - 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

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

Only devices from recognized manufacturers are considered suitable.

2.9.1 - 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 basket/bell and several replacements must be available in the onboard store.

2.9.2 - Fins

Fins must be worn for all jobs that are not on the seabed. They should always be available in the basket/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.

2.9.3 - 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 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 trapezoidal medals installed at chest level are often used by divers using wet suits in addition to the weights described above.

Among the systems described above, belts remain the most used with commercial surface oriented diving. 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.

2.9.4 - 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.

2.9.5 - 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. For this reason, liquid filled compasses are recommended.
Note that a lot of diving compasses designed for recreational scuba divers can be used as they are sufficiently strong to withstand pressures up to 11 bar.

2.10 - Hot water machine

This point describes the machine that supplies hot water to the divers and is situated on the surface support. It is the continuation of the hot water suits discussed in point 2.7.
As already said, the temperature of the surface of the sea varies according to the location and the season, 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. These machines can be electrically or fuel-powered.

2.10.1 - Recommendation IMCA

Among the procedures published regarding these machines, those adopted by IMCA can be considered appropriate: 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).
- When the system is used to supply a closed bell, the supply to the bellman must also be considered as too much heat to the divers may deprive the bell.

IMCA D 023 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 in case of a breakdown. However, it is accepted that procedures to recover the diver to the surface and safely complete their decompression, such as surface decompression, can replace such an arrangement.
- 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.

2.10.2 - Description of a hot water machine

The machine used for this description is the electric water heater fabricated by Comanex (http://www.comanex.fr/), a well known company based in Marseille (France). It 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 a closed bell with three divers bell during extreme conditions. The manufacturer fabricates a smaller model, specifically designed for surface-supplied diving operations, but he explains that most companies prefer buying the model intended for closed bells because it offers more possibilities and a doubled reserve of heated water for a minimal price difference. That gives their teams more time to react if a problem is encountered. This Machine is designed as follows:

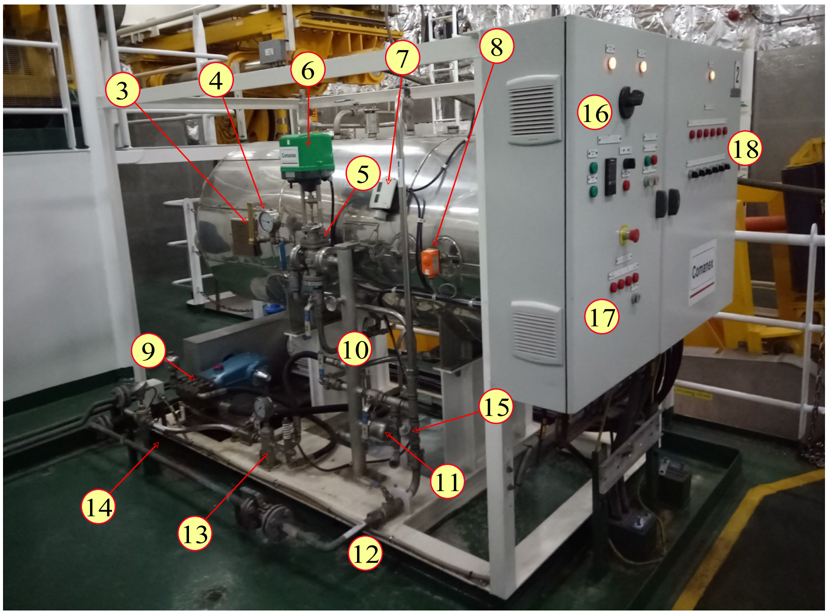
- The unit is composed of an isolated water tank of 830 litres capacity where the water is heated using six heat elements of 35 kW/h each (total = 210 kW/h). This tank allows regulation of the water temperature. Also, it stores sufficient hot water to supply the diver for 20 min in the case of a failure 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



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)

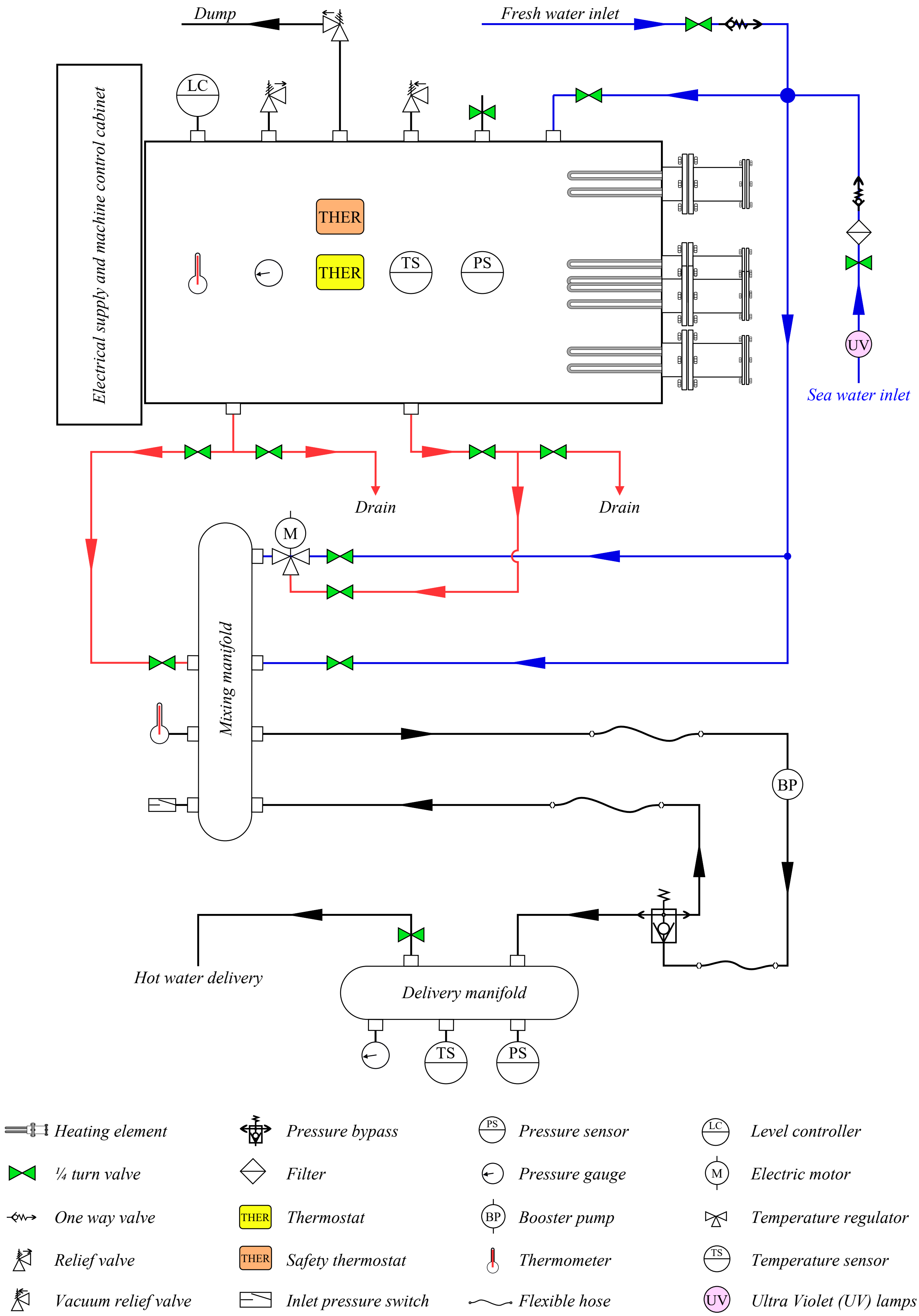
Control panels of the machines in the dive control:

- 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.

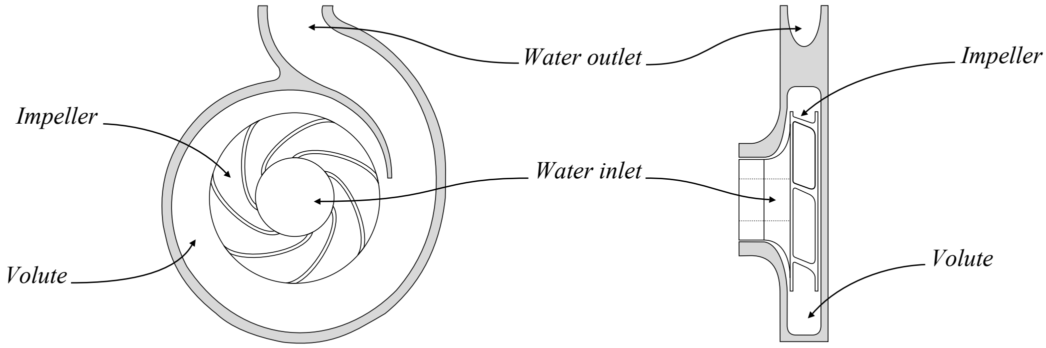
The elements of the machine described previously are more detailed on the scheme below.
Note that fresh water can be delivered to the hot water machine. However, fresh water is not used during the dives but mostly for the maintenance of the machine (Salt removal). Also, a Ultra-Violet (UV) light is added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



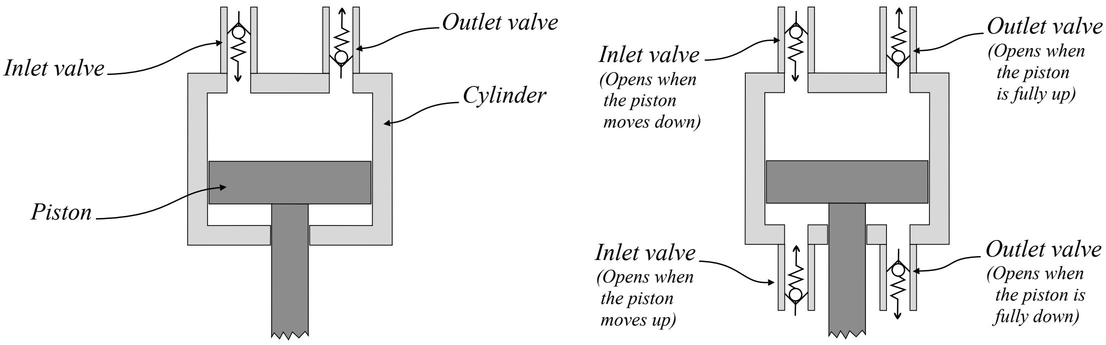
Important and not indicated previously: The control cabinet has a main and a backup electrical supply.

- 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)*

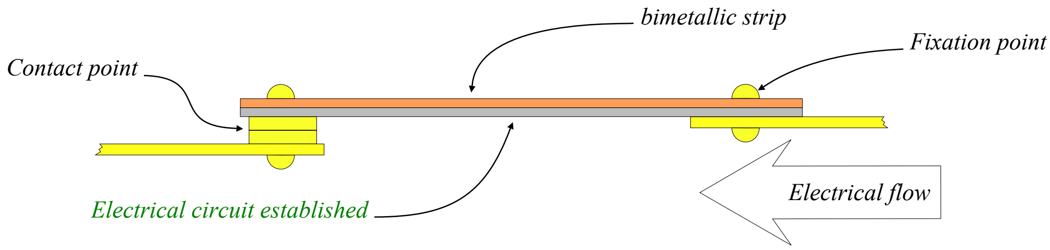


Single acting pump *Double acting pump*

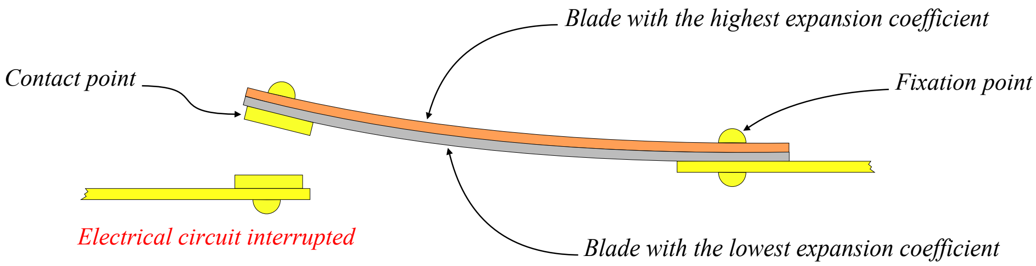
  The advantages of piston pumps are that they are less affected by variations of pressure than centrifugal pumps, they can deliver high pressures, and they are not affected by the heat. It is the reason they are also used with high-pressure water jets. Also, the pressure they deliver is not affected by 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.
  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.

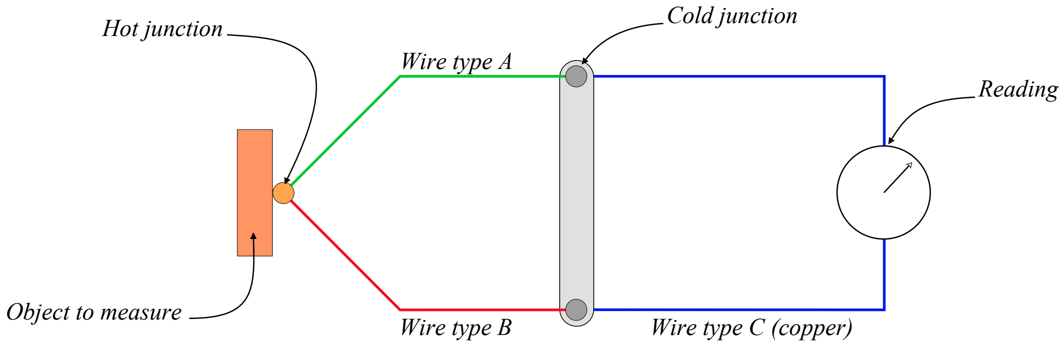
Electronic thermostats use the same principle, but they are controlled through a device called “thermistor”. A thermistor is a resistor that reacts on temperature. Thermistors are also used for electronic sensors. Depending on the application two types of resistors can be used:
With a Negative Temperature 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.

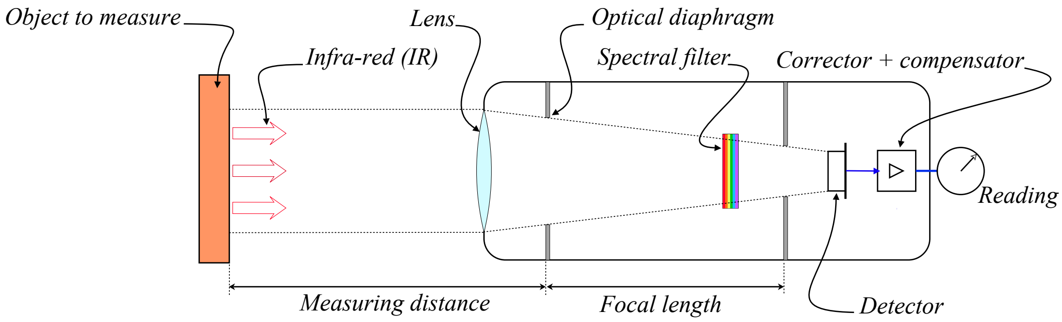
    The “bimetallic strip” system described above for thermostats is also used to design thermometers. In this case, the deformation of the blades, which is proportional to the heat, is used to display temperatures.

    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.

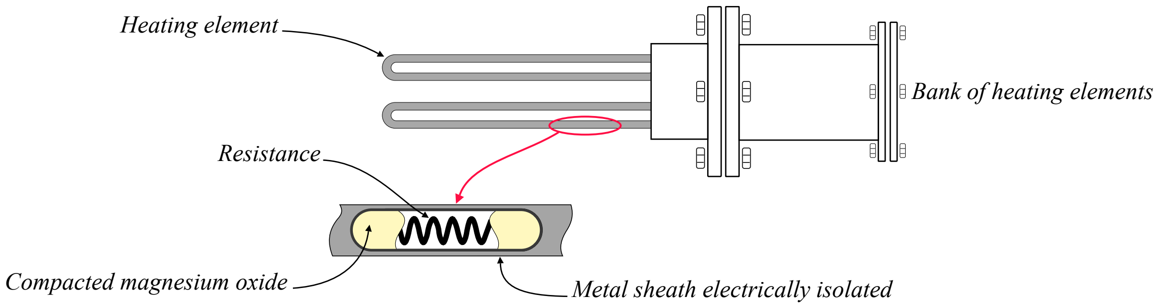


- A “resistance temperature detector” is a temperature sensor that contains a resistor that changes its resistance value as its temperature changes. The temperature sensor is made from a material whose resistance at various temperatures is documented and can be predicted. An electrical current is transmitted 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.



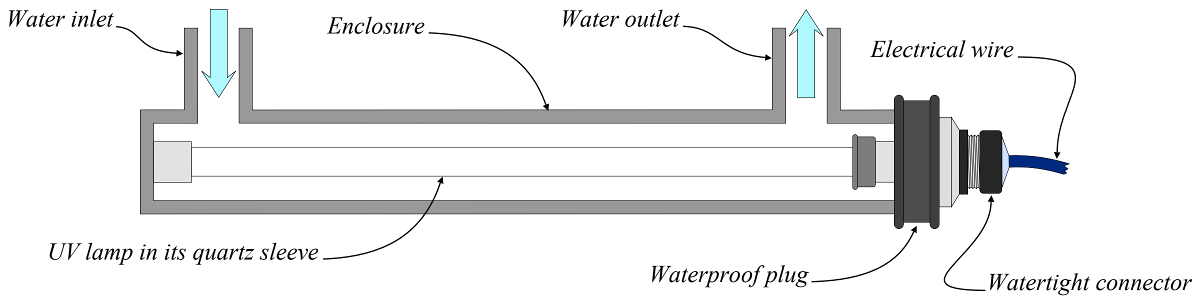
- Heating elements:
Electrical diving hot water machines use immersed heating elements that heat the water of a tank as it is the case with the Comanex machine taken as an example for this topic. The volume of this tank and the number and the power of the elements vary according to the design of the 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.

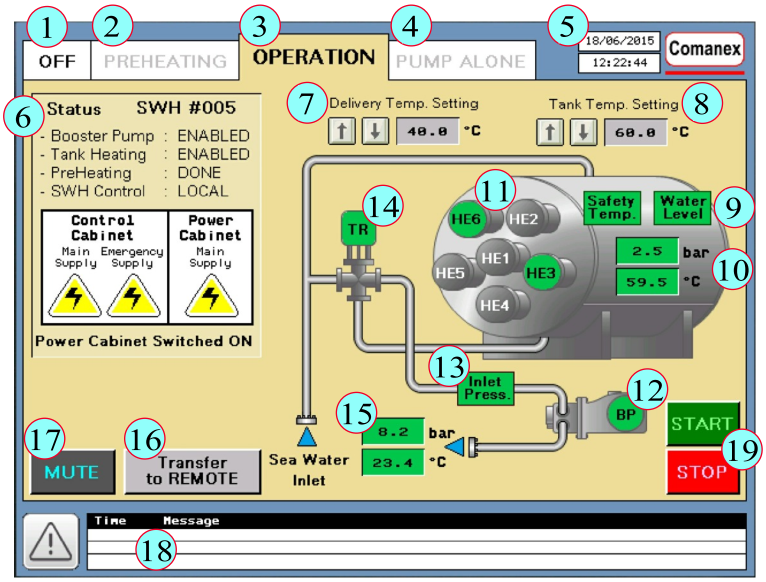
- It is true that it is possible to switch on or off some heating elements. However, in this case, the diving supervisor must ask the dive technician to do it from the panel of the machine where the six separate switches are installed *(See below and #14 in the photo of the machine on the previous page)*.
- 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)*

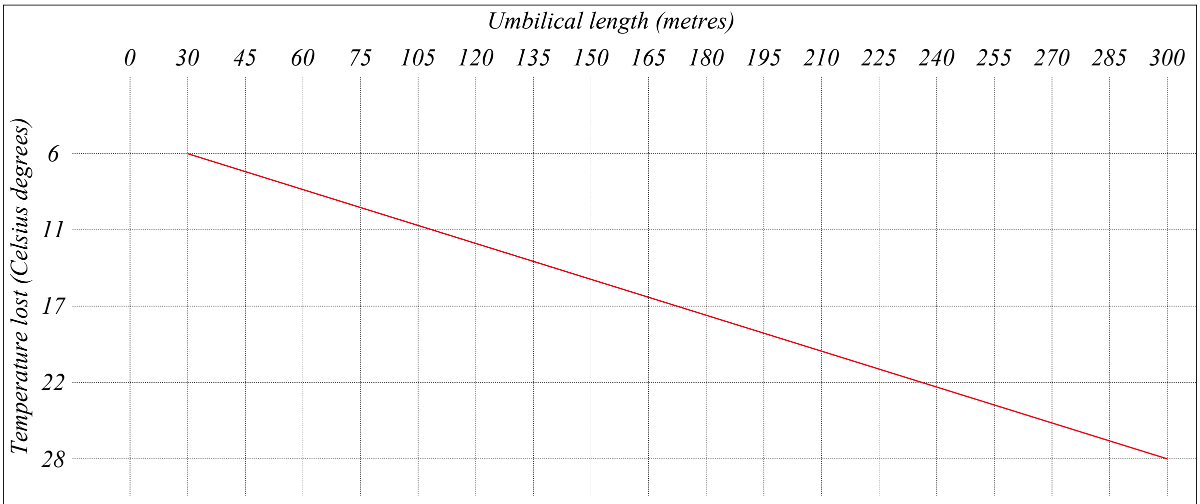
#15 - Temperature et pressure sea water inlet
#16 - Transfer to remote command *(activate the unit in the dive control)*
#17 - Alarm mute command
#18 - Alarm message records (time & description)
#19 - Machine start & stop commands

- 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.

2.10.3 - 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 - 5ºC (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 diver 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.

2.10.4 - 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 023 / 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 consist of extinguishers and fire lances. Deluge systems are sometimes installed.

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.

2.10.5 - 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 regularly.
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.

In addition to these recommendations, those from IMCA D 023, displayed below, should be taken into account.

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		

2.11 - Gas storage

2.11.1 - Purpose and minimum quantity of gas required offshore

Sufficient reserve of air, nitrox, oxygen and other therapeutic gasses is necessary to pressurize the chambers of the diving system and supply the divers with a suitable breathing gas. These gasses are usually stored in adequate containers from which they are regulated down to obtain the relevant delivered pressure. Also, low pressure compressors can be used to supply air divers, which gives the advantage of minimizing the reserves of High Pressure (HP) air to a minimum.

IMCA D 050 is a guideline that sets up the absolute minimum amount of emergency breathing medium (air or mixed gas) required to be kept at an offshore dive site before and during the dive.
This document is not perfect, as demonstrated in the "Diving management study CCO Ltd #7". However, it is today the reference in force that is the most used by the manufacturers, companies, and clients. It provides the following recommendations, which are reinforced here according to the "Diving management study CCO Ltd #7" recommendations. Note that this guideline classifies the gasses into two categories:

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

Note that backup supplies must be immediately available. Also, a gas container at less than 20 or 30 bar pressure cannot be considered part of the reserve.

- Consumable gasses:

- Sufficient gas should be provided for two dives that include the bottom time and decompression, based on a breathing rate of 35 l/min at work & 25 I/min at rest.
- Sufficient gasses to compress both chamber's locks to the max. surface deco depth + three (3) surface decompression cycles per chamber. The surface decompression cycles include the full compression and decompression of the chamber + the gas used for flushing. Note that 20 - 25 l/min is the breathing rate.
- Soda lime and Purafil for 3 surface deco. dives + the longer therapeutic treatment planned + the same quantity as a reserve.
- Sufficient quantities for the calibration processes of analysers recommended by the manufacturer for the entire duration of the project + the same quantity as a reserve.

- Reserve gasses:

- Sufficient gas to pressurize both locks of each Deck Decompression Chamber (DDC) to the maximum possible treatment depth for two treatment dives + 90m³ Oxygen. Also, plan for sufficient gas for 3 decompression of medics and 3 compressions of the entry lock.
  If a heliox table such as COMEX 30 is used: add 90 m³ heliox 50/50 and 90 m³ heliox 20/80.
- Diver personal gas reserve (Bailout): 10 m/min of umbilical deployed from the surface (basket) or the wet bell at a breathing rate of 62.5 l/min.
- Diver rescue air or nitrox: Two dives of 30 min bottom time to the maximum intended diving depth at a breathing rate of 62.5 l/min.
- Sufficient wet bell / basket gas reserve to recover the divers safely from the longest and deepest planned dive at a breathing rate of 62.5 l/min.
- Dive crew emergency air to evacuate the area at a breathing rate of 62.5 l/min.
- Oxygen to transfer the divers to the facility at a breathing rate of 62.5 l/min.

2.11.2 - 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.	Optional for compressed gases	50L

Description	Status	Example of sign
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
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 023 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.

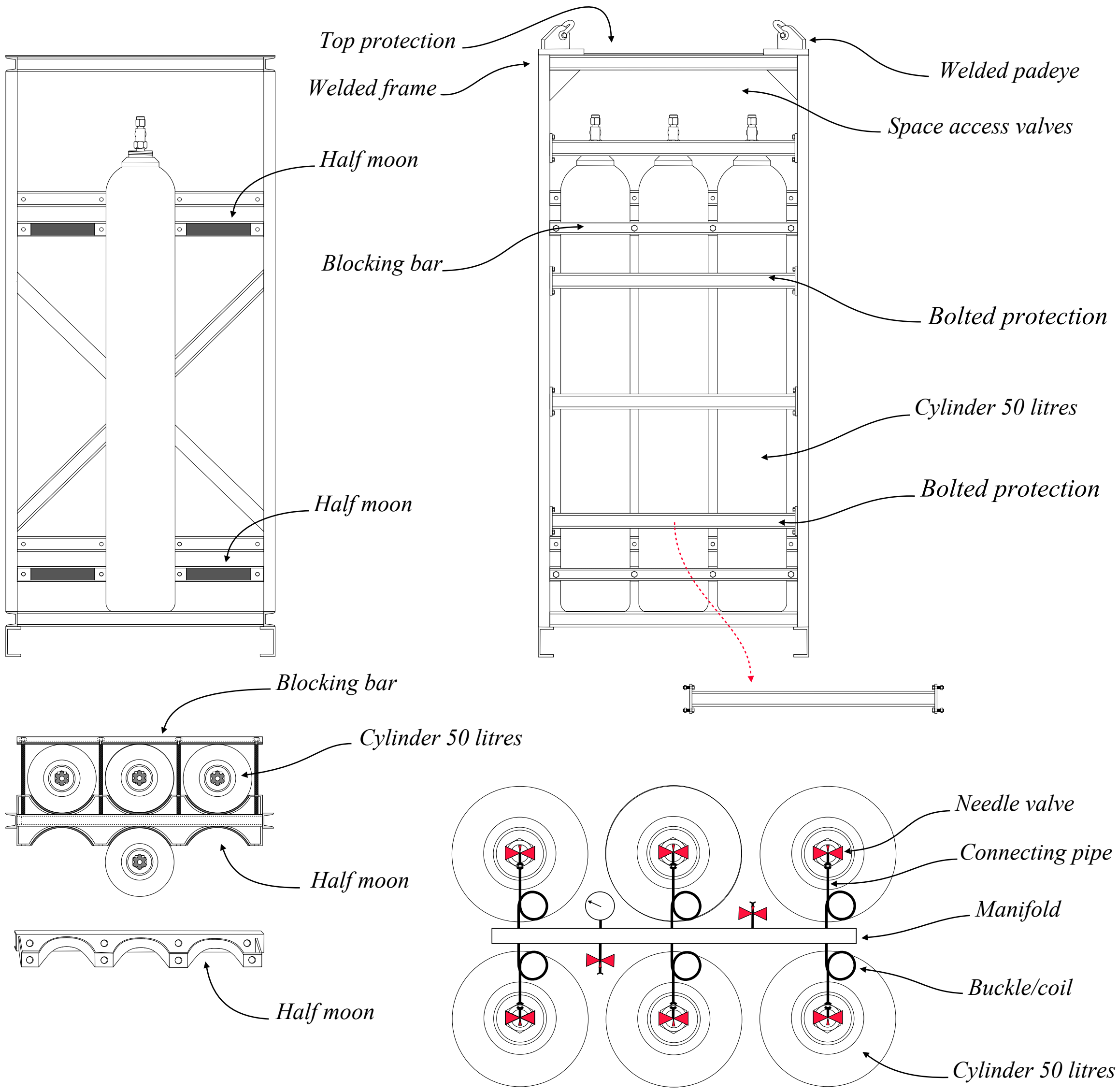
Guidelines for the tests and the inspection of these devices are also provided.

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.

2.11.3 - 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	*O_2*	*White*	*White*
Heliox	*HeO_2*	*Brown & white bands or quarters*	*Brown & white alternating bands 20 cm*
Nitrogen		*Black*	*Black*
Trimix Helium + Nitrogen + Oxygen	*HeO_2N_2*	*Black +white +Brown bands or quarters*	*Brown, white & black alternating bands 20 cm*
Air or Nitrox	*N_2O_2*	*Black & white bands or quarters*	*Black & white alternating bands 20 cm*
Carbon dioxide	*CO_2*	*Grey*	*Grey*
Calibration gas	*As appropriate*	*Pink*	*Pink*

IMCA D 049 also say the following:

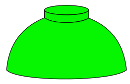
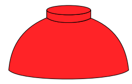
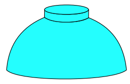
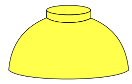
- Gas containers should be marked with the chemical symbol of the gas they contain, and the percentage of mixtures, quoting percentage of oxygen first. Also, their maximum working pressure should be highlighted.
- When the Multiple Elements Gas Container (MEGC) comprise cylinders containing different 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*	

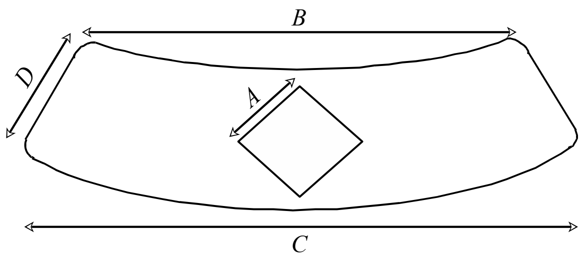
As a complement of the colour codes, precautionary labels should be attached and maintained so that they are clearly visible and legible for as long as the cylinders remain in the same gas service.
The purpose of precautionary labels on gas cylinders is to facilitate the identification of each cylinder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

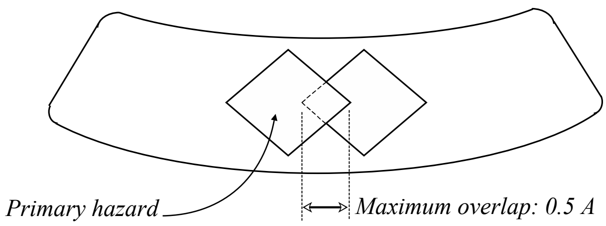
- Name of the gas or gas mixture
- Danger or Warning: International Maritime Dangerous Goods Code symbol and class for hazards *(see below)*
- Hazard statements
- Handling instructions
- Supplier identification and contact numbers

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

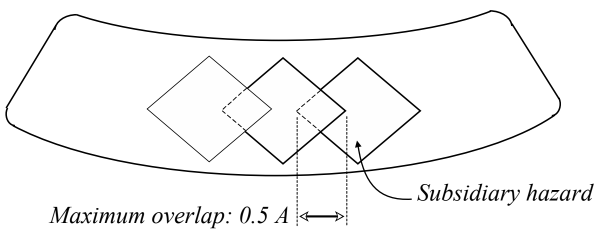
- UN number
- Chemical formula
- First aid advice
- Hazard chemical number
- Emergency respondent’s contact detail

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*



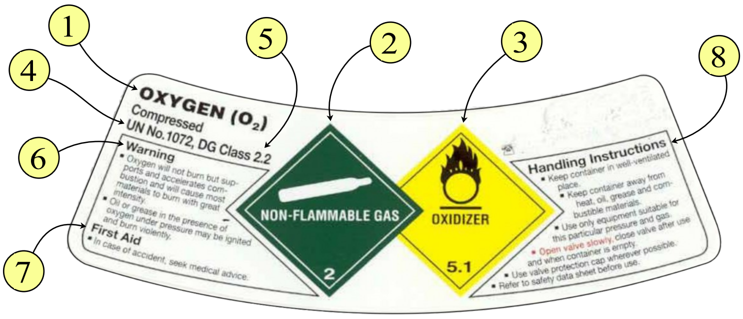
International Maritime Dangerous Goods Code classifies the hazards into the nine main classes displayed below that are also divided into sub-classes according to their characteristics - Note that gasses have three sub-classes:

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.



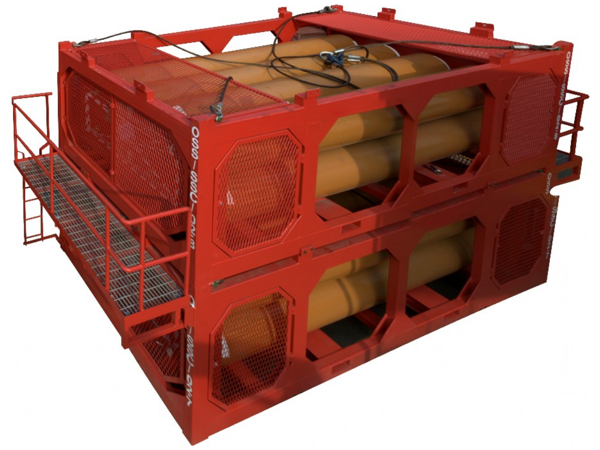
Number	***Information***	***Number***	***Information***
1	*Gas & formula*	*5*	*Primary hazard class*
2	*Primary hazard*	*6*	*Hazard statement*
3	*Subsidiary hazard*	*7*	*First aid advice*
4	*UN number*	*8*	*Handling instructions*

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.

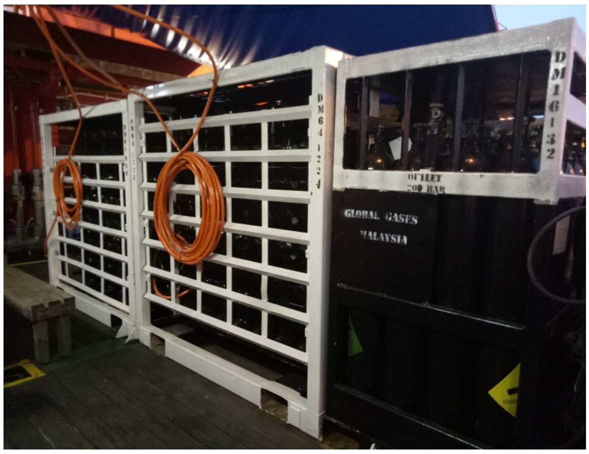
The super-quads above are examples of colour coding and content identification that can be encountered on worksites. Note that the words “Diving quality” recommended by IMCA D 049 are missing.
Also, IMCA D 049 says that when the cylinders or tubes are completely encapsulated within the framework and 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)*

2.11.4 - Storage and distribution of the gasses

Depending on the nature of the gas and whether the diving 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 surface supplied diving 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 centre 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

Built-in systems may be supplied with gas from kelly tubes installed in dedicated rooms situated on one of the lower decks. The gas is usually delivered through interconnected panels. On many boats equipped with a saturation system, These gas reserves are often stored with those dedicated to saturation diving. In this case, the tubes dedicated for surface supplied diving are identified and are managed by the life support technicians in charge.

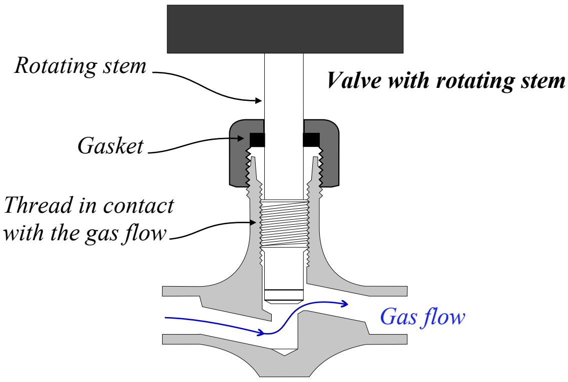
Oxygen and mixes considered as pure oxygen must be stored in open and well-ventilated areas that are clear of any fire hazard. For this reason, they are usually stored in a protected area of the deck away from potential hazards, and which access can be restricted, so the authorized personnel can work undisturbed and safely, and the gas containers cannot be operated by non-authorized people. Note that official bodies like the US Navy say that the threshold to consider mixes as pure oxygen is when it is over 25% O_2. However, this value has been reviewed by many safety organizations and statutory instruments that recommend lower values. Some of these values are listed below:

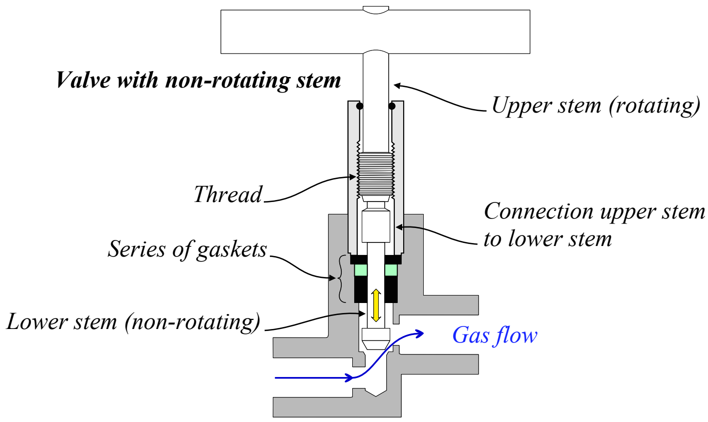
Organization	***O2 limit***	***Reference documents***
European standards	*22%*	*EN 12021 - 2014*
US Navy	*25%*	*Mil-Std-1330D*
ASTM international (American Society for Testing & Materials)	*25%*	*G126, G128, G63, G94*
NORSOK	*22%*	*NORSOK Standards U100*
U.S. Compressed Gas Association (CGA)	*23.5%*	*CGA Pamphlet 4.4*
OSHA (Occupational Safety & Health Administration) - USA	*23.5%*	*29CFR1910.134*
OSHA (Occupational Safety & Health Administration) - USA	*40%*	*29CFR1910.430*

A quick analysis of these standards suggests that the European value is the most stringent, explaining why it is adopted in many countries and in this handbook.
Oxygen, and mixes considered pure oxygen 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.
Note that the fact that OSHA standard 29CFR1910.430 is in force in the USA explains why many diving apparatus built in this country are rated suitable with nitrox up to 40% oxygen.

Air, nitrox and heliox is commonly distributed through 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 often used for gasses other than oxygen, nitrox, or enriched heliox. It 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 many diving systems, and valves and connectors are usually made of bronze or brass. Pipes of ½ inch diameter are commonly used.
Note that copper was used on previous generation systems. However, this metal has the inconvenience of oxidizing, causing it to become black, and finally green. This green corrosion changes in a fine powder that can ignite oxygen and clog the filters. For this reason, this metal is no longer used for oxygen piping.

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 22% - 25% 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.





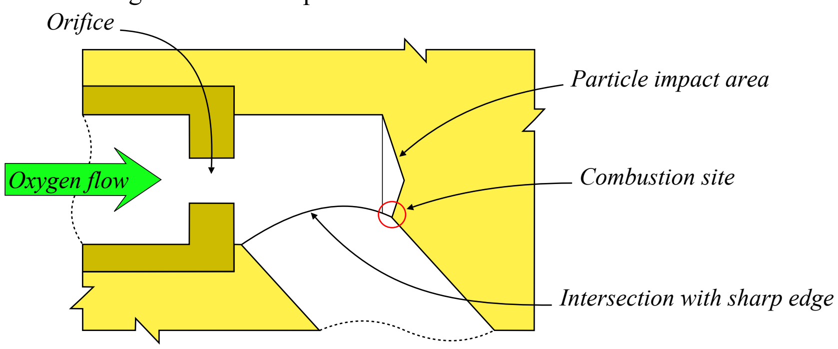
In addition to the recommendations above, note that IMCA D 023 says: *"When the oxygen or mix containing over 25% oxygen is regulated down to below 15 bar (225 psi), then quarter turn valves may be used as emergency shut off valves, provided they are clearly marked as such, and lightly secured in the open position during normal operations"*. Note that this rule is in force with many other organizations and is sometimes more stringent. It is the case with OSHA 29 CFR 1910.430, which says that oxygen systems over 125 psig (8.6 bar) and compressed air systems over 500 psig (34 bar) must have slow-opening shut-off valves. For this reason, the 2nd part of the text in point 8.5/section 2 of IMCA D 023 that says that quarter turn valves can be used up to 20 bar can be used, provided that a risk assessment is performed is not to be considered suitable. Another objection to this text is that it does not indicate who performs this risk assessment and evaluates the risk of explosion.

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

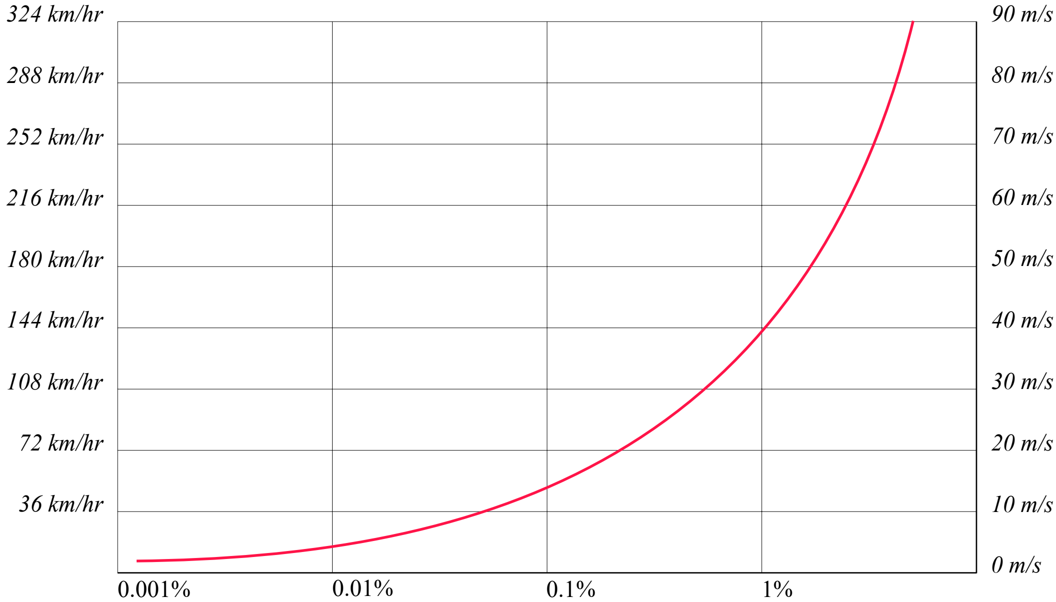
- Thermoplastic hoses are usual for the transfer of heliox, air, and calibration gasses. They are commonly made of non-toxic polyester with a reinforcement of aramid fibre braid and an external layer of polyurethane or similar material. However, such hoses are not oxygen compatible.
- ASTM says that 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% O2, depending on the standard used)* so they cannot be confused with other hoses.

The use of heat-resistant and not igniting materials is insufficient to protect the oxygen distribution system, and competent bodies such as ASTM say that a bad design can result in particles entrained in the flow stream being accelerated through orifices and impacting blunt surfaces downstream, so their kinetic energy is converted to heat.
In addition, dead-end parts exaggerate the problem by concentrating the heat from multiple burning particles, and sharp edges from intersections allow a kindling chain that can promote combustion.

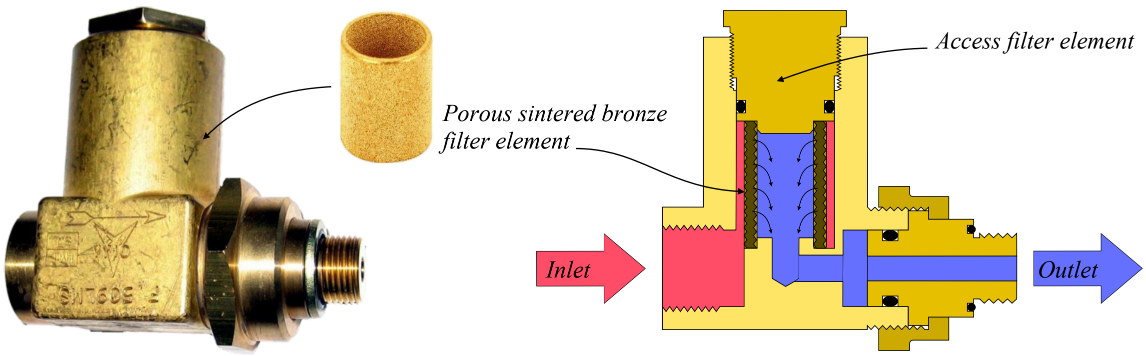


For these reasons, the piping system must be designed to eliminate particle impact ignition sources by limiting the gas velocity, minimizing contamination, reducing the potential for particle impacts on blunt surfaces, and avoiding burrs and small parts often susceptible to ignition.
Limiting the flow velocity minimizes erosion, reduces particle energy, and reduces the risk of particle impact ignition. It can be done by an appropriate configuration, considering that small pressure differentials across components can generate elevated gas speeds. For example, the table below from ASTM shows that a difference of only 1% initiates a flow of 40 m/s (144 km/hr). Note that start-ups or shut-downs are known to create gas velocities higher than those experienced during steady-state operations.



Based on the elements highlighted above, numerous areas of the piping system can trigger fluid acceleration, such as valves, regulators, and pipes connections. Even though the design can minimize it, the flow velocity is often high in these sections. For this reason, it is accepted that high-velocity and turbulent gas streams may be present, provided that the gas velocity is calculated to be acceptable, and the affected sections are designed to avoid particle impingement and reinforced with materials resistant to ignition by particle impact.
The risk of particle impact ignitions can be reduced by potential impact surfaces designed with small oblique angles to reduce the kinetic energy absorbed by the impact surface. In addition, the design should minimize particulate generation and accumulation. Thus, unnecessary sumps, blind passages, crevices, dead-ends, and cavities likely to accumulate debris should be avoided. Regarding this point, please take into account that threaded connections can also generate and collect undesirable particles, so their usage should be avoided or minimized. Of course, burrs and sharp edges that can ignite particles should be eliminated, and internal connections should be smooth.
Filters are commonly used to capture system particulates. They should be installed immediately upstream of the high-velocity areas, downstream of points where particles are likely to be generated, so where the presence of particles produces a risk, such as gas supply points, disconnect points, valves, and regulators.
ASTM says that these elements should not be fragile or prone to breakage. Thus, they should be able to withstand the full differential pressure that may be generated in case of clogging. Also, they must be made of burn-resistant materials because they may be exposed to flammability due to the debris collected on their surface area.
The filters commonly found on diving systems are made of bronze powders shaped using appropriate molds and then controllably fused to cause the metal to diffuse without becoming dense and solid. They have pores whose size usually

varies from 1 to 100 microns, and are installed in specific housings located on the sensitive areas indicated above.
Note that they must be verified and changed out regularly, so they must be included in the planned maintenance system. This operation usually requires depressurizing the entire line. The housings are typically provided with a threaded plug that allows accessing the filter easily and quickly if the housing is correctly installed.
Note that some diving systems are provided with a lot of units that must be highlighted to locate them quickly.



2.11.5 - Standardization of the connecting hoses and precautions for implementing them

The flexible hoses used to connect quads and tubes to the system should be standardized, so only a few model of hoses are used. 3/4" and 1/2" JIC connectors are commonly found. However, some company use different connection sizes or types to avoid connecting inappropriate hose by mistake. As an example, the oxygen 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"*.

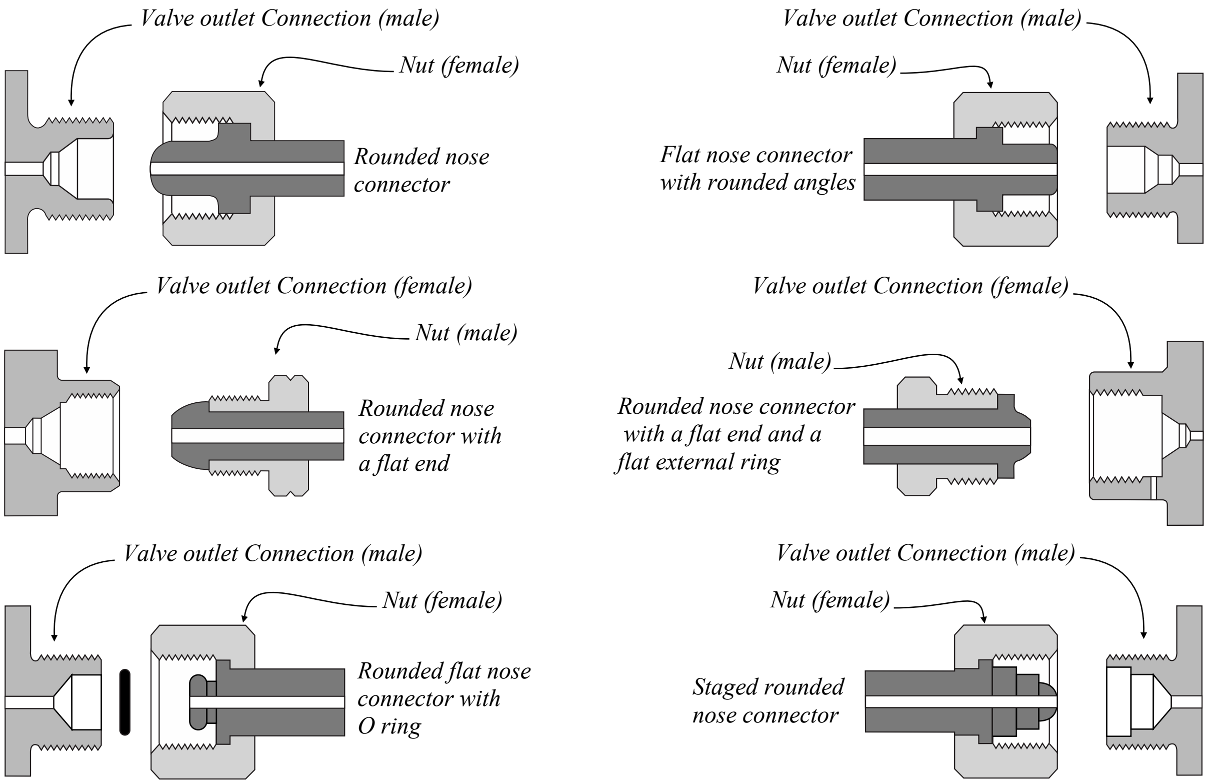
The ISO guidelines above are also explained with comparison with European and other international standards in the diving study CCO Ltd #2 *"Organize the maintenance of diving cylinders"* that is free of charge.

The gas reserves may have to be topped up from external gas containers. Also, empty gas cylinders in use may have to be replaced by new ones. It usually happens with those filled with oxygen. That can be a problem if the outlet connections of their valves do not correspond to those that are available onboard the diving vessel. Opposite with diving cylinders that are today limited to a few outlet connections, there are infinities of models of valve outlet connectors for gas cylinders and tubes, which usually are not compatible with each other, as a lot of countries continue using their national standards. 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*

Country of origin	*Air connectors*	*Helium connectors*	*Mixed gas connectors*	*Oxygen connectors*
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.



Essential precautions to be implemented:

- Breathing air containers can be stored in a specific room, the dive control, or the chamber room. An essential rule for gas containers installed in an enclosed space is that gas venting exhausts should not be situated in such a space. For this reason, hoses must be installed to vent gasses outside the room. The exhausts should be in an area far from where people are at work.
- 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 supports is too long and that the hose may be damaged at the supporting points. For this reason, this distance should be reduced to less than one metre.
- A ruptured flexible hose can move erratically and injure people at its proximity. For this reason, flexible hoses should be provided with a rope or a cable dedicated to preventing them from moving apart in case of a rupture. That is usually done with ties approximately every 20 cm. Note that grouped lines can be attached to a single rope or cable. Also, this procedure should apply to high-pressure hoses and low-pressure hoses. That is linked to the fact that the phenomenon that makes a ruptured hose move erratically is related to the volume of gas running out. That explains why high-pressure hoses are considered more dangerous. However, a large diameter low-pressure hose carrying a high airflow must be regarded as similarly hazardous.

2.11.6 - Maintenance

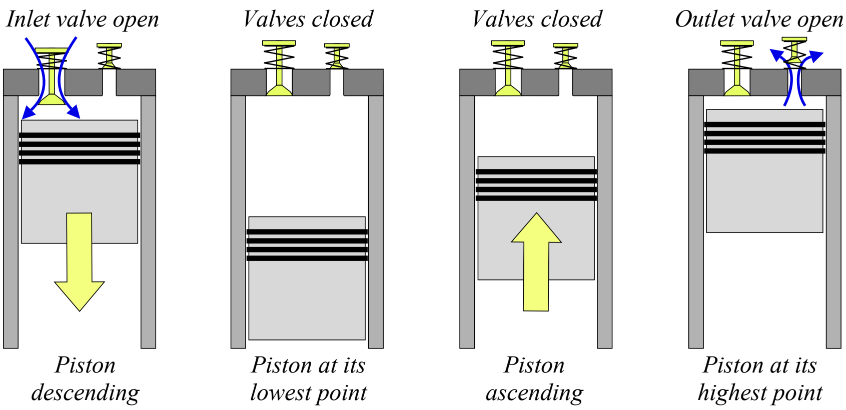
IMCA recommendations can be considered among the most suitable regarding the planned maintenance of gas storage and pipework.
However, note that this part does not include the maintenance of regulators that is discussed next.

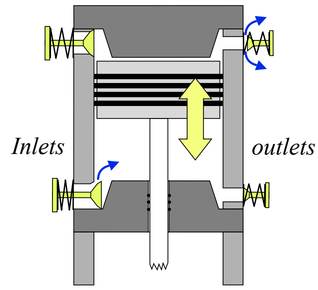
Items	*Visual external + function test , calibration or for lifting appliances: Load test 1.25 SWL*	*Visual internal + external + leak test at max. Working pressure*	*Internal + external+ leak test 1,5 max. working pressure or for lifting appliances: Load test 1.5 SWL*	*Other*
Cylinders	6 months	2 ½ years		Internal & Ext. Exam. + test max work. 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	
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			

2.12 - Compressors

2.12.1 - Reciprocating piston air compressors

High pressure and low pressure piston compressors are commonly used for air diving. Most compressors in service are multiple stage piston compressors. The working principle of a piston compressor is that the air is drawn into a compression chamber that is composed of a cylinder in which a piston is moving by the action of a crankshaft. This chamber is closed and opened using valves. The inlet valve is opened when the piston descends, and the volume of the chamber increases. Then the suction valve is closed, and the piston returns to the top, decreasing the volume of the chamber and therefore increasing the pressure of the trapped air. The outlet valve is opened when the piston arrives at the top and the air is discharged.





Some compressors have valves on both sides of the pistons

Valves can be of several types:

Poppet valves can be illustrated by the scheme above. They are maintained closed by dedicated springs.

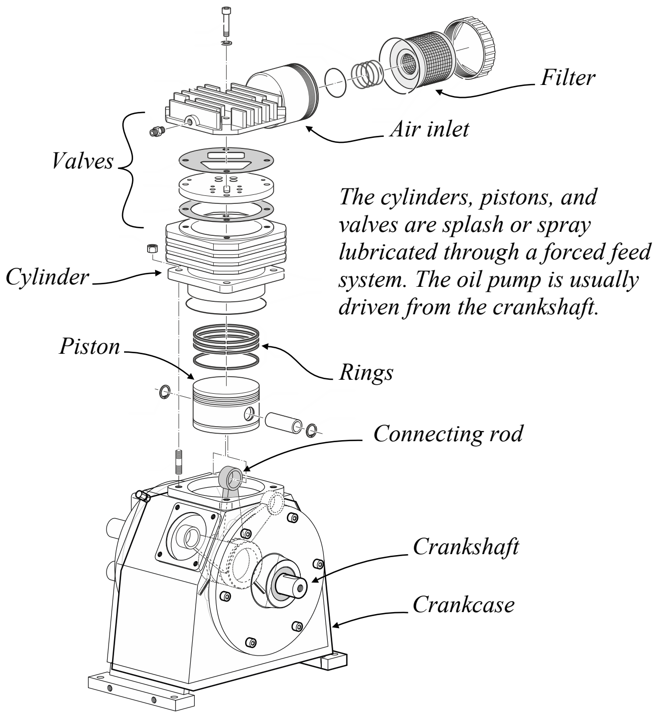
Ring valves consist of a plate with slots of concentric circular shape, which are connected by bridges. The free ring areas are sealed by non-metallic rings, which are held against the seat by coil springs (which in turn are enclosed on the circumference by spring pockets).

https://www.arielcorp.com/

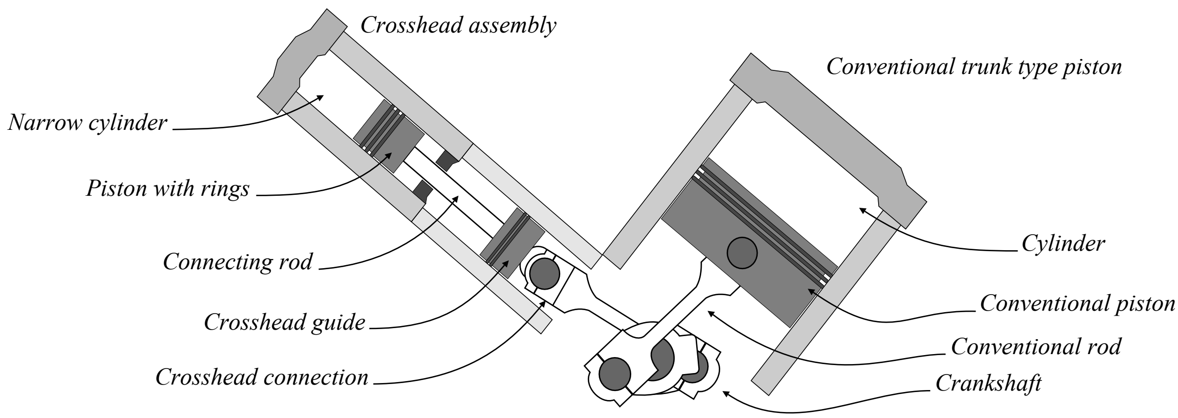
Plate valves consist of seat ports that are closed by a flexible steel or non-metallic material plates. Suction and discharge valves are of the same basic design and only differ with the location of seat and guard in relation to the working chamber.

https://m.made-in-china.com/

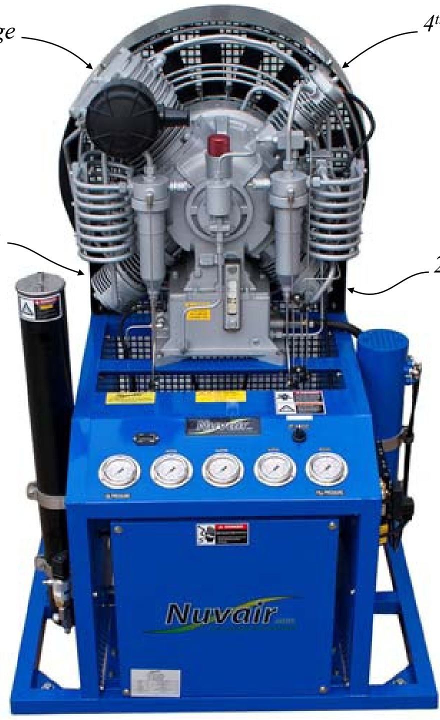
Others systems can be used.



Note that high pressure reciprocating compressors are often provided with a crosshead assembly. The purpose of this mechanism is 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 should not be possible with a conventional piston assembly.



A multiple-stage compressor uses several cylinders to obtain the final pressure: Thus, it pumps up the air at atmospheric pressure and compresses it in the 1st cylinder to obtain a more elevated pressure, then it uses a second cylinder with a smaller diameter to pump the compressed air from the 1st cylinder and compress it to a higher pressure. This cycle may continue with other cylinders, depending on the pressure to obtain. This is achieved with a determined compression rate. As an example, for a four stage compressor that is designed to deliver 360 bars, the air may be compressed to 5.625 bar at the first stage, from 5.625 to 22.5 bar at the second stage, from 22.5 to 90 bar at the third stage, and from 90 to 360 bars at the last stage.
The air is usually cooled in between the stages with an intercooler. This device is a small tube that runs from one head to another or to one side of the head to the other. Sometimes there is a full heat exchanger, that looks like a radiator.
Note that multiple-stage cylinders compressors must not be confused with one stage compressors with multiple cylinders used to compress LP air. A multi-stage compressor has cylinders of different volume. At the opposite, a compressor with multiple cylinder of the same volume is a one stage compressor.

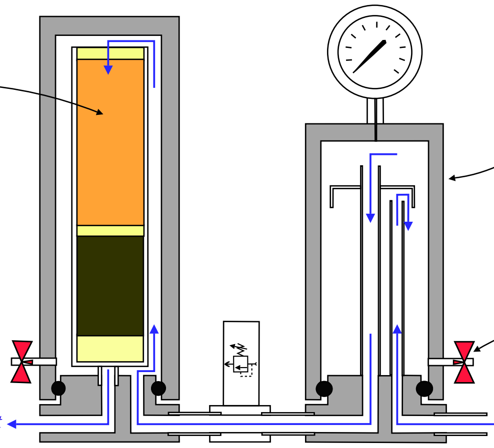


MCH36 vertical electric Nuvair (https://www.nuvair.com)

Modern divers breathing air compressors are designed to deliver breathing air that is in accordance with the European standard EN 12021 or another recognised standard. This is achieved by the use of separators and filtering elements. The separator removes the excess water and a part of lubricating oil from the air. The mix of water and oil that is commonly called "condensate" is periodically drained outside the separator by the means of manual (typically every 15 minutes) or automatic drain valves. Then the air is filtered through a filtering element.
The filtering element is composed of:

- a molecular sieve that absorbs the remaining water and oil,
- a particle filter that holds impurities,
- an activated carbon layer that removes the organic impurities such as oil vapours and hydrocarbons.

The size and the number of filter elements depend on the volume of compressed air to filter and of the final quality desired. The filtering element(s) must be periodically changed.



The European standard EN 12021 recommends two air standards: "Breathing air" and "oxygen compatible air". The standard for "breathing air" below is suitable for air diving only. It indicates the maximum carbon dioxide, carbon monoxide, oil, and water content values. The values for water are displayed in a separate table *(see on the next page)*.

Component	*Concentration at 1013 mbar & 20 °C*
Oxygen	*21% (± 1%)*
Carbon dioxide	*≤ 500 ml m³ (ppm)*
Carbon monoxide	*≤ 5 ml m³ (ppm)*
Oil	*≤ 0.5 mg m³ (ppm)*

Composition of breathing air EN 12021

Nominal maximum supply pressure (bar)	*Maximum water content of air at atmospheric pressure and 20 °C (mg m^3)*
40 to 200	*≤ 50*
> 200	*≤ 35*

Water content of high pressure breathing air - EN 12021

Nominal maximum supply pressure (bar)	*Maximum water content of air at atmospheric pressure and 20 °C (mg m^3)*
5	*290*
10	*160*
15	*110*
20	*80*
25	*65*
30	*55*
40	*50*

Water content for supplied breathing air up to 40 bar - EN 12021

Regarding water content, note that the document DMAC 19 says that a higher level of water vapour in breathing mixtures is not detrimental to the health of divers and is beneficial to their respiratory system. An example of the practical application of this concept is breathing mixture which is voluntarily humidified to achieve a high water vapour content, administered to hospital patients. Thus, the reasons for minimizing water content are to limit the number of foreign particles in the breathing gas and that too much moisture in the breathing circuit may cause malfunctions when diving in cold waters.

Operations may be performed in countries where European standards are not in force. The US Navy standard (see below), or CGA grade E (which is similar to the US Navy), are often, but not always, the references in such countries:

Constituent	***Specification***
Oxygen	*20 - 22%*
Carbon Dioxide	*1000 ppm (max)*
Carbon Monoxide	*10 ppm (max)*
Water	*24 ppm or .019 mg/L (max)*
** Total Volatile Organic Compounds (in methane equivalents)*	*25 ppm (max)*
Condensed Oil and other Particulates,	*0.005 mg/L or 5 mg/m 3 (max)*

Notes regarding Volatile Organic Compounds:

1. *Specification is 25 ppm in methane equivalents when measured by a laboratory-based flame ionization detector (FID) calibrated with methane and methane excluded.*
2. *Specification is 5 ppm in n-hexane equivalents when measured by a laboratory-based (FID) calibrated with n-hexane and methane excluded.*
3. *Specification is 10 ppm as measured by other portable photoionization detector (PID) containing a 10.6 electron volt lamp and calibrated with isobutylene (includes GEOTECH Dive Air 2 Portable Air Monitor).*

U.S. Navy Diving Breathing Air Requirements

Diving organizations suggest mandatory safety devices. However, these requirements are a minimum, and most compressor manufacturers provide systems allowing better control that should be installed.

- Solenoid switches may be fitted to automatically stop the compressor if it overheats or malfunctions. An alarm for this may be fitted in dive control. However, such systems are not mandatory with IMCA or ADCI.
- Any compressor used for gas transfer and not intended for use with gases containing over 25% oxygen should be fitted with a protective device that shuts the compressor down if the oxygen percentage entering the compressor exceeds 25%. This requirement is classified as “B” in IMCA D 023, which means that IMCA considers that there may be other ways of meeting this requirement.

- Protection against (CO2) and Carbon Monoxide (CO) should be in place. The traditional procedure is to install the air inlet at least 2 metres above the floor and away and not downwind of thermal engines. However, some manufacturers offer devices that continuously monitor the air quality delivered, warn the operator through illuminated displays, and switch off the compressor automatically if the air quality is outside the threshold values of the standard taken in reference (EN 12021). Such devices should be mandatory.
  In addition, the diving vessel may operate in areas where the outgassing of dangerous gasses such as hydrogen sulfide (H2S) may suddenly happen. In addition to classical precautions that consist of never running compressors when the vessel is within areas where such gasses are likely, an analyzer should be provided to, at least, warn the operator of the presence of such gasses.
- A relief valve should be fitted to any pressure container (e.g. an air receiver) if it could be over-pressured. Relief valves are also commonly provided in between cylinders to avoid over pressure.
- Rigid pipes and flexible hoses must be designed for the type of gas and the maximum pressure the compressor can deliver. As for every pressure hose, they must be secured and isolated. Besides, 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. This last recommendation is usually implemented by manufacturers.

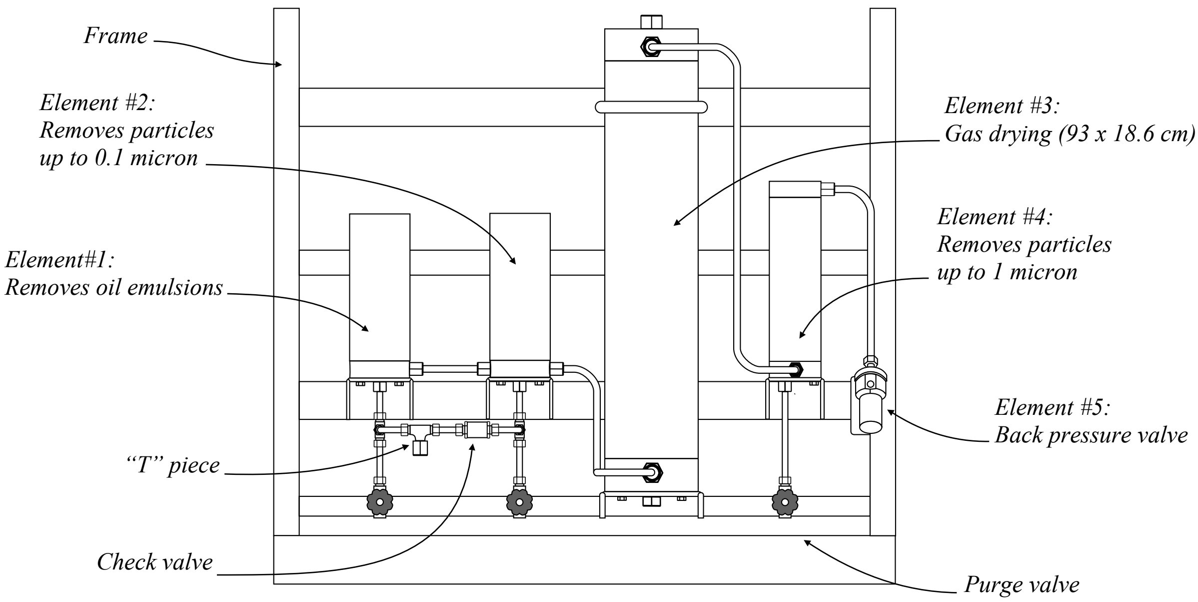
2.12.2 - Reciprocating piston “oxygen compatible air” compressors

When air is used in circuits where nitrox mixes and pure oxygen are also employed, it must be rated "oxygen compatible" to prevent any source of oxygen ignition. The variations of this norm compared with "standard breathing air" are that water and oil contents are more stringent. Note that the US Navy manual does not provide specifications for air used in circuits where oxygen or mixes considered oxygen are also breathed.

Component	*Concentration at 1013 mbar & 20 ºC*
Oxygen	*21% (± 1%)*
Water	*≤ 25 ml m³ (ppm)*
Carbon dioxide	*≤ 500 ml m³ (ppm)*
Carbon monoxide	*≤ 5 ml m³ (ppm)*
Oil	*≤ 0.1 mg m³ (ppm)*

Composition of oxygen compatible air EN 12021

Piston compressors can produce Oxygen-compatible air due to improvements in oxygen-compatible lubricants, anti-wear coatings, and self-lubricating treatments of the internal parts of the compressor addition to more efficient filtration systems. As a result, many air compressors currently sold meet the requirement of EN 12021 oxygen-compatible air. Also, air compressors initially designed for “standard air” can be adapted to produce “oxygen compatible air” by installing an additional filtration system. For example, the LB Bentley cleanup pack described below 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. 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.

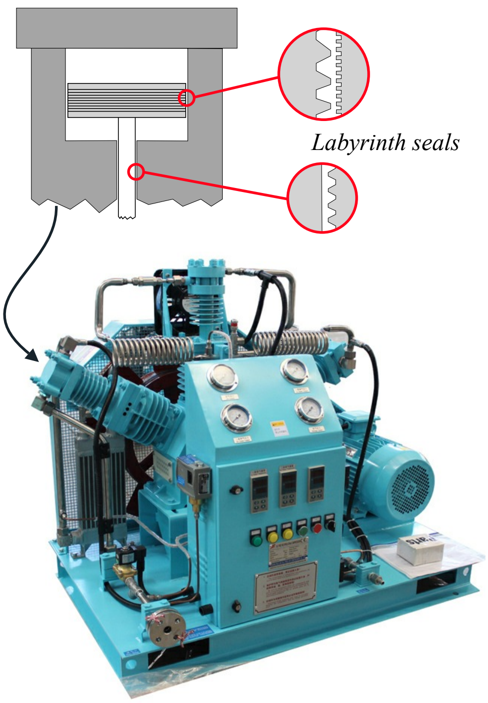
2.12.3 - Reciprocating piston “oxygen” and “nitrox” compressors

The progress of technology regarding oxygen-compatible lubricants, anti-wear coatings, and self-lubricating treatments, in addition to more efficient filtration systems, have also made the use of piston compressors possible to transfer oxygen. However, oxygen is known to ignite quickly, so compressors designed for air compression must never be used for oxygen, even though they are intended for oxygen-compatible air.
Also, based on the fact that the exact cause of an oxygen fire is usually complicated to evaluate because the material at and around the ignition site is wholly burnt, certification bodies require the manufacturers to take into account the following problems when designing reciprocating oxygen compressors:

- Inadequate materials and design may lead to the creation of particles and heat due to excessive rubbing.
- Inadequate filtration and piping design may lead to debris impacts.
- Improper design and assemblies may lead to vibrations.
- Inadequate cooling will lead to excessive heating.

As a result, metallic and non-metallic materials used for the construction of oxygen compressors must be heat and oxygen resistant, as previously described in point 2.11.4, “Storage and distribution of the gasses”. Also, the compressor should be designed according to standards like those mentioned below, which are from the document AIGA 048/18 “Reciprocating compressors for oxygen service”:

- Ported plate valves with damping plates should be used. The valve size should be sufficient to keep pressure losses across the valve below 5% of nominal suction and discharge pressures.
- The valve lift should be designed to keep opening impacts below 3.5 m/s and closing impacts below 1.3 m/s. Valve motion natural frequencies should not correspond to system pulsation frequencies since this can lead to rapid valve failure.
- The maximum piston velocity should be limited to 4 m/sec for ringed piston and 5 m/sec for labyrinth piston. The labyrinth seal principle consists of preventing leakage by the use of tortuous paths. Thus, a “labyrinth piston” is made with numerous tiny annular grooves machined around the piston, the piston rod, and the cylinder wall so that these many small cavities on the two sides make it difficult for the fluid to pass. Also, a limited contact creates a seal that prevents gas leakage. Synthetic materials such as polytetrafluoroethylene (PTFE) can be used for this purpose. This system should be designed with crosshead assemblies and guides so the piston is perfectly centralized and the limited contact-sealing action is possible without damaging the grooves.



An example of such equipment is the model aside, fabricated by “Bailian Compressors” (https://www.oxygen-compressors.com/), a company based in Xing ye Lu, China, whose compressors comply with European standards.
This three-stage compressor, which can be used to recover the remaining contents of oxygen cylinders, needs a minimum inlet pressure between 3 & 4 bar. Thus, it is a gas booster that can transfer oxygen to a maximum pressure of 150 bar and a flow rate of 30 m^3/h.
It is designed to run 24 hours, and is equipped with self-lubricated pistons designed to work 1500 hours before being changed, so it does not use any lubricate oil.
This model is cooled by air. However, some models refrigerated by water cooling are available on the market.

2.12.4 - Membrane compressors

“Membrane compressors”, which are also called “diaphragm compressors” and “Corblin”, which is the name of the inventor (1916), allow compressing 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.

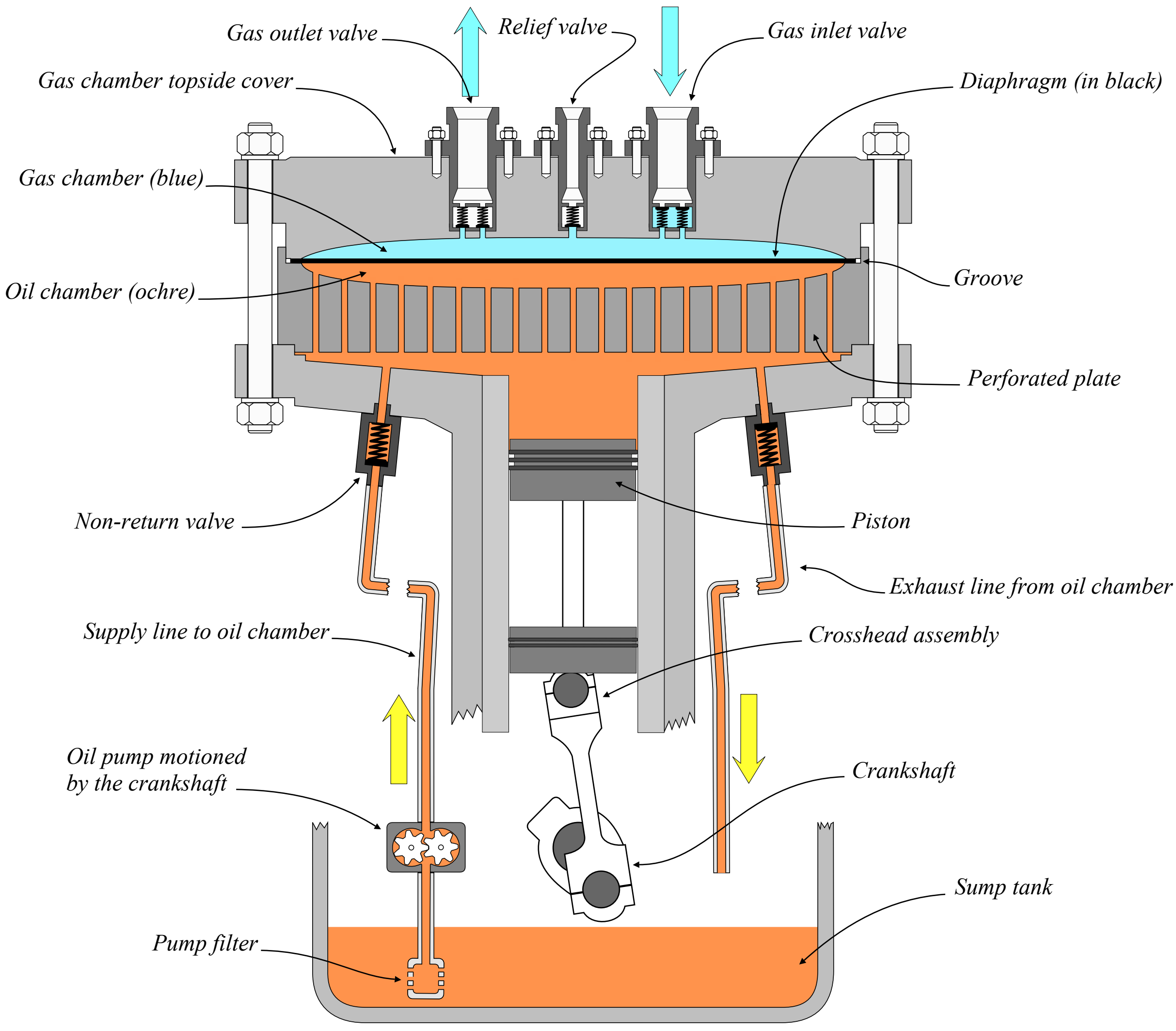
Membrane compressors were used to transfer heliox mixes and oxygen in the past, as they were the only machines capable of transferring such gasses. However, as explained in the previous point, the technical progress in materials results in that piston compressors and transfer pumps are today able to transfer such gasses. For this reason, a lot of manufacturers propose these devices in replacement of diaphragm compressors as they are less expensive. Nevertheless, these machines provide a lot of advantages that must be highlighted, 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.

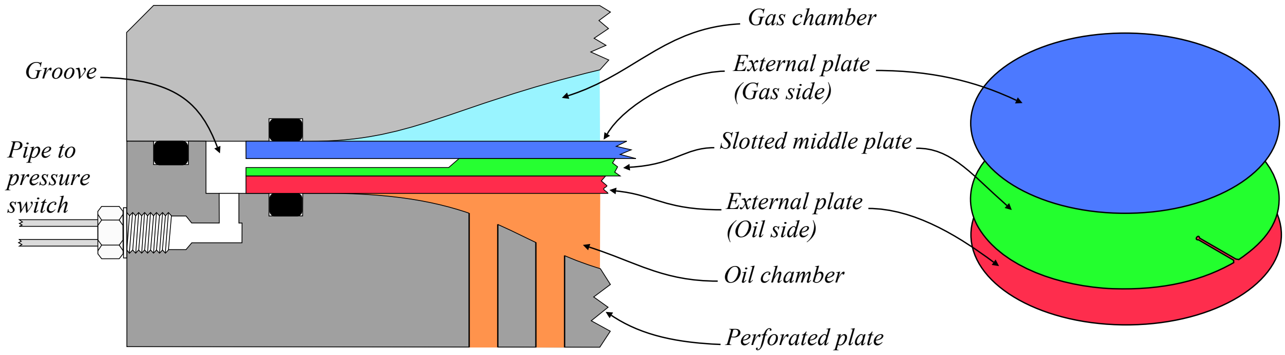


Manufacturers indicate that the life length of the plates that compose the diaphragm is approximately between 3000 and 5000 hours. However, they may fail before this time, which can result in gas contamination or machine damage. For this reason, *IMCA requires that a cracked plate detector which automatically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

This detection system is the reason the diaphragm is composed of three superposed plates:

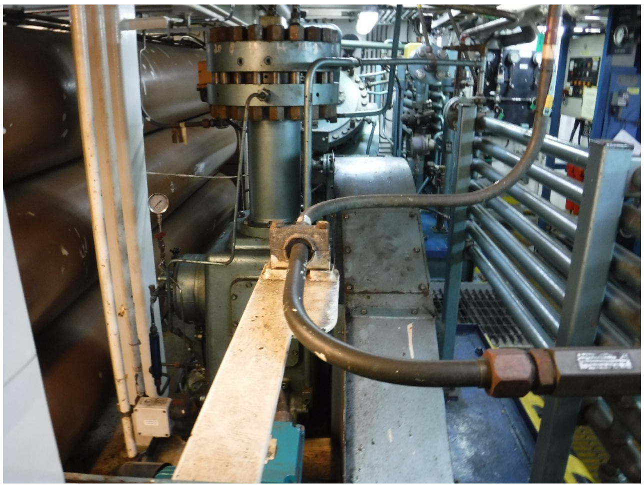
- One external plate is in contact with the gas *(see the blue plate below)*
- The other outer plate is in contact with the oil *(see the red plate below)*
- The middle plate is not in contact with the gas to compress or the oil and is slotted. This slot is positioned to guide any leakage to a groove to which a pressure switch is connected in addition to a pressure gauge and an alarm *(see the green plate below)*.

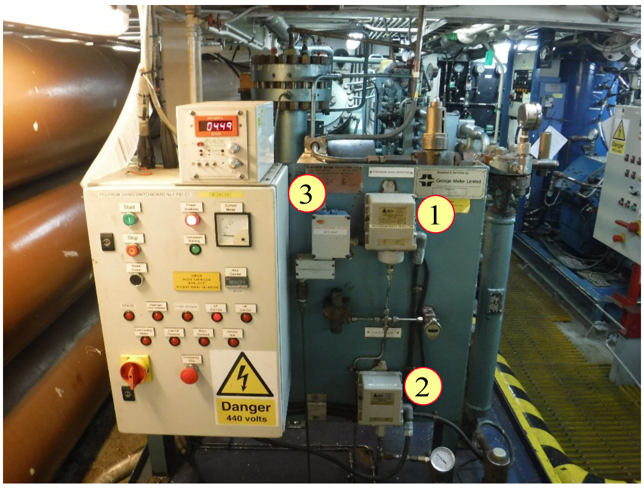
In the case of a diaphragm failure, the gas or oil penetrates the space between the external membranes and pressurizes it. As a result, the pressure switch is activated and shuts the machine down.



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:

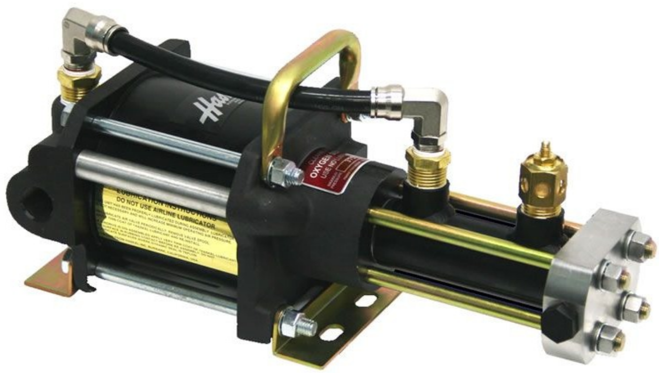
- Their gas chambers are fully sealed towards the outside, so the compressed gas is protected from contamination.
- Linked to above, there are no oil particles in the gas delivered, so the reinforced filtration of piston compressors is not necessary.
- These machines have a reputation of high yield: 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.

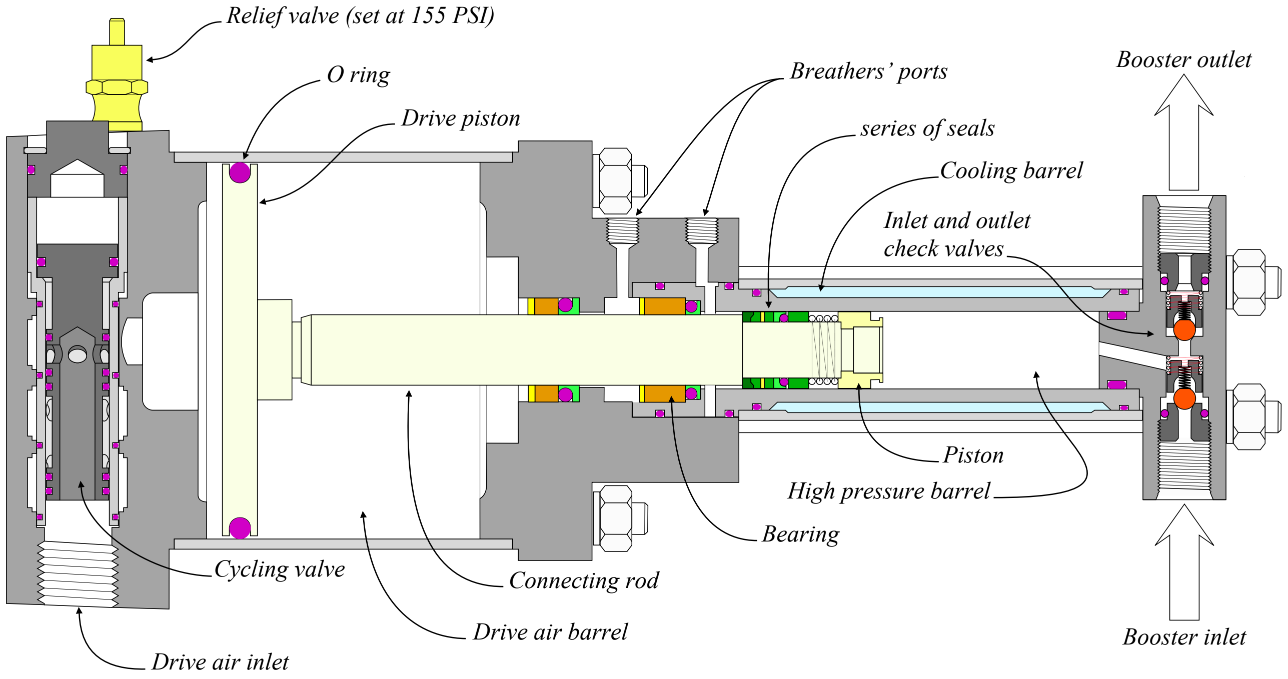
2.12.5 - Transfer pumps

Transfer pumps are machines used in replacement or as a complement of membrane compressors for transferring heliox, 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.



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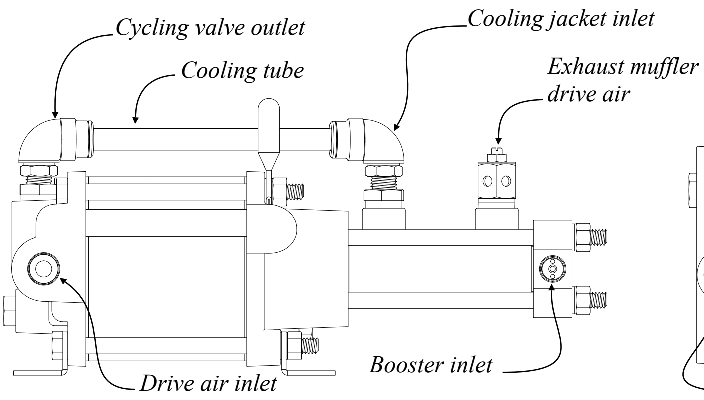
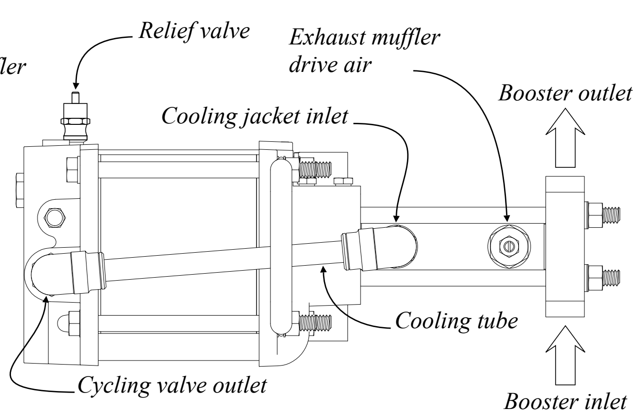
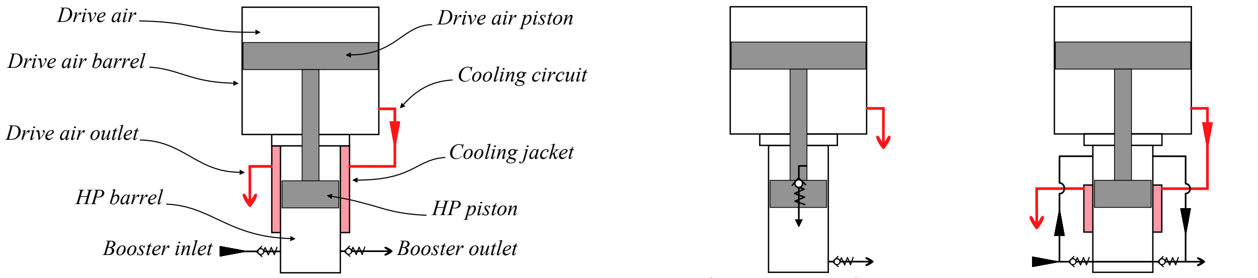


Side view



Plan view

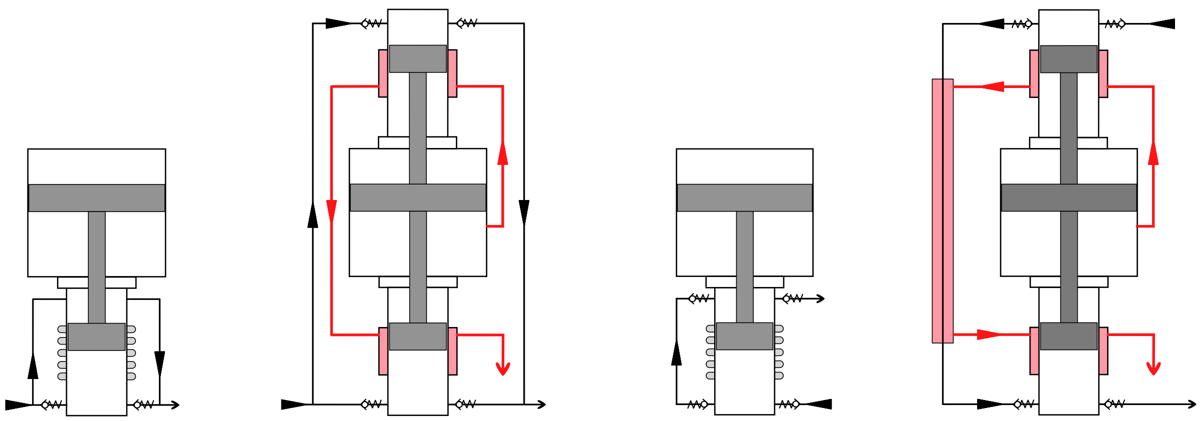
Haskel propose a wide range of machines which various configurations are summarized in the schemes below. Note that the models used in the diving industry are usually limited to 300 - 350 bar.
Also, more than one booster of the same ratio can be linked together to create a multi-stage gas booster, allowing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



Single stage & single acting with cooling jacket

Single stage & single acting Flow through the piston

Single stage, double acting with cooling Jacket



Single stage, double acting with cooling fins

Single stage, double acting, with cooling Jackets

Two Stage with cooling fins

Two Stage with cooling Jackets

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

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

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

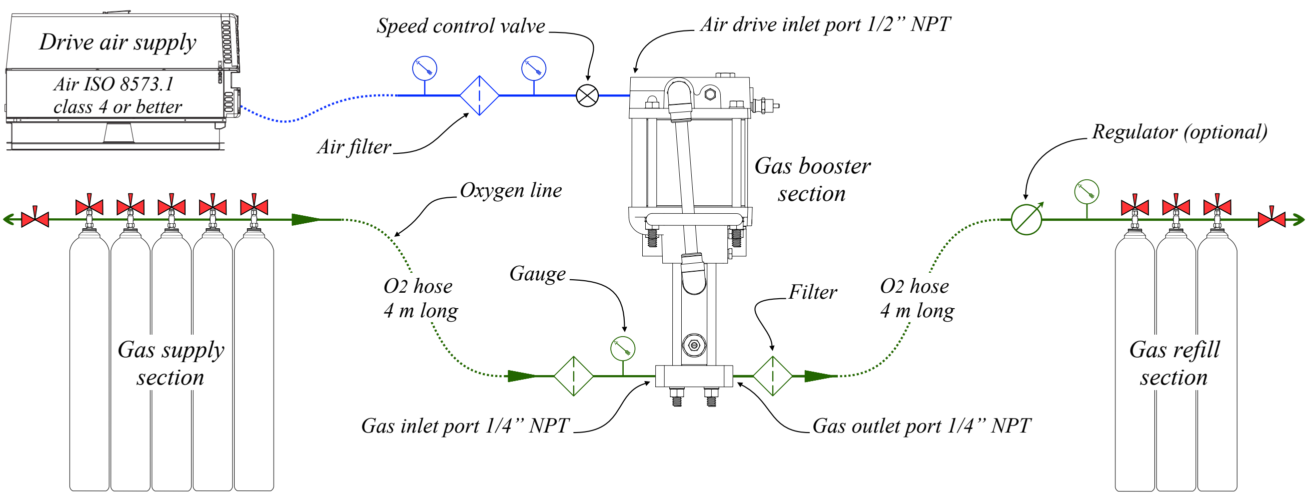
- The operator should ensure that a maximum of water and oil vapour condenses and can be efficiently removed. For this reason, the filters should be installed downstream of coolers and air receivers, and at the point where the temperature of the installation is the lowest. Such an arrangement also reduces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

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

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

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

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



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

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

Haskel also gives the following additional recommendations for transferring oxygen:

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

2.12.6 - Where to use such systems?

Compressors can be employed to pump air as long as the manufacturer's recommendations are implemented. These recommendations include the air intake position that must be at height and away from any potential source of dangerous gas. Also, whatever the type of gas compressed, the place where the compressor is installed must be exempt from pollutants that may ignite oxygen and contaminate the compressor. Thus, a risk assessment should be done to ensure that the precautions to operate the compressor are in place.

Note that the document IMCA D 022 recommends not to pump oxygen in point 9.9 of chapter 9. For this reason, many companies only transfer oxygen by decanting on the work site and use Haskel pumps or compressors to top-up oxygen and nitrox cylinders within specific onshore premises. Therefore, they supply the worksite by gas cylinder rotations.

However, a lot of companies ceased to apply this guideline and argue that, if relevant precautions are implemented, it is no riskier to pump oxygen on offshore sites than implementing other operations that are commonly done, such as fuel bunkering or the transfer of gas containers by crane. In addition, decanting oxygen is not exempt from risks, and we have not found any recent paper relating accidents with oxygen compressors or Haskel pumps.

For these reasons, we can consider that pumping oxygen (or nitrox mixes) is possible offshore and on any worksite if a risk assessment has been undertaken to ensure the desirability of doing it, that the fire surveillance and fire fighting systems are sufficient, and that this operation is performed in an isolated ventilated part of the deck where a fire can be easily and quickly contained.

In addition to extinguishers and fire lances in immediate proximity to the room, the fire fighting systems should be composed of a deluge or a water mist system with a fire alarm system linked to the vessel's bridge.

Of course, the vessel owner, the client, and the state representative can reject such a procedure.

2.12.7 - Maintenance

IMCA recommendations are among the most accurate regarding the planned maintenance of compressors. However, note that manufacturer requirements can be more stringent.

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			

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	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			

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 22% 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.

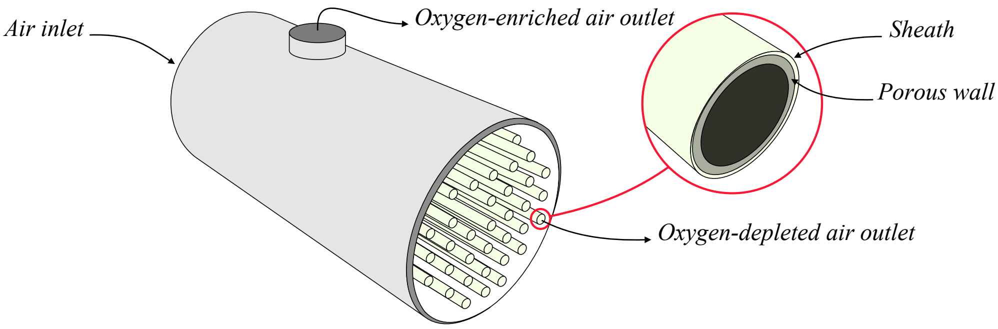
In addition to these methods, the analysis of gas samples should be done. Also, a lot of companies perform preventive cleaning at regular intervals as the methods indicated above do not allow to check all the inner parts of a system. They are often performed every six months or every year.
ASTM G93 is 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.

2.13 - Nitrox fabrication using membrane systems

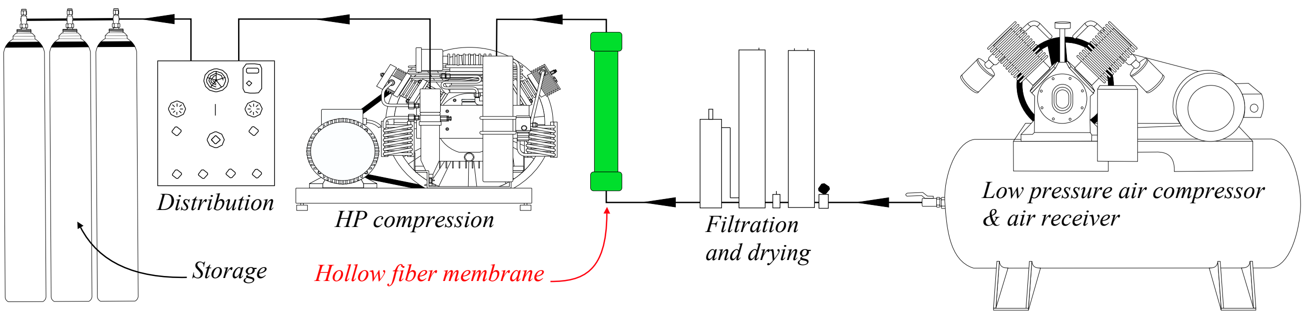
2.13.1 - Description

Membrane systems selectively separate nitrogen and oxygen, from the air. They have the advantages of fabricating nitrox at a low cost, reducing logistical problems, and being easily transportable. They can be classified into two main categories, which are not based on the same principle of work.

“Hollow fiber membranes” consist of hollow tubes made of fiber manufactured by a co-extrusion-like process. The permeance of gasses across the polymeric membrane is based on the solubility of the gas in the polymer and the rate of gas diffusion across the membrane. For these reasons, polymers are selected for the membranes that are conducive to high permeance efficiency, light-weight, and reliability.
The cross-section of a typical fiber has an outside diameter of 140-180 microns and an inside diameter of approximately 100 to 140 microns. The majority of the fiber wall thickness is a porous sponge-like material that makes up the fiber core. The purpose of the core is merely to support an outer boundary layer of a thickness of approximately 2 microns, called the sheath, where gas separation occurs. The sheath and the outer skin of this layer, measured in angstroms, determine the performance of the membrane.
These fibers are assembled in bundles to form the air separation modules. The air is supplied at one end of each fiber and moves to the other end. During this process, oxygen is absorbed through the polymer walls of the fiber due to the pressure difference. As a result, the gas that exits the downstream end of the hollow fiber is decreased in oxygen concentration. Therefore, oxygen-enriched air with oxygen concentration up to 40% is produced .
The advantages of this technology include the absence of moving parts, the low weight, the inexpensive nature of the materials of construction, and the lack of any substantial time lag in system start-up.

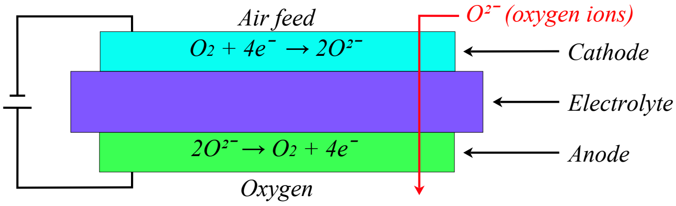


The air inlet pressure is usually between 13 & 14 bar. This inlet air should be filtered and dried to limit the particles size to 0.01µm, and having a maximum oil vapour content below 0.01 mg/m³.
Several companies produce modules that are designed to be compiled with adequate filtration systems and compressors. It is, for example, the case of Parker, L’Air Liquide, Gereron, and others. The scheme below shows how a nitrox production unit using these modules should be organized.



Note that the NASA study “Onboard oxygen generation system” says that that multi staging can improve the concentration of the oxygen provided by such membrane systems.

The second category of membrane separation systems is called “ceramic membranes”. The principle of the ceramic oxygen permeation process uses the catalytic properties of specialized ceramic materials to transfer the oxygen in the form of ions instead of molecules, so the ions of other gas molecules cannot pass through the membrane. As a result, the oxygen concentration can reach 99.5% or even higher. The system is based on a membrane where one side is the cathode, and the other is the anode that is separated from the cathode by an electrolyte. Oxygen molecules' absorption starts at the membrane's cathode side, where they are dissociated into oxygen ions. These oxygen ions migrate to the anode side through the membrane and then recombine into oxygen molecules. The compensation of electric charges during the process is achieved through reverse-direction migration of the electrons in an external electric circuit. Note that the operating temperature of ceramic membranes is between 600 and 900 °C.



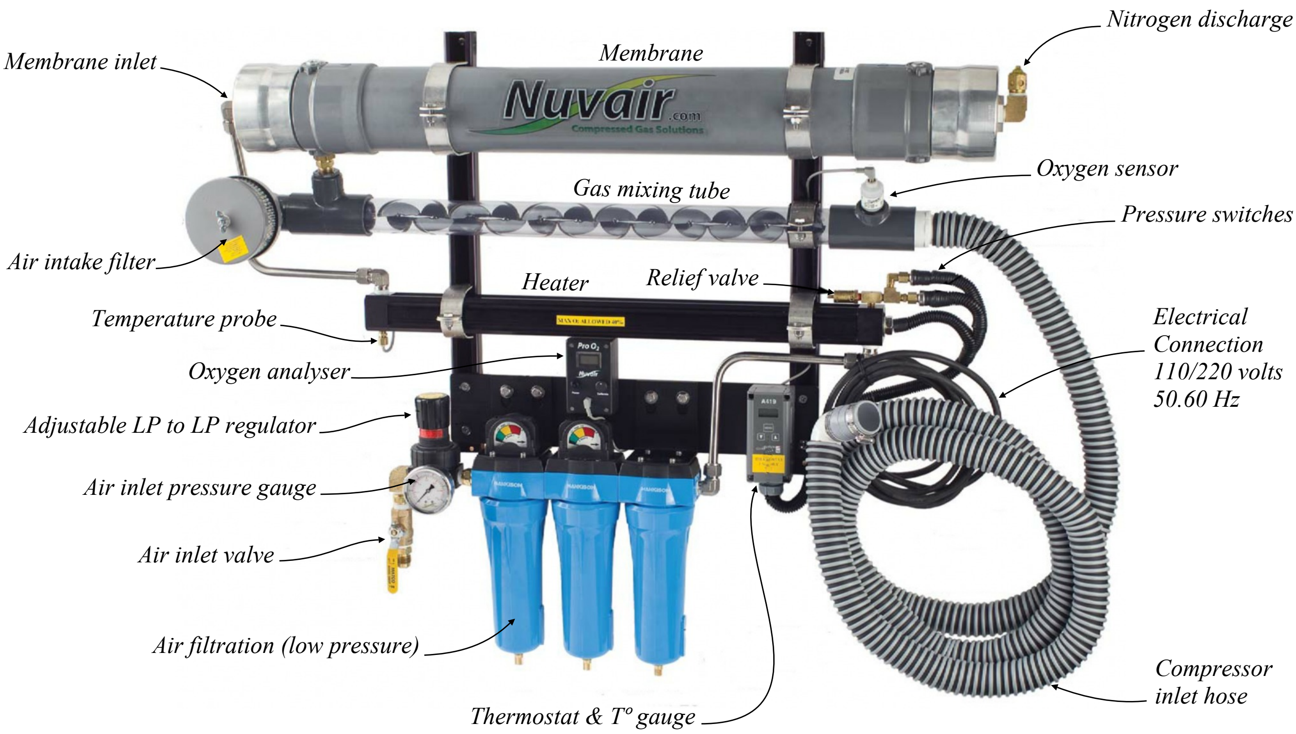
Like hollow fiber membranes, ceramic membrane systems do not use moving parts. In addition, they have the advantage of not being sensitive to water vapour and other contaminants. Nevertheless, these devices need to be energized by an electric circuit to work. These systems are fabricated mostly for aerospace and defense industries.

2.13.2 - Design and operating procedures of a system

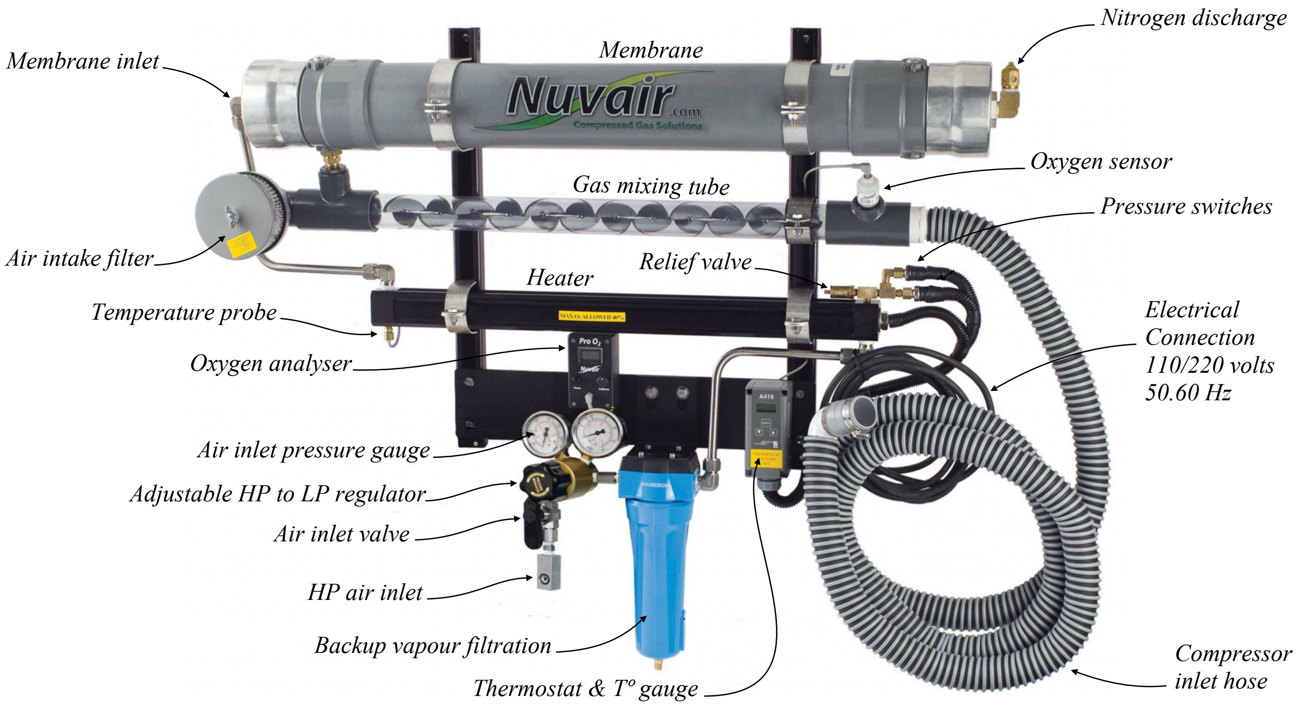
Like for other types of equipment, it is essential to study an existing system's design and operating procedures to understand better how such equipment can be adapted to commercial diving activities. The device taken as a reference is the "230n3 Series" created by "Nuvair" (https://www.nuvair.com/), a company based in Oxnard, California, USA. This system, which is among the most sold, can supply nitrox with an oxygen concentration of up to 40%.

1. The Membrane Systems require a source of clean, pressurized, and heated air for separation. The two most common sources are a Low Pressure Compressor (LP Supply) or High Pressure air storage tanks (HP Supply).
2. The air must be properly filtered to be "oxygen compatible" quality prior to entering the membrane system so it will not damage or plug the membrane fibbers. Standard systems are rated for maximum supply pressures of 17 bar (250 psi) for LP Supply and 345 bar (5000 psi) or sometimes more for HP Supply.
3. An "input pressure regulator" reduces these pressures to acceptable levels for the membrane.
4. The air is then heated to a temperature that provides stability over a wide range of ambient conditions and is optimal for membrane permeation.
5. The heated air enters the membrane, which is made up of thousands of miniature hollow fibers. The walls of these fibers are semi-permeable and designed for different gases to move through them (or permeate) at different speeds. The resulting gas mixture is known as the "permeate".
6. As air flows through the hollow fibers, both oxygen and nitrogen permeate through the fiber walls. The oxygen permeates faster than the nitrogen, which produces permeate with an oxygen content greater than air. The gas that reaches the end of the hollow fibers without permeating is almost entirely nitrogen and is discharged. The flow rate of this discharge is set by the factory via a fixed orifice to allow the membrane to operate at maximum volume and efficiency. The resulting permeate contains approximately 40% O_2 and is constant under all operating conditions.
7. The permeate is a concentrated mixture that must be diluted with additional air prior to entering the nitrox compressor. It exits the membrane at ambient to slightly negative pressure and travels into the "mixing tube", where it mixes homogeneously with filtered outside air. The amount of dilution, and thus final % O_2 , is obtained by adjusting the "input pressure regulator": As pressure is increased, permeate flow increases, air flow decreases, and a higher % O_2 Nitrox is produced. As pressure is decreased, permeate flow decreases, air flow increases, and a lower % O_2 Nitrox is produced. This relationship between permeate flow and air flow exists because the total of these two flow rates will always equal the intake flow rate demanded by the Nitrox Compressor.
8. The resulting nitrox mixture is analysed for approximate % O_2 before entering the nitrox compressor and again prior to use for precise % O_2 .
9. The input pressure that correlates to a specific nitrox % O_2 is repeatable. If nitrox with 36% O_2 is produced when the input pressure is at 9 bar (125 psi), then adjusting the Regulator to the same pressure during the next use will produce the same gas mixture.

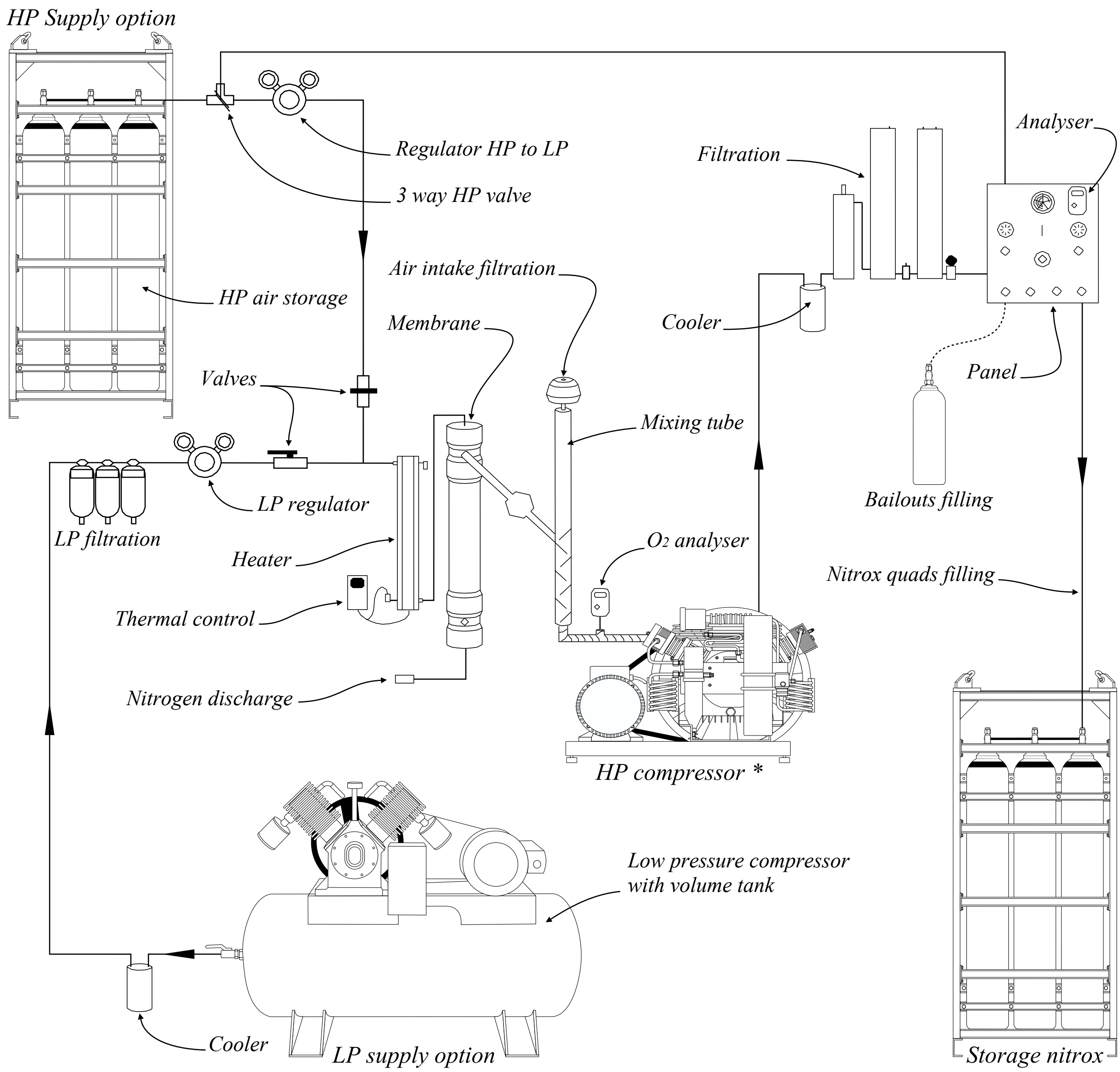
Identification of the components of a system supplied with low pressure



Identification of the components of a system supplied with high pressure



Overall view of the components of a system supplied with high and low pressure



HP compressor: The compressor must be designed for nitrox mixes with 40% oxygen minimum.*

As said previously, the higher the % of O_2 desired in the final product, the greater the volume of supply air, and the higher the input pressure required, as shown in the example below for a 10 cfm (283 L/min) membrane system:

Desired percentage	Supply Air Volume Required to Produce 28.3 litres (1 cu ft) nitrox	Input pressure range
32%	*35.39 - 38.23 litres (1.25 - 1.35 cu ft)*	*6.2 - 6.89 bar (90 - 100 psi)*
36%	*45.3 - 48.13 litres (1.60 - 1.70 cu ft)*	*8.27 - 8.96 bar (120 - 130 psi)*
40%	*56.63 - 70.79 litres (2.00 – 2.50 cu ft)*	*10.32 - 11.38 bar (150 – 165 psi)*

The air supplied should comply with EN 12021 or CGA G-7.1-1997 grade D or E.

Manufacturers of nitrox membrane systems also sell complete ensembles that include the compressors, such as the two machines below, designed by Nuvair that can produce up to 481 litres/min of nitrox 40 % (max. pressure: 250 bar).

Voyager Open IV

Voyager IV heavy duty

2.13.2 - Where to install the machine?

Like all air compressors used on worksites, the machine's air intake should be placed at height and away from any potential sources of dangerous gas. In addition, the area where it is installed should be cleared of pollutants that may ignite oxygen such as oil and grease. Thus, a risk assessment regarding its surrounding should be done.
Also, nitrox mixtures used for diving usually have proportions of oxygen above 25%, so they must be handled as pure oxygen. As already said for oxygen transfer, the document IMCA D 022 chapter 9/point 9.6 recommends not to pump oxygen. For this reason, many companies transfer pure oxygen and nitrox mixes by decanting only during operations at sea, and some others buy mixes fabricated in factories.
As already said for oxygen compressors, a lot of companies have ceased to apply this guideline and argue that, if relevant precautions are implemented, it is no riskier to pump nitrox mixes offshore than implementing other operations that are commonly done, such as fuel bunkering or the gas containers transfer by crane. We must admit that accidents with these machines are rare, as we have not found a recent paper regarding such events.
For this reason, we can consider that pumping nitrox mixes is possible if a risk assessment has been undertaken to ensure the desirability of doing it, that the fire surveillance and fire fighting systems are sufficient, and that this operation is performed in an isolated ventilated part of the deck where a fire can be easily and quickly contained. In addition to extinguishers and fire lances in immediate proximity to the room, the fire fighting systems should include a deluge or a water mist system with a fire alarm system linked to the vessel's bridge,
Of course, the vessel owner, the client, and the state representative can reject such a procedure.

2.13.3 - Maintenance

The manufacturer of the system taken in reference provide the following guidelines that may change with other systems:

- There is no specific maintenance for the semi permeable membrane (service life exceeds 20 years).
- The air intake filters of the compressor and membrane module are to be inspected every 3 months and changed every year, and the vapour filters are to be changed every 200 hours.
- The planned maintenance of the compressors should be organized as explained in point 2.12.7.

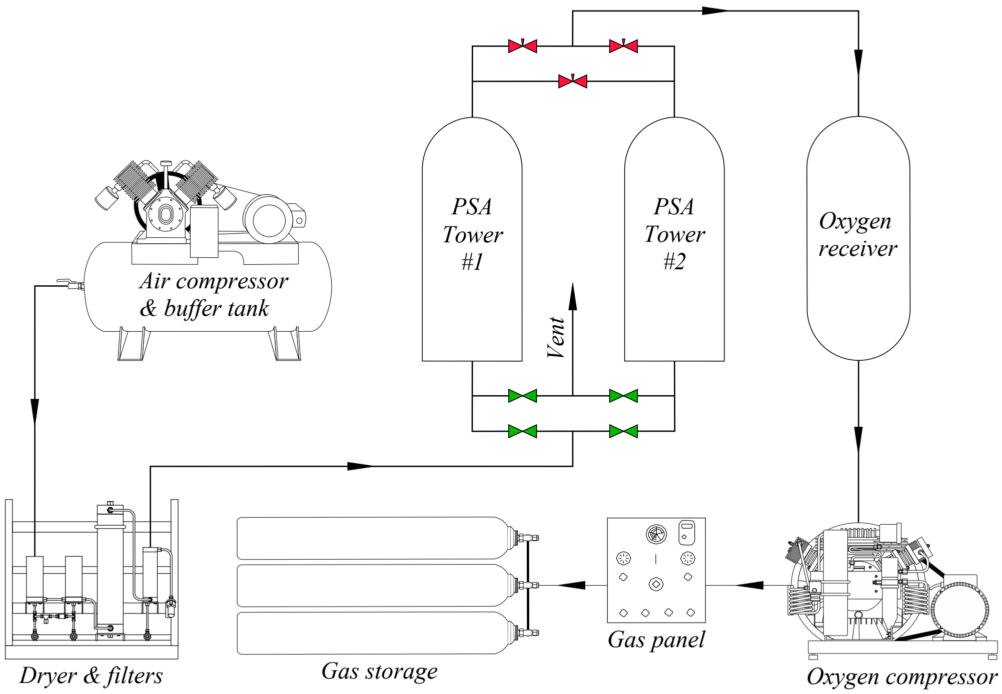
2.14 - Pressure Swing Adsorption (PSA) Oxygen generators

2.14.1 - Purpose and potential applications

Membrane gas separation systems used to extract the oxygen, such as the nitrox membrane system Nuvair described in the previous point or models from other manufacturers, provide nitrox mixes limited to approximately 40% oxygen. However, it is possible to obtain nearly pure oxygen with technologies such as Pressure Swing Absorption (PSA) oxygen generators. In recent decades, this technology has improved to become efficient, reliable, transportable, and financially accessible. Like the nitrox membrane system described in the previous section, these apparatus extract oxygen from the natural air. The purity obtained ranks from 90 to 99.5%, depending on the equipment. Note that 90% is the minimum required by standardization organizations.
Pressure Swing Adsorption oxygen generators are primarily used for medical support, particularly for mobile hospitals and those installed in isolated areas. They are also increasingly installed to reduce the cost of therapeutic gasses in hospitals established in towns and provide oxygen treatment for individuals at home. However, the study of their working process proves that they can be employed for other applications, such as the production of nitrox mixes.
For remembering, 99.5% is the minimum recommended oxygen purity of the European standard EN 12021, US Navy, and others. For this reason, oxygen not complying with this minimum must not be used for decompression and therapeutic treatments, as the tables have been calculated according to this minimum oxygen purity. Thus, except if the oxygen produced conforms with the above, these apparatus cannot be used to supply pure oxygen.
However, nothing prevents us from using oxygen extracted from the air with less than 99.5% purity for nitrox mixes, considering that the remaining 10 to 1% of impurities of the oxygen produced by these apparatus are nitrogen and argon. As a result, oxygen with more than 99.5% purity can be kept for decompression and medical treatment, and nitrox can be produced with oxygen extracted from the air without affecting these reserves. Note that most machines currently available on the market produce oxygen with a purity between 93 & 97%. However, a few manufacturers are able to sell machines producing oxygen with a minimum purity of 99.5%.

2.14.2 - Description

Molecular sieves used with “Pressure Swing Adsorption (PSA)” systems are crystalline synthetic or naturally occurring zeolites (aluminosilicate minerals with microporous structure) with pores of precise and uniform size that have the capacity to absorb and separate gasses and liquids. The absorption and separation of the molecules are based on the size of the molecules, so only small enough ones can enter the pores, and it is also based on their electric charge (electro-static fields). Molecular sieves are classified according to their chemical formula and pore sizes. They are used for applications such as drying gases, absorbing undesirable gasses such as ammonia, methanol, ethanol, carbon dioxide, hydrogen sulfide, and fabricating gasses such as oxygen, nitrogen, or hydrogen.
Molecular sieves type 13X are commonly used to separate nitrogen from the air to produce oxygen. They are the sodium form of the aluminosilicate molecular sieves with pore diameters of approximately 10 angstroms, an external diameter between 0.4 to 2.5 mm, and a light grey colour. They can be thermally regenerated at temperatures from 180 °C to 300 °C. Another regeneration method consists of gradually reducing the applied pressure.
Zeolites of Pressure Swing Adsorption systems have the inconvenience of increasing the proportion of argon in the oxygen delivered. As an example, for a system delivering a mix with 93% oxygen purity, the ratio of argon is 4% instead of 1% in the atmosphere. For this reason, NASA studies on onboard oxygen generation systems recommend using a 2nd bed made of carbon to absorb the excess argon.
Most systems use two zeolites towers so that one unit is in use when the molecular sieves in the second unit are regenerated. The basic scheme of the systems commonly used is similar to the one displayed below.

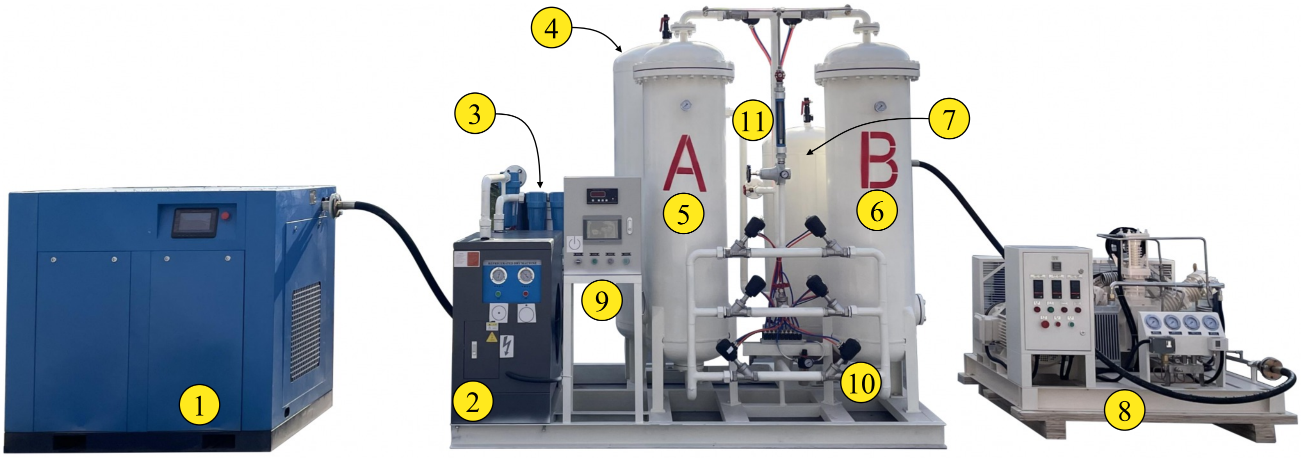


Note that the air from the compressor should be oxygen compatible. The following specifications are commonly asked:

Pollutant	***Concentration***	***Pollutant***	***Concentration***
Moisture	*≤ 0.07g/m³*	*Solid matter content*	*≤ 0.5mg/m³*
Carbon dioxide	*≤ 0.01%*	*Odours*	*No odours*
Particle size of solids	*≤ 10 µm*	*Oil*	*≤ 0.01mg/m³*

Oil free screw air compressors are known to deliver high flow of low pressure air, and are often preferred to supply the installations. Also, most installations are provided with a low pressure storage tank.

As an example of machine that can be adapted for the production of nitrox, the Pressure Swing Adsorption (PSA) Oxygen generator model NZO-30 PSA below, designed by Hanghou Nuzhuo Technology co, Ltd (https://www.hznuzhuo.com/), can deliver 30 m3/hr of oxygen with 95% purity, so 3 cylinders 50 litres/200 bar/hour. It is made of the following components:



1 - Screw compressor 7.5 m3/min

2 - Air purification: Dryer 6 m3/min

3- Air purification: Filtration

4 - Air buffer tank

5 - Absorption tower "A"

6 - Absorption tower "B"

7 - Oxygen buffer tank

8 - Oxygen compressor 30 m3/h @ 200 bar maximum.

9 - Controller

10 - Valves

11 - Flow meter

12 - Manifold or control panel for cylinders filling.

This equipment was initially designed to be installed in ventilated rooms with a surface of at least 30 m² and a height not less than 4 m.

However, Hanghou Nuzhuo Technology provides the photo on the side that shows that this machine can be installed in a 20 feet container, provided that adequate ventilation and fire fighting systems are in place.

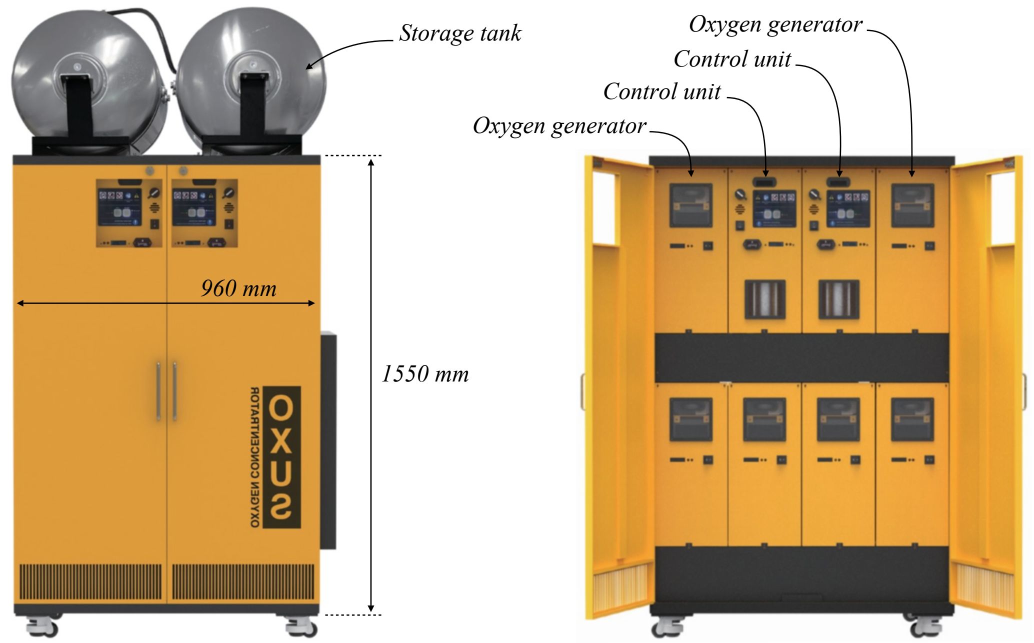
The manufacturer recommends to keep the machine at an ambient temperature of not less than 5 ºC and not more than 49 ºC. Low noise fans directing the hot air to the outside of the room are suggested for this purpose and to avoid the accumulation of oxygen in the room. Note that the heat and gas accumulation problems that may arise due to lack of space in offshore containers can be efficiently compensated by providing large top and bottom openings, ensuring adequate air circulation. Usually, such openings are provided with louvers so they can be kept open when it rains. Waterproof external shutters are typically provided to close these openings when the machine is not used and transferred to another place.

Note that the controller allows managing the oxygen production and sieve regeneration automatically.

This machine is the less powerful of the range sold by the manufacturer taken in reference. It allows providing the necessary oxygen (95% purity) for 24 hours diving operation at 18 m using a mix 50/50 and 1 diver in the water within less than two hours of compression. However, many diving operations do not need so powerful machines, and the space available on the surface support may not be sufficient to accommodate a container like the one above.

Some manufacturers specialize in less powerful and more transportable machines initially designed for small hospitals and individuals. It is the case of the models developed by OXUS (https://www.oxus.co.kr/en/), a company based in

Korea that sells a range of machines installed in cabinets mounted on castors.
These cabinets accommodate several small appliances that can be switched on and off, depending on the volume of oxygen to fabricate. For example, the model RAK-U06M2E below is composed of an ensemble of six small oxygen generators, each of which can work independently and two control units.
The size of the cabinet (W x D x H) taken in reference is 960 x 600 x 1,550 mm. Optional oxygen storage tanks are provided on the top of the cabinet. However, the system is designed to supply hospital circuits at the outlet pressure delivered (4 - 5 bar), and an HP compressor is to be added to the machine to fill HP gas cylinders. OXUS provides a high pressure booster that can compress the cylinders to a maximum pressure of 150 bar for this purpose.



This system can fabricate 3600 l of oxygen per hour, so 89400 l per day.
Note that smaller units are also available on the market. For example, the manufacturer of the model described above sells a machine designed to provide 43200 litres per 24 hours and another tiny unit designed for 7200 litres per day. Even though this last machine is unsuitable for the fabrication of oxygen for the diving team, it can be used in the onboard hospital for oxygen supports other than hyperbaric treatments.

2.14.3 - Implement the machine

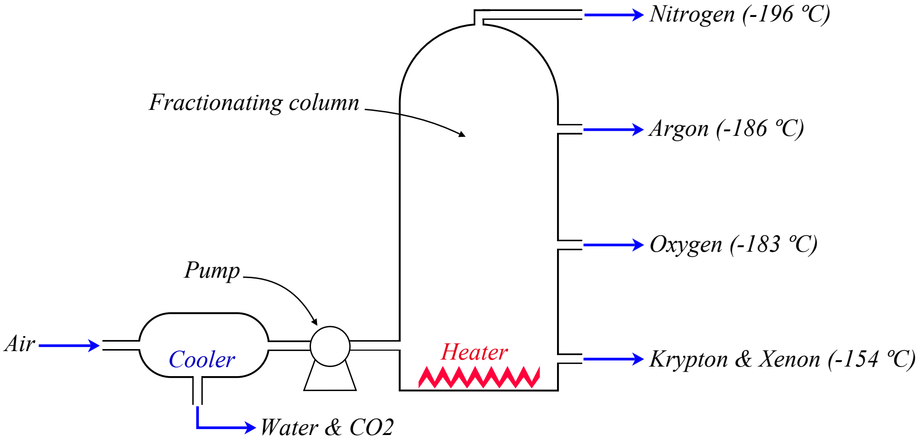
Using such machines on worksites is a new idea. However, considering that they are successfully used for hospitals in isolated areas, there is no reason for not implementing them, provided that the precautions indicated by the manufacturers and above are implemented. These precautions include the position of the air inlet of the compressor and the elements already discussed for the implementation of oxygen compressors or the nitrox fabrication using membrane systems. Thus, a risk assessment should be done to ensure that the machine's surroundings are safe.
Of course, as for oxygen compressors, the vessel owner, the client, and the state representative can reject using such a machine onboard the ship.
In addition, using the oxygen produced by such a machine to fabricate various nitrox implies that the personnel implementing it and then performing mixing of the oxygen with air to make the desired nitrox must have a relevant formation.

2.15 - Other systems used for oxygen generation

Oxygen is also produced using other methods, which is essential to know.

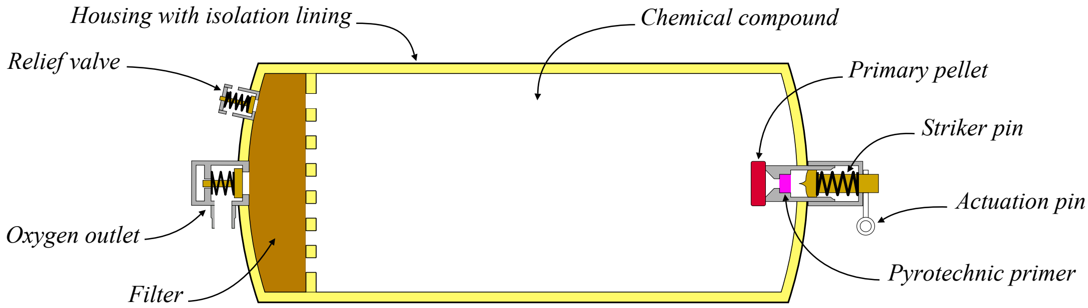
2.15.1 - Cryogenic separation

Cryogenic separation is the method used by gas manufacturers to produce medical/diving quality oxygen of the highest purity. It consists of liquefying air and distilling it to separate its components in a specific column that is warmed at the bottom. The liquefaction is done by alternately compressing and expanding the air so that each expansion reduces the temperature up to - 200 ºC. The molecules move more slowly and occupy less space as the temperature lowers, so the air becomes a liquid. At - 200 °C, the water and the carbon dioxide are frozen and can be removed using filters. As the nitrogen boils at -196 ºC, it can be removed as a gas at the top of the column. The oxygen liquefies at -183 °C so that it can be taken out from the bottom of the column. The oxygen obtained can transferred in a liquid or gaseous form: 1 litre of liquid O_2 = 860 litres of gaseous oxygen.
It is evident that this process, which requires a large installation and competent personnel, cannot be employed on a worksite.

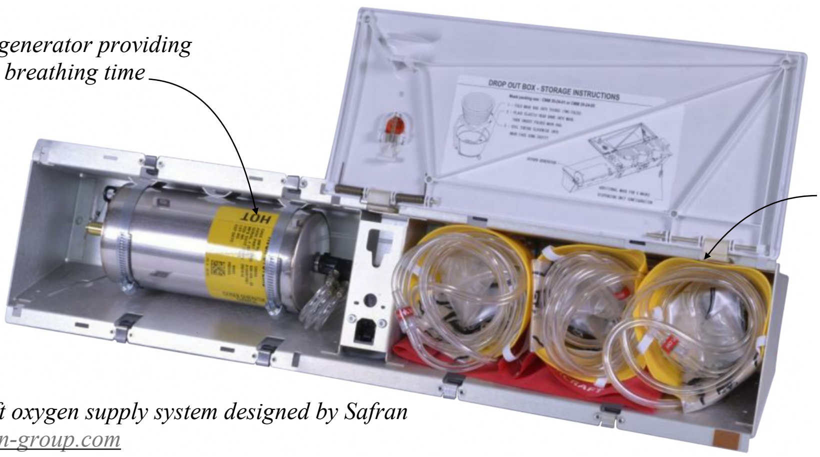


2.15.2 - Chemical oxygen generators

Chemical oxygen generators release oxygen by a chemical reaction. They are composed of a container where sodium chlorate is ignited by a phosphate match that creates the initial heat source. The resulting chemical reaction produces oxygen until the chemical compound is consumed.
These oxygen generators can occupy a more reduced space and are lighter than compressed oxygen cylinders capable of containing the same volume of gas. They have good chemical stability, which allows for keeping them ready to be operated for a long time. For these reasons, they are used to provide emergency oxygen supply in the aviation, space, and defense industries. They are notably employed in submarines and passenger airliners.



The system is started by freeing the striker pin, which then hits the pyrotechnic primer that ignites the sodium chlorate.

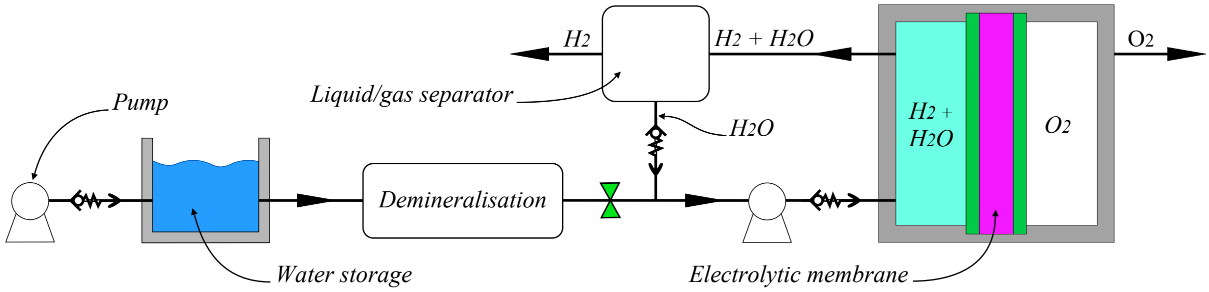


Passenger aircraft oxygen supply system designed by Safran
https://www.safran-group.com

Chemical oxygen generators are commonly used by militaries and emergency rescue teams to provide immediate oxygen support to victims during fast evacuations to rescue facilities. They have the advantage of being compact, light, and easy to implement. Also, the oxygen provided usually has a concentration above 99.5% at sea level and average temperatures, which makes them suitable for such interventions.
However, this oxygen concentration may fall below 95%, and variations of the flow may happen at extreme temperatures and altitudes. In addition, the limited duration of oxygen production and their cost make these devices not adapted to long treatments.

2.15.3 - Electrolysis separation

Electrolysis separation involves breaking down water (H2O) molecules to obtain hydrogen and oxygen by running a current through demineralized seawater or freshwater. These systems commonly used in the defense industry also produce hydrogen and may develop within the near future.

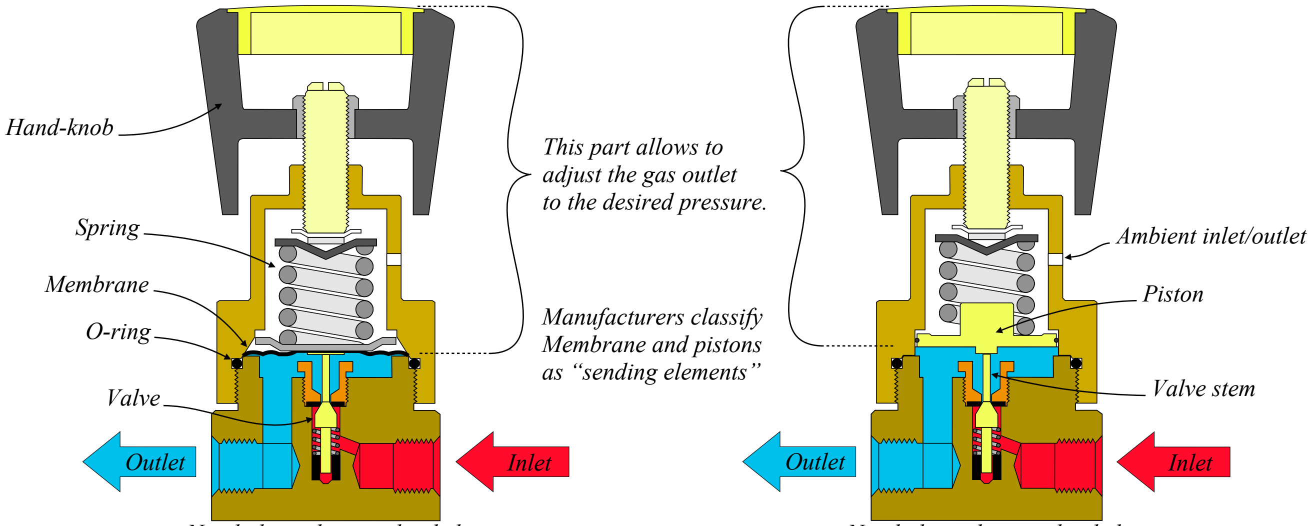


2.16 - Pressure reducing regulators

High or low-pressure gasses produced by compressors and stored in gas containers must be regulated to pressures and flows compatible with the helmets and chambers they supply. It is the function of the pressure reducing regulators.

2.16.1 - Description

The principles of the work of the regulators used on gas distribution panels of dive systems are similar to those of the SCUBA regulators described in section 2.5, "Bailouts systems", except that the hydrostatic pressure is replaced by a spring that is compressed or released by rotating a hand-knob to obtain the desired outlet gas pressure. This mechanism, commonly called "Spring loading", allows adjusting the opening and closure of the valve according to the depth of the diver or the suitable pressure of element to supply. It has to be readjusted as the depth of the diver varies. This spring acts on the opening and closure of the valve through a piston composed of a thick plate sealed by an O-ring or a diaphragm made of a reinforced rubber-like piece that reacts to the outlet pressure changes and allows to maintain a regular flux. As for the 1st and 2nd stages of SCUBA regulators, the valve can be balanced or not.
With some models or regulators, the spring and the adjusting knob is replaced by pressured gas in a sealed compartment separated from the valve by a strong membrane. These regulators, called "dome regulators", are not employed on diving panels. However, they may be in place to control some chambers' High Pressure (HP) supplies.



Non balanced spring loaded membrane regulator — *Non balanced spring loaded piston regulator.*

Manufacturers' catalogs show that membrane regulators are usually limited to outlet pressure less than 35 bar above the atmospheric pressure. That is mainly due to the risks of rupture. The material used to fabricate the membrane can be elastomers such as Buna-N, Viton-A, Ethylene Propylene. etc. Some regulators also use a thin plate of flexible metal (e., g. Stainless steel) for this purpose.
As a result of the above, most regulators employed on diving panels use a piston as a sensing element. This system has the advantage to allow for higher pressures and is robust. However, o-ring failures may happen. Also, these O-rings may have to be lubricated or made of a self-lubricated and oxygen compatible material if the regulator is used to transfer mixes with more than 22% oxygen (mixes with more than 22% oxygen are considered pure oxygen in this handbook).

The bodies of diving systems' regulators are usually made of metals such as aluminium, stainless steel, and brass. Aluminium is found with air regulators. Stainless steel is often used for regulators designed for very high pressures. Brass is commonly preferred for regulators designed for oxygen, even though "stainless steel 316" is also used. Regarding this point, remember that 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".* Note that "Monel 400", is a nickel-copper alloy with good withstanding corrosion and combustion resistance in oxygen-enriched atmospheres, which is also sometimes used.

Note that the regulators designed for oxygen and nitrox transfer must be specifically designed for this purpose. Thus, in addition to selecting appropriate metals, the engineers configure them to avoid phenomenon such as pneumatic impact and adiabatic compression.
Also, plastics and elastomers used for seals and gaskets can be ignited at temperatures from 150°C to 500°C instead of 900°C to 2 000°C for metals. For this reason, they are selected according to the following rules:

- The materials selected must be those that are the most difficult to ignite. Note that in some applications materials with low auto-ignition temperatures may perform as well as higher rated materials.
- Low heats of combustion are preferred; heats of combustion of 41000 J/g or higher are unsuitable.
- Materials with high oxygen index values should be used (oxygen index is the ability to sustain combustion)
- Continuous and rapid flexing of a material can generate heat and ignition.
- The thermal conductivities of non-metal materials are lower than those of metals. Dissipation of heat from non-metallic components can be facilitated by close contact with metallic components and by limiting the mass of non-metallic components.

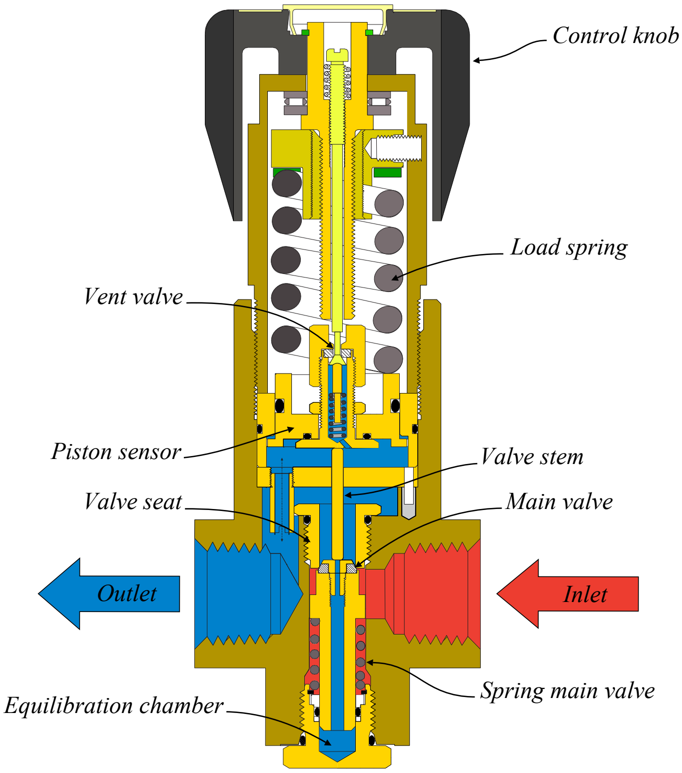
- Non-metallic materials in contact with oxygen can undergo chemical changes that affect their mechanical properties. Maintenance schedules should take such changes into account.
- Reactions may happen due to mechanical impact.
- A material with a low flame temperature is preferred.
- A material with a low flame-propagation rate is preferred.
- To maximize the resistance to ignition, designers tend to choose materials with the highest auto-ignition temperatures. However, polymers with high auto-ignition temperatures can emit lethal gases. It is the case of polytetrafluoroethylenes (PTFE) and polychlorotrifluoroethylenes (PCTFE) which can emit gases that have been used as combat gases during the 1st world war. ISO 15001 says that combustion of a non-metallic component in breathing devices might not be immediately apparent and the products of combustion might be contained within the equipment. In this case, these toxic products might either be delivered as a bolus of high concentration or adsorbed onto other materials and then slowly released. The gases that are produced during combustion depend not only upon the chemical composition of the polymer, but also upon the conditions of combustion, particularly temperature, pressure, and oxygen concentration.
  For these reasons, the selection of the materials should not be only linked to their oxygen compatibility performances, but also to the toxicity of the gases they may emit. Note that some manufacturers compensate the loss of performances of the materials they select by a perfect design of the regulator.

For the reasons listed above, regulators that are not certified for oxygen use by their manufacturers must not be used for transferring pure oxygen and nitrox mixes.

Non-Balanced regulators have the advantage of being inexpensive and easy to maintain. However, as already explained in the section about SCUBA regulators, the opening of their valve partially depends on the inlet pressure. As a result, if the inlet pressure decreases, the pressure opening the valve diminishes, and the output pressure drops as well. That obliges the supervisor to readjust the regulator according to the inlet pressure in addition to the depth of the diver. Also, manufacturers say that this configuration limits the maximum flow and inlet pressure and that when used with high inlet pressures, it requires enforcement of the seat. For these reasons, most regulators used on dive systems are balanced. As a rememinder, a balanced regulator is organized in such a manner that there is no intervention of the inlet pressure in the opening of the valve. As a result, its opening and closure depend only on the outlet pressure.

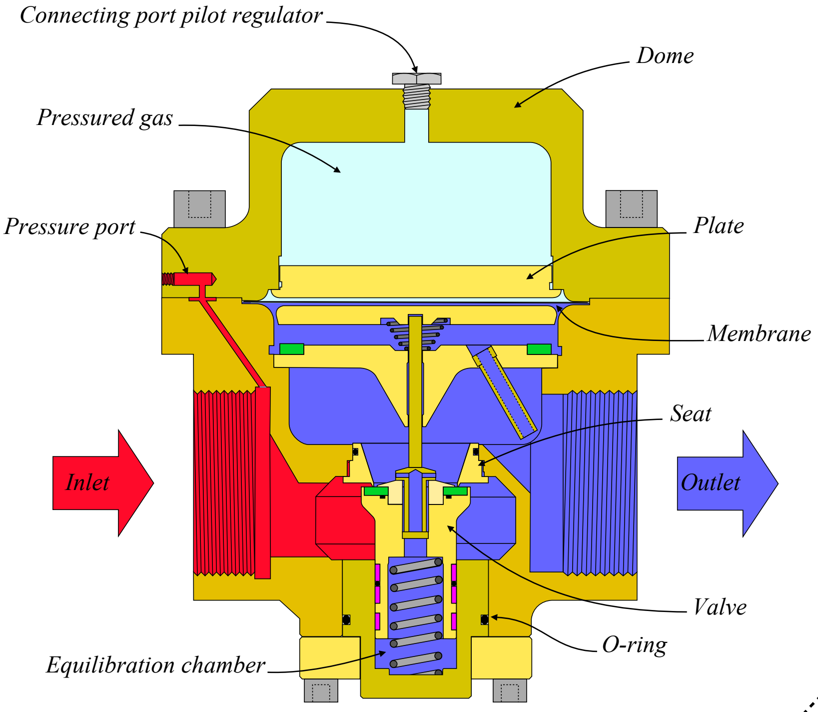
Some regulators are equipped with self-venting. This feature allows to completely relieves the downstream pressure when the control knob is readjusted to decrease the desired outlet pressure. In this case, the regulator incorporates a 2nd valve to vent the downstream pressure. Note that a vent port is usually provided that should be used to vent outside the control room, so the operator is not distrurbed with venting noise, and oxygenated mixes are not released in the room, preventing undesirable oxygen from accumulating in the room.

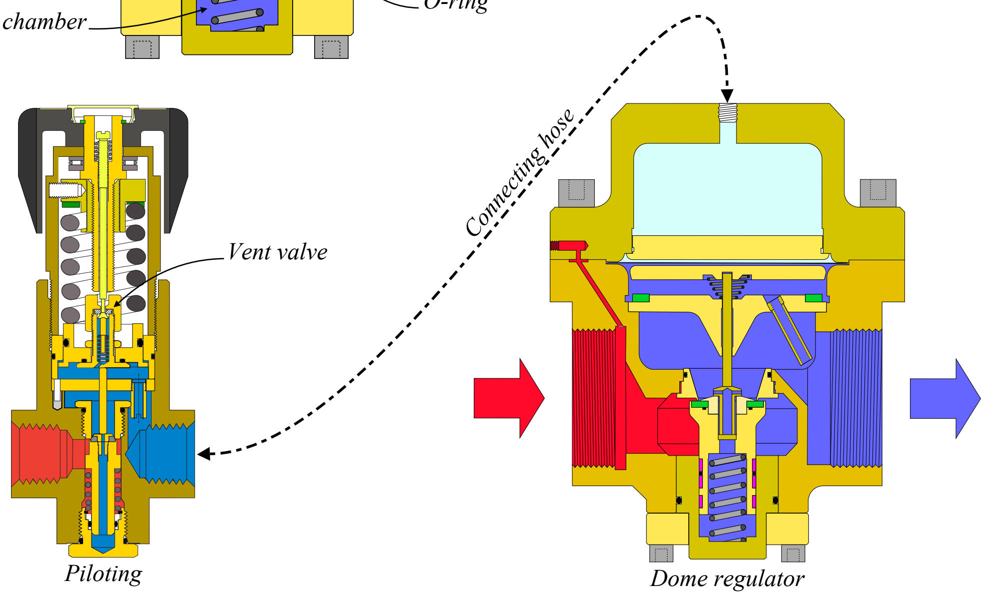
There are a lot of models of spring-loaded regulators that are compensated and equipped with a self-venting option. For example, the Tescom 44-1300 Series represented below is one of the most used on diving panels. It is designed for inlet gas pressures up to 300 bar and provides a high flow of gas.



As already said, dome regulators are sometimes employed on surface-supplied diving systems, notably to regulate high-pressure supplies of Deck Decompression Chambers (DDC). They are often selected for this purpose because they can usually deliver low-pressure outlets at high flow, which is ideal for pressurizing chambers to the desired depth sufficiently quickly. Dome regulators can also be remotely controlled by using a pilot regulator. That allows, for

example, to control gasses that are regulated at the source from a control panel situated in the dive control or another control room.
The principle of dome regulators is based on the fact that gasses can be compressed and then return to their initial state like a spring. This principle is used for many industrial applications such as hydraulic accumulators or hydropneumatic suspensions. Thus, the gas kept in the sealed dome and isolated from the valve by a membrane that also acts as a sensing element replaces the spring of spring-loaded regulators. It is filled and purged by specific ports. If the regulator is to be remotely controlled, a port, usually on the top of the dome, is used to connect the dome to the pilot regulator equipped with a self-venting valve. Note that the self-venting feature is essential to be able to decrease the pressure in the dome and, thus, control the regulator.
The scheme below is based on the D 291 from IMF. This model, which can deliver high flow and is reputed for its robustness, is commonly employed to pressurize deck decompression chambers (DDC).





Note that some regulators combine dome-loading and spring-loading systems. The purpose of this arrangement is to combine the advantages of both systems. However, they are not usually employed on dive systems.

2.16.2 - Problem encountered and maintenance

Harmonic resonances sometimes occur with regulators mounted on gas distribution and diving panels:

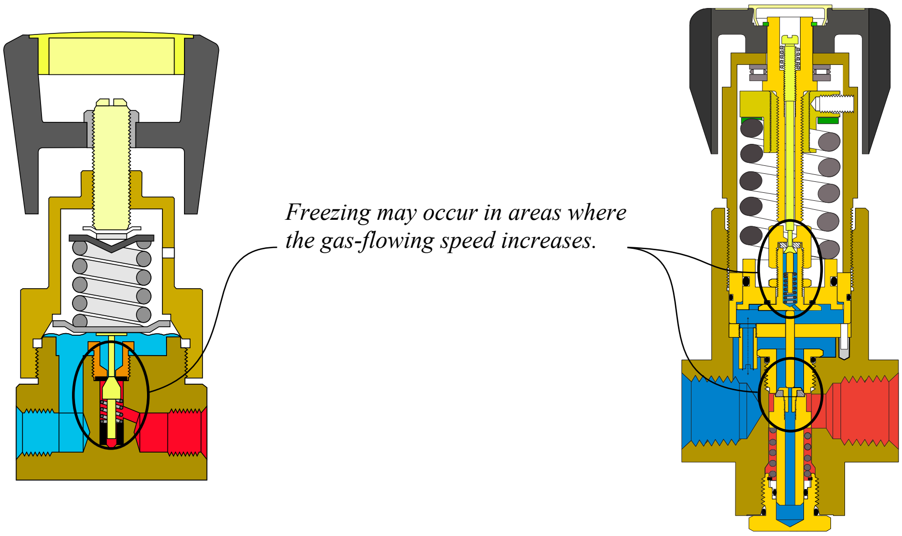
- Manufacturers such as Tescom say that it may happen with spring-loaded regulators equipped with metal diaphragms due to the sound produced by leaks of the diaphragm that acts as a speaker in the bonnet that, in turn, amplifies the sound. The source of such harmonics, characterized by a hissing sound, can be verified by covering the port of the bonnet with a finger to see whether the sound disappears. They indicate that the membrane is damaged and has to be changed.
- Another type of harmonic resonance is characterized by unpleasant vibrations of medium frequencies of the diving panel equipped with piston regulators, such as, the model taken as an example. These vibrations, which can be temporarily ended by slightly readjusting the control knob, result from micro leaks of the piston or the valve seals that are amplified by the piping of the diving panel. Changing the regulator's gaskets and reviewing

the diving panel's piping fixations to absorb parasite vibrations usually solve the problem. Note that unsolved vibrations of the diving panel can result in many components gradually being damaged.

- Harmonics can also result from the regulator springs' vibrations amplified by the pipework of the diving panel. In this case, the regulator should be changed or/and the piping corrected as indicated above.

Continuous free flowing can happen as a result of freezing or internal damage

- As already explained in point 2.4.11 "Helmets using demand regulators", freezing is linked to the fact that the Venturi effect is used by the gas supply system of the regulator. The Italian scientist Giovanni Battista Venturi demonstrated in 1797 that if a fluid arrives in a convergent that consists of a pipe section that gradually restricts, its speed increases, and its pressure and temperature diminish as it progresses in this pipe section. The problem resulting from the Venturi effect is that moisture present in the gas can freeze and result in the regulator not responding or free-flowing without the possibility of stopping it. This effect can be increased when the regulator is situated in a cold area, such as regulators installed on quads exposed to weather conditions in cold countries.



The 1st recommended procedure to avoid such an effect is to ensure that the moisture present in the air or the nitrox conforms to the minimum of the selected breathing gas standard because one of the reasons standards indicate such a minimum is to avoid such an incident (remember that DMAC 19 says that water vapour above the minimum required in standards is not dangerous to health). As an example, the maximum water content in EN 12021 is < 50 mg m³ for standard air at pressures between 40 and 200 bar and is < 25 mg m³ for oxygen compatible air. These minimums can be obtained by using appropriate filtration. However, they should not be diminished outside the recommended values without medical advice as breathing too dried air is uncomfortable and can cause respiratory ailments such as asthma, bronchitis, and sinusitis. It can also cause general dehydration since body fluids are depleted through respiration.
A 2nd procedure is to regulate the compressed gas through several stages to minimize the cooling resulting from the Venturi effect. That can be done by installing a two-stage regulator or installing two or more regulators on the supply line to obtain more reduced differential pressures and thus, reduce the Venturi effects.
Another well-known procedure (already described with diving helmets) is to heat the regulators and gas reserves. That can be done by merely ensuring that they are situated in rooms protected from the cold, enveloping regulators situated outside rooms in heated shrouds, or applying a heated directional airflow to them and the gas quads. Using specific electrically heated regulators is another solution if the model corresponding to the needs exists (electrically heated regulators exist for industrial gasses).

- A regulator can also be kept in continuous free-flowing due to an internal breakdown resulting in the valve stuck in the open position.
That can be due to foreign debris or broken internal parts such as a destructed o-ring or a ruptured spring. Internal corrosion or salt deposits resulting from seawater intrusion in the gas line are other possible reasons. Such breakdowns require that the regulator is removed and repaired.
Foreign objects can be avoided by installing online porous sintered bronze filter elements. The risk of having destroyed internal seals can be minimized by changing them each internal inspection. Broken springs can result from the issuance of high frequencies that cannot be absorbed and withstood by the spring involved, so be linked to engineering problems. Internal corrosion can be avoided by sealing the regulator or piping inlet and outlet when it is not in use. Salt deposits should be removed by opening the regulator and rinsing it in addition to the parts of the piping that has been invaded by seawater.
- Another cause of continuous free-flowing can merely be an incorrect supply pressure.

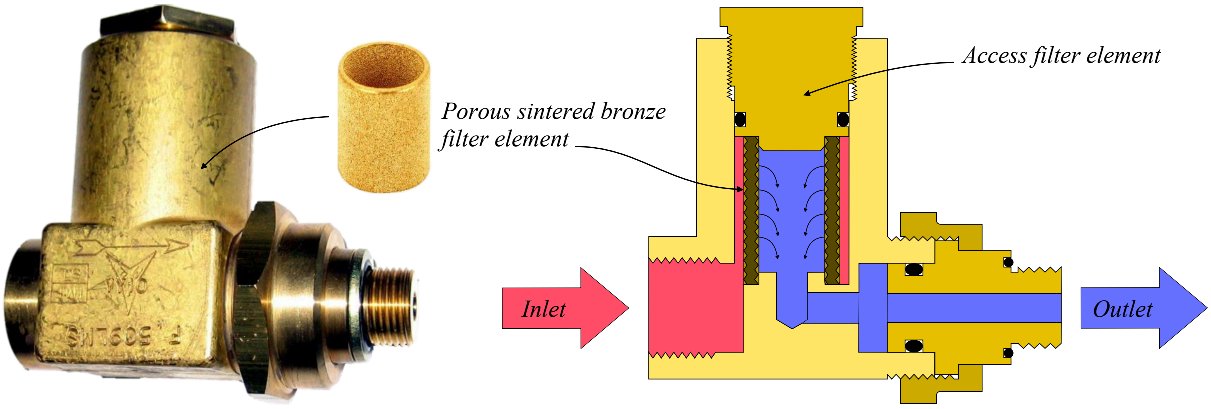
The outlet pressure of the regulator may build up after final adjustment. This phenomenon is also called "creep".

- Outlet pressure building up can be due to foreign objects preventing the valve from closing or damaging the valve seat. The regulator will have to be opened, cleaned, and its damaged parts changed out. That can be avoided by installing appropriate online porous sintered bronze filter elements.
- Outlet pressure building up can also be the fact of a too old valve seat that becomes porous or deformed (it is usually said "marked") as a result of the numerous closure cycles of the valve.

Such an incident can be prevented if the seat is changed during every internal inspection.
The valve seat's life can be increased by implementing good practices such as removing the residual pressure in the pipework after the dive, so the only force against the seat is from the valve spring. Also, slowly opening the inlet valve reduces the initial compression shock of the valve against the seat when pressuring the line.

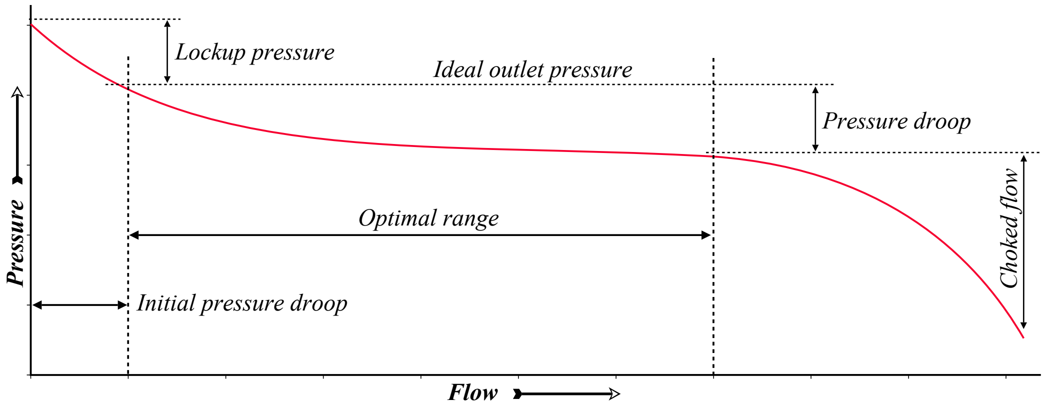
An insufficient outlet flow may be noticed despite a normal inlet pressure. That can be linked to the following:

- The hand-knob may be incorrectly adjusted, so the delivered pressure is incorrect. Gauge failure may also happen, so the pressure read is incorrect.
- The reasons for insufficient output flow can also be those already described for regulators stuck in free-flow. Thus, freezing, foreign debris, corrosion, or salt deposits may prevent the valve from working correctly. The remedies are those previously indicated for regulators stuck in free-flow.
- The online porous sintered bronze filter element may be clogged. These filters, usually installed in a separated housing, are made of bronze powders shaped using appropriate molds and then controllably fused to obtain pores whose size usually varies from 1 to 100 microns. They become clogged with time, depending on the cleanness of the installation. For this reason, they must be verified and changed out before starting the operations and regularly during the operations. Note that a clogged filter may block the inlet line, such that it remains under pressure. Thus, venting the section upstream is an essential precaution before intervening.



- There may be a loss of sensibility of the diaphragm or the piston resulting from these elements being damaged. Note that gas leaks through the bonnet indicate such defects.
  Again implementing good practices such as backing out the pressure adjustment knob before pressurising the regulator can avoid diaphragm or piston o-ring failure. The reason is that if the regulator is left in the open position, the pressure rapidly hits the diaphragm or the piston, which may cause a diaphragm deformation, or damage the piston seal.

A decrease in the outlet pressure while the flow rate increases can be noticed. It is not to be considered a breakdown because it happens in all regulators. However, it is more visible with some models than with others.
This phenomenon, called "pressure regulator droop" or "proportional band", varies in function of the conception of regulators. It is expressed in percentage and used as a comparison criterion to evaluate the accuracy of a regulator. As an example, a regulator with 10% "droop" has 90% accuracy. Manufacturers usually use flow charts to represent the "pressure droop" of regulators:



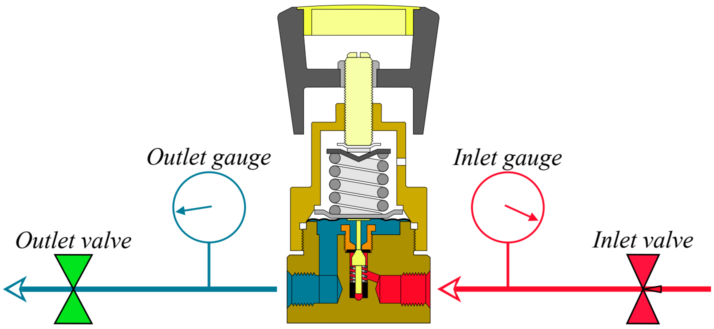
Notes:
"Lockup pressure" is the pressure above the set-point required to shut the regulator valve off and ensure there is no flow.
Engineers call "Hysteresis" the retardation of an effect when the forces acting upon a body are changed. This phenomenon occurs with regulators due to friction forces caused by springs and seals.

- The proportional band depends on variables that influence the ability of the regulator to respond to gas flow. The three principal are the following:
  - The stroke length is the distance travelled by the regulator's valve to open and close. It is said that a short stroke length is preferable to a long one.

- ◦ The size of the sensing element influences the response of the regulator. It is recognized that large diaphragms or pistons respond more accurately than small ones. As a result, a lot of regulators used for industrial applications are provided with broad sensing elements. However, it is not possible to install such models on diving panels for compacity and handling reasons. Thus the size of the membranes and pistons of the regulators used for diving applications is usually limited to the diameter of their bodies.
  - ◦ The spring rate is a method of measurement used to evaluate the softness of springs. It refers to the amount of weight it takes to compress a spring a certain distance. It is said that the lower the spring rate, the more sensitive the regulator.
- In addition to the above, the design of regulator also influence its "proportional band". It is said that:
  - Non balanced spring loaded regulators have between 10 and 30% droop.
  - Balanced spring loaded regulators between 5 and 10% droop.
  - Dome regulators have only 2 to 5% droop as the result of the more efficient response of the compressed gas that replaces the spring.
  - High flow regulators are less accurate than standard units.

The maintenance schedules of regulators should be organized by taking the elements above into account. Thus the planning may vary according to the weaknesses of the models in use.
Note that documents such as IMCA D 023, and those from other professional diving organizations do not provide any guideline, except that the regulator must be free of corrosion and operate freely.
However, based on manufacturers' recommendations, and except if weaknesses require more attention, we can consider that intervention frequencies can be organized on the following basis.

- Function test and external inspection should be performed prior to use, and on a daily basis during operations.
- A leak check should be performed every month. This test can be performed by the diving supervisor or the operator using the following procedure:
  1. The regulator must be fully closed by turning the adjusting knob counterclockwise until the stop is reached. Then the regulator inlet is pressurized, and the supply valve is closed so that a small amount of gas is kept in-between the supply valve and the regulator's valve. The pressure should be monitored for at least 5 minutes using the inlet gauge. A pressure decrease indicates that the valve of the regulator or a connection leaks. Note that a pressure increase suggests that the inlet valve leaks.
  2. The operator then ensures that the outlet valve is closed, opens the inlet valve, adjusts the regulator to a selected pressure, listens for any suspicious noise, and checks all connections for leaks using a gas bubble leak check solution. In addition, and if no leak of the regulator's valve and the inlet valve was detected, the tightness of the regulator and the outlet valve is checked by closing the inlet valve and checking the outlet pressure for at least 5 minutes.



- The internal inspection should be performed at least every two years.

As already indicated, standard precautions should be implemented by the operators to preserve them from excessive wear and unexpected damages:

- Regulators should not be used as a shutoff valve: The supply valve must be closed when the system is not operated, and the regulator vented and backed out to the no-flow position.
- Regulators must not be left at a preset when the gas supply valve is opened. Instead, they should be kept in no-flow condition , and then adjusted.
- The regulators' supply valves should be opened slowly. It is why safety organizations recommend needle valves for high-pressure supplies.

2.17 - Gas analysis systems

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

2.17.1 - Types of analysers used

The air commonly used for surface supplied diving operation is usually natural standard air compressed on-site according to the needs. Pure oxygen is typically manufactured in production plants. It is also the case with some nitrox mixes. However, nitrox mixes are also commonly fabricated onboard by a competent person. For these reasons, oxygen purity and its proportion in nitrox mixes should be checked as a priority. Carbon dioxide resulting from respiration must also be monitored in chambers. In addition, the person in charge should also look for pollutants whose maximum proportions are indicated in the standard of gas purity selected. Two categories of analysers are used:

1. Panel analysers are fixed units that are not designed to be transported. They are installed on the divers' gas supply panel, the chamber’s control panel, and gas mixing panels. Oxygen and carbon dioxide are usually the gasses controlled.
2. Portable analysers are commonly used for the analysis of the content of the gas containers delivered. Some last-generation models are very compact and designed to be calibrated with air.

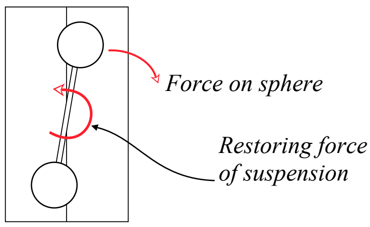
These analysers that can be designed to detect several gasses, may use one or several systems of detection that are described below. Note that the industry regularly provides new concepts and products.

1.17.1.1 - Magneto-dynamic (Paramagnetic)

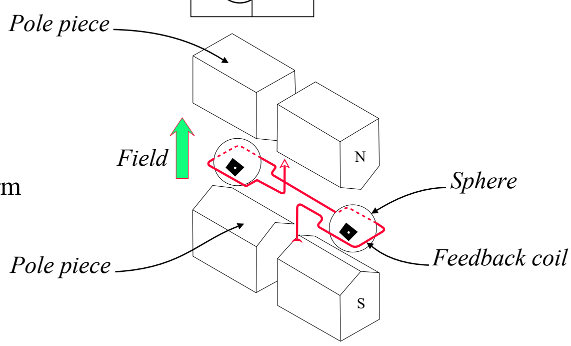
This technology is frequently used with oxygen analysers mounted on panels.
This system is based on the measures of the paramagnetic susceptibility of the sample gas by means of a proven magneto-dynamic type measuring cell.

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

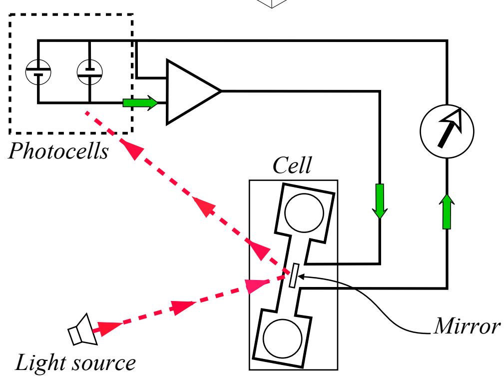
- The test body of all measuring cells oxygen analysers consists of two nitrogen-filled quartz spheres arranged in the form of a dumb-bell.



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



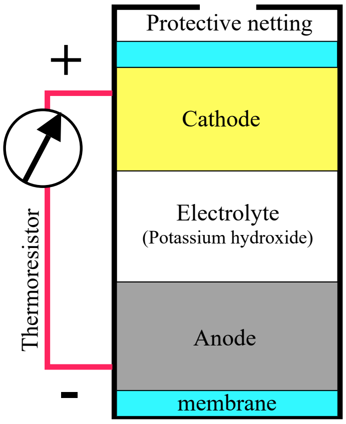
- The angular rotation of the dumb-bell is sensed by a light beam projected onto a mirror attached to the dumb-bell from which it is reflected onto a pair of photocells. The difference in the outputs from these photocells is fed to an amplifier whose output is zero when both photocells are illuminated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



1.17.1.2 - Fuel cell analysers

Fuel cell analysers are widely used to detect oxygen, because they are robust, lightweight and suitable for remote readings. They are often used with portable or fixed analysers due to these advantages.

The device attached to the gauge allows either a measurement of the partial pressure or a measurement in expanded gas (percentage).



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

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.
Also, errors may be caused by condensation on the fuel cell, changes in chamber temperature, changes in the temperature of the wires carrying the signal to the analyser and radio transmissions and other electromagnetic fields.

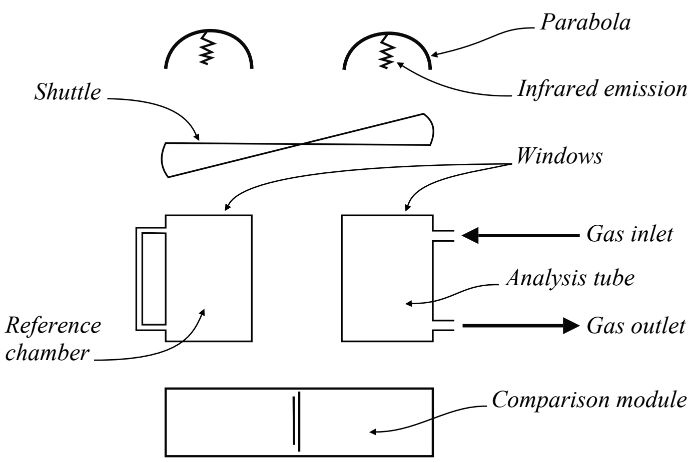
Since the fuel cell is a battery, it will run out, normally in about six months, but depending on the concentration of oxygen in the gas analysed, it will often be less. Erratic reading is an indicator that the cell needs to be changed.

1.17.1.3 - Infra-red analysers

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

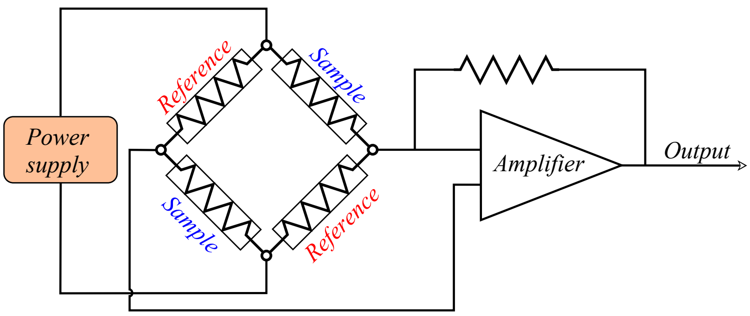
- Equal infra-red beams of the appropriate wavelength are shone onto two cells. One cell contains a reference gas, and the other cell contains the sample gas.
- The sample gas absorbs radiation in proportion to its carbon dioxide content and heats up.
- By comparing the temperature rise with the temperature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

Calibration normally requires a zero gas and scale gas



1.17.1.4 - Thermal conductivity detectors (also called universal detectors)

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

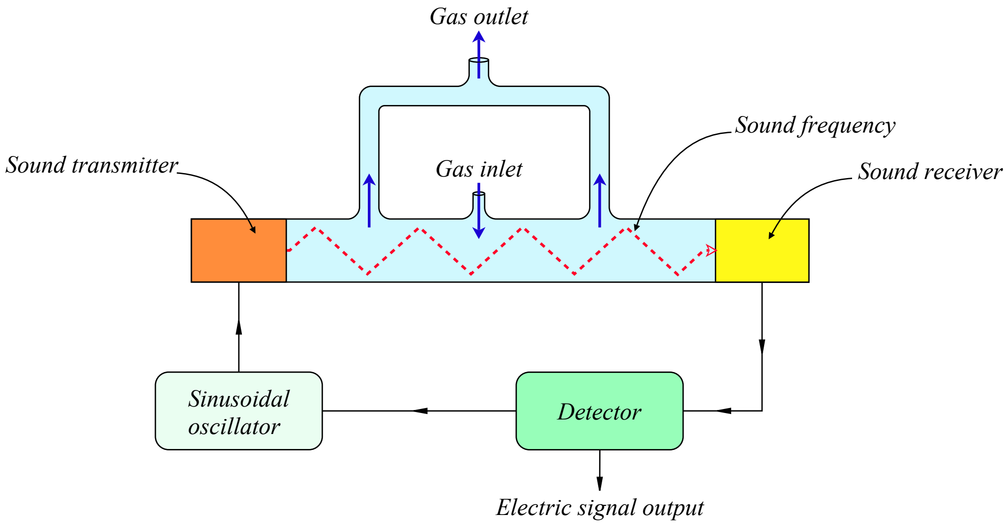


Thermal conductivity is used to detect various gases such as:

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

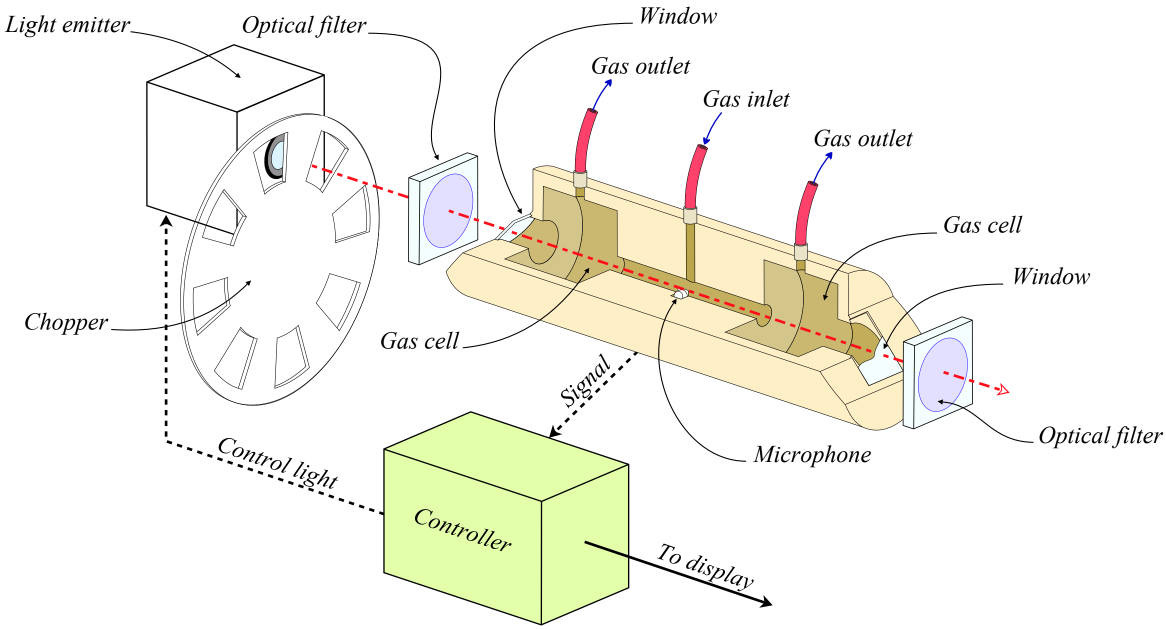
1.17.1.5 - Acoustic Gas Analysis (Also called speed of sound)

Acoustic Gas Analysing (AGA) is a technology that consists of measuring the speed of sound through a mix to evaluate its components. It is used by scientists in laboratories and adopted by analysers that are used for diving activities. It is the case of the "Analyzer Solo" proposed by Divesoft, which is a portable analyzer that detects oxygen and helium and is offered to advanced sportive divers using trimix blends.
This system that is usually calibrated with air is composed of a small chamber that is filled with the gas to analyze.
A sound at a particular frequency is emitted at one end of this chamber and received by a dedicated sensor at the other end. The speed of the sound depends on the gas the operator is looking for, the temperature of the mix, the humidity of the mix, and the frequency of the sound emitted.
The differences of sound propagation in the sample chamber are recorded by a detector that converts them into an output voltage in proportion with the difference with the calibration sample, which is displayed on a screen and allows evaluating the percentage of gas the operator is looking for.



1.17.1.6 - Photo-acoustic gas analysers

Photo-acoustic spectroscopy is the measurement of the effect of absorbed electromagnetic energy (particularly light) on the matter using acoustic detection.



The system consists of a light, commonly an infrared laser, that is used to excite a gaseous molecule that absorbs its

electromagnetic radiation. By modulating this radiation source, the temperature changes periodically, giving rise to a periodical pressure change, which can be observed as an audible signal which can be detected with a sensitive microphone. These sounds are converted into electric signals that are sent to the display.
These analysers can detect all the gasses used in the diving industry and their potential pollutants with a very high accuracy. They are currently used for:

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

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

*1.17.1.7 - **Chemical sampling tubes** (also called colorimetric tubes)*

Colorimetric tubes were widely used for carbon dioxide analysis in chambers, and even though other systems have replaced them, they should be available. The range of chemical sampling tubes is very vast, and for this reason, they are often used to test gas supplies for various contaminants that may be present, such as carbon monoxide, oil, hydrocarbons, and others.
The most widely used chemical sampling tubes are probably those manufactured by Dräger. It is the reason they are commonly described as Dräger tubes. However other manufacturers, as an example SKC, provide similar products.

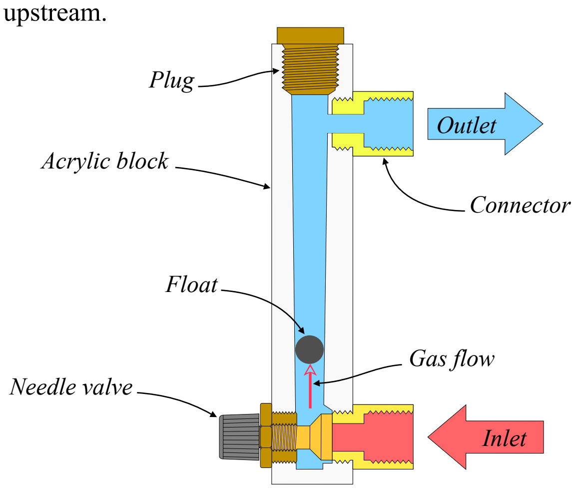
The system consists of a glass tube that contains a chemical which changes colour in proportion to the amount of the sample gas drawn through the tube. The tubes are usually calibrated in percentage or parts per million, for use on the surface, but actually, measure the partial pressure of the gas.
If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

- There may be different models of pumps, and the volume of gas drawn through the tube is critical. For this reason, the person in charge of providing such equipment should ensure that the model supplied is correct for the tubes to be used before starting the diving project. The condition of the pump must also be checked.
- The operator ensures he has the correct tube for the gas to be analysed and that it is in-date.
- The operator verify the number of pumps needed, which is normally indicated on the tube.
- The pump should be checked by fitting the unbroken tube into the pump and exhausting the bellows. The pump should not re-inflate. If it does, it is leaking and the reading will be inaccurate.
- When the checks are completed, the operator breaks the ends off the glass tube and fit it into the pump with the arrow pointing towards the pump. The gas is then drawn through the tube.
- The operator exhausts the bellows and allows them to re-fill entirely at their own speed. The chain on the pump must be tight before exhausting the bellows again.
- If the tube shows adequate coloration after one pump, the operator takes a reading from the one pump scale. If not, he carries on for the maximum number of pumps shown.

If there is no discolouration at all, some tubes can be sealed with the rubber caps provided and re-used up to two more times. Check the manufacturer's instructions.

2.17.2 - Flow-meters

Gas samples delivered to panel analysers must be controlled in pressure and flow according to the recommendations of the manufacturers. It is the function of flow meters that are installed upstream.
Most surface-supplied diving systems use traditional flow meters made of a clear acrylic plastic block that is longitudinally bored in which a small ball, usually called "float", is encased. Note that the float is a small pierced cylinder guided by a rod with some models. The gas sample to the analyzer is flowed through the bore and is controlled by a small needle valve, so the small ball is pushed to a certain height according to the flow. Graduation on the transparent body allows the monitoring of the ball's position that is to be adjusted close to the middle or according to the recommendations of the analyzer's manufacturer
Note that the flow meter's selection depends on the analyzer to feed and the gas to monitor. These traditional systems are rarely subject to breakdowns and are inexpensive, which are the main reasons they have been used for a long time. However, more precise electronic devices are available today.



2.17.3 - Last generation analysers

Analysers used with chambers and dive control panels of surface supplied are mostly analogical systems, which oxygen monitoring is usually based on the fuel cell technology. The reason for selecting this technology is that it considered inexpensive compared to others, despite the fact that fuel cells have to be frequently changed during intensive diving operations, and considered sufficiently accurate for the task they are designed for by many dive systems manufacturers. Note that infra red systems are still the most employed for CO_2 monitoring.
However, last generation analysers designed with digital technologies offer more functions and are more accurate than those of previous generation described above. As an example, manufacturers such as Fathom systems, a company based in the United Kingdom, group the analysers in modules that are designed to analyze the O_2 and CO_2 at the same time and can display some measurements in different units. As an example, oxygen can be shown in percentage and partial pressure at the same time. Also note that carbon dioxide must be accurately monitored in chambers.
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.

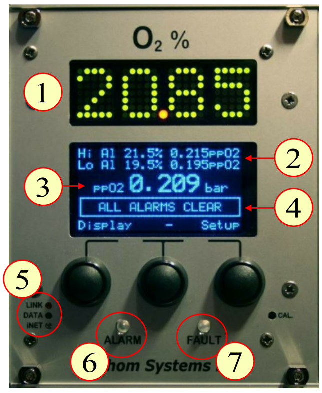
III - Accepted Alarm: An alarm that has occurred has been acknowledged or accepted by the operator (by pressing the appropriate front-panel button). In this case, and provided there are no other active alarms, the display changes to solid red, the alarm LED remains on red (not flashing) and the audible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

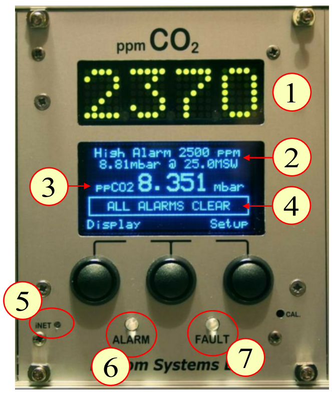
#3 2nd display in Partial Pressure

#4 Alarm display (all clear)

#5 Telemetry status

#6 Alarm LED light

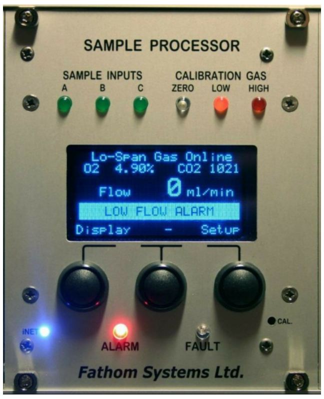
#7 Fault LED light



With the new systems described for example, the sample and calibration gases being sent to the CO_2 slave and O_2 master analysers are managed by the "sample processor", which is a slave module.
With this module, the classical flow-meter 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 O_2 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)*.

2.17.4 - Maintenance

The maintenance of analysers depends on the system used and the guidelines provided by the manufacturer. However, most manufacturers recommend the following:

- A visual inspection and calibration should be performed at least every 12 hours.
- A function test should be performed every day.
- The full inspection and calibration of all components should be performed every year.
- The equipment should be sent to the factory for a complete revision and update every two years.
- Sufficient replacement fuel cells should be provided for analysers based on this technology. They should be changed according to the recommendations of the manufacturer. However, they must be renewed at least every six months after installation, even though they have not been used .
- Routine calibration of depth sensors should be performed every three months for last-generation analyzers like the model above.

2.18 - Dive control panels

Dive panels group the elements previously described allowing the supervisor to:

- Provide primary and secondary gas supplies to the diver.
- Monitor the gas pressure delivered to the diver and the remaining reserve online.
- Verify the oxygen percentage of the gas delivered to the diver.
- Control the depth of the diver.

The panels installed in dive control rooms vary from basic to complex design, depending on the number of divers to supply, the gasses used, and whether the company performs oxygen stops in the water. Note that the panels described in this topic are designed for air and nitrox diving only. For obvious reasons, a supervisor needs to have a minimum knowledge of how they are designed and how they must be maintained. It is also crucial to be able to emit specifications to select those that are the most appropriate for the planned operations.

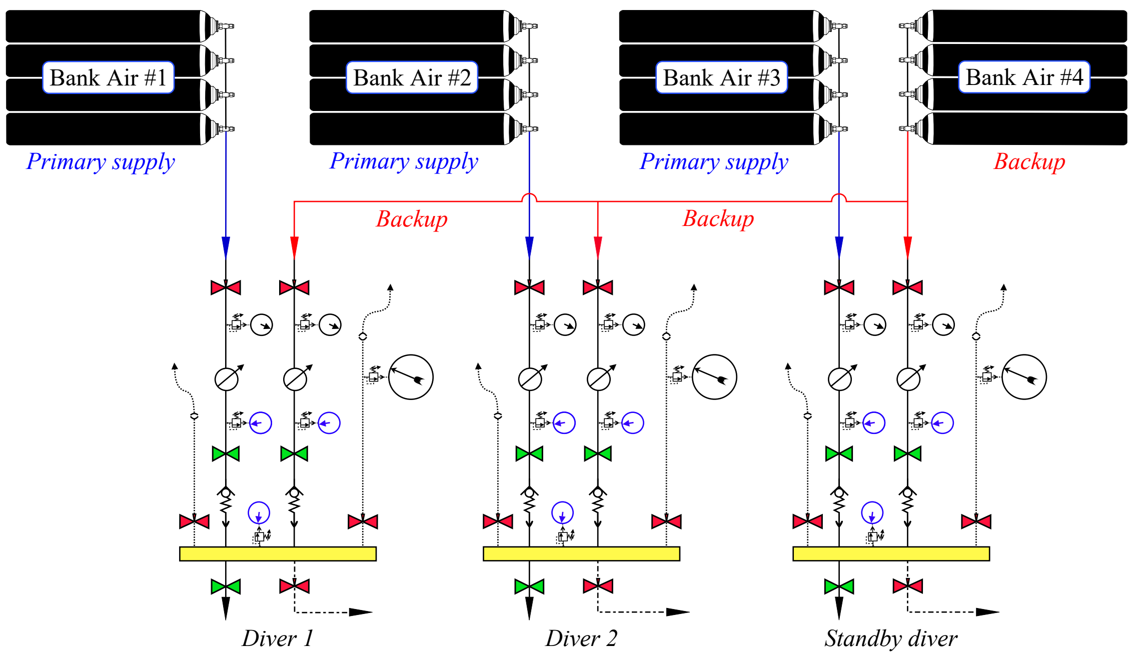
Like all parts of the diving system, diving panels must be certified by an approved competent body, and some clients require that the diving system is under a classification scheme. Note that diving with not-certified equipment exposes the company to prosecutions and fines. Thus, it is not wise to self-produce such elements unless the company is adequately skilled to successfully undertake such a technical and jurisdictional process, which is generally not profitable for only one unit. Note that the procedures for certification and classification are explained in point 4.2 of Book #2.

Other elements the supervisor needs to monitor the dives are described in the next sections.

2.18.1 - Essential components of diving panels

Manufacturers design diving panels according to official norms, the requirements of the certification bodies appointed to witness and approve their construction, and documents published by diving and safety organizations. Note that most diving organizations focus on only a few key points instead of the overall device; of these publications, IMCA D 023 remains the most precise and used. Of course, the most accurate documents are those emitted by the certification bodies. Based on all these documents, it is possible to summarize the following basic guidelines:

- Regarding the gas supplies:
  NORSOK standards U 100 and most certification bodies say that the divers and the stand-by diver must have their own dedicated primary gas supplies with a separate, secondary gas source immediately available to supply either diver as a backup. In addition, these organizations say that these gas supplies, which must provide adequate pressure and flow rates for the maximum planned depth, must be arranged such that the failure of one line does not interfere with the supply to another diver.
  IMCA D 023 says that when only one diver is at work, he should be at least supplied by a primary gas source and an independent secondary one, and when two divers are at work, they should be fed by three sources connected either as a separate primary source for each diver with a common secondary or else a common primary source feeding both divers but with independent and separate secondary sources to each diver. IMCA D 023 also says that the primary gas source of the standby diver must be sufficient to allow him to rescue an injured diver and must be separate from the primary and secondary sources of the working diver(s). However, his secondary source can be shared with those of the working divers, provided it is protected from malfunction.
  Considering what is written above, most dive system manufacturers organize the minimum supplies of their diving panel for three divers (2 divers at work + 1 standby diver) with four sources: One primary source for each diver plus a shared backup source. Also, many manufacturers consider it preferable to supply two divers at work and the standby diver through dedicated separate sources. The reason is that two divers breathing simultaneously through the same supply will be affected by a harmful gas or the failure of a device at the same time, which may oblige the standby diver to rescue two victims.



The gas supplies can be delivered from high-pressure (HP) containers or running low-pressure (LP) compressors. The air from LP compressors is regulated according to the depth the diver operates. Some manufacturers organize the regulation on the compressor only, so there is no regulator on the panel. However, many manufacturers install an LP regulator on the panel, allowing the supervisor to better control the pressure delivered to the diver. The gas from high-pressure containers can be delivered to the panel and reduced to the desired pressure through the HP regulator installed on it, so the panel is fed with HP air. Another method is to reduce the pressure at the source, so the HP gas container, and then through an LP regulator installed on the panel. Both solutions have advantages and inconveniences:

- Direct HP supply to the panel is straightforward and allows for monitoring the pressure of the cylinders on the diving panel. The inconvenience of such systems is that the supply lines are at high pressure, so a high flow of gas may pour out of them in case of a rupture, making flexible lines not adequately secured dangerously whipping. That can be controlled by implementing the precautions indicated in point 2.11.5.
- HP supply regulated at the source provides the advantage that the gas delivered to the panel is at low pressure with a flow delivered through the hose that is not high enough to make the whipping of this hose dangerous in case of a rupture. Also, this system can allow for a softer two stages regulation with a 1st stage at the source and a 2nd stage on the panel. The main inconvenience of such an arrangement is that the reduced inlet pressure read on the panel doesn't allow for monitoring the content of the gas container. An old control procedure still in use is to assign the lead diver or the technician to report the remaining pressure at regular intervals. More modern techniques can and should be implemented to compensate for this inconvenience, such as installing electronic pressure sensors with remote displays in the dive control or installing a CCTV camera looking at the pressure gauge of the source so that the pressure can be monitored through a combo (This straightforward method requires additional cameras and screens). Another efficient means of control that should be mandatory on all low-pressure supply lines is an alarm system such as the model below, designed by MST (https://www.modsafe.com/), a company based in Hicksville, USA. This device, provided with a small backup battery that keeps it active in case of an electrical shutdown, allows to set up an audio and visual alarm at pressures between 2 and 20 bar.

Remember that oxygen and nitrox mixes (> 22% oxygen) must be regulated at the source, and that the maximum inlet pressure of such mixes is limited to 40 bar.

A lot of manufacturers cumulate the solutions described above. Also, it is usual to supply the standby diver with compressed air from a dedicated bank instead of from a compressor for the reasons already discussed.

Another point to consider is that although they are mandatory, the cylinders of the diving basket are not considered a backup supply, unlike the gas reserves of wet bells. The main reason is that these bottles are not part of the supply circuit and thus cannot be put online to the diver's umbilical.

- Valves and piping

The piping system components are selected to allow for adequate flow during the most demanding conditions the diving system is expected to be used. These components are assembled so that the gas flows in the appropriate direction. Stop and check (one-way) valves are installed for this reason. Also, arrows indicating the proper direction are usually marked on pipes and components, that must be figured on the cover board.

Pipes of ¾ inch or ½ inch diameter are commonly used for the flow lines and ¼ inch for the gauges and the analyser. However, there may be variations from one manufacturer to another.

Certification bodies require that the minimum thickness of pipes is calculated to withstand at least a pressure of 1.5 times the working pressure. A hydraulic pressure test verifies that. In addition, a gas pressure test is usually undertaken at the maximum permissible working pressure to locate leaks. The Lloyd's Register recommends using nitrogen with 10% helium for such tests.

The metals employed for diving panels piping are those previously discussed in point 2.11.4, *"Storage and distribution of the gasses"*. As a reminder, stainless steel is often used for gasses other than oxygen, nitrox, or enriched heliox. Copper and aluminium bronze are also authorised for this purpose by some certification bodies. Some austenitic stainless steel (300 series) can be used with oxygen; however, nickel-copper alloys are preferred by organizations such as ASTM (American Society for Testing and Materials), most certification bodies, and also IMCA.

Connectors and welds used to assemble the components must be approved by the certification body. Flexible, non-metallic hose and tubing may be used, provided that their materials are suitable for the combustibility, toxicity, pressure, and temperature of the gas they are exposed to.

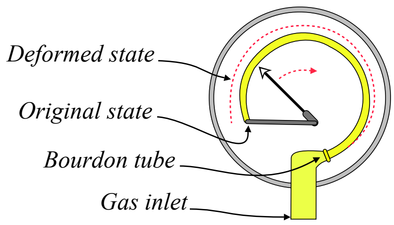
Adequate relief valves must be provided to prevent damage from overpressure of the piping and the other components.

The rules regarding valves is the one already described in point 2.11.4, *"Storage and distribution of the gasses"* Thus, needle valves are to be used to control high pressure supplies (> 33 bar) and ¼ turn valve can be used to control Low Pressure supplies. Needle valves are also to be used to control mixes with more than 22% oxygen and pressures exceeding 15 bar. Note that Lloyd's Registers and ABS lower this limit to 8 bar.

- Gauges

There must be enough suitable gauges so that the diving supervisor is aware of the depth of each diver and of the supply pressures of each main and secondary breathing supply. Thus, they must be organized such that the supervisor can read the inlet and outlet pressure of each supply line, the pressure delivered to the diver, and the depth of the diver.
These gauges must be protected by pressure limiting devices to avoid over pressurization that may damage them. Not indicated by IMCA, but very important, the gauges used with mixes containing more than 25% oxygen (22% with NORSOK and this handbook) must be oxygen compatible and cleaned. The gauges 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.

Certification bodies and system auditing guidelines such as IMCA D 023 divide the gauges into two categories according to their function: Depth monitoring 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.
    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.

- Regulators

  The regulators installed on dive panels conform to those described in point 2.26. They are an essential part of the diving panel, so the model selected must be approved by the competent body. As a result, in case a replacement of such a device is necessary, the new unit must be the same model. If another model is to be installed for technical or logistical reasons, this adaptation is to be approved by a certification body.
- Analysers

  IMCA D 023 says that there must be an oxygen analyzer with an audio/visual hi/lo alarm fitted inline on the downstream gas supply to each working and standby diver. Most certification bodies also implement this rule, so we can consider it is now an international standard. Some people say an oxygen analyzer is unnecessary for air diving panels, as the air used is natural compressed air whose composition never changes. However, it must be said that such devices have been made mandatory by diving organizations following several accidents resulting from wrong gas unintentionally online. Also, companies may use synthetic air that must be analyzed before connecting and during the dive.

  The analysers are of the models described in point 2.17, “Analysis”, and controlled flowing is to be installed. A valve is provided to isolate the circuit in case of a malfunction.

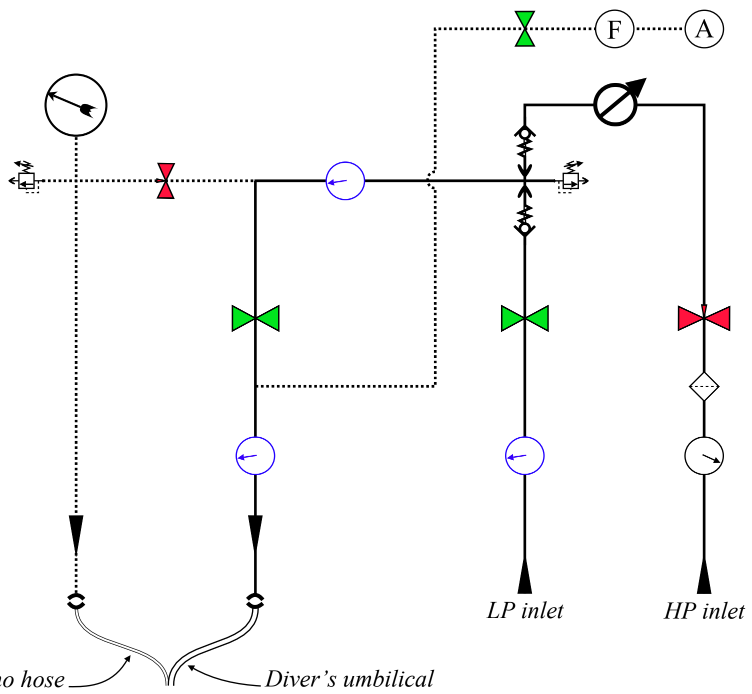
  Note that when using compressed natural air in areas where simultaneous activities may emit gasses such as CO and other harmful gasses, it is wise to use analysers capable of detecting such pollutants.

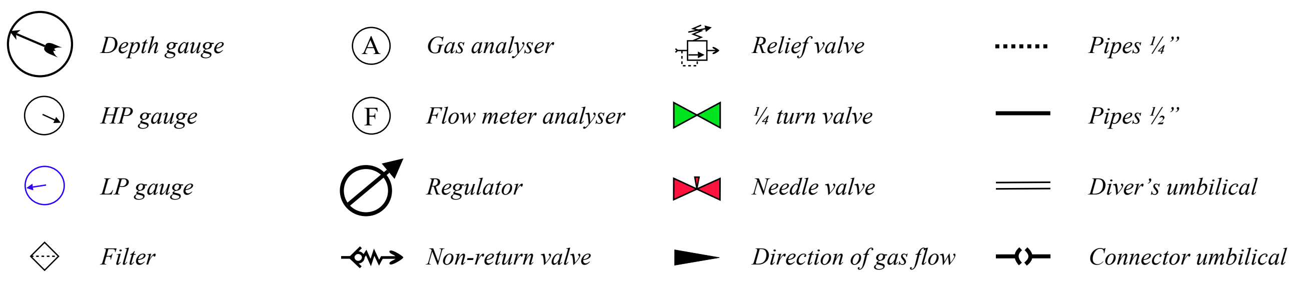
2.18.2 - Various designs of air diving panels

The air diving panels presented below are examples of the two main design philosophies based on the abovementioned rules. Note that, apart from a few models, most diving panels have their components not visible that, as already said in point 2.18.1, must be represented on the cover board.

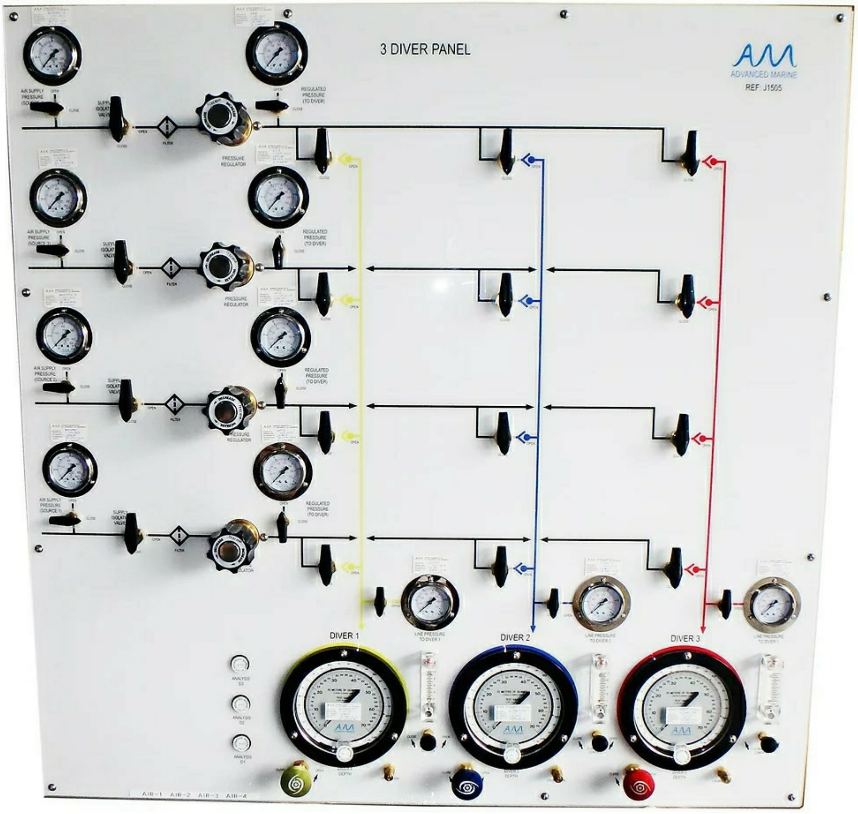
Separate single diver panels are usually straightforward units with the minimum required equipment. They have the advantage of being compact, easy to install and remove, and easy to maintain. The number of panels installed in the dive control depends on the number of divers to supply. Usually, manufacturers provide dive controls designed for three divers. The inconvenience of these panels is that they are generally not linked together, and some supervisors prefer having more possibilities of backup supplies. Also, many models have no regulator to refine the LP supply.

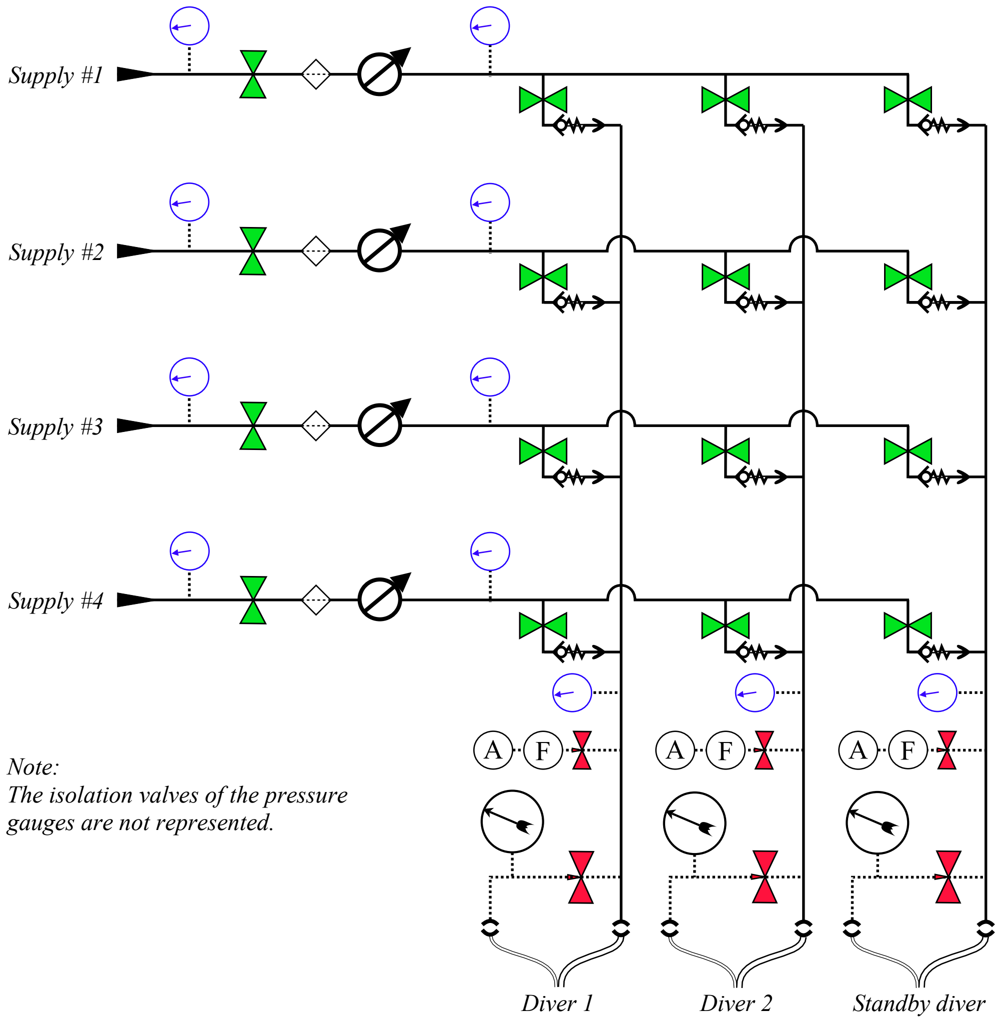
The model below is designed by Submarine Manufacturing & Products Limited, better known under the acronym “SMP” (https://www.smp-ltd.com/). It comprises one HP supply and one LP supply without a regulator. The O_2 analyzer is a portable model. Note that the gas sampling inlet is after the final valve to the diver.





As said above, some supervisors prefer using dive panels with more options than the single panels above to supply the divers in extreme emergencies. A good reference for such panels is the model underneath, designed by Advanced Marine Pte Ltd (https://www.advanced-marine.com.sg/). The version presented is supplied with low pressure with a regulator on each supply line, so the pressure delivered to the divers is fully controlled. This design also allows for building versions with high-pressure supplies or mixing the two options, depending on the user's desires.

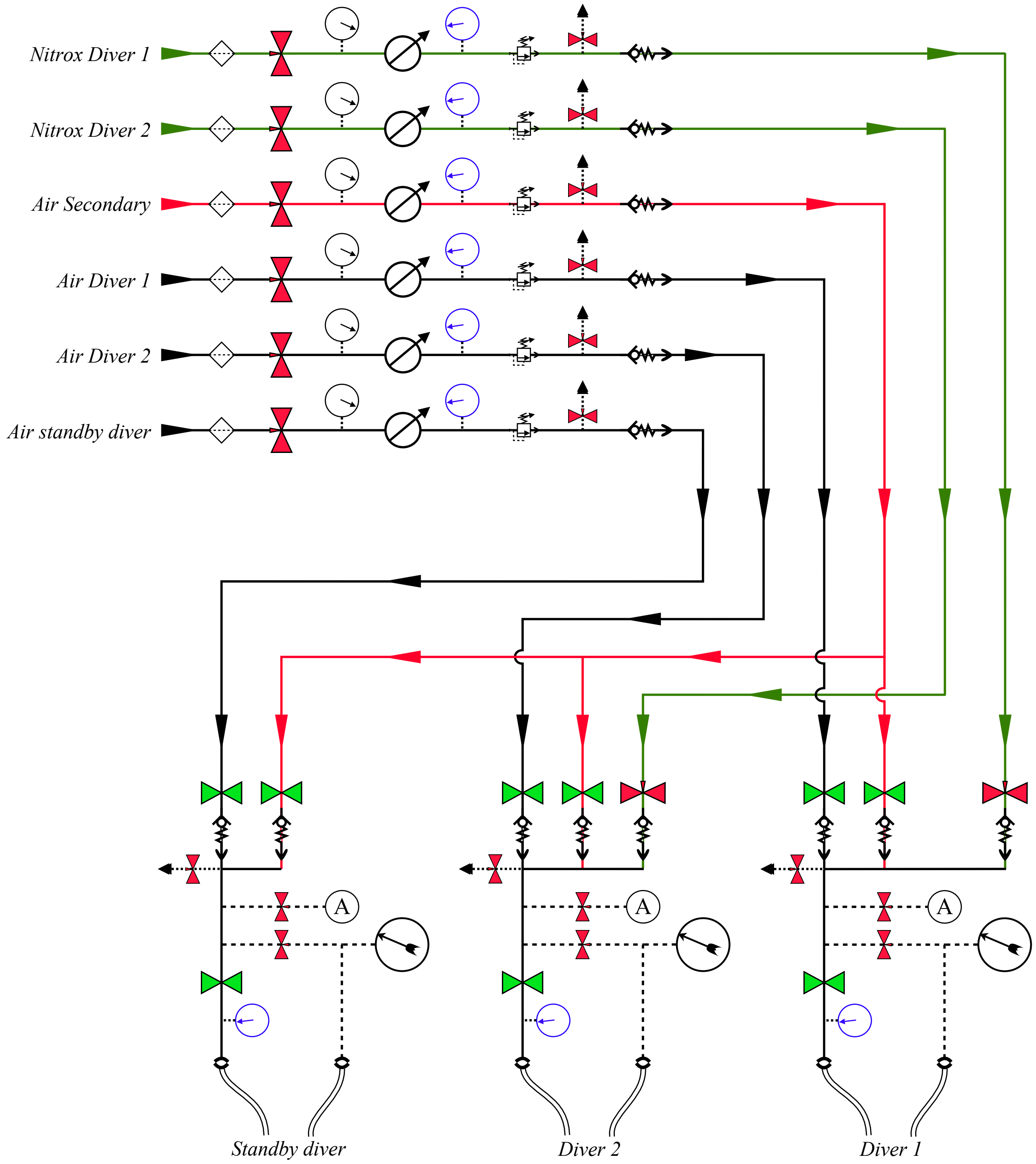




2.18.3 - Diving panels designed for nitrox

As already said, nitrox mixes are to be considered pure oxygen and additional precautions have to be implemented for the conception of panels using such mixes.
These precautions, indicated in point 2.11.4, “Storage and distribution of the gasses”, consist of oxygen compatible materials, valves that should be needle valves with a non-rotating stem for pressures above 15 bar or 8 bar with classification societies, such as the Lloyd's register or the American Bureau of Shipping (ABS), and the piping system that must be designed to eliminate particle impact ignition sources. It is, however, admitted that ball valves may be used as emergency shut-off valves in place of needle valves as they can be closed faster.
Based on such features, most certification bodies recommend oxygen piping systems as simple as possible, with the smallest possible number of valves and fittings. Also, the Lloyd’s Register says that valves in gas systems are to be so arranged that a valve leakage cannot lead to an unintended mixture of gases, and oxygen or oxygen-like gas cannot penetrate lines intended for other gases. Thus intersections between oxygen and non-oxygen systems are to be avoided or isolated by twin shutoff valves with venting valves in between.
Note that mixes considered oxygen cannot be vented out in the dive control room to avoid the risk of fire as the oxygenated mix does not immediately blend with the atmosphere and accumulates near the floor where it can favor a fire. For this reason, oxygen mixes vent lines must be organized to pour out in a ventilated area outside any room.

The scheme below is based on a three divers air and nitrox panel designed by Flash Tekk Engineering Pte Ltd that conforms with the recommendations above and is approved by DNV. It comprises two nitrox lines, three dedicated air supplies, and a shared secondary air supply. Note that the lines are designed with minimum connections and components. Also, the gas supplies and distribution are separated on two distinct panels *(see the photo on the next page)*.
Not represented on the scheme but visible on the photo on the next page, the analysers are supplied by whips with quick connect couplings. That allows the supervisor to use several analysers to confirm a reading or in case of a breakdown.



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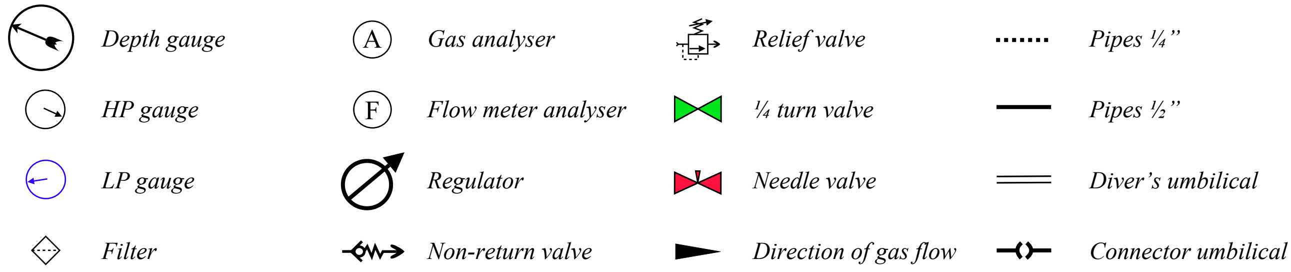
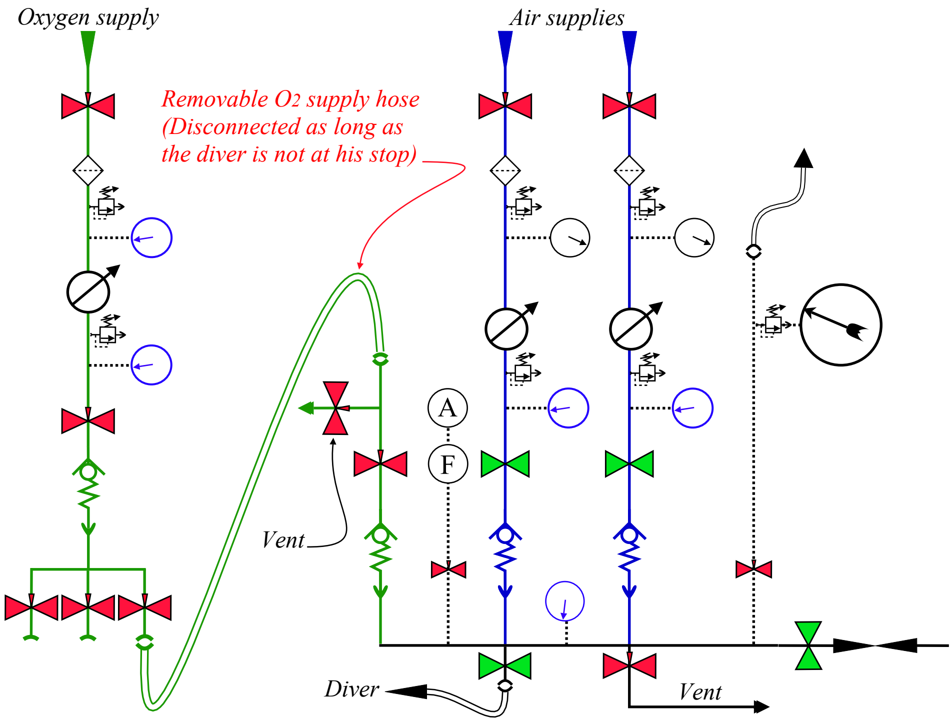


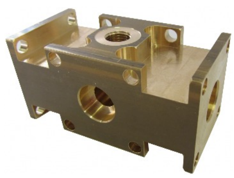
2.18.4 - Diving panels allowing in-water oxygen decompression

When performing in-water oxygen decompression (6 m), it is vital to be 100% sure that the oxygen supply cannot be connected inadvertently. One option, already mentioned, is to isolate the oxygen supply by two shutoff valves with venting valves in between, such as with the panel above designed by Flash Tekk, so that the oxygen supply and distribution valves are closed, the line fully vented with the vent valve kept open, and the regulator set to zero as long as the diver is not at the required stop depth. Thus, the line is activated only when the diver arrives at his stop.
A 2nd option is to supply the panel with a removable flexible hose connected to a separate oxygen panel. This line is physically disconnected during the dive and connected and pressurized only when the diver arrives at his stop.



2.18.5 - Diving panels Built using "Integrabloc system"

"Intégrabloc" is a patented modular assembly system manufactured by IMF (contact@imf-fluidcontrol.com) and designed for creating manifolds and gas distribution panels. This system, used and sold by Comanex (http://www.comanex.fr/diving-systems-1.html) to make diving and gas management panels, allows mounting valves, regulators, gauges, filters, relief valves, and other components onto integral connections. That reduces the risk of leaks associated with pipe fittings, limits the possibilities of vibrations, and makes aids replacement under regular maintenance plans.
These modules interconnected by screws and sealed by O' rings are made of brass or aluminium bronze. They allow for inlet pressures ranging from 250 to 400 bar.
It must be noted that this system was used to design COMEX diving panels during the 80s, some of which are still in service. These modules have not been modified, so an old COMEX panel using such modules can be easily maintained, renewed, and modified to the latest standards.



2.18.6 - Maintenance

Note that the maintenance of some components such as regulators or analysers are already indicated in the sections where they are described.
The panel must not show any external sign of damage or corrosion. Thus, even minor superficial decay should be removed, and the panel and its supply piping should be shiny.
As indicated in point 2.16.2, vibrations from the regulator may affect the diving panel. Vibrations may also come from an incorrect piping design or a damaged component. As already said, vibrations can be the source of damage to many panel elements. For this reason, their origin must be investigated to solve them.

Based on the elements considered for regulators that are an essential part of the diving panel, function tests and external inspections of all components should be performed prior to use and on a daily basis during operations. Also, the following preventive maintenance is to be organized:

- A leak check of each regulator should be performed every month. This operation involves each unit's inlet and outlet valves and gauges. For this reason, it should be extended to the entire piping. Note that the filters must be new when starting the operations and changed every month, particularly for those of oxygen lines.
- Regulators' manufacturers say that they should be internally inspected every two years. This internal inspection should be extended to the valves and filters.
- In addition to the internal inspection of the valves, the pipework must be tested at the maximum working pressure every two years.
- The relief valves should be function tested every six months, internally inspected, and pressure tested at the maximum working pressure every 2 ½ years (IMCA rule). Note that it is suitable to simultaneously do it with the regulator and the valves every two years.
- IMCA D 023 says that the gauges should be checked and calibrated every six months.
- Most analyzer manufacturers recommend the following:
  - A visual inspection and calibration should be performed at least every 12 hours.
  - A function test should be performed every day.
  - The full inspection and calibration of all components should be performed every year.
  - The equipment should be sent to the factory for a complete revision and update every two years.
- Cleaning of the oxygen lines should be performed at least every 6 months.

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

2.19.1 - Purpose and organization

The reserves, quality, and pressure, of gas delivered to the divers and the indication of their depth, are, of course, only some of the information the diving supervisor needs to control the dive as he needs to monitor what the divers are doing, guide them, and be informed of every event onboard the vessel or on the facility that may impact the operations. Also, like in the aviation industry, elements for investigation must be available in case of undesirable events. For this reason, communications, surveillance, and recording systems are of utmost importance.
These elements, grouped close to the gas and depth monitoring panel in the dive control room, can be divided into two segments: Communication and supervision of the divers and communications with the bridge and other vital parts of the vessel involved in the diving operation. In addition, it is crucial to ensure the electrical supplies of these elements during routine and emergency processes. The guidelines from the document IMCA D 023 remain the most used regarding these points and indicate mandatory features and some others that are optional. However, clients or other safety organizations may require these optional elements. For this reason, new diving systems are often fitted with them to avoid last-minute installation and improve their efficiency and safety. They can be classified into the three tables below:

Communications and monitoring divers

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	Backup two way voice communications divers	Optional	Optional	Having a portable unit ready for use is a basic precaution. They are identical to those described above and installed ready for use on the control panel of many new diving systems..
3	Video cameras divers	Not indicated	Mandatory (NORSOK and most clients)	According to NORSOK U100, a diver must be monitored by an ROV or a 2nd diver camera.
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" (7.11.3.3)*
8	Communications divers - supervisor recording (voice)	Mandatory	Mandatory	Retention of records is 24 hours with IMCA and 48 hours with NORSOK
10	Divers' video camera recording	Not indicated	Mandatory with NORSOK and most clients	Retention of records should be 48 hours with NORSOK
11	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

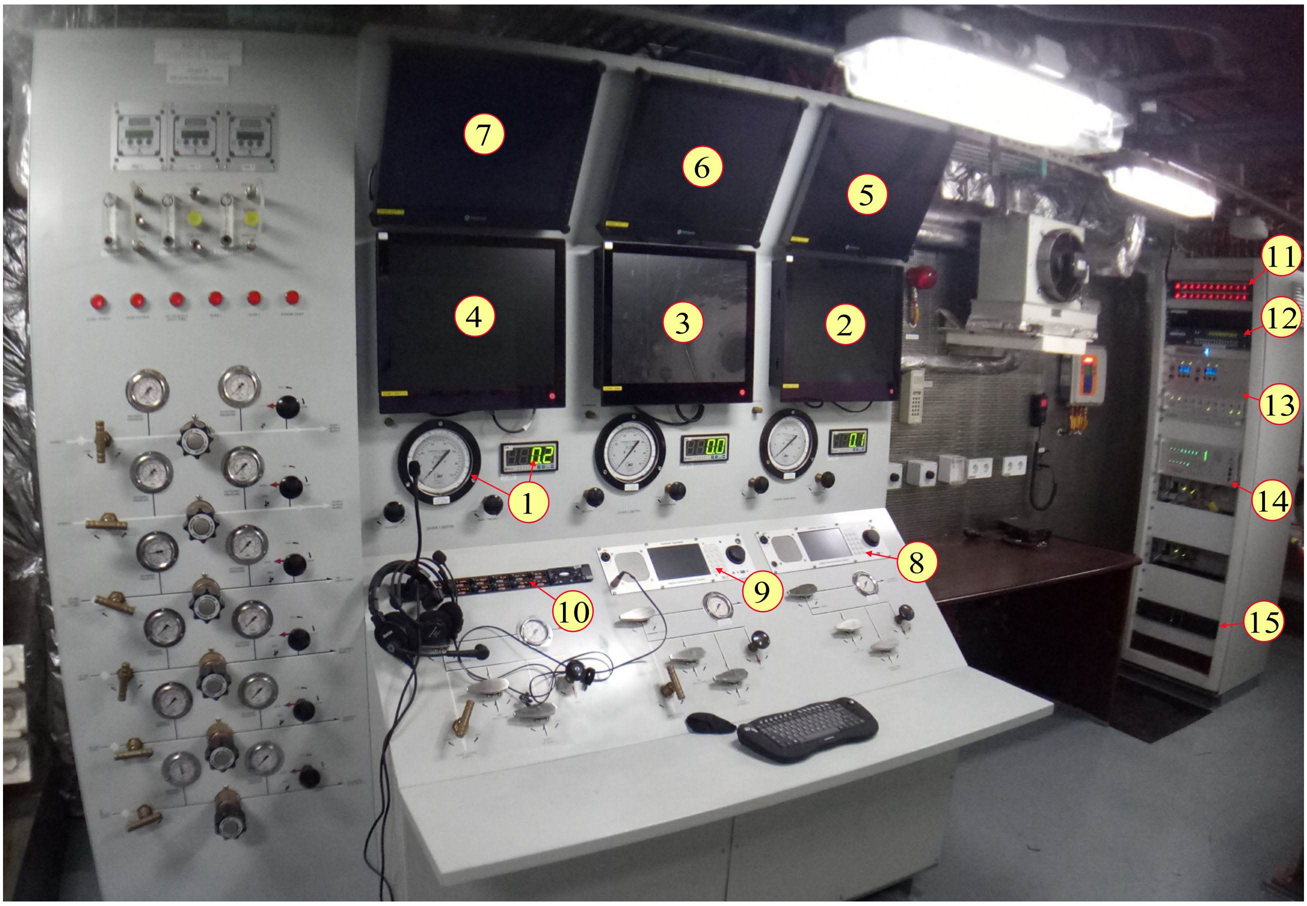
No	*Description*	*Requirements IMCA*	*Requirements from clients and other organizations*	*Additional information*
1	Hard wired communications to and from the bridge or the control room	Mandatory	Mandatory	The primary link must be hard wired, immediately available and unable to be interrupted. The secondary link can be hard wired or a dedicated radio channel. One of these links must work without an external power supply.
2	Wired secondary communications to and from the bridge or the control room	Optional	Optional	
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)	Recommended	Mandatory	Radio is no more accepted by most clients as main communication with the crane.

Communications, monitoring and alarms vessel (continuation)

No	***Description***	***Requirements IMCA***	***Requirements from clients and other organizations***	***Additional information***
5	Hard wired communications to and from the ROVs (Intercom)	Mandatory	Mandatory	
6	Hard wired communications to and from the saturation dive control room (if the dive controls are separate)	Optional	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.
7	Hard wired communications to and from the survey control room (Intercom)	Optional	Mandatory with most clients and contractors	IMCA does not say the nature of the means of communication. We recommend hard-wired units.
8	Hard wired communications (Intercom) to and from Offshore Construction Manager (OCM) office	Nothing indicated (It can be the phone)	Mandatory with most clients and contractors	See above
9	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
10	Hard wired communications (Intercom) to and from the inspection office	Optional (It can be the phone)	Optional (It can be the phone)	See above
11	Radio communications to boats cruising within the vicinity of the vessel	Nothing indicated	Mandatory with some clients and companies	The bridge does the boat traffic surveillance and management. However, many clients and companies provide a radio to the supervisor to make him aware of the events.
12	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
13	Phone (wired) communications to the areas indicated before and other parts of the vessel	Optional (It can be the intercom or the radio)	Mandatory with most clients	Onboard new vessels, office and cabins are generally connected to the dive control by phone communications
14	Video signal from the ROV	Mandatory	Mandatory	The picture is the same as the pilot
15	Video signal from the saturation divers	Not indicated	Optional	
16	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
17	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.
18	Video signals to the bridge (It must be the same picture as the one displayed in the dive control)	Not indicated	Mandatory with most clients	A video screen showing the ongoing operation is mandatory for most clients. A similar screen from the ROV and the saturation dive-control is also compulsory.
19	Video signals to client office (It must be the same picture as the one displayed in the dive control)	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 saturation diving is also compulsory.
20	DP alarms	Mandatory	Mandatory	The diving supervisor must be able to mute the alarm if it is disturbing the communications.
21	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
3	220 volts AC or relevant current 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)



1 - Depth divers *2 - Screen camera diver 1* *3 - Screen camera diver 2*

4 - Screen diver monitoring system *5 - Screen cameras LARS* *6 - Screen camera ROV*

7 - Screen saturation diving cameras *8 - Communications divers (main)* *9 - Communications divers (Backup)*

10 - Intercom system *11 - Electrical supplies* *12 - Recorder & video system*

13 - Helmet lights & cameras supplies *14 - Diver monitoring system unit* *15 - Server PC*

Note: This system is installed on a Dynamic Positioning Vessel: The DP alarm and the hot water machine controls (used in cold waters) are not visible in the photo. The phone function is part of the divers' communicators described in the next point

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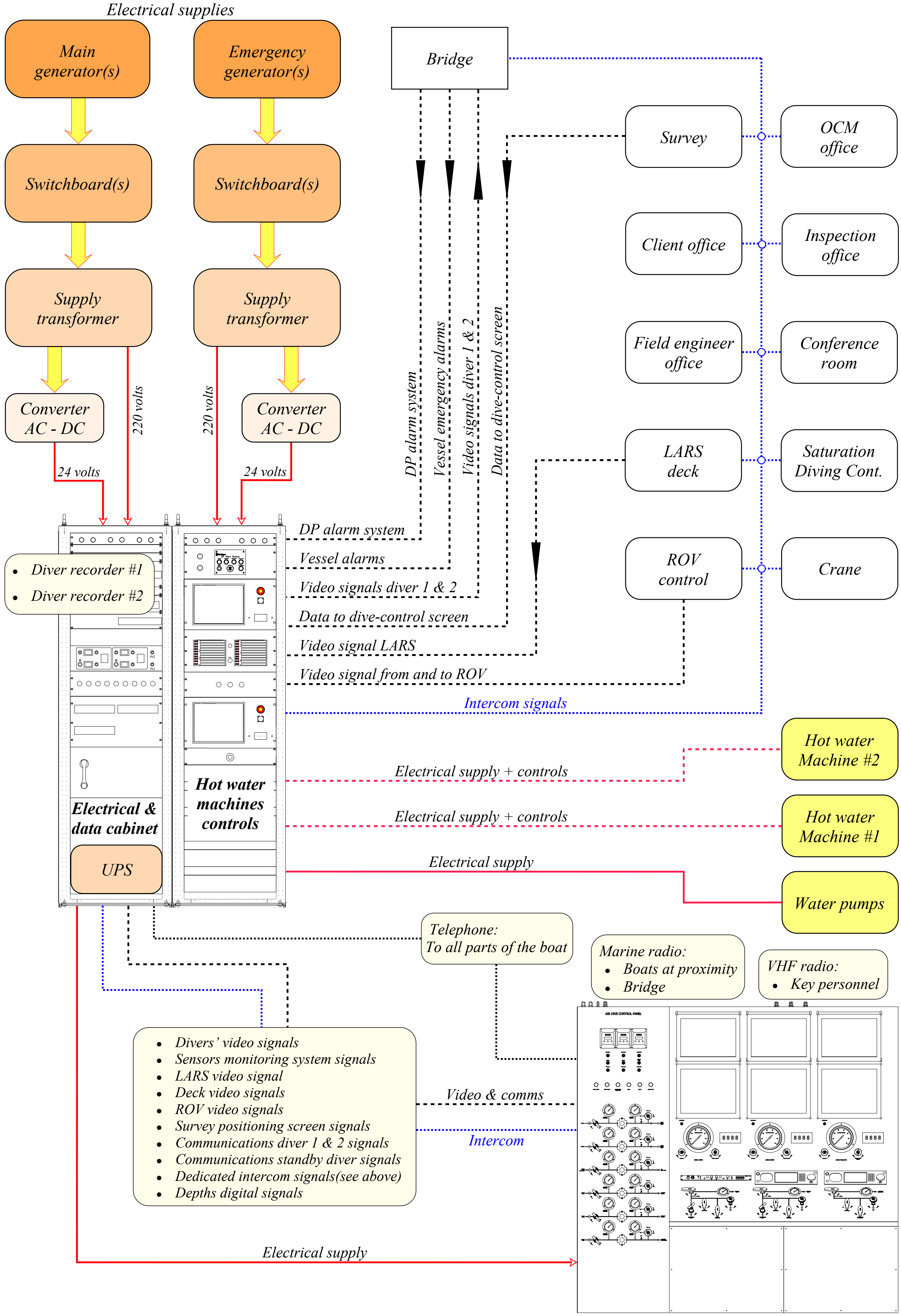
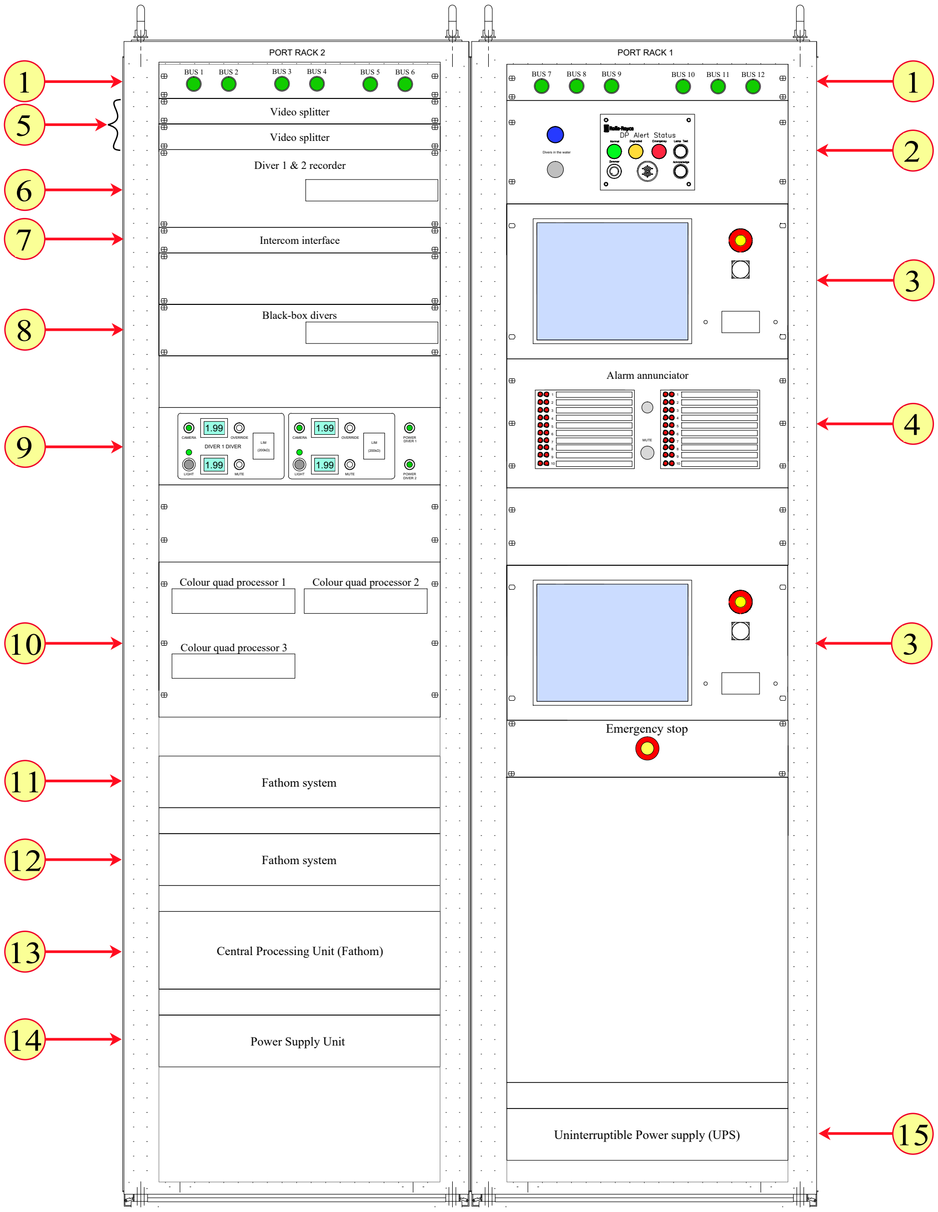
The scheme below represents the dive control's main electrical supplies and wired communications. Note that the video signals to and from the bell control room and to the client representatives office are not in this scheme. Video signals and alarms are also usually provided in the OCM office. The client representative office is discussed on the next page.



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. 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 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 - Video splitter	6 - Video recorder divers
7 - Intercom interface	8 - Black-box communications divers	9 - Supplies cameras and lights divers
10 - Video colour quad processors	11 - Intelligent acquisition unit *	12 - Intelligent Network Logger *
13 - Central Processing Unit *	14 - Power supply Unit	15 - Uninterruptible Power Supply

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

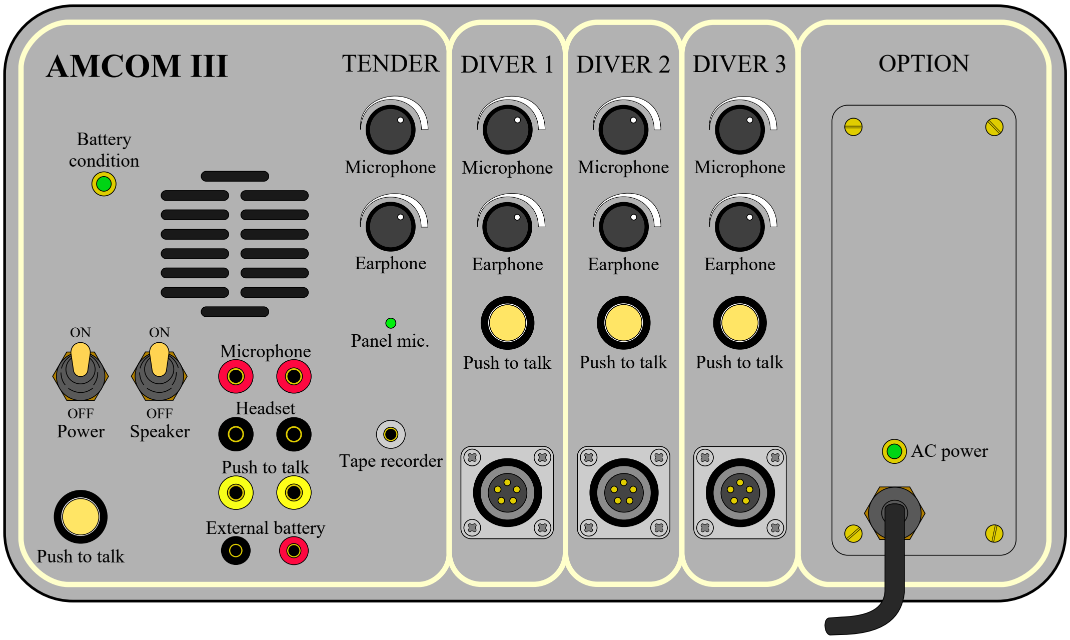
Definitions:

- The communications to divers are "analog" or "digital". In "analog" technology, the wave is transmitted and recorded in its original form. Thus, the wave from the microphone is read, amplified, and sent to a speaker to produce the sound. In "digital" technology, the wave is sampled at some interval and then turned into numbers that are sent to the receiver or stored in a device. These numbers are then turned into a voltage wave that approximates the original wave to allow the listener to hear the sound. As an example of devices, the wired phone systems used during the sixties were analog, while current cell phones are digital.
- 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.
- Dynamic Positioning (DP) alert status panel *(see #2)* is mandatory and provides visual and audio alarms on DP vessels . Note that last generation systems are provided with a "blue status" when the divers are in the water.
- Interfaces with hot water machines *(see #3)* are described in the relevant topic on the previous pages. Hot water systems are usually not installed on systems designed to dive only in tropical waters.
- The Alarm Annunciator Panel *(see # 4)* displays the status of alarm signals using lights and sound features. This device is not present in many dive controls.
- A video splitter *(see #5)* is a device that takes one signal from a video source and replicates it over multiple monitors.
- Video + audio recorders *(see #6 & #8)* are usually used as divers "black boxes". They are today based on digital technology and provided with large hard discs allowing to store hundreds of dives.
- Intercom interface *(see #7)* 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 #9)*. A resistor allows dimming the lights of the divers when needed.
- A "colour quad processor" *(see #10)* 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.
- The Diver Monitoring System *(see #11, #12, #13, #14)*, also called "DMS", is a specific electronic system which is optional with IMCA, but mandatory inside some national waters. It is explained on the next pages.
  - The Intelligent Acquisition Unit *(see # 11)* acquires and processes measurement signals and converts them for the control of the applications of the 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.
  - The intelligent network logger *(see #12)* 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 #13)*. It performs the basic arithmetical, logical, and input/output operations of a computer system.
  - The Power Supply Unit (PSU) converts mains AC to low-voltage regulated DC power for the internal components of the computer of the DMS *(see #14)*. This unit may supply the analysers and digital gauges.
- The Uninterruptible Power Supply (UPS) *(see #15)* is described previously in the list of power supplies to the dive control. Note that in addition to the devices described in the list, it must also supply the Divers Monitoring System, which is mandatory in some national waters. Also, note that the batteries should be housed in an open-air area outside the room.

2.19.2 - Communications with divers

Divers communicators used in diving control rooms are generally designed to be inserted in the control panel *(see the photo in 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 diving 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.
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 the photo on the next page)* and is a representative example of such equipment is described.
This model is a three diver communicator to which an optional unscrambler for heliox diving can be 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. Remember that the battery that allow to communicate even though the main electrical supply is lost is mandatory and must be kept in perfect condition. 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.



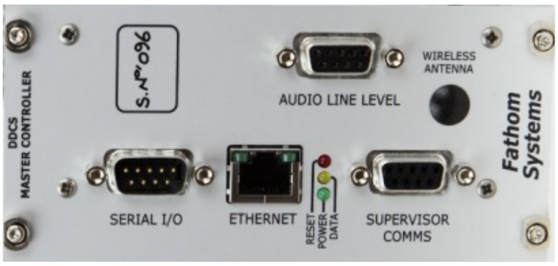
The portable communicator described above is based on reliable technologies that have evolved over the years and continue to be updated by small touches. Nevertheless, it is based on a concept from the nineties in which the quality of the sound is optimised using a series of potentiometers, and that 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 communication 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:

- It provides 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. Saturation divers and supervisors also report that the helium speech unscramblers allow for more intelligibility of conversations, which is a proof of their efficiency.
- It provides fully isolated diver interfaces, and are configurable on multiple channels.
- The architecture of such systems 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.
- These systems also include a phone and intercom function.

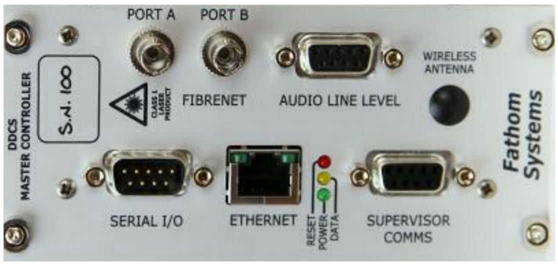
In addition to the extensive possibilities of interconnections, one crucial element to take into account with this new generation of communicators is that their control is based on series of menus that are accessed from the touch screen of a terminal that is linked to a master station which is installed 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.

The 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 communication units which link to the various “remote devices”.
The remote devices can be a diver’s helmet 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.



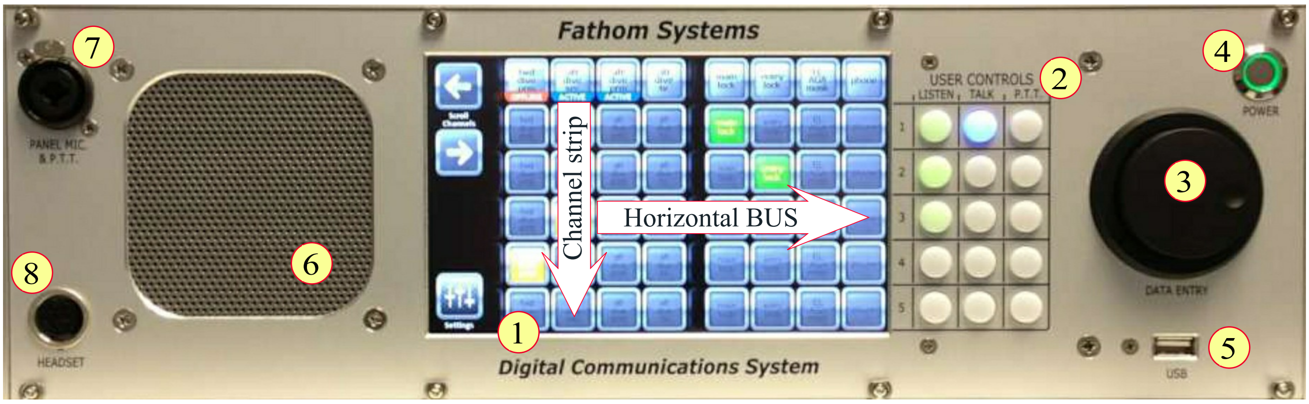
Master controller module (rear)



Master controller module with fibre optic interface (rear)

- A module provides galvanically isolated audio channels to the divers and, if configured for, to the Deck Decompression 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.
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)*.

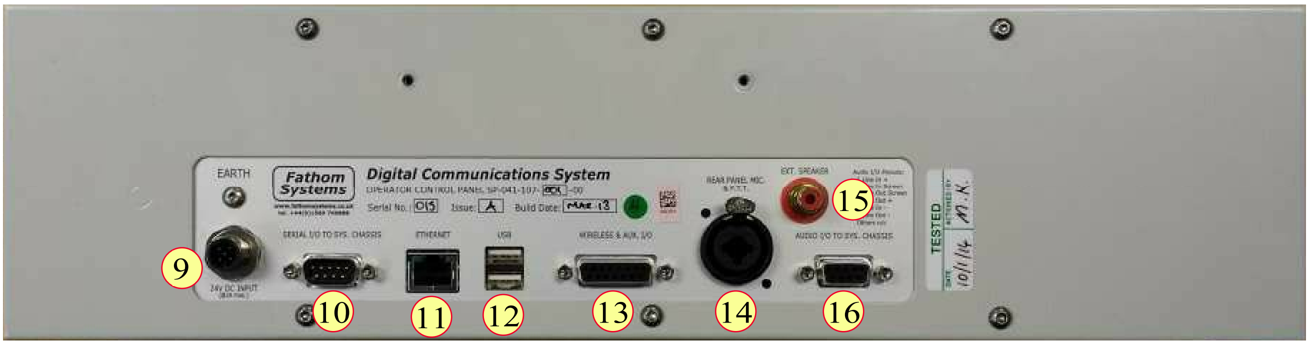


- This Operator Control Panel (OCP) is composed of a touch-screen display which is connected to an internal embedded computer card that manages its functions *(see #1 above)*. This touch-screen provides information about the connected channels and the settings of the system. Also, it allows the user 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 were 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

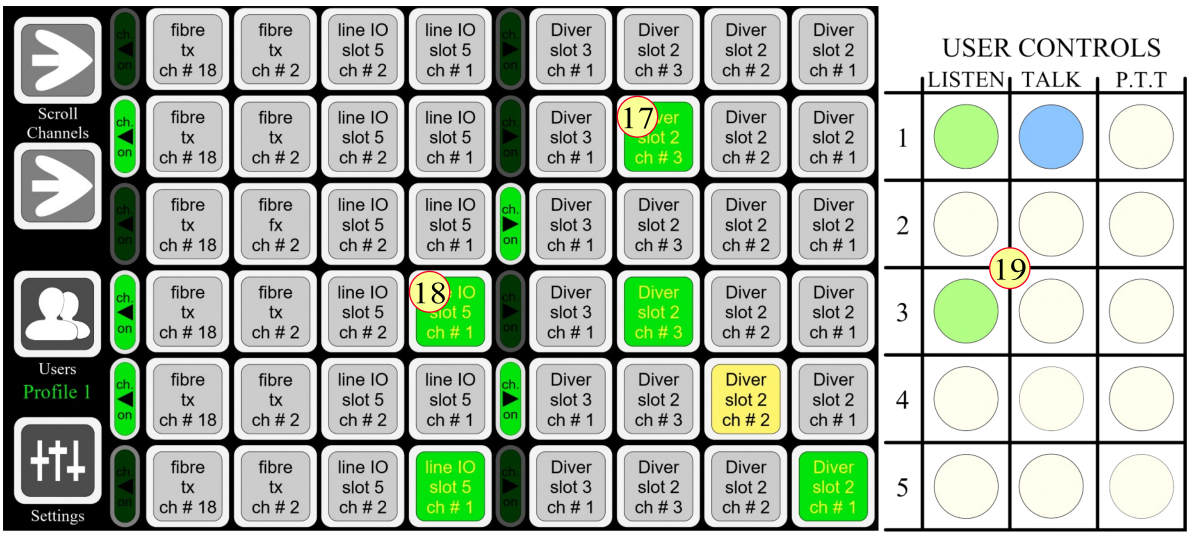
phone USB charger. A keypad allows selecting one of three of the buses, and a press-to-talk button is used to communicate with the selected Bus. A failsafe system informs the user in the event of a link failure.
Additional wireless units can be configured in the system for other users such as an example 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.

Hand-held unit

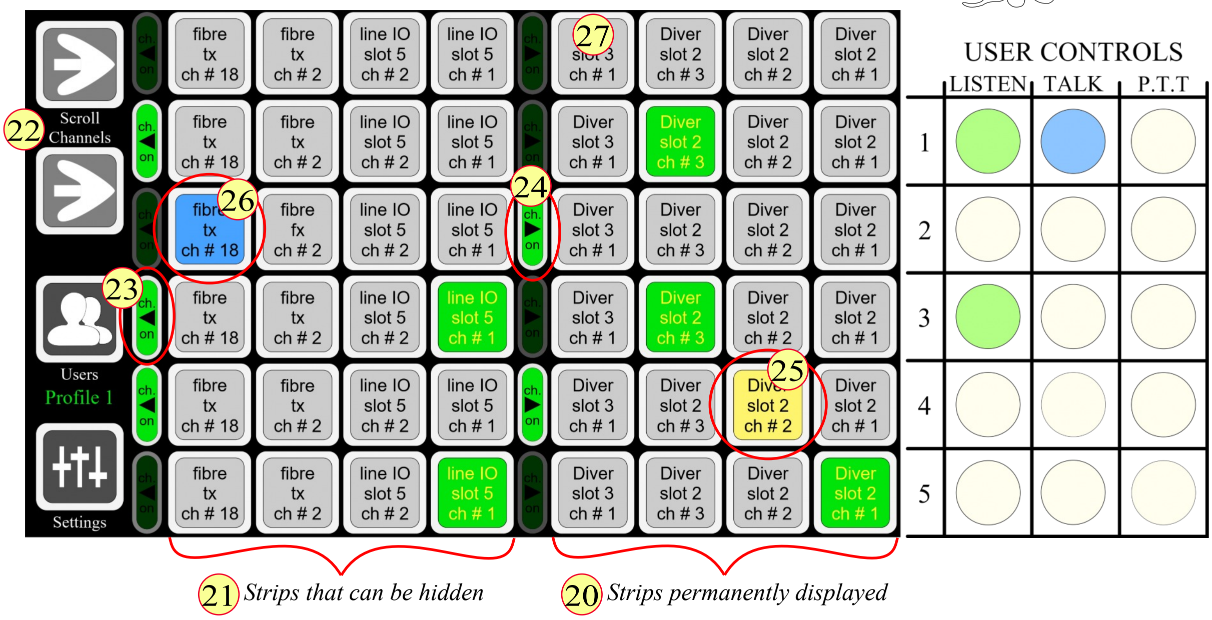
belt-worn unit

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 communication 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)*.

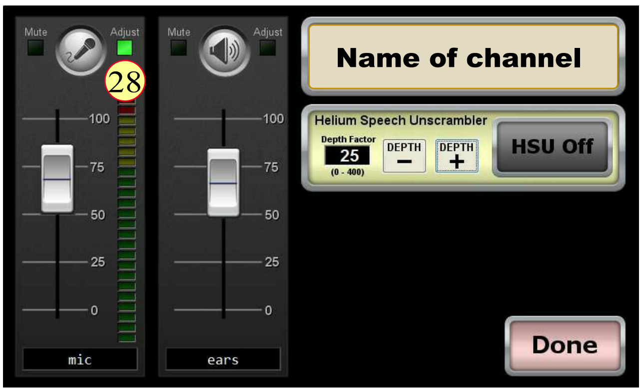
Note that there are theoretically no limits to the number of remote users connected on the same bus. However, the manufacturer recommends limiting to two or three connection on a single bus as it can get quite confusing trying to understand who is talking if there are too many stations connecting at once.

Adjusting the volume of the channels is performed through the touchscreen:

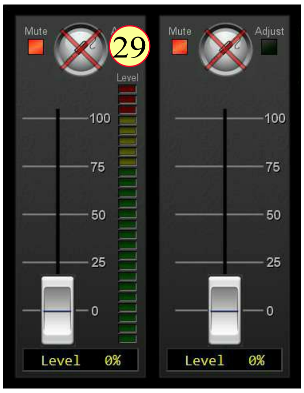
The user press first the ‘title tile’ at the top of the vertical channel strip he wants to adjust *(see #27 in the drawing above)*.

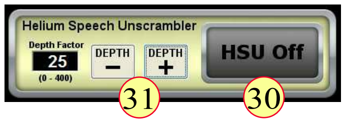
As a result, the display changes to the channel adjustment page where two linear adjustment controls, also called “sliders”, for the volume of the microphone and the speaker/headset are displayed with the name of the channel and the commands of the unscrambler.

Note that the unscrambler must be off if no heliox mix is used.



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 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 supervisor or, if fitted to it, the decompression chamber occupants to talk to people such as doctors, company managers, and others.
Note that satellite phone communications in the dive and saturation controls are mandatory with the majority of the IOGP members and other clients.

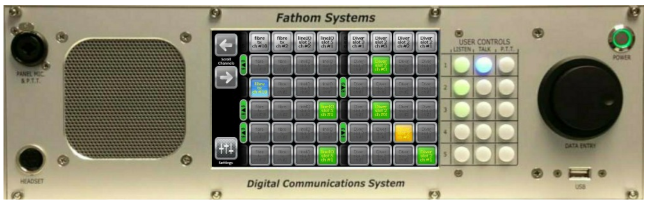
The telephone page is displayed when the title tile for the phone channel at the top of the vertical channel strip is pressed.
This page provides a dial pad that is used to compose the number to call and the sliders to adjust the volume of the microphone and the speaker that are similar to those used 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 the picture on the side)*.
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 in 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)*.

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.

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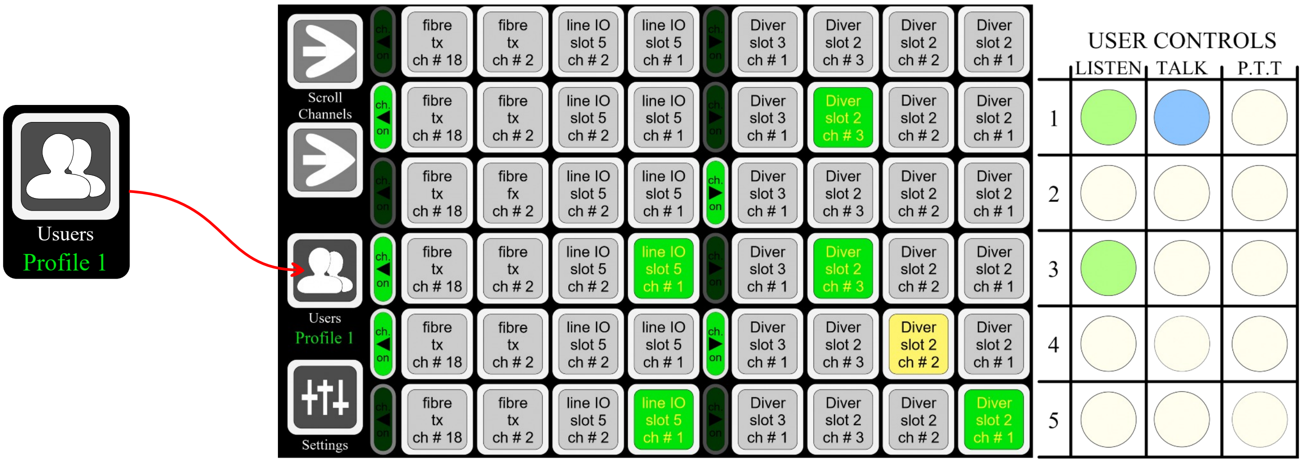
When the system is adjusted according to his preferences, the supervisor can save his settings. The system provides twelve profiles that can be stored in the machine or saved on memory sticks that can be connected to the USB port of the facade. To do it, the supervisor touches the button labeled “Profiles” 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 on the side)*.
Note that the stored profile should be recorded on a document that is easily visible to avoid another supervisor from erasing it 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 the memory stick provided must be compatible, not contain other files, and be certified without viruses.
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.
It must be noticed that the fully digital system presented is one of the most advanced that can be found on the market. Such a last generation computing technology system 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 allows 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 is provided for the communications outside the diving area *(see #10 in the photo of the control panel point 2.18.1)*. As a conclusion, 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.

2.19.3 - Closed Circuit Television system

Closed Circuit Television (CCTV) systems are commonly employed to monitor and help the divers and control various areas of the dive station. This trend increases as supervisors know the benefits of having a detailed view of what the divers are doing and an overall view of what is happening on the dive station and around, in addition to the fact their use is mandatory with some diving standards. Also, the ease of installing such systems has improved, and their price has decreased over the last twenty years.
The cameras used for the surveillance of the dive station are similar to those used for inland surveillance applications, except that those installed externally are of a waterproof type or in housings that resist the aggression of saltwater. The divers’ cameras used underwater are of similar types to those already described for ROVs, except they are light enough to be held on a helmet. To remember what is said for ROVs, manufacturers express their performances as follows:

- Minimum light sensitivity is expressed in “lux”(lx), which is the International System (SI) unit of luminance (light). One “lux” is equal to one lumen per square meter.
  The “lumen” (lm) is the unit used for the total luminous flux in a light beam. For convenience, it is common to

compare the lumens emitted by a light beam with the power of light bulbs, so 150 lumens can be roughly correlated with the light emitted by a 10-watt bulb, and 1500 lumens corresponds to the light emitted by a 100-watt bulb. Thus, a 100-watt bulb that fully illuminates a surface of 1 m² is equal to 1500 lux, and 1 lux is equal to the luminescence of a bulb of 0.0666 watts.

Another simple and practical method to compare the luminance is to keep in mind the following values:

- Overcast night = 0.0001 lux
- Star light night = 0.001 to 0.002 lux
- Quarter moon with clear sky night = 0.01 lux
- Full moon night with clear sky = 0.1 to 0.4 lux
- Sunrise or sunset on a clear day = 400 lux
- Overcast day = 1,000 to 2,000 lux
- Daylight 10,000 lux
- Sunlight = 110,000 lux.

The lower the lux rating the more the camera is able to see in low light conditions.

- The resolution of analog cameras and monitors is calculated in Television Lines (TVL).
  - “Horizontal Resolution” is the number of alternating vertical black and white lines from the left to the right of the screen.
  - “Vertical Resolution” is the number of the alternating horizontal black and white lines from the top to the bottom of the screen.

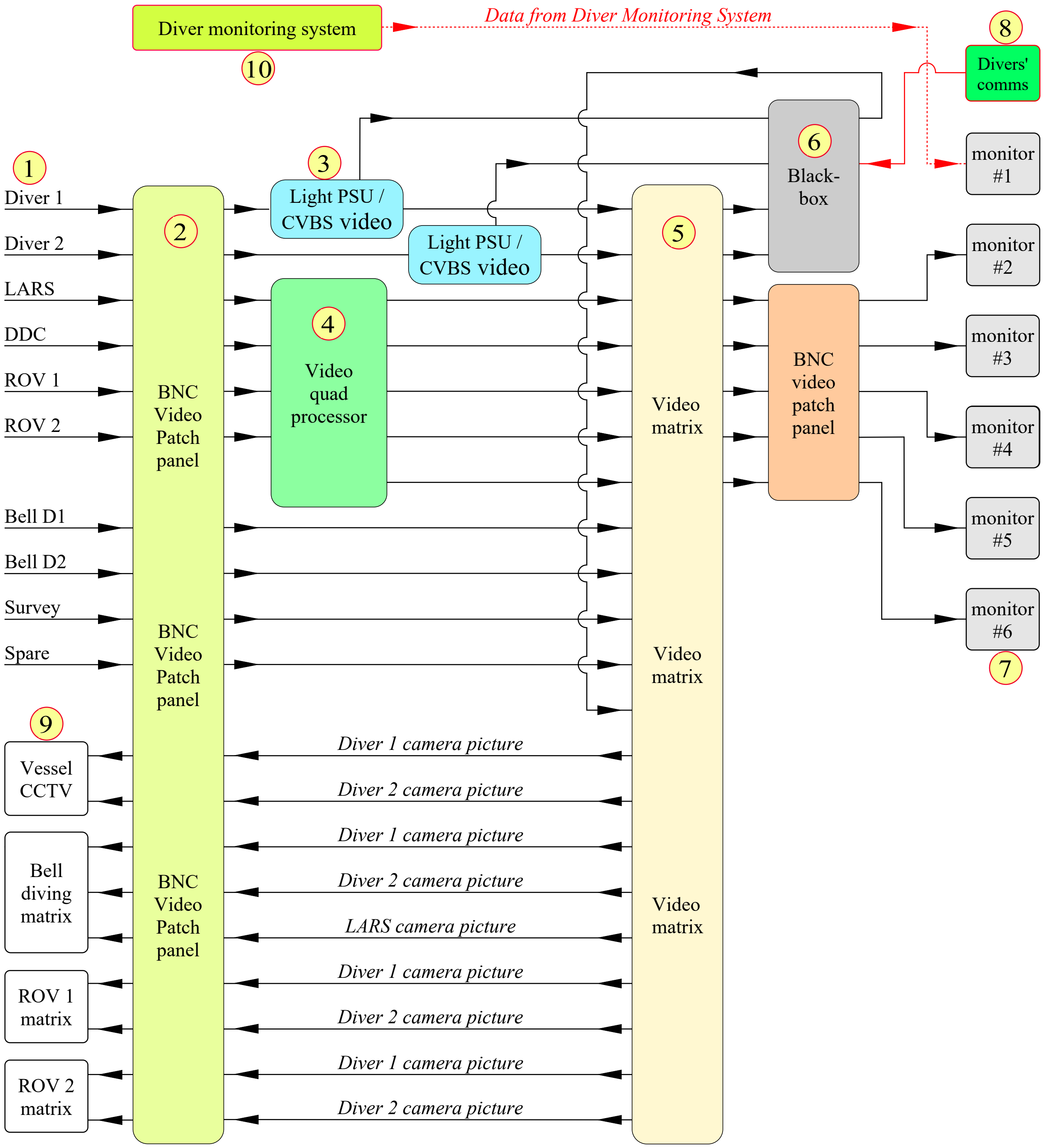
  It is common to use the measure of the horizontal lines to indicate the resolution of a camera or a screen. Note that the highest resolutions are those that have the highest number of lines.
- Digital screen specifications of TV and computers are given in “horizontal” and “vertical resolutions”. The “horizontal resolution” corresponds to the number of elements, dots or columns from left to right on a display screen, and the "Vertical resolution" is the number of rows, dots or lines from top to bottom.
  As examples of resolutions that are found with computers and video combos note 1280 x 720 and 1920 x 1080 that are also called 720p & 1080i (“p” refers to progressive scan, and "i" means "interlaced").
- The resolution of digital cameras and screens is often indicated in megapixels.
  A pixel is a tiny colour square that is assembled to others to create a digital image. So, the more pixels used to represent an image, the more accurate the picture is. Pixels can be plus or less numerous in a picture and used as a unit of measure, such as an example 2400 pixels per inch.
  Megapixel means one million pixels. Thus, a 12-megapixel camera can produce images with 12 million pixels. The formula to calculate the resolution of a digital picture is “Number of horizontal pixels × Number of vertical pixels”. As an example, a camera with 4928 by 3264 pixels has a resolution of 16 megapixels.
- Some cameras are also provided with zooms, which are devices that are used to make a subject appear closer. However, this option is not usually used with helmet cameras. High resolution colour cameras are usually preferred and are arranged so that the unit shows what the diver see.
- Lights are the complement of cameras and should be powerful enough to illuminate what the camera can show perfectly during optimal conditions. Due to the water's absorption of light, the more powerful the lighting, the better it is. Most lights are today made of Light Emitting Diodes (LED) and use 24 to 48 volts DC. These lights are lighter and more efficient than traditional bulbs. However, due to water turbidity, lights may not be usable at their full power. For this reason, manufacturers provide systems allowing dimming them.

Signals from divers’ cameras are usually analogical and cannot be directly displayed on the combos in the dive control and other parts of the vessel. For this reason, they are treated through the following elements in the scheme on the next page that represents the video system of a surface-supplied diving system installed on a vessel also equipped with a saturation diving system and two Remotelly Operated Vehicles (ROV):

- BNC video patch panel *(see #2 in the scheme)*:
  BNC stands for “Bayonet Neil-Concelman” or “British Naval Connector”. These connectors link a computer to a coaxial cable in a 10-BASE-2 Ethernet network. The wires from such a network can extend up to 185 metres. A patch panel in an assembly that contains ports used to connect and manage incoming and outgoing Local Area Network (LAN) cables.
- Light PSU / CVBS video *(see #3 in the scheme)*:
  “PSU” stands for “Power Supply Unit”. These devices supply electricity (usually 12 or 24 volts) to cameras and lights.
  “CVBS” stands for “Composite Video Baseband Signal”. It is an analog video transmission signal without audio containing image data in a standard resolution of 480 or 576 lines interlaced. It consists in a pair of wires that can transmit video and power from the camera to the recorder, producing video surveillance. It was the first kind of technology introduced into the security industry, and it is still employed today.
- Video quad processor *(see #4 in the scheme)*:
  A “video quad processor” is a video mixer designed for visual applications that require multiple video feeds to be displayed on the same screen. In other words, it allows showing the pictures of four cameras on a unique monitor. This display can be simultaneously in a quad display or individually in sequence.
- Video matrix *(see #5 in the scheme)*:
  The video matrix transports signals from multiple video sources to multiple display units. It is a combination of

a video switch and a video splitter. Any of the inputs can be displayed on any of the outputs, or the same input can be displayed on all the outputs. These video matrix units can be cascaded together to form a larger matrix of sources and displays. They deliver crisp and clear image quality as if each display is directly connected to the source.

- Black box *(see #6 in the scheme)*:
  The black box groups the recording of the divers' cameras and audio communications. It consists of a digital video recorder that can store thousands of dives on a computer hard-disk. The divers' communications are provided by a connection from the communicators *(see #8)*. By comparison, the analogical systems used in the old time were able to store only 2 hours recording on Video Home System (VHS) cassettes.
- Monitors *(see #7 in the scheme)*:
  They are digital LCD (Liquid Crystal Display) screens. LCD is a type of flat panel display that uses the light-modulating properties of liquid crystals combined with polarization modules to produce pictures. LEDs screens are also found in smartphones, televisions, and computers. Note that in this system, one of the monitor is used for displaying the data from the diver monitoring system *(see #10)*.
- Videos signals are also sent to other parts of the vessel *(see #9 in the scheme)*. Note that it is usual to transmit audio communications with the video signals.



Note that the number of cameras and receivers depend on the size of the system. Thus , some dive controls are limited to a few monitors, and some are extended to the elements listed above and in point 2.18.1.

2.19.4 - Diver Monitoring System (DMS) for surface supplied diving operations

The Diver Monitoring System (DMS) for surface supplied air or nitrox diving operations described in this point is made by "Fathom systems" (http://www.fathomsystems.co.uk). It is designed for "Flash Tekk engineering" diving systems. Such monitoring systems are gradually adopted in the diving industry as they allow for better control of the ongoing operations. Another reason for implementing these systems is that they are mandatory with NORSOK standards 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, companies working in this country are mandated to use such equipment.

It is not anticipated that surface decompression procedures are performed routinely when nitrox diving procedures are used. Thus, the Deck Decompression Chamber (DDC) is planned only for therapeutic decompression treatments.

This DMS is composed of a system for the divers in the water and another for the decompression chamber. A central server communicates with hardware devices that acquire data from sensors fitted to various parts of the dive system. It displays, records, and provides alarms for the following parameters:

- Divers depth.
- Divers' breathing gas analysis.
- Hot water delivery parameters
- Duration of each dive.
- Chamber's locks depths
- Chamber's locks depths gas analysis

2.19.4.1 - Elements provided in the dive control

- The Diver Monitoring System (DMS) installed in the dive control consists of the following elements:

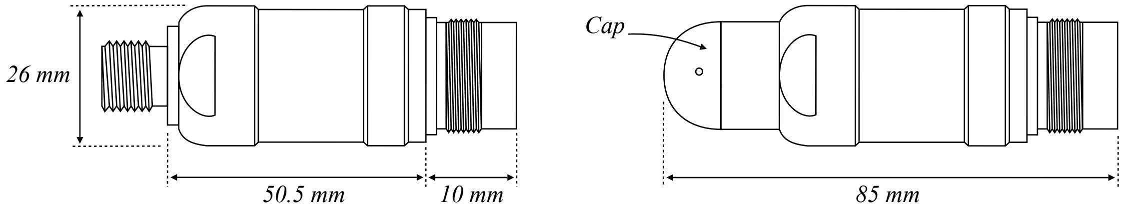
- A monitor and and a keyboard which interface to the DMS server that are installed in the dive control console. They provide the operator interface for the dive supervisor giving him data displays of the measured parameters. The keyboard is used to enter commands and to interact with the system as required.
- The appliances of the Diver Monitoring System that monitor and control the dive system parameters and functions. They are assembled in an electrical and data cabinet, similar to the one presented in point 2.19.1 "Purpose and organization". These apparatus consist of the following:
    - The Intelligent Acquisition Unit (iAU) acquires and processes measurement signals and convert them for the control of the applications of the system. It collects data from sensors such as diver pneumo transducers, depth transducers, and gas analysers, convert them to an RS232* data stream that are received by a serial card on the back of the server that reads and stores them for later retrieval by the system. Also, precise system diagnostics are provided by multiple status Light-Emitting Diodes (LED) which indicate the condition of input signals from sensors and the state of power supplies and telemetry links.
    - The redundant diver communication system provides galvanic isolation and signal processing
    - The DMS server, 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.
        - It receives and stores diver depth and gas analysis data from the iAU.
        - Runs the dive client software which displays the dive system parameters on a graphical interface.
        - Holds the configuration files containing calibration data, personnel database, video matrix setup, and other information.
        - Allows the remote management of the divers' cameras & hat lights power supplies from the DMS software screen.
    - The network switch links Links the DMS Ethernet Network between the equipment in the Air Dive cabinet and the decompression chamber scanning analyser to the DMS ethernet network
- Notes:
    - The Central Processing Unit (CPU) of a computer is a piece of hardware that carries out the instructions of a computer program. It performs the basic arithmetical, logical, and input/output operations of a computer.
    - RS232* (already explained in point 2.19.2) stands for "Recommended Standard 232". It 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. An RS232 serial link is found on any desktop.

- Divers' depth sensors:

Divers' depths are obtained from two separate sources: The depth transducers mounted to the divers and depth transducers mounted onto the divers' pneumo lines. That allows for depth readings to be recorded even in a failure or loss of the signal from one of the sensors.

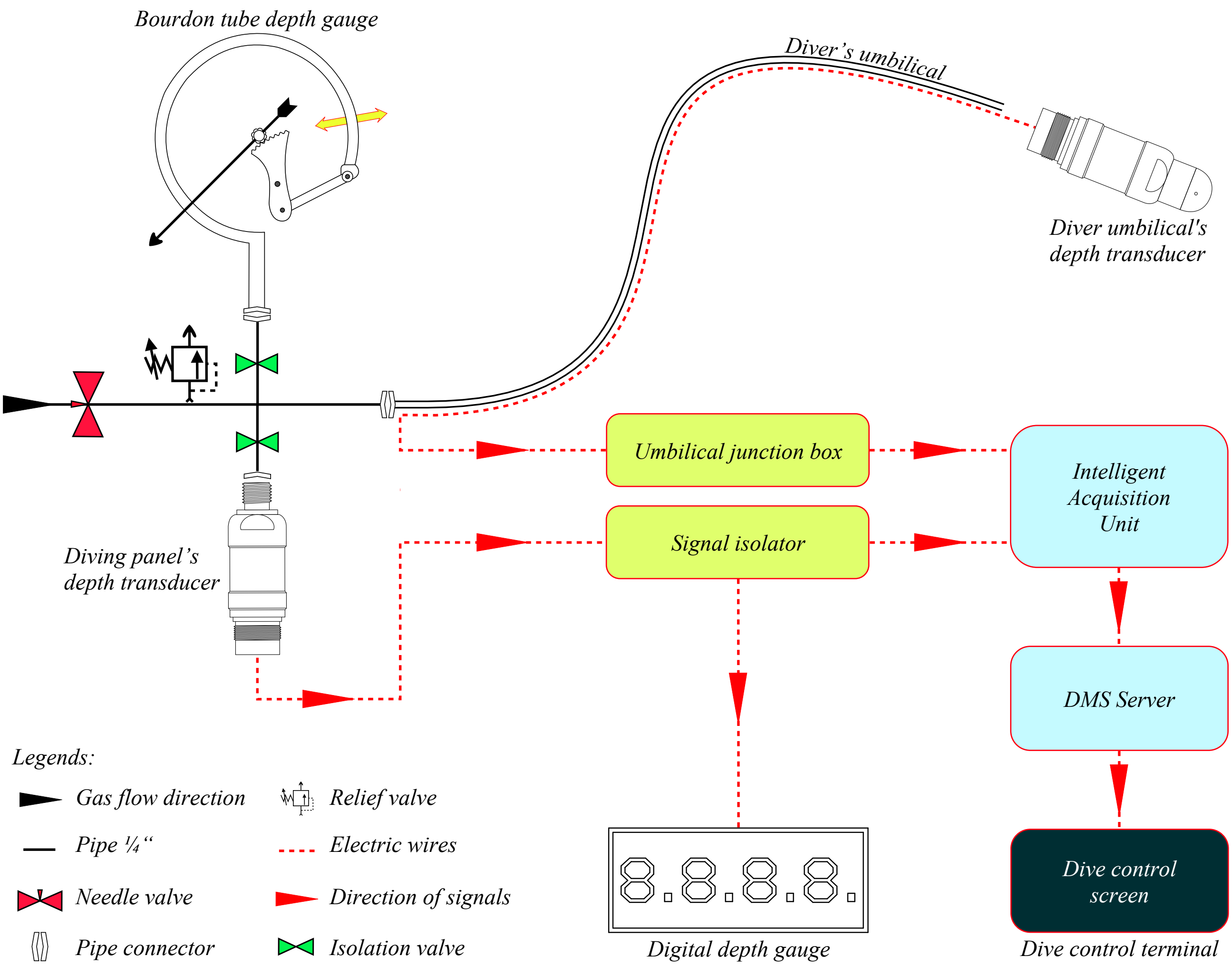
- Pneumo transducers are 4-20 mA loop-powered pressure transducers fitted to the depth gauge pipework behind the gas panel in the Dive Control Room:
    - The primary current loop from each transducer is connected to a digital depth display, in the air dive control panel, which provides the primary readout for critical decision making.

  - A signal isolator mirrors the primary loop onto a secondary loop which supplies the reading to the DMS system via the iAU.
- A depth transducer is also installed at the end of the excursion umbilical of each diver. It measures the depth as the diver moves around in the water, like the electronic depth gauges and computers used with scuba diving.
  - These depth sensors of 85 mm long and 26 mm diameter are robust and lightweight. They offer the advantage of providing continuous records of the depth, which is not the case with the pneumo gauge system that must be periodically refilled. They should be installed at the chest level.



  - An electrical cable is installed in the excursion umbilical to carry the 4-20mA signal from the depth sensor. It should be kept tight to the umbilical with no loop, as these would be prone to snagging and would be a weak point in the cable.
  - The signals from the transducer are connected to the intelligent Acquisition Unit (IAU) via the umbilical junction box, which is provided for the connection of the divers' pneumo sensors. It is mounted into the back of the dive control panel and contains the signal isolators.
- The Air DMS systems use 0-90 MSW (10 Bar) type sensors fitted with Souriau Jupiter connectors. These connectors are designed for waterproof electrical wire connections in harsh underwater conditions.

The scheme below summarizes what is said above regarding the positions and interconnections of the depth sensors. Note that the pneumo gauge (bourdon tube) works parallel with the digital depth gauge and the diver monitoring system. Also, the depth sensors used with the diving monitoring system must be those designed by the manufacturer.



- Last point gas analysers divers:

  The paramagnetic oxygen analysers, located in the air dive control panel, monitor the last point gas breathing gas samples to each diver. This analyser should be the model described in point 1.2.8.5 “Last generation analysers”. A 4-20 mA output from the analyser is read into the DMS system via the iAU.

- Hot water temperature sensors divers:

  A temperature sensor provides a reading of the hot water flow to the divers’ heated suits. This temperature sensor should be installed into the hot water flow between the hot water machine and the diver supply manifold *(refer to point 2.10 - Hot water machine)*.
  The sensor ranges from 0 to 100 ºC and provides a 4-20 mA output, which is read into the DMS system by the Intelligent Acquisition Unit (iAU). It is connected to the system via the umbilical signals junction box. This junction box is mounted in the LARS area and provides a connection point between the divers’ umbilical and ship wiring.

- Software:

  Two software applications run the dive control’s Diver Monitoring System (DMS) computer:
  - The “Server application” is used to manage the interface to the external hardware.
  - The “Client application” is used to provide “live data” display and interface to the dive supervisor.

2.19.4.2 - Elements provided to monitor the decompression chamber

The Diver Monitoring System (DMS) designed to control the chamber consists of the following elements

- Chamber operator interface

  The interface to the chamber DMS system is provided through the same keyboard and monitor as the dive control DMS but using a separate software application. They provide the operator interface for the Chamber operator giving a ‘live’ data display of the DMS measured parameters. The operator uses the keyboard to enter commands and interact with the system as required.

- Chamber Depth Sensors

  Two depth transmitters are used to measure the chamber compartment depths. These depth sensors are typically fitted to the bourdon tube gauge pipework in the back of the chamber control console.
  The primary current loop from these is used to display the depth on a local readout in the chamber control panel. It is mirrored via an isolated current mirror to form a second current loop, fed to the intelligent Acquisition Unit (IAU), which collects the data and sends them to the DMS server, where they are recorded and used by the Diver Monitoring System Software. Thus, we have the same configuration as for the control of the divers in the water.
  Depth displays in the air dive chamber control panel are powered by the 24V power supply located in the dive control electrical cabinet.

- Main Lock and Entry Lock O2 Analysers

  A single gas analyzer is provided to monitor the atmosphere of both chamber compartments. This analyzer is also of the model described in point 1.2.8.5 "Last generation analysers". It can either be set to analyze a single sample continuously or to scan between the two chamber compartment samples. It’s 4-20 mA output is read into the DMS system via the intelligent Acquisition Unit (IAU).
  Scanning is started and stopped from the chamber client software screen. However, if the DMS software fails, the analyzer can be controlled independently using the buttons on its front.

- Software applications:

  Like the monitoring of the divers in the water, two software applications run the chamber’s Diver Monitoring System (DMS) computer:
  - The “Server application” is used to manage the interface to the external hardware.
  - The “Client application” is used to provide “live data” display and interface to the chamber operator.

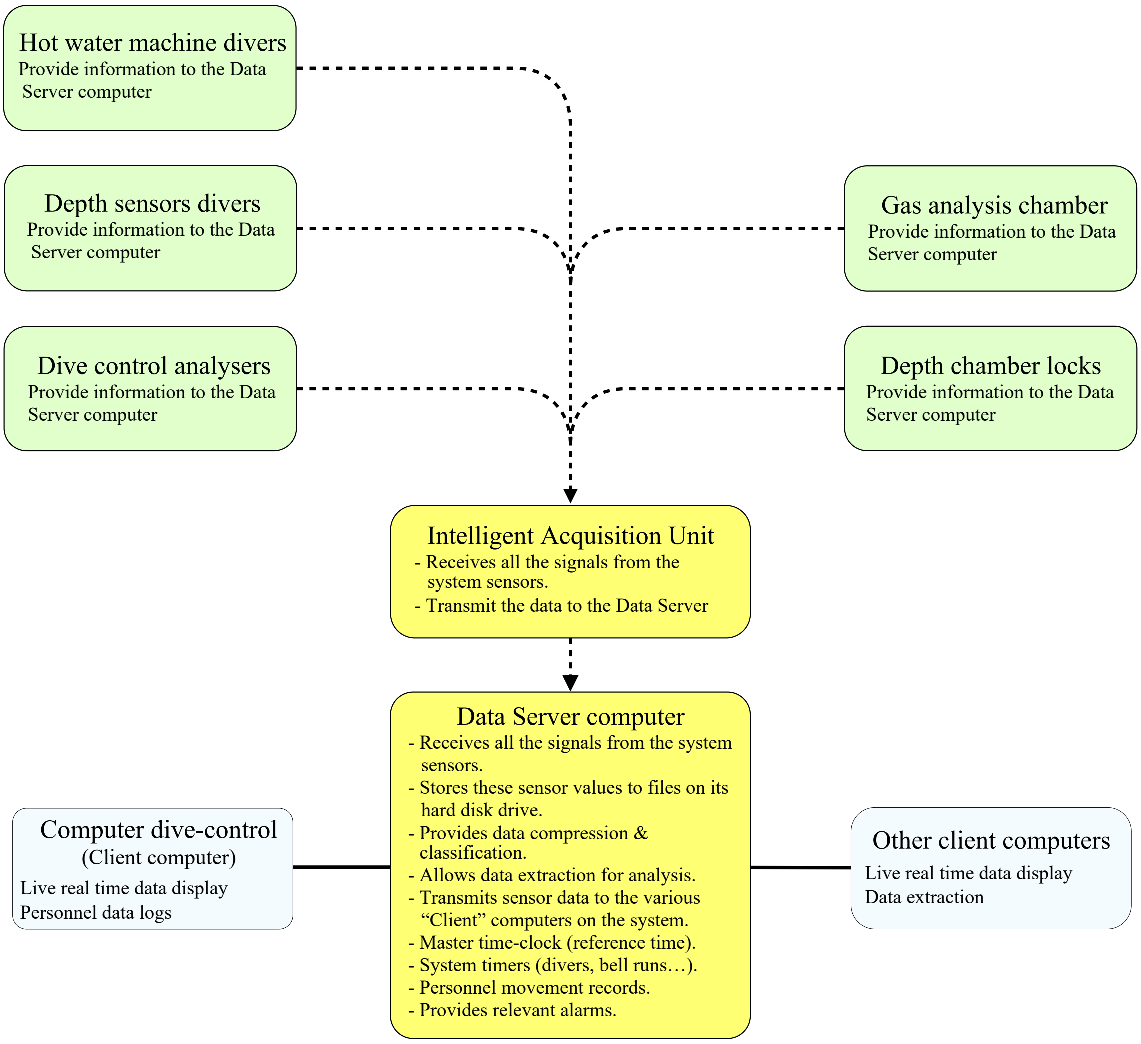
2.19.4.3 - Data server management system

The data server collects and stores information received from sensors and allows the management of hardware devices. A single server application enables the management of data received from both the divers in the water and the decompression chamber. The server software contains the facility to interface to many different hardware devices that may not be all installed on the system. Note that not installed controls remain inactive and are displayed greyed out.

- The server receives sensor data from sensors or sensor interface hardware via either the Air DMS Ethernet network or an RS232 connection to the intelligent Acquisition Unit (IAU). It stores these sensor values to files on its hard disk drive. These stored files are subsequently archived by copying to CD ROM /DVD ROM for off-line processing, subsequent examination/analysis, and long-term archival. One blank CD ROM disk can typically store seven days of continuous (24-hour operations) diving. With external data compression (e.g., ZIP), approximately one month’s recorded data can be stored on a single CD ROM disk.
- The server records the personnel movements on the system, ranging from the login status and identity of all diving supervisors on duty to the identity and location of the divers. Note that it assigns an identification number to each person working with the diving system. It also controls the various system timers that measure the Divers' in-water duration and bottom times. These timers have alarm thresholds and are synchronized to the server master time-clock. Audible and visual alarms that can be set are provided for all critical sensors.

- The recorded data are stored in specific files. These data files contain the record of all dive system data parameters, measured and stored once per second, together with the locations and identities of the divers and supervisors at work. One data file is created every hour. There are, therefore, 24 separate files recorded to disk every day, with their filename identifying the start and end times of the data they contain, plus the date the file relates to. The names and identity numbers of the divers and supervisors who have been involved with a project performed with the diving system are also stored on a separate data file that can be used to track the diving personnel's movements.
- Note that the “Data Server software” has numerous displays and interfaces that allow the technicians to access information about the system for maintenance and diagnostic purposes. These technicians should be qualified enough to set up and run the server, ensure that it is running at all times, that data is archived at appropriate intervals, and that all equipment attached to the server is functioning correctly. Of course, the server software can be tailored to particular requirements.

The elements described above can be summarized as follows:



2.19.4.4 - Server system set up and management

- Server main display

When opened, the main server screen displays the functions mentioned below. The reference numbers allow situate them on the screenshot on the next page.

1. Event log:
   The records of events, and the list of messages to the user are displayed in this slot. Optional upgrade of the server software allows the user to filter the events into different categories.
2. Log file name:
   This slot shows the log file name of the data file opened and being written, together with the directory path where the file is located. The filename includes the date of the recorded file and the start and stop times in 24 hrs format the data-set covers. For example: “C:\Fathom_ADMS\Data Archive\FSL_10_11_08-May-17.dmd” means that the file was recorded on the 8th of May 2017, between 10:00 and 11:00. The recorded files are written to the data archive folder as indicated previously. Thus, referring to the example above, they are recorded in “C:\Fathom_ADMS\Data Archive”.
   Also, a new log file is created on the hard disk of the server at the start of every hour. This file is named according to the convention above, and the file from the previous hour is closed, ready for archiving. Prior to closing the file at the end of the hour, the personnel database and all calibration information/files are updated.

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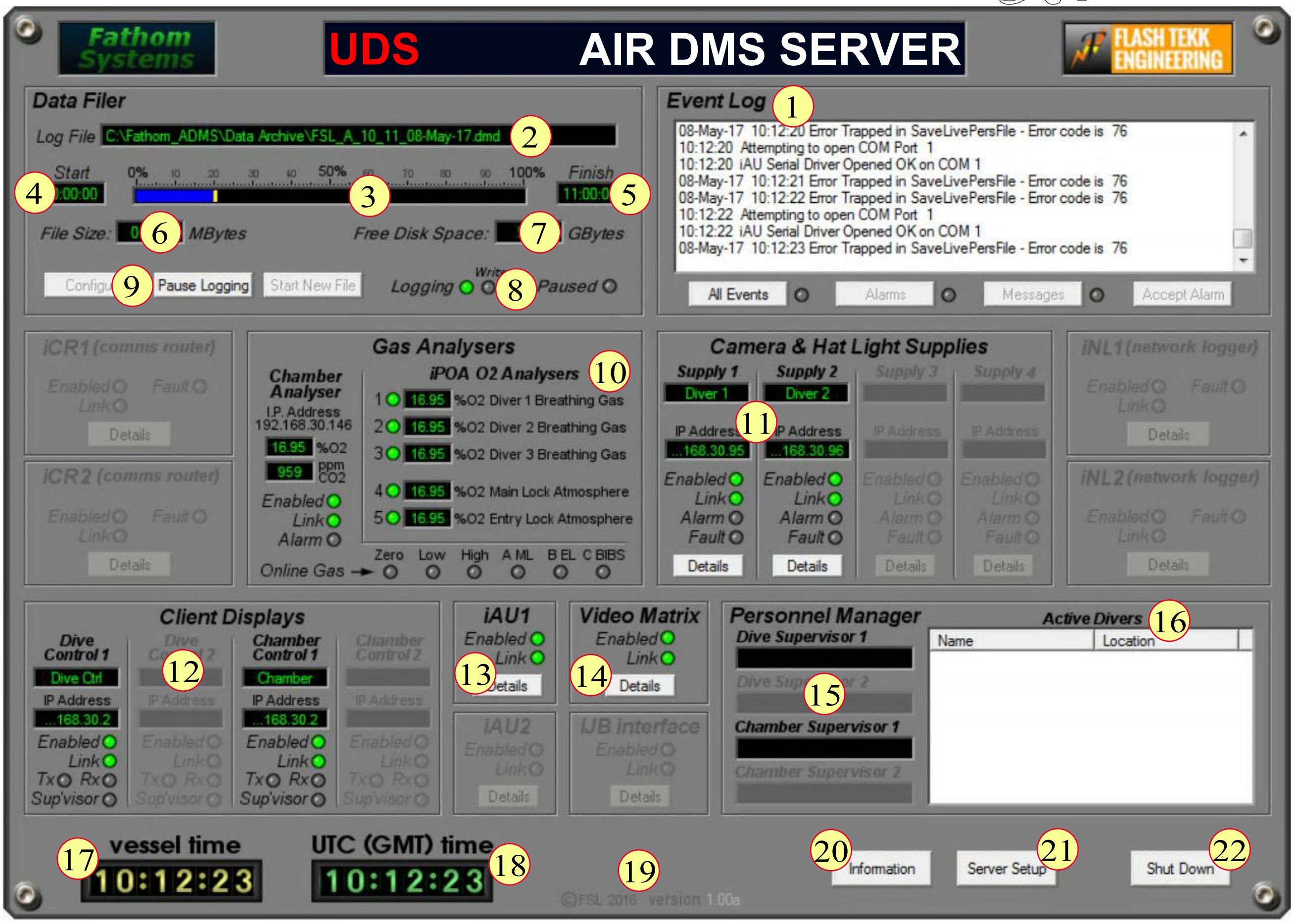


3. Log file recording progress status bar:
   This coloured bar graph represents the status of the recording to the log file. The bar graph, filled from the left to the right, represents the single 1-hour file that is being written to the disk.
   It is colour-coded to show the status as follows:
   - Black: No data written yet
   - Blue: Historical time where no data has been written
   - Yellow: Valid recorded data
   - Red: Recorded data with the "recording paused" flag enabled

   Note that when the data recording is paused by clicking on the "pause logging' button", the data are still recorded to the server hard disk.
4. Log file start time:
   The time at which the file being logged was started is shown in 24-hour format in this slot.
5. Log file finish time:
   This slot displays the time when the file being logged will end. This display is done in 24-hour format.
6. Log file size:
   The size in megabytes of file being logged will occupy on the disk is displayed in this slot. This size is always the same for every file written.
7. Free disk space:
   This slot shows the free disk space on the server's hard drive expressed in gigabytes. It is recommended that files are archived from the server PC to make space when this value decreases below 5 gigabytes.
8. Logging indicators:
   The left-hand indicator is illuminated green when the system actively logs data to the disk. This indicator is illuminated red when in "paused mode". The right-hand indicator flashes briefly once per second as the data are written to the disk.
9. Pause logging button:
   Clicking the pause button toggles between recording mode and paused mode.
10. Gas analysers:
    This slot displays the status of data links to the gas analysers and the latest analysis reading.
11. Camera & hat (helmet) light power supplies
    This slot displays the status of the camera and hat (helmet) light power supply units. Clicking the "Details" button allows to navigate to the camera and hat (helmet) light power supply dialogue window.
12. Client broadcast display:
    This area of the main screen shows the status of the data broadcasts made by the server to the client applications. The indicators in this display area flash when data is transmitted to the remote clients across the Ethernet

network. The 'TX' indicator flashes when the server sends data to the client application, and the 'RX' indicator flashes when the server receives data from the client applications.

The client applications send a signal to the server every second to allow the server to monitor that the client application is running correctly.

The 'Active' indicator is illuminated green/yellow when the client applications operate correctly.

13. Intelligent Acquisition Unit #1 (iAU1) Status:
    These lights show the status of the RS232 link to the intelligent Acquisition Unit (IAU). Clicking the "Details" button in the iAU section navigates to the iAU status display. Note that the intelligent Acquisition Unit #2 is not used with the Air dive system.
14. Video matrix status:
    Indicator lights show the status of the RS232 link to the video matrix. Clicking the "Details" button in this section allows to navigate to the matrix status display.
15. Supervisors logged on:
    The names of the supervisor who is logged on at the supervisor's station is shown here with the name of the designated chamber operator.
16. Divers in the system:
    The names of the divers at work are shown in this slot and their location.
17. Vessel Time display:
    This digital display shows the time reference for all DMS displays. This readout is the master clock in the system as displayed on the various client computers on the network that is synchronized to this clock once per minute. This time display is corrected for regional time zones and daylight-saving policies as per the server settings.
18. UTC (GMT) time display:
    The "coordinated Universal Time" or UTC can be verified in this slot. It is the timestamp used to record all DMS data. It is not adjusted for regional time zones or daylight saving.
19. Software revision
    Like many software makers, Fathom Systems provides updates which revision code is displayed in this place.
20. Software information button:
    Detailed information about the current version of the server software can be accessed by clicking this button.
21. Server setup button:
    Clicking this button opens the server setup window.
22. Shut Down button:
    The "Shut Down" button allows ending the server application. Thus clicking it stops the DMS data logging and the data acquisition/signal distribution. For this reason, and like every computer, the user is prompted for confirmation before the Server application shuts down.

- Signals and Channels:

The Diver Monitoring Software uses the concept "signals" and "channels," where a "channel" refers to a physical hardware input channel on a particular device. As an example, it can be a current-loop input on the intelligent Acquisition Unit (IAU).
The input channels are physically connected to sensors that measure the various system parameters.
The "signals" are the software system variables that must be recorded and displayed. For example, a Diver depth signal, a diver's hot water temperature signal, or a Diver breathing gas O2 reading.
The server software allows to map or assign signals to different input channels. The standard configuration defines the signal assigned to a channel, but this may be modified if required. Reconfiguring a signal to another channel makes the data stored in the recorded data file take its signal source from this new channel. It also follows that there must be a one-to-one relationship between signals and channels, i.e., only one signal can be assigned to one channel and vice versa. Therefore, it is necessary to un-assign a signal from a channel before it can be reassigned to a different one.

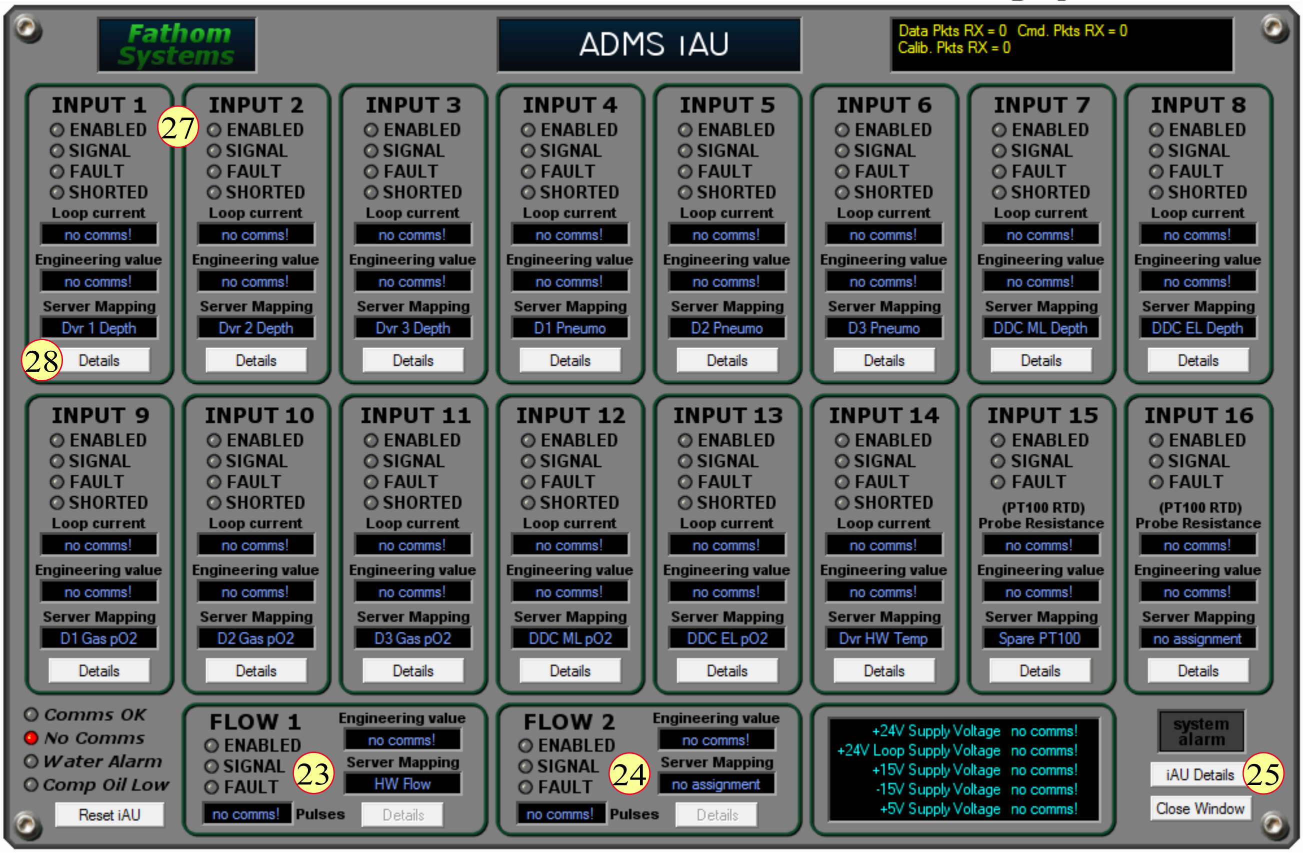
- Engineering Units Calibration:

The server software processes the physical inputs that connect to different channels and converts this information into an "engineering units" value for the particular signal assigned to the channel using a calibration file stored on the server hard disk. From this point onwards, all signal displays will be in engineering units rather than in Analogue-to-Digital Converters* (ADC) values.
Note*: An analog-to-digital converter (ADC) is a system that converts an analog signal, such as a sound picked up by a microphone, into a digital signal. In other words, an analog to digital converter takes a snapshot of an analog voltage at one instant in time to produce a digital output code that represents this analog voltage.
The update of the calibration information and the engineering units matching with the physical parameters is done by the diving system technician.

- Intelligent Acquisition Unit (iAU) Status Display:

The Intelligent Acquisition Unit (IAU) is connected to the Dive Control DMS server serial port (COM1), and communicates using RS232 telemetry.
The Dive Control main server menu allows accessing to the status window displayed on the next page that shows the condition of the various input channels of the system.

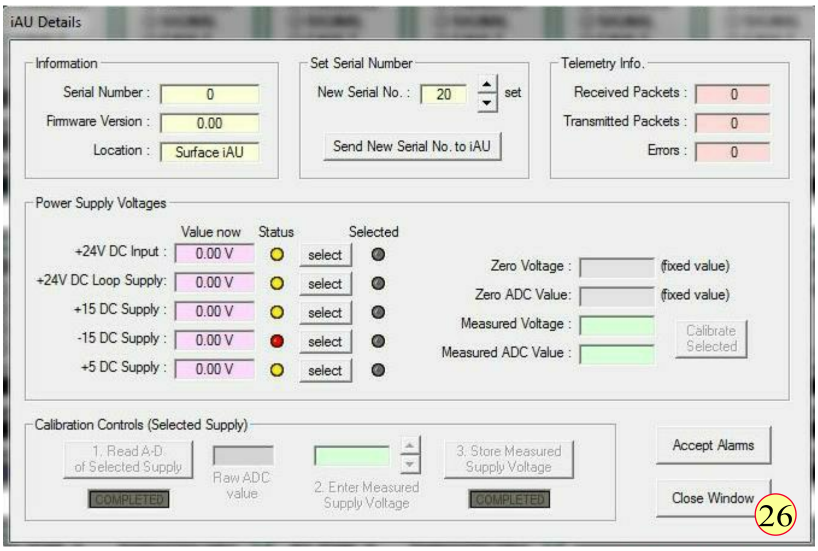
Hyperlink Table of contents



The intelligent Acquisition Unit (IAU) has 16 analogue input channels:

- Channels 1 to 14 are 4-20mA current-loop type, fully fault protected against short-circuits in the external field wiring/umbilicals.
- Channels 15 and 16 are RTD inputs for PT100 temperature probes (a Resistance Temperature Detector, also known under the acronym "RTD" is a sensor whose resistance changes as its temperature changes) that are not used with air dive systems.
- Two pulse counting flow meter inputs are also available *(see #23 & 24)*. They indicate the engineering values, server mapping, the condition of the flow, and number of pulses
- Clicking the "iAU Details" button (see #25) brings up the Intelligent Acquisition Unit details window below, which allows to see various details about the iAU, such as:
  - The serial number & firmware version.
  - Telemetry info
  - Power supply voltages.
  - Calibration controls and the button "accept alarms"

  The tile "Close window" (see #26) allows to return to the previous page



- Back on the Input channels page, each analog input channel has an indicator that shows whether the channel is enabled, if a signal is present and if there is a fault *(see #27)*. A text display is provided for the loop current (in mA), the converted engineering value for the assigned signal, and the name of the signal assigned to the input channel.

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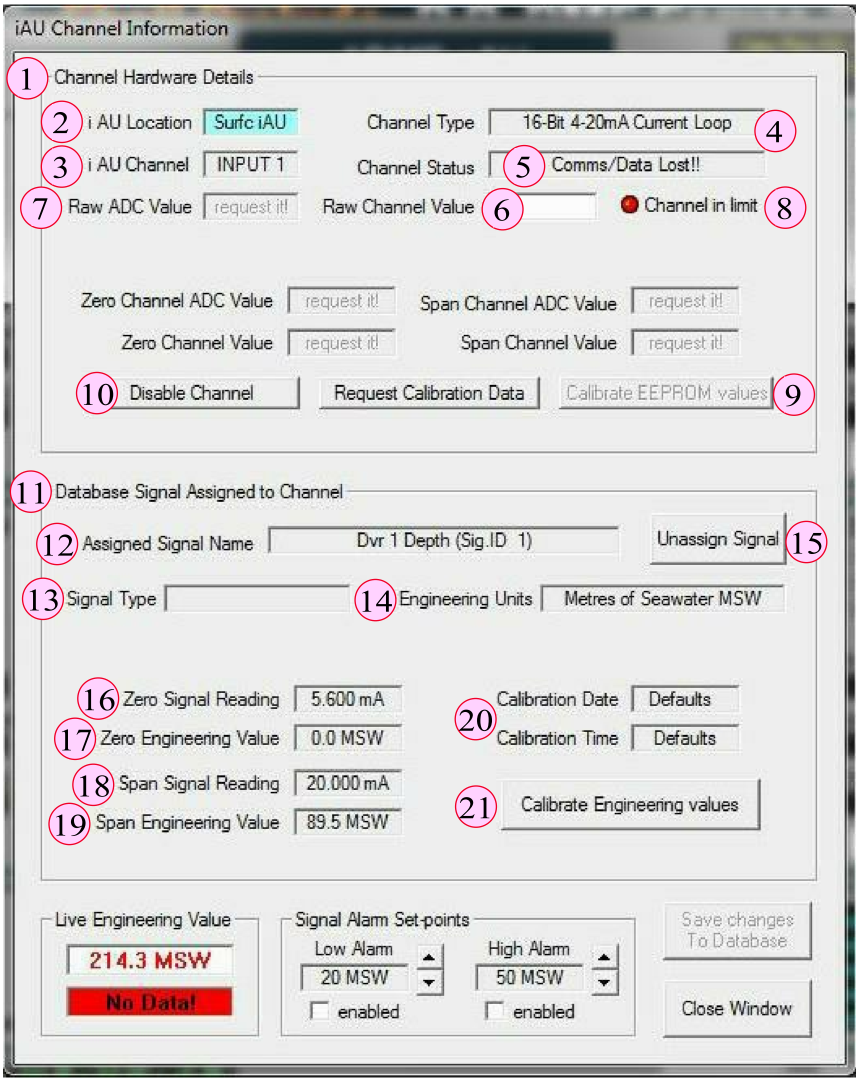
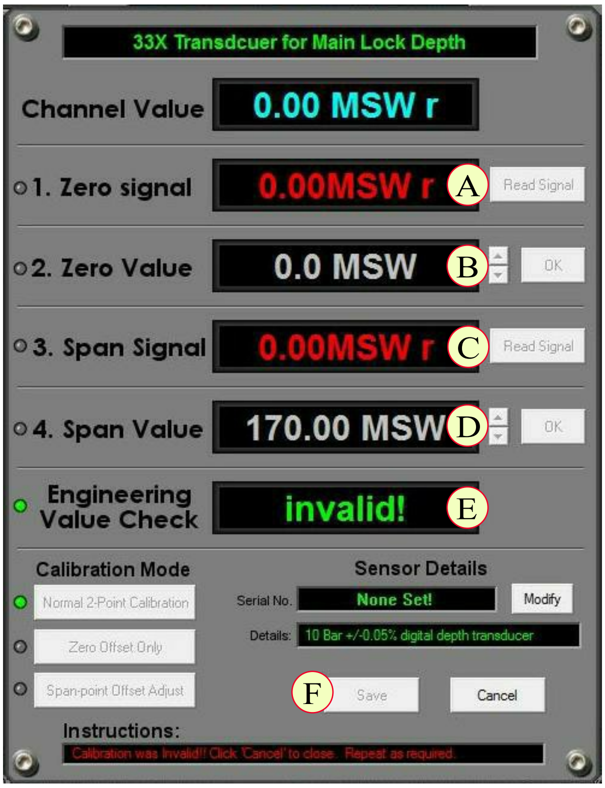
- The “Details” button at the bottom of each channel opens the intelligent Acquisition Unit (IAU) channel information window of this channel. This window provides the following details:



1. “Channel hardware details” provide information of the physical hardware channel selected.
2. “iAU location” shows the channel's location in the Intelligent Acquisition Unit (IAU). The number of iAU depends on the number of dive controls.
3. “iAU Channel” shows the channel number in the range 1 to 16 displayed on the previous page.
4. “Channel Type” displays the interface type for the channel selected (e.g. 4-20mA current loop).
5. “Channel Status” shows information about the channel condition.
6. “Raw channel value” shows the value displayed in mA for current loop channels, or ohms for RTD channels.
7. “Raw ADC value” shows the raw channel Analogue-to-Digital converter (ADC) value displayed in counts. The iAU ADC is a 16-bit device, so the entire input range is from 0 to 65,535 counts. Note that the “normal” range should typically be between 27,000 and 60,000. The raw ADC values are not automatically transmitted from the iAU to the iCR and then to the server. Instead, the operator must request that the iAU send the raw values by clicking on the ‘Request Calibration Data’ button.
8. “Channel In Limit” is an indicator that is illuminated green when the channel signal is within limits (e.g. between 4mA and 20mA for a current loop sensor), and is illuminated red if the signal is outside its electrical limits.
9. “EEPROM calibration information” allows to calibrate the non-volatile EEPROM storage on the iAU processor PCB. This procedure is normally carried out by Fathom Systems engineers and should not be modified by the user.
10. “Disabled/Enable Channel” is a button that allows to enable or disable the channel as required. When disabled, a current loop channel will have no signal current flowing.
11. “Database Signal assigned to Channel” is the display screen area involved with the signal assigned to the selected hardware channel.
12. “Assigned signal name” is the slot where the identification reference of the signal assigned to the channel is indicated. For information, each signal in the database has a named description and an ID number.
13. “Signal type” is a slot showing the type of signal assigned such as either a 4 - 20 mA analogue input signal or an RTD (Resistance Temperature Detector) input.

14. “Engineering units” refer to the unit system used for the assigned signal.
15. "Unassign Signal" & "Assign Signal" is a button that can be clicked to remove the association between the signal and the channel to free the input channel, allowing a different signal to be assigned to it if needed when it is labeled "Unassign Signal". This function also places the signal on the list of unassigned signals that can be subsequently re-assigned to the same or a different channel later. After unassigning a signal, the user must click the "Save Changes to Database" button to make the unassignment permanent. When the unassignment is effective, the button is labeled "Assign Signal".
16. “Zero Signal reading” is the raw channel at zero point.
17. “Zero Engineering value” is the value associated with zero-point (as recorded during the calibration). The units used for display are defined by the type of signal assigned to the channel.
18. “Span Signal reading” is the raw channel value at the span point (as recorded during the calibration).
19. “Span Engineering value” is the value associated with the span point recorded during the calibration. The units used for display are defined by the type of signal assigned to the channel.
20. “Calibration date and time” is the slot where the date and time the signal was last calibrated is displayed.
21. “Calibrate Engineering Value” is a button that opens the engineering value on the calibration screen. This screen is used to perform a 2-point calibration of the signal.
The technician performing the calibration must initially set the engineering value at the transducer to its zero level (e.g., by venting a depth transducer). Then the system is instructed to read the input channel data. Then, the technician enters the actual engineering value at the zero point. Then a span signal is applied to the transducer, and the system is commanded to measure the input channel, followed by the technician entering the engineering value at this span point.
Calibration typically takes place against a reference standard. The engineering value calibration screen is the same as that shown for the intelligent Network logger (INL). Clear instructions are provided to the operator in the status line at the bottom of the window during the calibration process. Once the calibration is complete and the engineering value displayed in the “Engineering Value Check” box is correct, it is saved to disk. Suppose the calibration process is not within limits required by the system. In that case, (e.g., there is an insufficient span range between zero and span points), the server software will not allow the calibration to be saved. It will highlight the parameter that is unacceptable in red. The system can be configured for specific depth sensor signals to allow three different calibrations “modes”, but the DMS systems only permit “Normal 2-point Calibration”. This procedure consists of measuring the “zero-signal”, then entering the engineering value for the zero point before applying a span signal to the sensor measured by the system. The “Engineering Value” is entered from the calibration reference and the settings are checked and saved.
The following steps are used to calibrate the transducer:
    A. The pressure transducer is isolated. Then, using a pressure calibrator on the calibration test port the pressure is set to zero metres seawater on the pressure calibrator and the “Read Signal” button is pressed.
    B. The noted value from the pressure calibrator is entered into the “Zero Value” box using the up & down arrows. The “OK” button is then pressed.
    C. Using the pressure calibrator, the pressure is increased to the span value (max working depth). Once the pressure is stable, the reading on the pressure calibrator is noted and the “Read Signal” button is pressed.
    D. The reading (in msw) from the pressure calibrator is entered into the “Span Value” window using the up & down arrows. The “OK” button is then pressed.
    E. The software then ensures that a valid span between the zero and high-pressure readings has been used. If the calibration is correct, the depth reading from the transmitter is shown. If “Invalid !” is displayed, the calibration is incorrect.
    F. Press the save button to save the calibration.



“Zero Offset Only Calibration” is a mode that allows the sensor to have its zero-point adjusted to read zero without the requirement for span calibration. This function does not change the calibration ‘slope’ or gradient; it simply moves the sensor ‘offset’ at zero (and therefore across the whole range). The system only allows this function to adjust small discrepancies in the zero signal.

- Video Matrix Status Display:

Hyperlink
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The 16 x 16 video matrix is connected to the Dive Control DMS server serial port (COM2) and communicates using RS232 telemetry. The status window is accessed from either the Dive Control server main screen or Dive Control client main screen *(see #14 below)*.

The video matrix consists of 16 input channels that can be mapped to any of the 16 output channels by touching the intersection between the red and yellow output lines. When they are selected, the solid blue dot moves to the intersection between the selected input and output *(see in the picture below)*. An input can be mapped to more than one output but not the other way around.

Input 1 "Diver Camera 1" is mapped to:

- *Output 1 "Inspection DVR Feed 1"*
- *Output 13 "Dive Control Monitor 5"*

Input 2 "Diver 1 Camera with Overlay" is mapped to:

- *Output 3 "Black Box DVR Diver 1 Feed"*
- *Output 6 "Rack Cabinet Monitor 1"*
- *Output 11 "Diver Control Monitor 3"*

Input 3 "Diver 2 Camera" is mapped to:

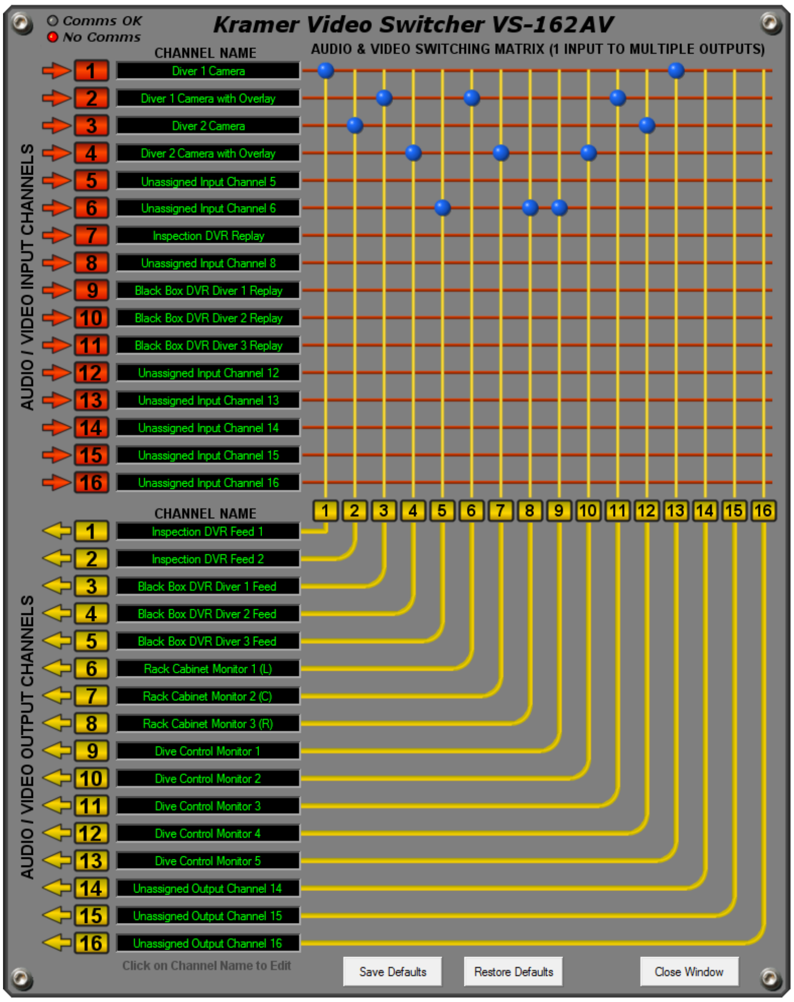
- *Output 2 "inspection DVR feed 2"*
- *Output 12 "Dive control Monitor 4"*

Input 4 "Diver 2 Camera with overlay" is mapped to:

- *Output 4 "Black box DVR Diver 2 feed"*
- *Output 7 "Rack Cabinet Monitor 2"*
- *Output 10 "Dive Control Monitor 2"*

Input 6 "Unassigned input Channel 6" is mapped to:

- *Output 5 "Black box DVR Diver 3 feed"*
- *Output 8 "Rack Cabinet Monitor 3"*
- *Output 9 "Dive Control Monitor 1"*



Input and output channels may be renamed by clicking the text box containing the channel name and typing in new text

- Camera & Hat Light Power Supply Status Display:

The Camera & Hat Light Power Supplies communicate via the DMS Ethernet network with the DMS server.
The status window is such as the one displayed on the next page, and is accessed from either the Dive Control server main screen or the Dive Control client the main screen *(see #11)*.

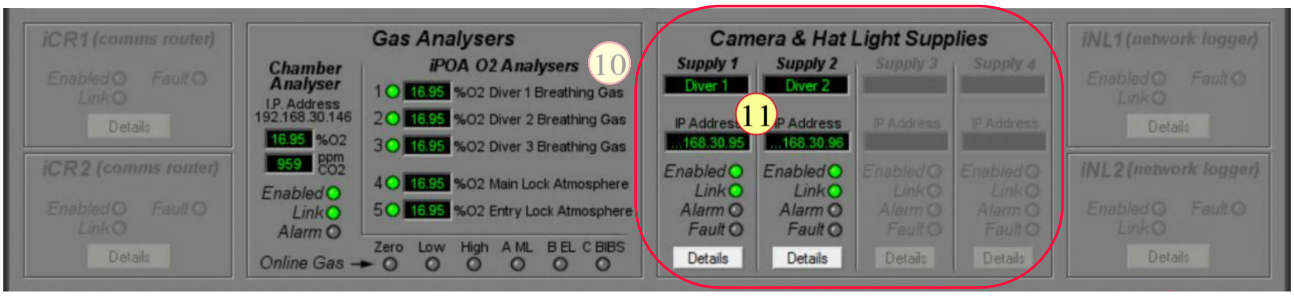
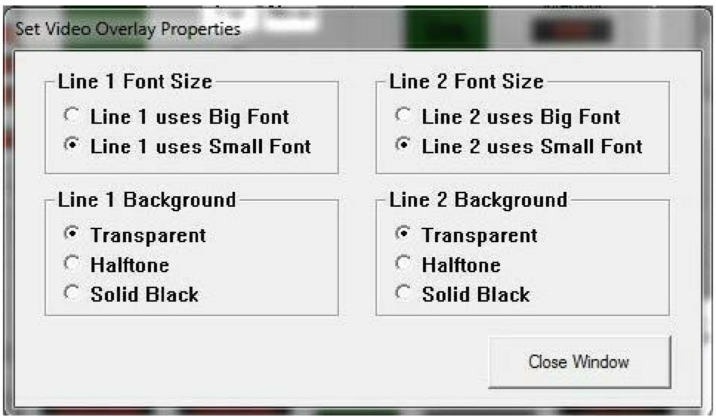


Table of contents

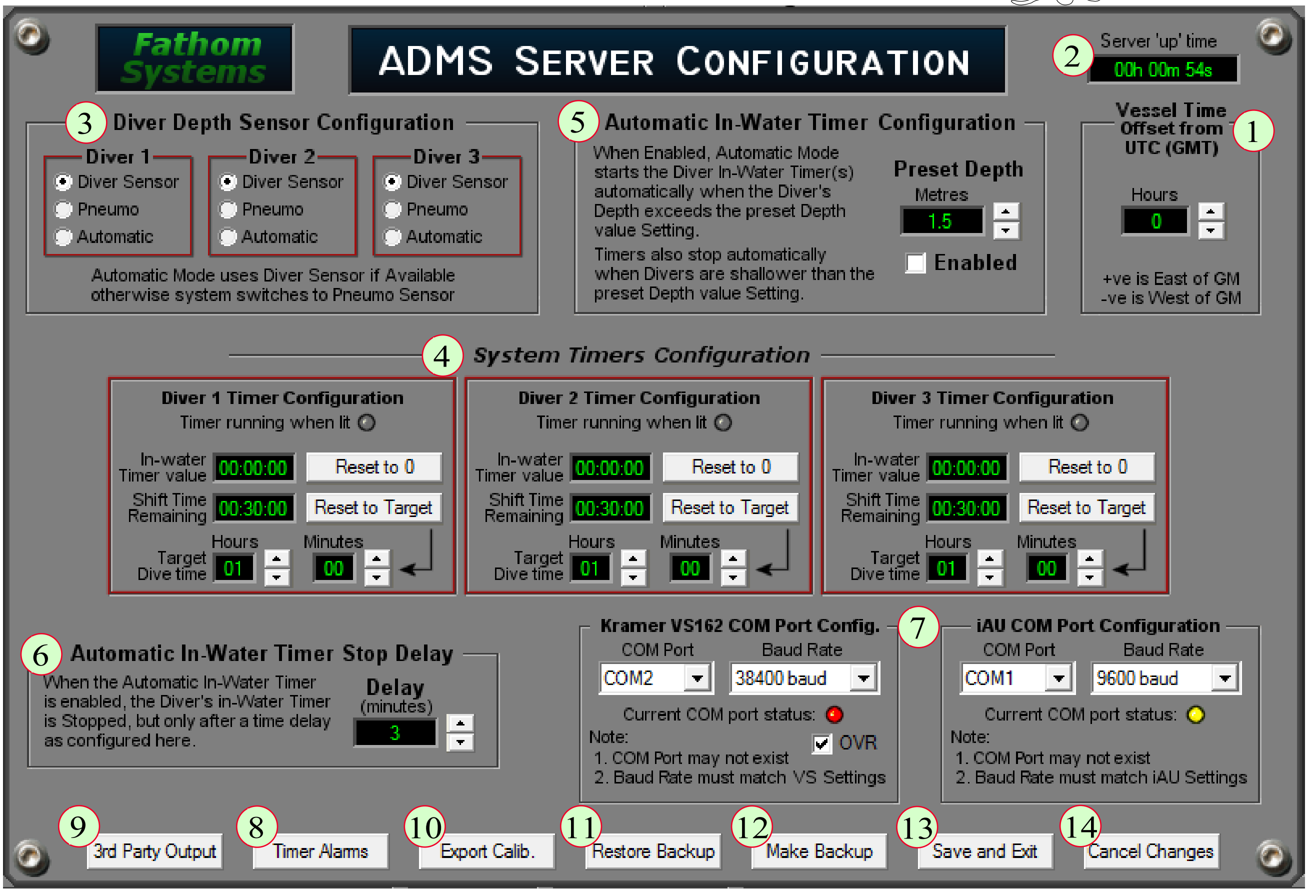
The controls on this screen are as follows:

1. Camera Power
   - “ON”/”OFF” buttons turn the power to the camera on and off
   - Indicator window illuminates green when the power is on and is dark when the power is off.
2. Focus
   - “Far” button adjusts the focus for objects further away from the camera.
   - “Near” button adjusts the focus for objects close to the camera.
3. Zoom
   - “Wide” button zooms out/expands the camera view.
   - ”Tele” button zooms in/magnifies the camera view.
4. Hat Light Power
   - “ON”/”OFF” buttons turn the power to the camera on and off
   - Indicator window illuminates green when the power is on and is dark when the power is off.
5. Hat (helmet) Light Intensity
   - Controls the brightness of the diver’s hat light, adjusted by a slider.
   - Intensity readout displays selected intensity setting.
6. Video Overlay Settings
   - Video overlay applied by the DMS software, note that it is separate from any overlay applied by the Camera & hat (helmet) light power supply hardware.
   - Up to two overlay text lines can be selected using the drop-down menus
   - Overlay can be turned on/off using the “ON” and “OFF” buttons
   - Software overlay overwrites any overlay set on the unit itself.
7. Status Displays
   - Camera and Light voltages and currents show the values measured by the Camera & Hat (helmet) Light Power Supply. Voltages are set using the buttons on the front of the units.
   - “LIM Status” shows the state of the line insulation monitoring. If an insulation fault is detected the indicator will illuminate red and show “FAULT”.
   - “Ethernet Connection” shows the status of the connection between the Camera & Hat Light Power Supply and the DMS server. The number of Ethernet packets sent and received are shown for diagnostic purposes.
8. “Overlay Properties” Button
   - Clicking this button brings up this menu which allows the properties of the overlay text to be controlled.



- Server Setup display:

At the bottom of the main server display window there is a button marked “Server Setup” *(see #21 below)*. Clicking this button opens the server setup display window:



1. Vessel Time Offset from UTC:
   This control allows the dive technicians to adjust the vessel time offset according to the Universal Time Code (UTC). These adjustments are to be made when the vessel changes time zone or daylight-saving policy.
2. Server "UP" Time:
   This slot displays the time duration the server is running in hours, minutes, and seconds.
3. Diver Depth Sensor Configuration:
   The Diver's depth sensor source can be configured to be "forced" from either the Diver's sensor (carried at the end of his umbilical) or the surface pneumo sensor.
   Typically, however, this parameter is set to "automatic," with the Diver's sensor being used in preference to the Pneumo and the Pneumo only being used if the Diver's sensor is not operating correctly.
4. System Timers Configuration:
   A comprehensive set of displays and controls are provided in these slots to allow the technicians to adjust and monitor the status of the bell-run and diver in-water timers. The functions offered here are also duplicated via the dive control client display software.
   The technicians can adjust the alarm settings and timer target values and reset timers to either a zero or a target duration. An indication is also given for each timer to show when it is running.
5. Automatic In-Water Timer Configuration:
   The feature that automatically starts the diver in-water timers can be enabled and disabled in this slot, and the depth threshold below which the timer is running can be adjusted. When enabled, this feature applies to all three Diver in-water timers.
6. Automatic In-Water Timer Stop Delay:
   The feature allows a configurable delay to be set that prevents the automatic in-water timer from stopping for a period of time after the diver's depth is shallower than the trigger threshold. The reason for this facility is to allow divers to come to the surface, say for the collection of tools or equipment – but without the dive timer being stopped immediately. When set to 0, this feature is disabled.
7. Kramer VS162 and iAU COM Port Config.:
   This slot allows the serial port and baud rate for the video matrix and Intelligent Acquisition Unit (IAU) to be set.
8. "Timer Alarms" Button
   This button opens a display screen to allow the technicians to view the timer alarm status:

9. "3 rd Party Output"
   This button allows a serial data output to a 3rd party computer system to be configured.
10. "Export Calib"
    Clicking this button exports a text file containing all system calibration data. This facility is provided for maintenance and diagnostics by engineers.
11. "Restore Backup"
    This button allows restoring a previously backed-up server configuration file from the disk.
12. "Make Backup"
    This button allows writing a backup file to the disk that contains all signal assignments and server configurations.
13. "Save and Exit"
    This button is used to save the changes that have been made to the server setup and to close the setup window.
14. "Cancel Changes"
    This button is used to cancel any changes made and to close the setup window.

- Day-to-day operations of the system & archiving of data:

The system should be checked regularly. It can be done by visual inspection of the hardware and viewing the various status displays on the server software. Accessing the server software can be done either at the DMS PC itself or, more conveniently, via a remote desktop session. Any faults or alarms on the system should be investigated and repaired.
The data from the hard disk of the server and chamber PC should be archived onto memory-sticks or external hard disks. Having all data files on a separate machine also provides greater system and data integrity. The backup server can also be used to provide data backup facilities.
The data files should be manually copied to the external archiving support, typically every week. Care should be taken to ensure that the data files do not build up to a sufficiently large size that disk space becomes short on the server or chamber PC.
Once the data has been archived, the company operating procedures may require that the data are sent onshore for permanent storage. The data files written to the disk are approximately 3MB each, with one data file being created for every hour. If the files are compressed using a file compression utility such as WinZip, up to 30 days data can be archived onto a single CD-ROM (approximately 800 mb). These data comprise the binary data files created by the server which have the "dmd" file extension. In addition, the calibration files and personnel database file should also be archived. Archival data security is the responsibility of the operator.

2.19.4.5 - Diving supervisor's workstation set up and management

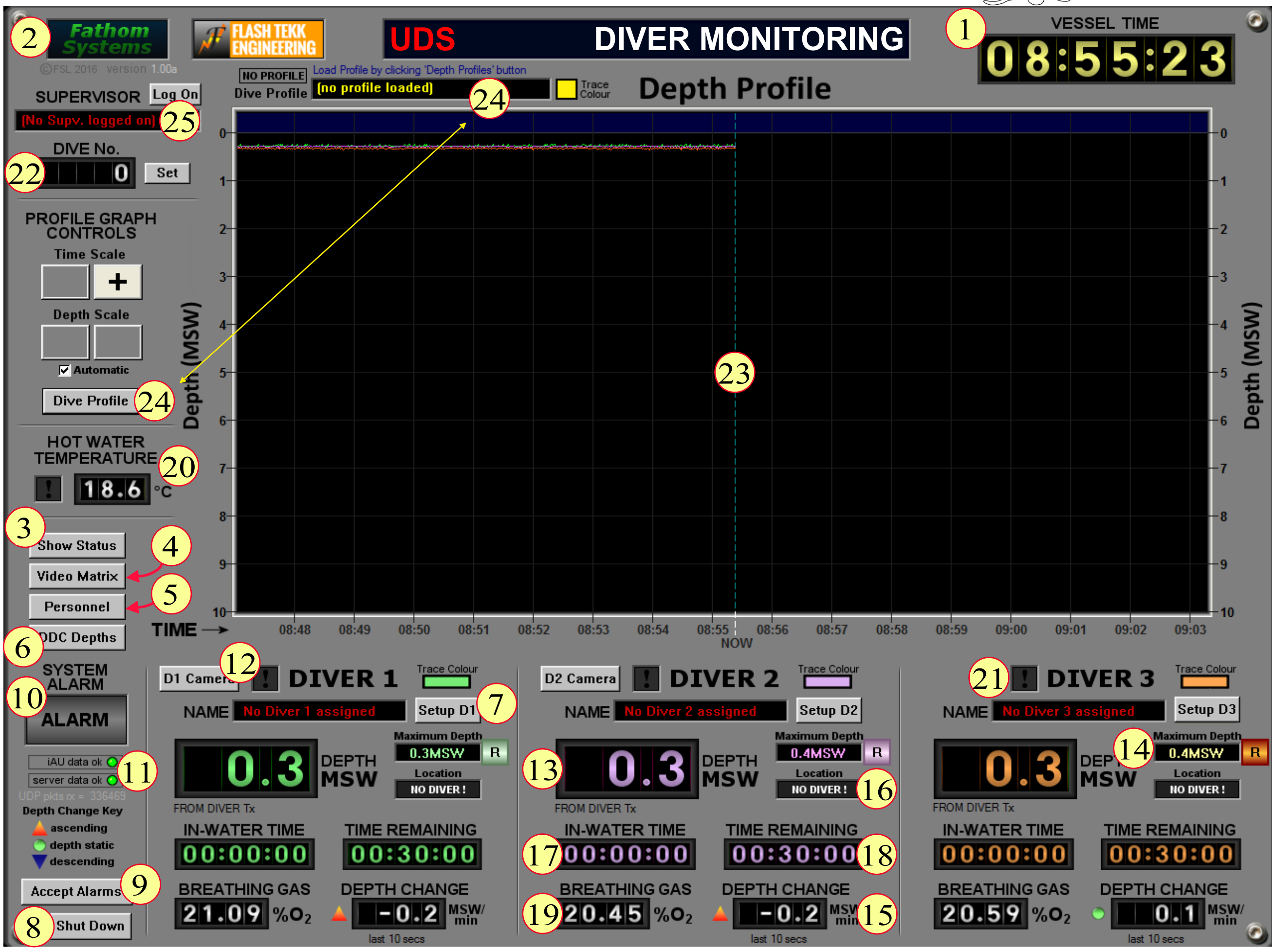
- Overview:

The Dive Supervisor's workstation is provided with a monitor, a keyboard, and a computer mouse as every desktop computer. They are used to provide a real-time display and interaction of all the diving parameters related to the surface supplied diving operations. The monitor should be located near the supervisor so that they can have a clear view during operations.

As already said, the system is designed to track the dive supervisor and the diving personnel at work for the project. For this reason, the supervisors must log on to the system at the start of their shift. It is achieved by clicking the appropriate button at the top of the screen, near the "Fathom logo" *(see #25 on the snapshot on the next page)*, and selecting their name from the list provided. The supervisors are then prompted to enter their password before login is permitted. They also must log off at the end of their shift.

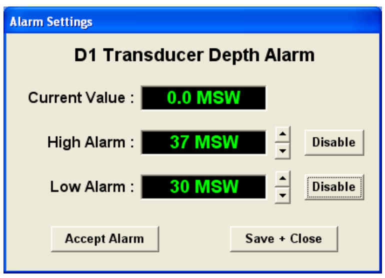
The following elements are displayed to the supervisor, that can be seen in the picture on the next page:

1. Vessel time display:
   It shows the time reference used onboard the vessel and used for recording data. As already explained in the setup procedures of the server, this time is adjusted for regional time-zone and daylight-saving policies against the "Coordinated Universal Time", also known as "Greenwich Mean Time or GMT". It is the time used on the vessel bridge for all vessel time operations. The dive technician adjusts this time through the server setup procedures already described.
2. Fathom systems logo:
   Clicking the Fathom Systems Logo on the top of the display opens a page that indicates the software version, copyright, and Fathom Systems phone number that can be contacted in case of an emergency.
3. "Show Status"/"Hide Status":
   This button shows and hides the software status window for the dive client software. It also displays the logs of software events and errors. It normally only displays loading statuses and alarm events, with no errors.
4. "Video Matrix":
   This button opens the video matrix details window described in the previous point.
5. "Personnel":
   This button opens the personnel database editor. It is the editor already described.
6. "DDC Depths":
   This button displays a window showing the depths of both locks of the decompression chamber.
7. Diver setup button and identification window:
   This button allows a diver to be assigned or unassigned from a diving role for a particular dive. When this button is clicked, a pop-up window appears to allow the Supervisor to assign a position to a diver from the list.



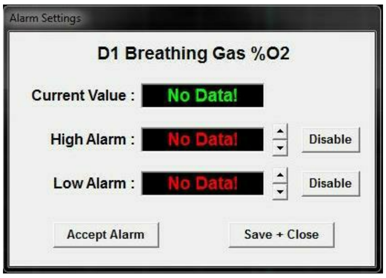
8. "Shut Down":
   This button shuts down the client display software.
9. "Accept Alarms":
   Pressing this button acknowledges all system alarms. Flashing red warning indicators will be turned to a solid red and audible alarms are silenced.
10. System Alarm Indicator:
    This indicator panel is illuminated red and flashes whenever there are one or more active system alarms on the system, or is illuminated steady red when all system alarms are accepted.
11. Data Link Status Indicators
    These indicators show the status of the data links to the Server and iAU. The following colours are used to make their status visible: Green means that the connection is good, amber indicates that the link is faulty or intermittent, and red means no connection is established.
12. "D1 Camera", "D2 Camera" & "D3 Camera".
    This button opens the setup window of each Camera & Hat (helmet) Light Power Supply. Again these setups can be done from the Server panel.
13. Diver depth:
    Three display readouts show the divers' depths 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 outside the pre-set alarm limits, the digital display changes from its normal colour to red. A signal fault is represented as a row of red dashes like in the picture on the side.

    As said in the presentation of the set up procedures of the server, the signals for these readouts come from the divers' depth transducers attached to the end of the excursion umbilical (at chest level) and connected back to the iAU mounted in Air Dive Control. In this case, a small label under the depth reading shows "FROM iAU".
    If the iAU depth signal is unavailable, the system automatically reverts to the surface pneumo depth transducer. 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 diver's depth display readout opens the depth alarm settings adjustment window on the right.
    The diving supervisor can adjust the diver's minimum and maximum depth alarms using the up/down arrows. The supervisor then accept the setting by clicking the button "Accept Alarm". Two button "disable" can be used to remove high and low alarms.

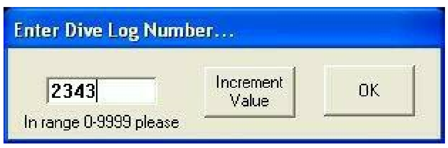


The calibration of the depth is made in metrics. However, when the mouse is passed over the depth display readout on the screen, a pop-up window provides a depth reading in feet of seawater (FSW). This value, calculated automatically from the MSW reading, can be used if decompression tables in imperial are used.

14. Maximum Depth Record:
    The system tracks the maximum depth that each diver has reached. This figure is updated continuously as the diver works. The depth value should be reset at the start of a dive by pressing the colour-coded “R” button.
15. Depth change:
    This colour-coded digital display readout provides the rate of change of depth of each diver.
    This is displayed in MSW/minute. There are no alarms available for this parameter.
16. Diver location indicator:
    This status display panel shows the diver's location during his shift, either at the surface or in the water. The information displayed comes from the pushbutton switches operated by the Dive Supervisor. As said for the setup procedure for the server, this information is also stored in the master data file on the server to allow dive profiles to be recorded for each diver.
17. Diver in water timer display:
    A digital display is provided for each diver that displays the time spent in the water (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 started the timer via the software timer control page to indicate that the diver has entered the water.
    When the timer is stopped, the timer display stops incrementing but continues to display the last total time figure.
    The system can be configured to start and stop the in-water timers automatically, and if set this way, the timer status is controlled by the diver’s depth transducer. The threshold below which the in-water timer switches ON is adjustable via the server software previously discussed in the procedure to set it up.
    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 “in-water” or “time remaining”).
    The in-water timers are provided with an alarm system that triggers a red alarm status when the elapsed in-water time exceeds the set threshold. The configuration of the alarm thresholds is made via the timer configuration window.
18. Diver shift-time remaining display:
    A digital display is provided for each diver to show the time remaining for their operational shift. This display is decremented every second so long as the supervisor has pressed the pushbutton on the panel to indicate that the diver is in the water. When the pushbutton is returned to the off (at the surface) 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 target shift time to a particular value via the timer configuration window (accessed by clicking on “in-water” or “time remaining”).
    As above, an alarm system is provided that triggers a red alarm status when when the shift time remaining is less than the alarm threshold.
19. Diver’s breathing gas % O_2 display:
    O_2 percentages are shown for each diver. These mirror the readings from the paramagnetic oxygen gas analysers installed in the diving panel.
    Regarding this point, Fathom says that the Diver Monitoring System gas analyzer readings should not be relied upon for safety-critical/life support decision-making.
    Clicking a display brings up the alarm dialogue window for the corresponding sensor similar to the one displayed on the side with the same design as the one used to adjust the depth alarms. Thus, the setting can be done using the up/down arrows and enabled/disabled buttons. Then the “Accept Alarm” button must be clicked. That silences the audible alarm and turns the red flashing visual alarm into solid red.

    Note that these alarms are local to the software and do not affect the primary sensor alarms.
20. Diver Hot Water Temperature Display:
    It shows the temperature of the hot water flow being supplied to the divers. The reading is taken between the hot water flow machine and the manifold which splits the flow out for the three divers.
21. Alarm indicator (shown as alarm healthy):
    The alarm indicator is grey when the conditions for the diver selected are within limits, and the signal is normally transmitted. The alarm indicator is illuminated red when a depth or analysis alarm condition for that diver is outside limits, or the signal is faulty. The alarm indicator flashes until the supervisor accept the alarm (via the Alarm Settings window).
22. Dive Number Display:
    This display shows a sequence number that is to be used for the dive Logs. Clicking on this display opens a small pop-up window the supervisor uses to set the dive log number.

23. Profile Display Depth Scale:

This large graph shows the real-time plot of the divers' depths against Time. It is updated automatically and provides a depth chart (on the Y-axis) against Time (on the X-axis). Colour codes are used to represent the dive curves of the divers. They conform to those used to identify the diving data of each diver on the screen. Thus: Green identifies diver 1, purple diver 2, and orange diver 3.

A graticule is provided to allow the scales to be read easily. The Data shown on this display are held local to the dive control display application and retained for 12 hours in the "client PC" memory. Data older than 12 hours are discarded, so the Report Generator application should be used if a review of older data is required.

The depth profile is scaled horizontally in Time. The timescale for the data is either 1, 4, or 12 hours, and the current Time of day (Vessel time) is shown on the horizontal display. The time scale used for the Depth Profile trend display can be manually adjusted with the increase (+) and decrease (-) buttons.

24. Diver Depth Profile

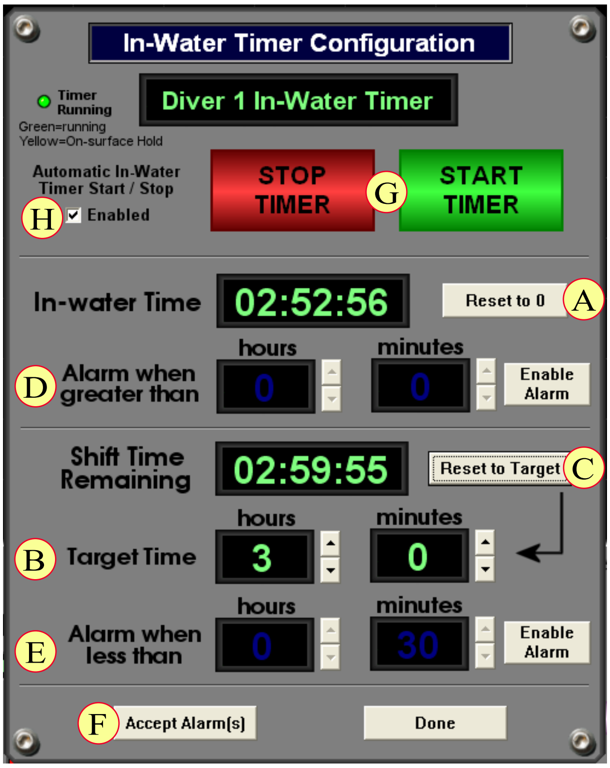
The dive profiles can be displayed on the "Depth Profile" graph to assist the dive supervisor in ensuring the divers follow the planned dive profile. Clicking the "Dive Profile" button opens a window which allows dive profiles to be created, loaded, edited and saved on the server. The loaded dive profile is shown in a text box above the depth profile.

25. Dive Supervisor Identification (name and ID number):

This slot shows the name of the supervisor when he has logged in. When the supervisor has completed his duty, he must log off the system. When that is done, his name is no more visible but kept in the list, and the new supervisor can log in.

- Timer configuration display:

The timers tracking the time the diver is in the water (the total elapsed time the diver has spent in the water), and remaining time on shift (the amount of time remaining for the shift ongoing) are displayed on the screen as explained above. The timer configuration display for each of the Diver's timers looks as follows:



A. The in-water timer is reset to zero by clicking on the "Reset to 0" button. This is normally done by the supervisor prior to the start of the Dive.
B. The Supervisor can adjust the duration of the shift for the diver by clicking the up and down arrows next to the hours and minutes target time boxes.
C. When the desired target time for the shift has been entered, the supervisor clicks on "Reset to Target" button to transfer the values set in the hours and minutes boxes to the "live" timer.
D. An alarm system is provided to alert the supervisor when the diver's in-water time exceeds a pre-set limit. The alarm set point is adjusted using the up and down arrow controls next to the hours and minutes alarm boxes.
E. A similar alarm is provided to alert the supervisor when the shift time remaining is less than a pre-set limit.
F. When timer alarms are generated, the timer screen display is displayed in flashing red digits. Accepting and clearing alarms is performed via the alarms configuration screen.
G. The Start and Stop buttons are used when the Automatic Start/Stop check-box is not ticked.
H. If the automatic mode is enabled, the timer will run whenever the diver is deeper than the pre-set threshold

- Pre-dive set up and checking:

Prior to commencing the dive, the Supervisor must set up the timer controls by resetting the divers' roles and the in-water timers, adjusting the shift target times, and resetting the maximum depth indicators. The in-water timer switches on the control panel behind the Supervisor should all be "off" (at the surface). These set-up activities should be a part of the pre-dive checklist.

During pre-dive checks, the dive supervisor should check that all instrumentation on the DMS display cross-checks to the primary instrumentation. That should preferably be a systematic check of all display items against a checklist. If any DMS displayed parameter disagrees with a primary instrument reading, the reason for the discrepancy should be investigated and the problem solved before commencing the dive.

- Personnel management:

Moving divers between the surface and the water is achieved by starting the "In-water Timer" as described above. The status of the "In-Water Timer" is transferred to the server, which updates the master data file to record the location of the diver on a continual basis.

At the end of a shift the diver must be either moved to the deck or the decompression chamber. This is accomplished by pressing the "Setup On" button and selecting the appropriate location to move the diver to.

- Alarm management:

The Dive Supervisor may be alerted when a system parameter enters an alarm condition such as:

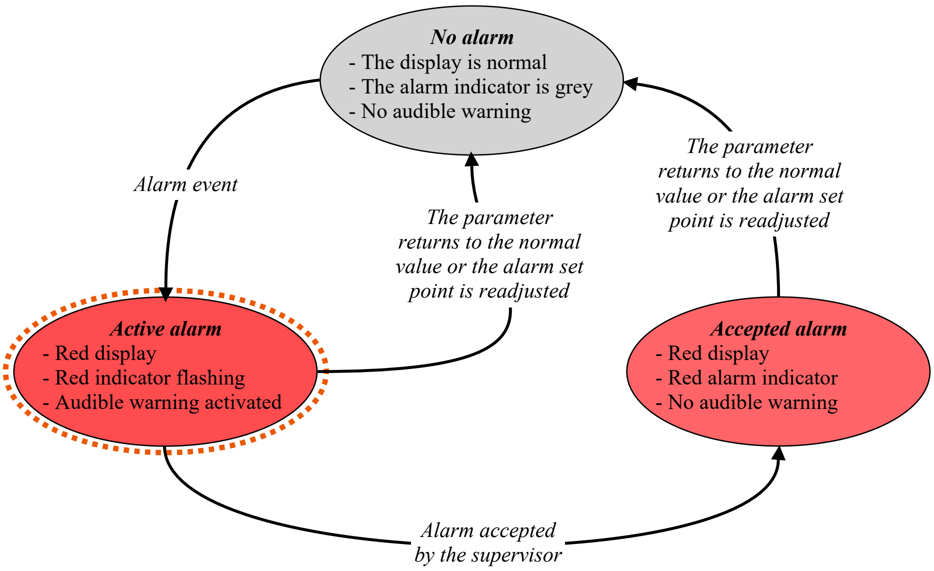
- Diver in-water timer alarm for each diver (target duration has been exceeded).
- Diver shift remaining timer alarm for each diver (time remaining is less than the alarm set point).
- Diver depth alarm for each diver (maximum or minimum depth alarm set point has been exceeded).
- Hot water supply to the Divers temperature alarm (water temperature is above or below alarm set point).

This alarm status results in:

- The digits of the element affected turning red
- The alarm indicators are illuminated red and flashing
- An audible warning generated every 10 seconds
- In case of a system error or fault alarm is generated, the display changes to a row of red dashes.
- A description of the problem is published in the status box that can normally be opened by clicking on “show status” *(see #3 in the drawing of the monitoring screen)*.

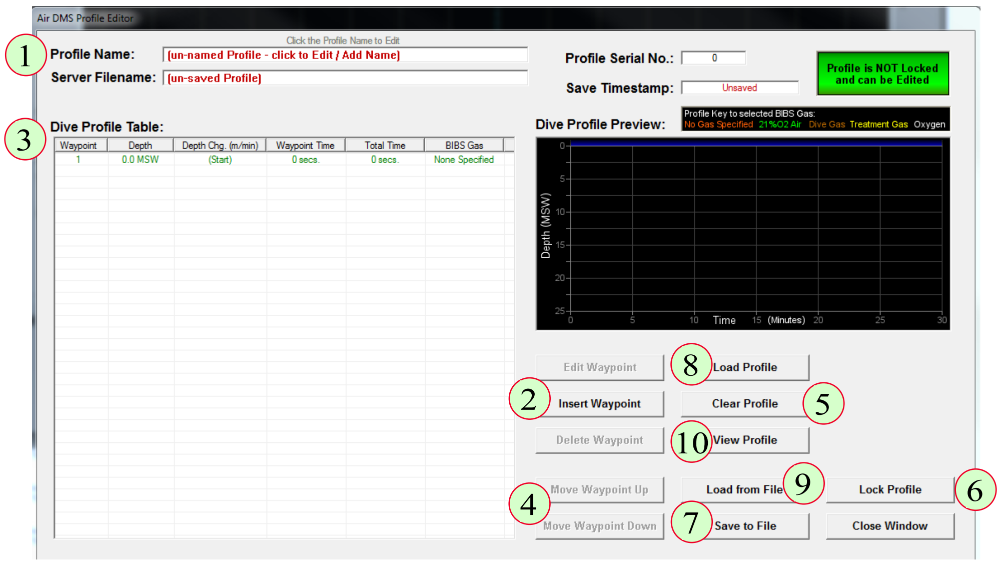
Remember that the active alarm must be accepted by the supervisor to stop the indicator from flashing and the audible warning from being repeated *(see #9 in the drawing of the monitoring screen)*.
Clicking on the red numeric display of the parameter in the alarm state opens the “alarm settings window” for the particular sensor.
Once accepted, the alarm indicator remains illuminated red and the digital parameter display remains red also.
When the alarm returns within the set point(s), the display returns to its normal display colour and the alarm indicator returns to grey.

The alarm processes can be summarized as follows:

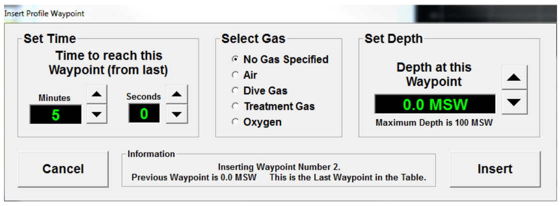


- Diver Monitoring System Profile Editor:

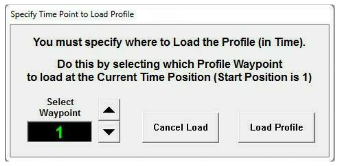
This tool is designed to create a depth versus time dive profile which is displayed on the “Depth Profile” graph on the main dive control software screen. The main use of the profile is to ensure the divers do not exceed the ascent rates specified in the dive tables and to plan decompression stops. It can also be used to plan therapeutic treatment. It can be opened by clicking on “Dive profile” *(see #24 in the drawing of the monitoring screen)*.



1. Creating a New Profile:
   Click on “Profile Name” at the top of the window, a dialogue box opens and promps the user to enter a name for the profile *(see #1 in the scheme on the previous page)*. Enter the required name for the profile and click “Done”
2. Insert the “waypoints”:
   Press the “Insert Waypoint” Button *(see #2)* to open the window displayed on the side



   Enter the required data for the Waypoint and click “Insert”. As a result, the new point appears in the “Dive Profile Table” *(see #3)* and on the preview graph.
   In the “Dive Profile Table”, select the Waypoint after which the new Waypoint is to be inserted, and press the button “Insert Waypoint” *(see #2)*. Continue the same way for all Waypoints. Press “Done” to save the changes. Note that the buttons edit Waypoint and “Delete Waypoint” allow modifying the data entered, or erase the Waypoint.
3. Moving a Waypoint:
   In the table, select the Waypoint to be moved.
   Press the “Move Waypoint Up” and “Move Waypoint Down” buttons to move the Waypoint as required *(see #4)*.
4. Clearing a Profile:
   Pressing the “Clear Profile” button will remove all “Waypoints” from the profile *(see #5)*.
5. Locking a Profile:
   Pressing the “Lock Profile” button *(see #6)* locks all the editing controls so that the profile points cannot be accidentally moved. The profile can be edited again by clicking on the “Unlock Profile” button.
6. Saving a Profile:
   Ensure a name has been entered in the “Profile Name” field *(see #1)*
   Click on the “Save to File” button *(see #7)*. As a result, the save file dialogue opens. In this dialogue box, navigate to the folder where the profile is to be saved and enter a file name for the profile. Click the “Save” button.
7. Loading a Profile to the Dive Control Screen:
   Press on “Load Profile” *(see #8)* to open the small window on the side.



   Select the waypoint at which the profile is to be started and click “Load Profile”
   To start the profile, click the “Start” button on above the “Profile Depth” chart on the main Dive Client Software screen *(see #23 on the scheme of the main control Window)*.
8. Loading a Profile from a File :
   Click the “Load from File” button *(see #9)*. As a result, a dialogue box opens, navigate to and select the required file. Then, click on “Open” to load the dive profile Waypoints.
10. Note the button “View Profile” that allows checking a profile *(see #10)*.

- Closing the Dive Control Client Display
  The supervisor clicks "Shut Down" to close the "dive control client" display. Like many computers, that opens a message of confirmation asking to confirm the intention to quit the program.
  When this application is shut down, the data are still being logged by the server, so the only problem with shutting down the “dive control client” is that all the stored depth profile data (up to 12 hours) will be lost, as this data is not preserved between sessions (however, the logged information for this period is still stored on the server).
  The supervisor double clicks on the desktop icon to restart the application.
- Operation when the Data Server is Unavailable:
  A warning is displayed if the data server is unavailable. Additionally, if a function is selected, that requires interaction with the server, such as, for example, personnel movements, a message is presented to the dive supervisor informing that the server is not available.

2.19.4.6 - Chamber workstation set up and management

The set up and management procedure of the chamber workstation is explained in point 2.20 “Decompression chambers”.

2.19.4.7 - Personnel management system

This part explains how the personnel database, which is used to attribute the roles in the diving team and provide the identification number the supervisors and chamber operators need to access the system, works.

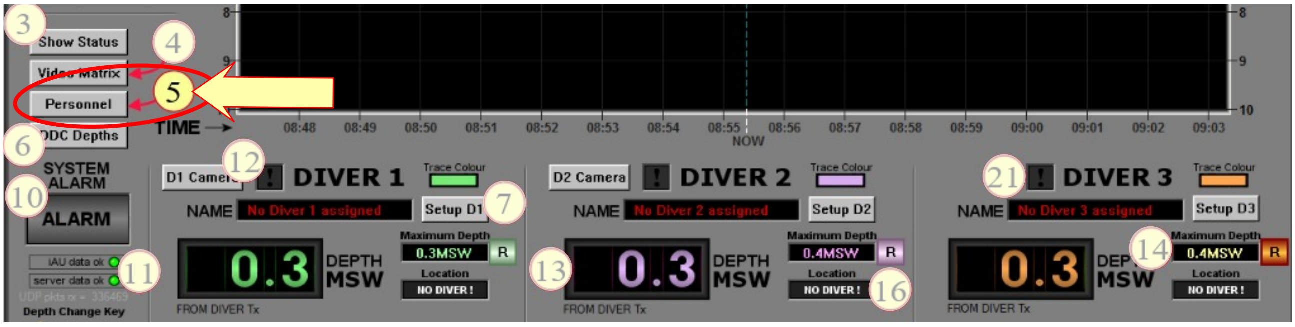
- Concept:
  The personnel database is stored on the dive DMS server in the electrical cabinet situated in the dive control and mentioned previously. Thus, the procedure to access and manage it is as with every computer or tablet.
  The networking configuration maps the data server hard drive to the drive letter “N:”. That means that when the local client machine accesses the “N:” drive, it is in fact accessing the DMS data server PC on the network.
  The personnel database is in the following directory: “*C:\Fathom_ADMS\Personnel\Fathom_ADMS Personnel.dmp*”.
  It is in a proprietary Fathom Systems format, so accessible only through the client display(s) via the following embedded database editing facility in the Dive Control.
  This system is designed to attribute an identification number in the range 001 to 999, which is prefixed with a digit that represents his function to each person, such as in the example below:

Names	Job function	Prefix	ID number	System ID
	Diver	*1*	*from 001 to 999*	*from 1001 to 1999*
	Diver medic	*2*	*from 001 to 999*	*from 2001 to 2999*
	Diving supervisor	*3*	*from 001 to 999*	*from 3001 to 3999*
	Chamber operator	*4*	*from 001 to 999*	*from 4001 to 4999*

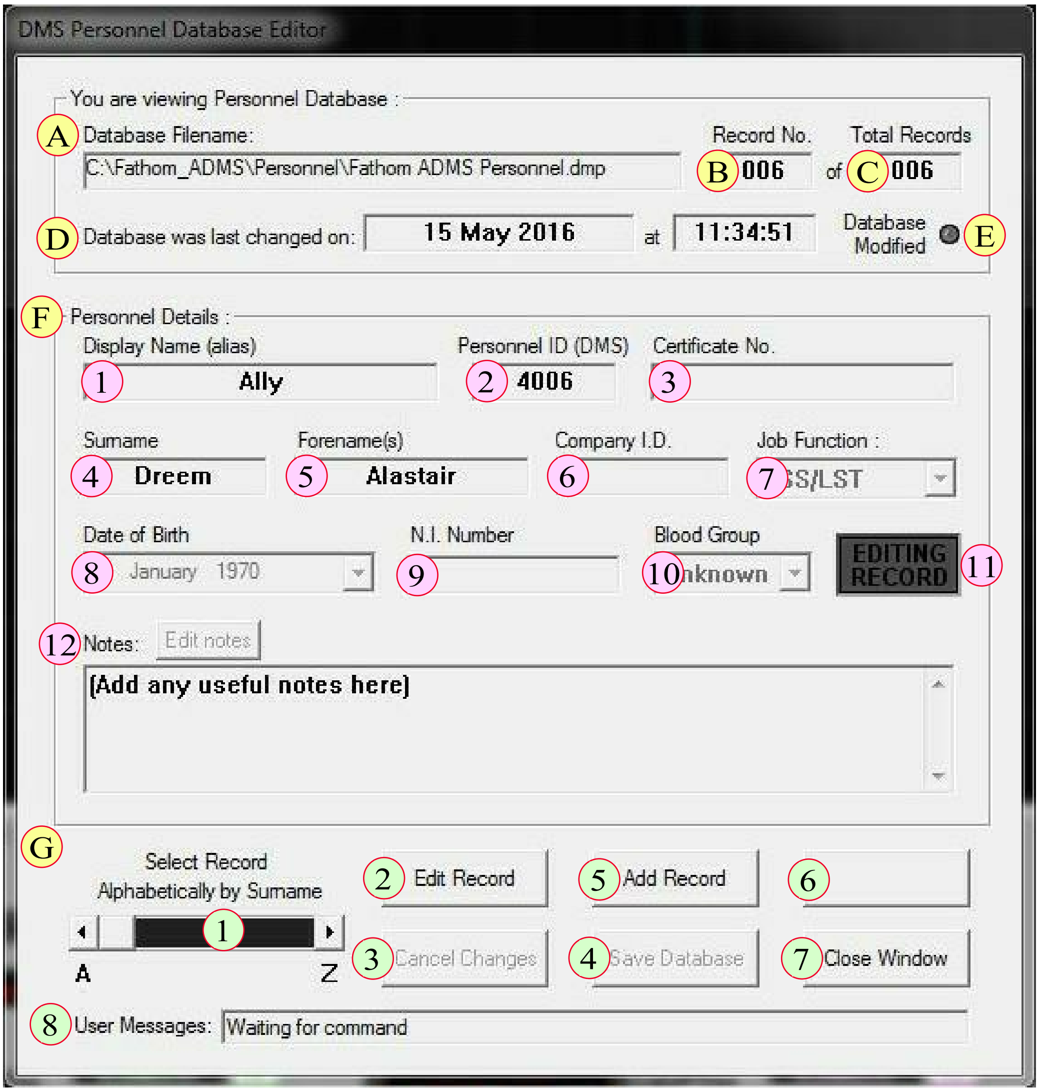
Personnel who have never worked with the system must have their details entered prior to commencing work. This task is normally carried out by the diving supervisors. However, this is not necessary for people who have already worked with the system as their ID numbers are normally not changed or attributed to other persons.

- Personnel Database Editor:

An editing utility allows the manipulation of personnel records stored in the personnel database on the server. To access this editor, the Supervisor clicks the "Personnel" button *(see #5 on the diver monitoring work station).*



The editor, which is represented below, can be reached by selecting either the "Personnel Database Editor" or "Show selected Diver's information" options from the pop-up menu on the diver name list-boxes in the application. As with all system functions that access the server, the data server PC must run.

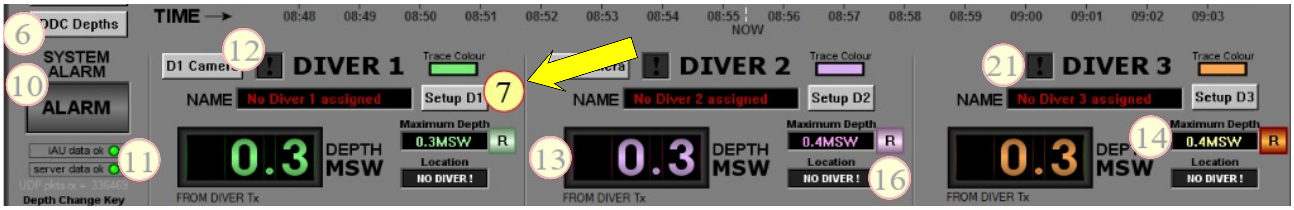


A. Database filename:
   This shows the Filename and Server drive-letter path for the personnel database file stored on the data server.
B. Record number:
   This number is the the person's ID number without the job function prefix digit.
C. Total records:
   This slot shows the total of records stored in the database.
D. Database last changed on date and time:
   These fields show the date and time at which the database was last modified. Note that whenever the database is modified, a backup copy is saved on the server prior to writing the modified version to disk.
E. Database modified indicator:
   This indicator changes from grey to red when the database has been modified.
F. Personnel details:
   This part of the form contains the following details *(the reference numbers to locate them in the document are pink)*:
   1. Display name (alias):
      It is the name displayed in the list boxes and on the client display screens. This field is to be filled by the diving supervisor. The name the person typically uses instead of his official name can be entered here.
   2. Personnel ID (DMS):
      It is the identification (ID) number of the person recorded. It includes the prefix digit that indicates the person's job function. It is an automatically generated field that cannot be edited.
   3. Certificate No.:
      This slot can be used to record a certificate number for the displayed person. It may be left blank, and can be edited.
   4. Surname:
      The person's surname or family name is to be filled in this slot
   5. Forename(s):
      The official person's forename(s) or given name(s) are to be edited in these slots.
   6. Company ID:
      This optional slot can be used to record a separate ID number used by the operator for the displayed person. It may be left blank, and can be edited.
   7. Job function:
      This box is used to specify the job function of the person. It must be filled and can be modified later on.
   8. Date of birth:
      The person's date of birth must be entered in this slot.
   9. NI Number:
      This field can be used to record the person’s National Insurance number. It may be left blank, and can be edited.
   10. Blood group:
      This slot is used to specify the blood group of the person displayed. If the person's blood group is not known, the “Unknown” option should be selected.
   11. “Editing Record”:
      This indicator panel illuminates green when the displayed database record is being edited.
   12. Notes:
      This area allows writing notes about the person. It can be left blank.
G. Navigation Controls:
   This part of the document allows to save the information entered and to access them as required *(the reference numbers to locate them in the document are green)*:
   1. Record selection scrollbar:
      This horizontal scrollbar allows searching a person's records through the database. The records are sorted alphabetically by surname.
   2. “Edit Record”:
      This button displays the record for editing. 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. Only one record can be edited at a time.
   3. “Cancel Changes”:
      This button is enabled only during an editing session. If clicked, the changes made since the database was last saved are abandoned. After clicking this button, the display window returns to the “non-editing” viewing mode (with the ‘Editing Record’ indicator grey).
   4. “Save Database”:
      This button is enabled only during an editing session. When clicked, the records are added to the database on the server. This function automatically creates a backup file on the server. After clicking this button, the display window returns to the “non-editing” viewing mode (with the “Editing Record” indicator grey), and the “last saved” date and time indicators are updated.
      Note that the changes made are automatically re-loaded to the personnel database and that these changes are updated throughout the entire system.

5. “Add Record”:
   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 Supervisor can enter additional details about the person. After entering all the required information, the person's profile can be saved by clicking on "Save Database," or the changes can be canceled by clicking on "Cancel Changes".
6. “Delete Record”:
   This button allows to delete the displayed record from the database. Clicking on it leaves the record in the database, but marks the record as deleted so that the ID number associated with the record cannot be reused for a different person. Once deleted, a record cannot be used again.
7. “Close Window”:
   This button allows to close the database editor. It cannot be clicked when in the “editing” mode.
8. User Messages:
   This single line of text provides messages from the system.

- Assigning and moving personnel:

In point 2.19.6.5, "Diving supervisor's workstation set up and management", it is said that clicking on "Setup D1", "Setup D2", and "Setup D3" opens the windows allowing to assign a diver to dive.

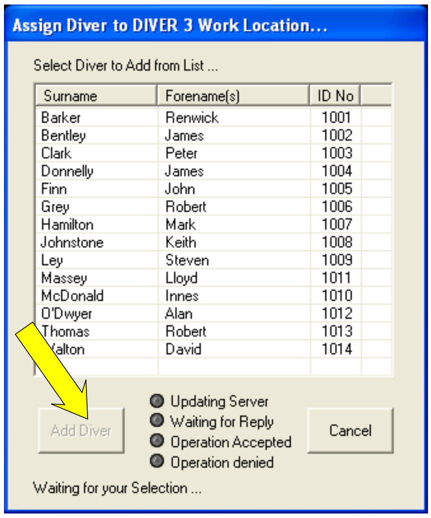


The Supervisor selects the diver to add to the system from the list *(see on the side)* and clicks the button "Add Diver".

After clicking the "Add Diver" button, a message is passed to the data server requesting to add the diver to the system.

When the request is acknowledged, the diver's name automatically appears in the diver's name box to which he is added.

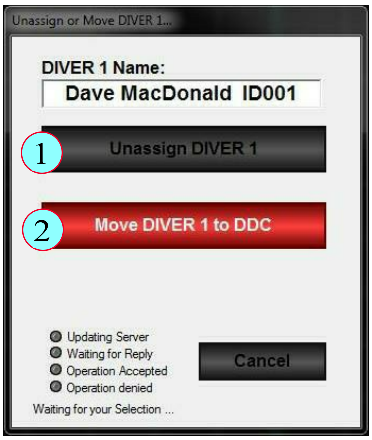
This process is repeated until all divers are assigned to work duties.



At the end of the dive, the diving supervisor can:

- Remove the diver from duty (un-assigns them, placing them ‘on deck’)
- Move the diver into one of the Chambers.

To start this process, the Supervisor clicks the ‘Setup D1’, ‘Setup D2’ or ‘Setup D3’ button on their control screen, and the pop-up window below offers him the choice:

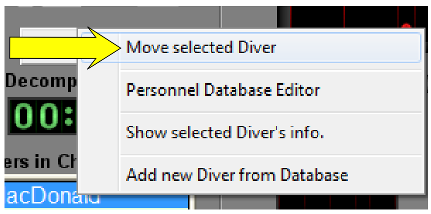


If the Diver is to be un-assigned, clicking the “Unassign Diver nb” button places the diver on deck *(see #1)*.

If the Diver is to be moved into the Chamber, the supervisor clicks “Move Diver n to DDC” button *(see #2)*.

When the chamber operator wants to move a diver around the system, he selects the diver to move by either right-clicking the diver's name in the list box or by double-clicking the diver's name with the left-hand mouse button.

Both actions cause the pop-up menu to be displayed with more options available, as shown in the example on the side. Selecting the “Move Diver” option from the list initiates the diver movement sequence. As a result, the “Move DIVER in Chamber” dialog window opens.



This window, which is exactly similar to the one above, provides two options:

- Remove the Diver from the chamber.
- Move the diver from one compartment to the other in the chamber.

The chamber operator selects the destination for the diver and clicks the appropriate button. 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.

This window automatically closes when the move is acknowledged, and the diver’s name is transferred.

2.19.4.8 - Essential elements to consider for starting the computers:

Each PC terminal requires a USB software key dongle to be inserted into the computer to allow the software to run. If this key is not inserted, the software shows a warning when it starts and automatically closes after 300 seconds.

In case of the failure of a terminal that results in its replacement by a standby 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 copied over from the data server where the updated version of all files should be kept.

The various networked devices use static the following IP addresses on the server network:

- Air DMS Server, Dive Control Client & Chamber Client: 192.168.30.2
- Diver 1 Camera & Hat Light Power Supply: 192.168.30.95
- Diver 2 Camera & Hat Light Power Supply: 192.168.30.96
- Chamber Scanning Gas Analyser iGA1: 192.168.30.146

Note that programs such as Microsoft Excel and Windows Explorer are provided to communicate data reports in addition to the Fathom software applications described.

2.19.5 - Maintenance

The maintenance of the devices described in this point should be primarily based on the recommendations from their manufacturers.

In addition, IMCA D 023, which is considered a reference by the members of this association and many clients, says that communications links should be examined and function tested in the last six months, in addition to any standard pre-dive checks. However, these guidelines, written before 2000, do not consider that new complex systems based on digital processes are today implemented and that, despite the progress of the computing industry to make its products more reliable, the chances of breakdown are multiplied with the number of added devices that may impact the diving teams as despite they are not considered the primary systems of control, these electronic devices become essential tools for the communications and the management of the dives, in the same manner, that cell phones are today considered necessary and have been made mandatory in some countries to control the famous Covid 19 virus.

In addition, the six months rule has shown its limits with some devices.

For these reasons, increasing this close inspection frequency to 1 month during operations appears reasonable in the absence of published recommendations from manufacturers.

2.20 - Decompression chambers

2.20.1 - Purpose

Decompression chambers, often called Deck Decompression Chambers (DDC), are pressurized containers designed to provide a means of recompression to treat decompression sickness and arterial gas embolism. They are also employed for hyperbaric oxygen treatment of non-diving related injuries and patients affected by gasses such as CO. In addition, they are commonly used to conduct diving operations where surface decompression procedures are used or may be used, Based on what is said above, chambers are mandatory on the worksite or close to it with most diving organizations and published national and international regulations. As an example, IMCA D 014 says *"No surface supplied diving operation within the scope of this code is to be carried out unless a two compartment chamber is at the work site to provide suitable therapeutic recompression treatment",* NORSOK Standards U100 say *"During surface oriented diving operations a double-lock decompression chamber shall always be available at the work-site"*, and ADCI requires *"One double-lock decompression chamber and adequate air source to recompress the chamber to 165 fsw"* for all surface-supplied diving operations.
In addition the International Maritime Organization (IMO) code of safety for diving systems says: *"A diving system should, as a minimum, include either one surface compression chamber with two separate compartments, or two inter-connected separate chambers so designed as to permit ingress or egress of personnel while one compartment or chamber remains pressurized. All doors should be designed so that locking mechanisms, if provided, can be operated from both sides"*. Thus, inflatable chambers and hyperbaric stretchers that are mono compartment units are not described in this chapter and should not be considered "decompression chambers" as they do not allow for such operations. Note that the conditions of use of hyperbaric stretchers are explained in the book "Diving accidents".

2.20.2 - Minimum configuration

National and international certification bodies have emitted minimum mandatory requirements regarding the conception and size of decompression chambers. These minimum requirements are implemented and sometimes increased by the diving organizations and the clients.

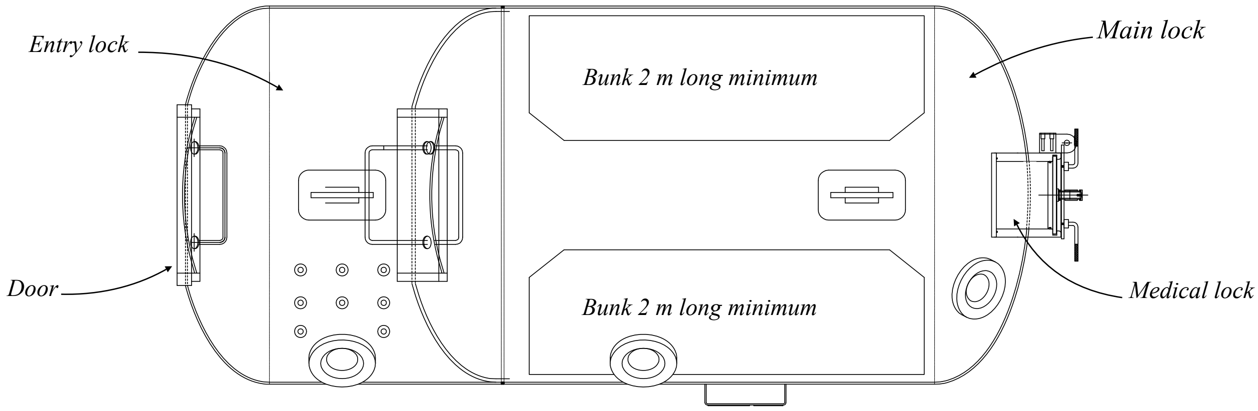
2.20.2.1 - Shell design and minimum size

Decompression chambers designed for surface supplied diving usually consist of a large steel pipe provided with oblate spheroid ends, in which the two compartments are grouped. Most competent bodies require that the main lock has sufficient internal dimensions to accommodate two persons lying in a horizontal position but do not provide any dimensions. However, some organizations such as those indicated below require a minimum diameter and length:

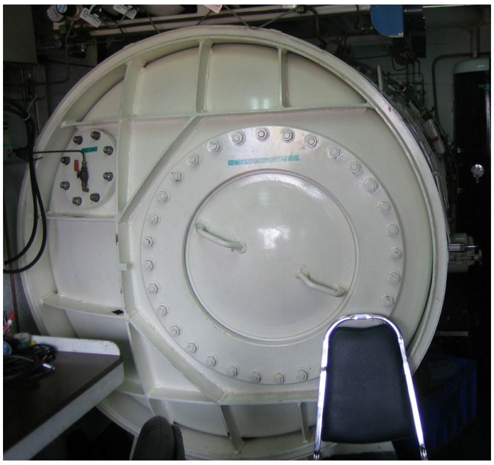
- IMCA D 023 says: *"Any chamber manufactured after 1 January 2015 should have a minimum internal diameter of 60 inches if using imperial measurements or 1500 mm if using metric measurements. Chambers manufactured before that date do not need to meet this size requirement"*.
- NORSOK standards U100 says: *"The main chamber shall be minimum 1,6 m inner diameter and 2,0 m length, with possibility for the occupants to lie down. It shall be equipped and designed so that a doctor/assistant can efficiently carry out any first-aid required. When surface oriented diving with decompression stops are planned, the chamber shall have an inside diameter of minimum 1,8 m. The diameter may be less if ergonomic principles that improve the entry and egress and possibility for treatment etc. are implemented"*.

Based on the requirements above, many manufacturers design chambers with at least a 1.8 m internal diameter and a length sufficient to accommodate two metres long bunks with the internal door fully opened.
As indicated by ADCI in point 2.20.1 above, the chamber must be able to allow for a compression depth of 165 fsw (50 m), which is the maximum depth of the US Navy medical tables and other recompression procedures. For this reason, manufacturers design chambers with a working pressure that allows to go to deeper depths than 165 fsw/50 msw, and units designed for depths over 60 msw are common. Note that the chamber must satisfy the overpressure test or engineering investigations, such as Finite element analysis (FEA) supplemented by a Non-Destructive Examination (NDE), depending on the certification body involved in the construction of the chamber. Note that many classification

societies and certification bodies apply the two methods with an overpressure test varying between 1.5 (bureau Veritas) and 1.4 (Lloyd's Register) times the agreed maximum working pressure.
The locks consist of the entry lock and the main lock where the treatment or the surface decompression is performed. The main lock is in the dimensions previously mentioned, and the entry lock is smaller as its function is only to transfer the supporting personnel to and from the chamber. It should be long enough to accommodate the person transferred and allow for the opening of the doors



Note that downgraded saturation chambers, so units that are no longer accepted for the storage of divers at the pressures attained during saturation dives but still capable of withstanding the depths mentioned previously, can be used as Deck Decompression Chambers. Such chambers are usually composed of two separate locks linked by a trunk and are larger than normal DDCs as they are initially designed for long periods under pressure. Of course, a certification body must approve their use for this function.
Also, even though they are not frequent today, some chambers are made of aluminium *(see the photo below)*. In addition, rectangular hyperbaric chambers exist that are installed in medical facilities, such as the unit in the picture underneath designed by CCC Group, a company based in San Antonio, Texas, USA (https://www.cccgroupinc.com/). This chamber is limited to three ATA, and is not designed for diving support.

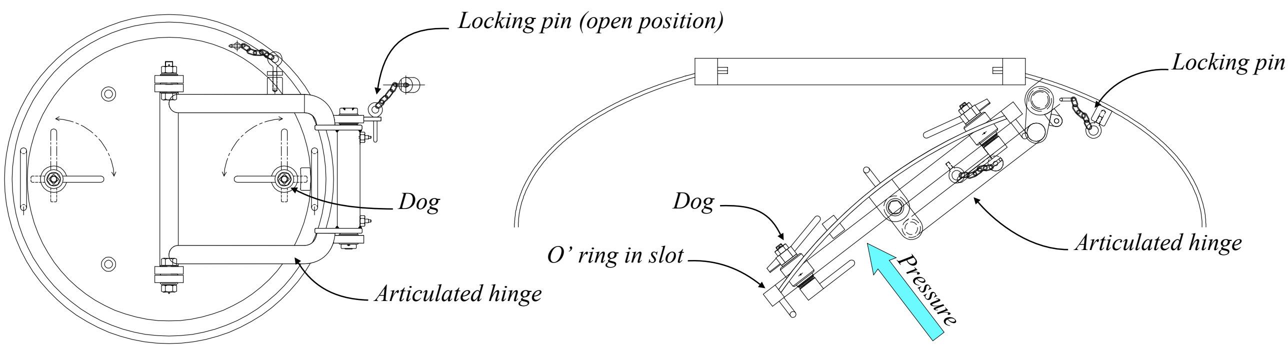


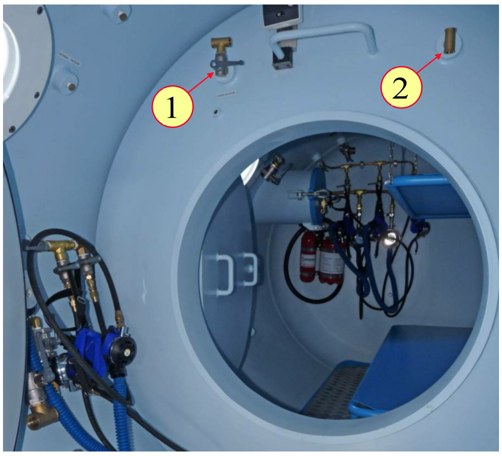
Chamber made of aluminium

Rectangular chamber designed by CCC Group (San Antonio, USA)

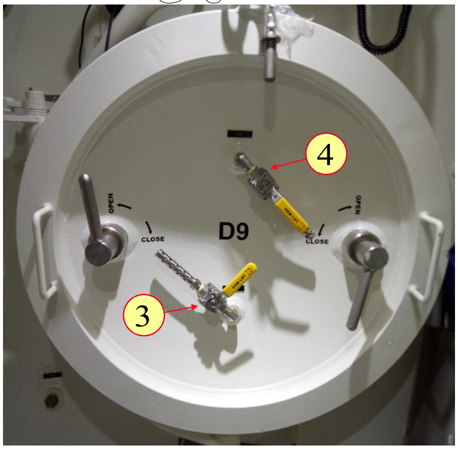
2.20.2.2 - Access doors:

The access doors are typically circular, mounted on an articulated hinge, kept closed by the chamber's internal pressure, and sealed by an O' ring secured in a slot. Note that they can be rectangular in hospitals and tunneling to allow easier access *(see the rectangular chamber above)*.
They should be designed so that their locking mechanisms can be operated from both sides. For this reason, the dogs that are used to secure them in the closed position can be operated from both sides. Also, two equalization devices must be provided (not visible on the drawing below) because these doors are kept closed by the pressure inside the chamber: One device must be open in the main lock and closed in the entry lock, and the other must be open in the entry lock and open in the entry lock. These devices can be mounted on the door or on the bulkhead that separates the two locks.
A system should be provided to secure the door in the open position. That can be a locking pin, as in the drawing below.



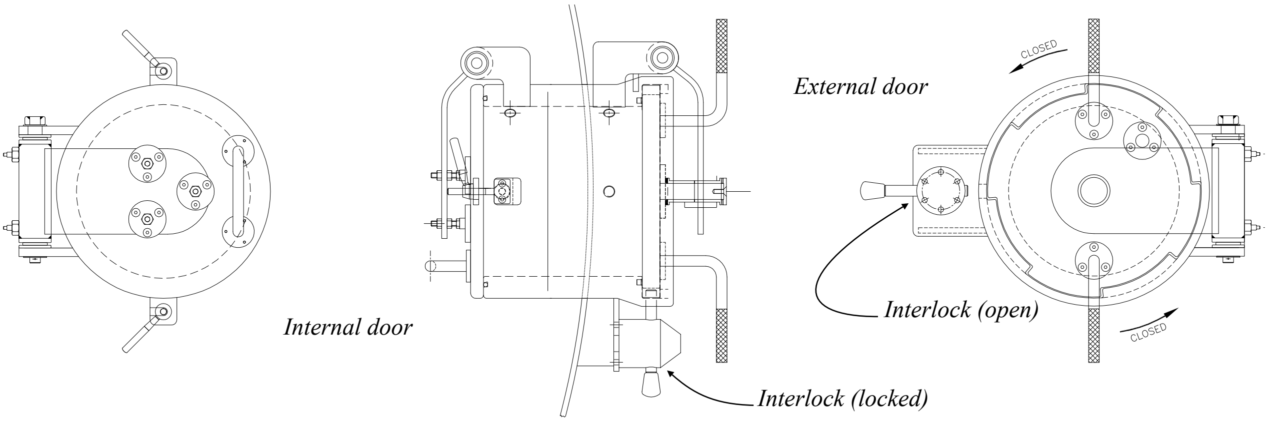


Equalization devices on the bulkhead (#1 & #2) and on the door (#3 & #4).
The devices on the bulkhead are closed by only one valve (chamber Comanex), and the devices mounted on the door are closed by two valves. In this case, they must be opened and closed as indicated previously, so we can see that one valve is closed (#3) and the other is open (#4).



2.20.2.3 - Medical lock

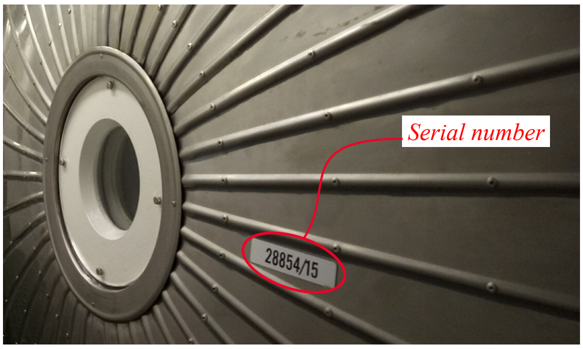
A medical lock is fitted on the side or at the extremity of the main lock to transfer medicines, small equipment, water, and food if necessary. It consists of a cylinder of an approximate diameter of 30 to 40 cm and approximately 40 cm long. Opposite to the doors described above, its external door usually 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, IMO, certification bodies, and diving organizations say that a safety interlock system must be fitted to the clamping mechanism securing the outer door. This interlock makes it impossible to open the mechanism/door if there is still pressure inside the lock, and it is impossible to obtain a gas-tight seal on the lock if the door/mechanism is not correctly closed. It usually consists of a pin pushed by the internal pressure to lock the opening mechanism and pushed back by a spring when the pressure inside the lock is back to zero.

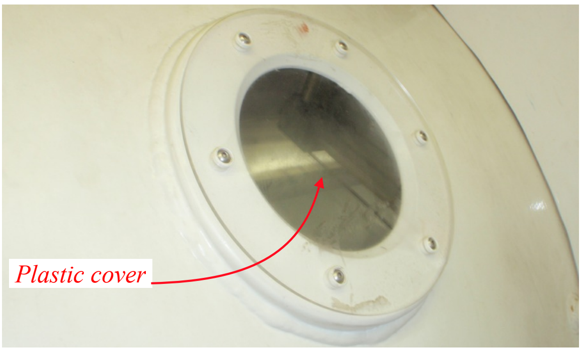


We can say that nearly all medical locks are designed as described above. However, there may be exceptions, such as the medical locks of the chambers designed by Advanced Marine, a company based in Singapore, that, opposite to the “classical” solution described above, are provided with rectangular medical locks. The first advantage of this design is that it offers an internal volume that is more optimized than those of cylindrical ones, avoiding using a bottom plate to transfer water bottles and food (remember that in the real world, these containers must be open during the transfer under pressure). Another advantage of this medical lock is that its external door is kept closed by the internal pressure, like the other doors of the chamber; thus, it is not working against the pressure as described above. As a result, this Advanced Marine door, which closing and opening mechanisms look like those of some garage doors, is simpler to operate, cannot be opened by accident, and is easier to seal because it is closed by the internal pressure.

2.20.2.4 - Viewports

Viewports are mandatory to allow observing the divers in the chamber during the diving operation. For this reason, they should be accessible to the chamber operator.
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 an alternating current of 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 023 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"*. Cameras may also be mounted on viewports.
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 See the photos below. It can be engraved or be prominently marked adjacent to it on the outside of the chamber. Also, organizations such as IMCA also say 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 *(see below)*.

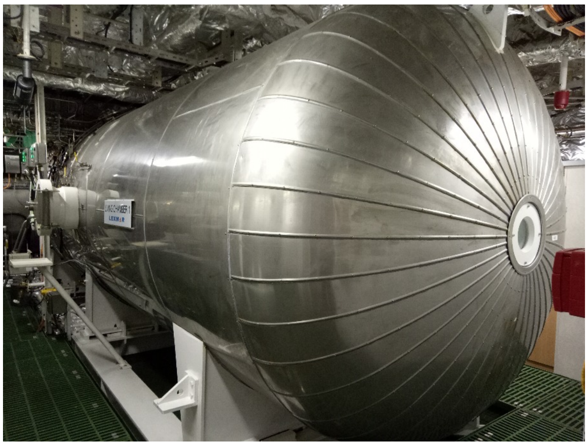




ASME recommends that the windows for human occupancy pressure vessels are fabricated from cast polymethyl methacrylate. In addition to its resistance to pressure and shocks, the advantage of this material is that it is more transparent than glass. As an example, it is still perfectly transparent with 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 that is part of the methacrylate family, and the main inconvenience of these materials is that they degrade with time. As a precaution, the document ASME PVHO-2 says that no window may remain in service for more than 10 years or 5,000 cycles beyond its design life unless they are tested in accordance with some specific ASME requirements. Based on the above, diving organizations such as IMCA recommend renewing them every 10 years.

2.20.2.5 - Protection from extreme weather conditions and falling objects

Certification bodies and diving organizations such as IMCA require that the chamber and the persons operating it are protected from the effect of extreme weather conditions and falling objects.
Isolation materials can be installed on the chamber shell as usual with units designed for saturation diving. These isolation materials are usually protected by a cladding made of stainless steel sheets, such as in the photo below, or composite materials. Heating and cooling systems are provided in the chamber. However, most surface-supplied diving chambers are not isolated and are merely installed in an isolated room or 20 feet container (see the picture below), where an air conditioning system provides a continuous temperature. Installing the chamber in a dedicated room allows to protect it and the operators from falling objects. If the chamber is isolated and installed on deck, protections must be in place above its sensitive parts such as viewports and valves. In addition the control panel and cooling/heating of the chamber must be installed in a specific isolated room. Note that by today the quasi totality of chambers are installed in rooms, and that it often happens that the chamber is installed in the same room as the dive control.

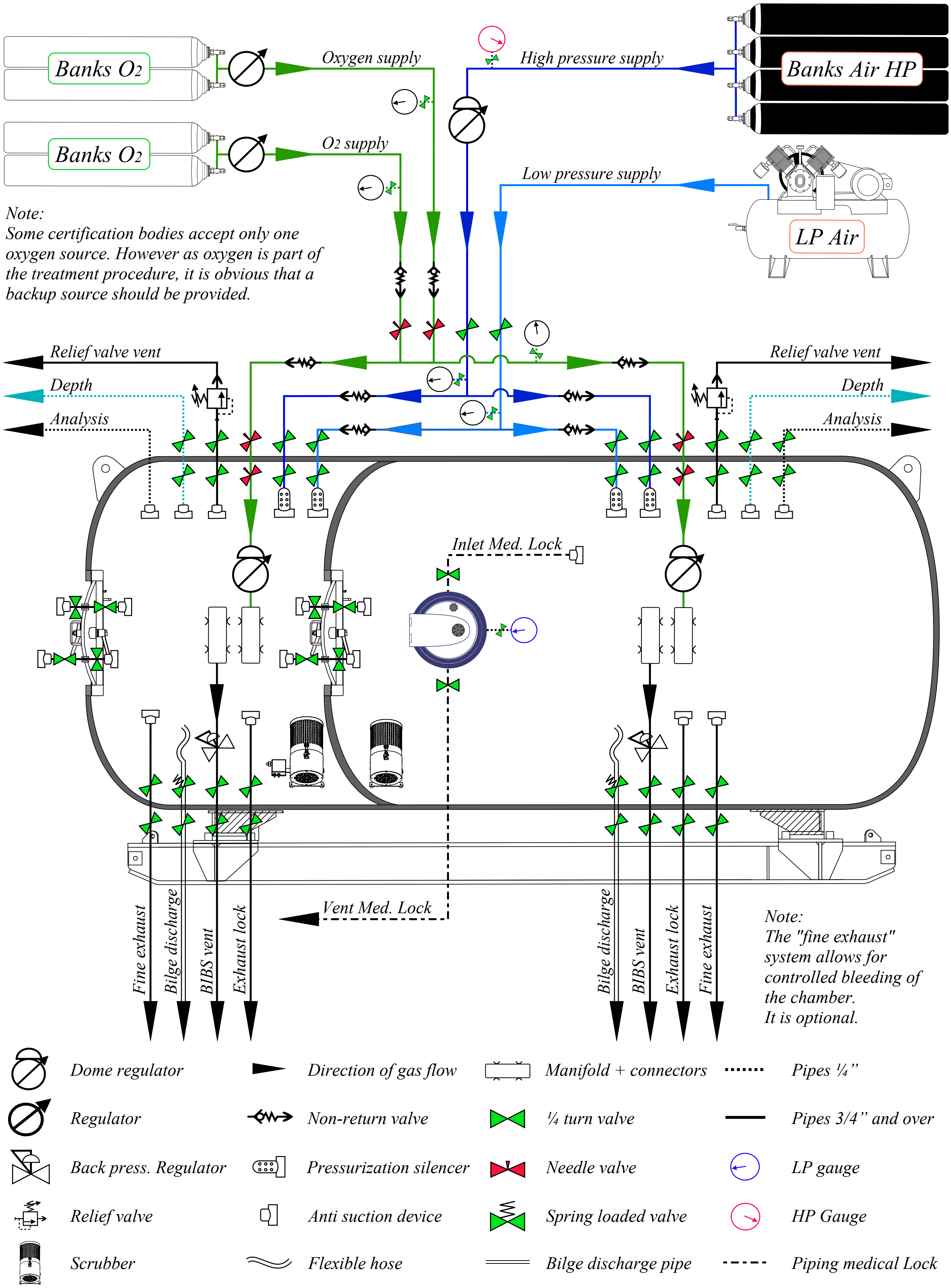


Isolated saturation diving chamber

Surface-supplied diving chamber in an isolated container

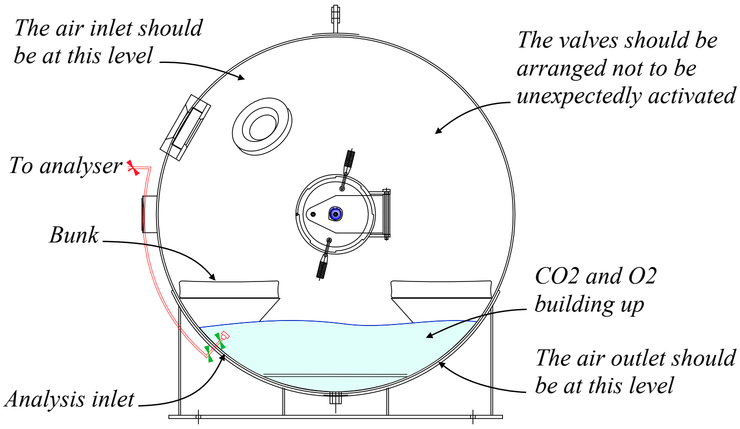
2.20.2.6 - Gas supplies and exhausts

The gas supplies and exhaust of the chambers are organized like diving monitoring panels. Thus, primary and backup supplies are to be organized for the pressurization and treatment gasses, and the piping must be designed according to the recommendations previously discussed in Points 2.11 "Gas storage", & 2.18 "Dive control panels".
Penetrators are used to passing the pipes and electrical cables through the hull. The function of each of them must be indicated at its direct proximity. Also, the gas or liquid penetrators must be fitted with a valve or other similar device close to the hull to stop a sudden pressure loss. Quarter turn valves are used for this purpose because they can be quickly closed. As for all pressure vessels, an overpressure valve must be fitted to each lock. The supplies and relief valves are usually organized as follows:



Some precautions are to be implemented for organising the piping system inside the chamber:

- The valves inside the chamber must be arranged such that they cannot be unexpectedly opened or closed. For this reason, it is recommended to organize them at height and in the extremities of the locks, so far from areas where the victim of the assistant can activate them while sleeping or by an uncontrolled movement. The valves also need to be immediately accessible from the inside and outside the chamber.
- The analysis inlet should be near the floor or at least below the level of the bunks because CO2 and oxygen produced by breathing and leaks are heavier than air and do not mix immediately with the chamber's atmosphere. As a result, they accumulate first in the lower parts of the lock. Thus having the analysis inlet at this level allows detection of these gasses sufficiently early. For the same reasons the exhaust should be at the same level. Also the pressurization outlet should be within the upper level of the chamber (*See more in point 2.20.1.9)*
- Silencers must be installed on the ends of the primary and secondary inflation pipes, and anti suction devices should be installed at the inlet of every exhaust pipe, even the smallest. They consist of termination shaped in T or with multiple organized holes, such as in the photo below.




Air inlet valve with silencer


Air outlet valve with anti-suction device

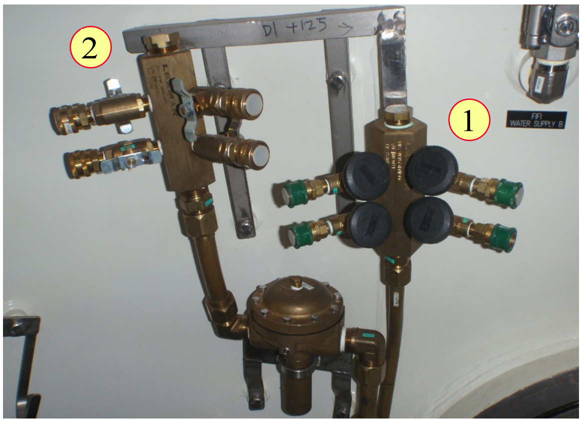
- The valves inside the chamber should be kept open except the units listed below:
  - The oxygen inlet to the Built in Breathing System (BIBS) as a precaution to avoid an oxygen leak as long as the system is not used.
  - One of the equalization valves between the two locks (with the other end open)
  - When installed, the spring loaded valve of the bilge drain closes automatically.
- It is common to secure the opened valves inside the chamber with a small cable tie. This cable tie must be weak enough to break if the valve is operated. The external valves of the penetrators should also be kept open except if they are used to control the chamber. Thus, they should be kept open if the chamber is controlled from a panel mounted on it or installed in a separate room. All valves used to manage the chamber should be kept closed until the operator needs to operate them.
- IMO "code of safety for diving systems" says that the oxygen supply of the chamber must be done through dedicated piping. As indicated previously, this piping should conform with the recommendations for diving and gas distribution panels. This document IMO also says that the oxygen should be stored in a ventilated area, which is not the case when the chamber is in an isolated room or 20 feet container. For this reason, oxygen cylinders should not be stored in the room. In addition to the problem of accumulation and flammability, oxygen bottles stored in the chamber room would oblige to refill them, which is to be typically done in a ventilated and secured area. The only systems used for diving operations where it is admitted that oxygen can be in a closed space are the Self Propelled Hyperbaric Life-boats (SPHL) used to evacuate saturation from their system in an emergency. The reason is that there is no other possibility to store the necessary oxygen in them, and this system is intended to be used in an emergency only.

  The chamber is to be pressurized with breathing air from High Pressure (HP) containers or/and Low-Pressure compressors. There is no particular published rule regarding the preference for a specific means of supply. However, the pressurization systems must allow reaching the intended decompression depth in the chamber at the descent rate required by procedures such as the surface decompression tables that allow for a surface interval limited to only a few minutes. For this reason, the supplies from HP containers are preferably regulated by regulators allowing for high flow, and large gas receivers are fitted to LP compressors. Also, the air supply systems should be selected according to the risk of contamination, and HP compressed air is preferable in areas where simultaneous works that may emit polluted gasses are performed.
  Note that most certification bodies and diving organizations say that the primary and secondary supplies of the chamber must be from two separate sources that are also entirely independent of those of the divers in the water. Also, the control valves of both locks should be grouped in the same place.

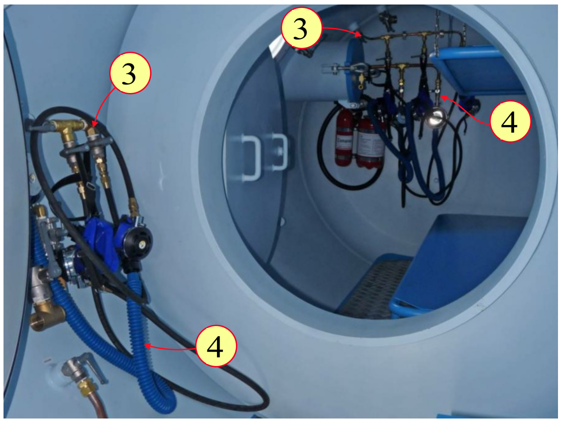
2.20.2.7 - Built-In Breathing System (BIBS)

Built-in breathing system (BIBS) masks must be provided for each diver in both locks to allow breathing oxygen.
Also, there must be one spare BIBS connection and mask available in case of a problem with one device.
The masks of some systems are connected using quick connectors on separate manifolds: The gas inlet manifold (see #1 in the photo on the next page) groups the gas inlet connectors and the gas outlet manifold (see #2 in the same picture)

groups the gas outlet connectors which are of a different diameter than the inlet connectors, so it is not possible toconfuse them. Other systems do not use quick connectors (See #3 & #4 below).

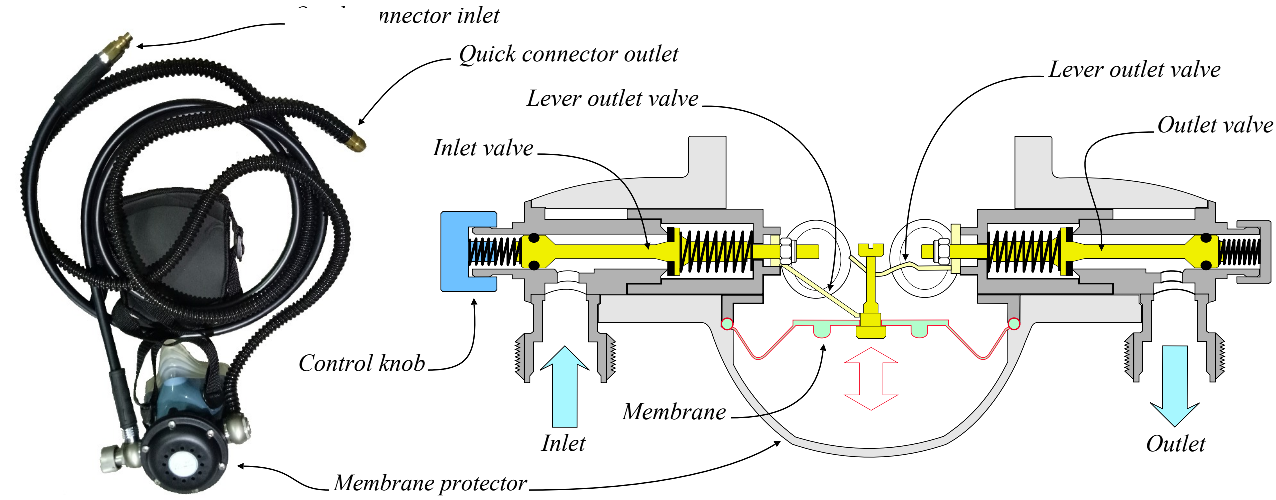


Quick connectors inlet (#1) and outlet (#2)

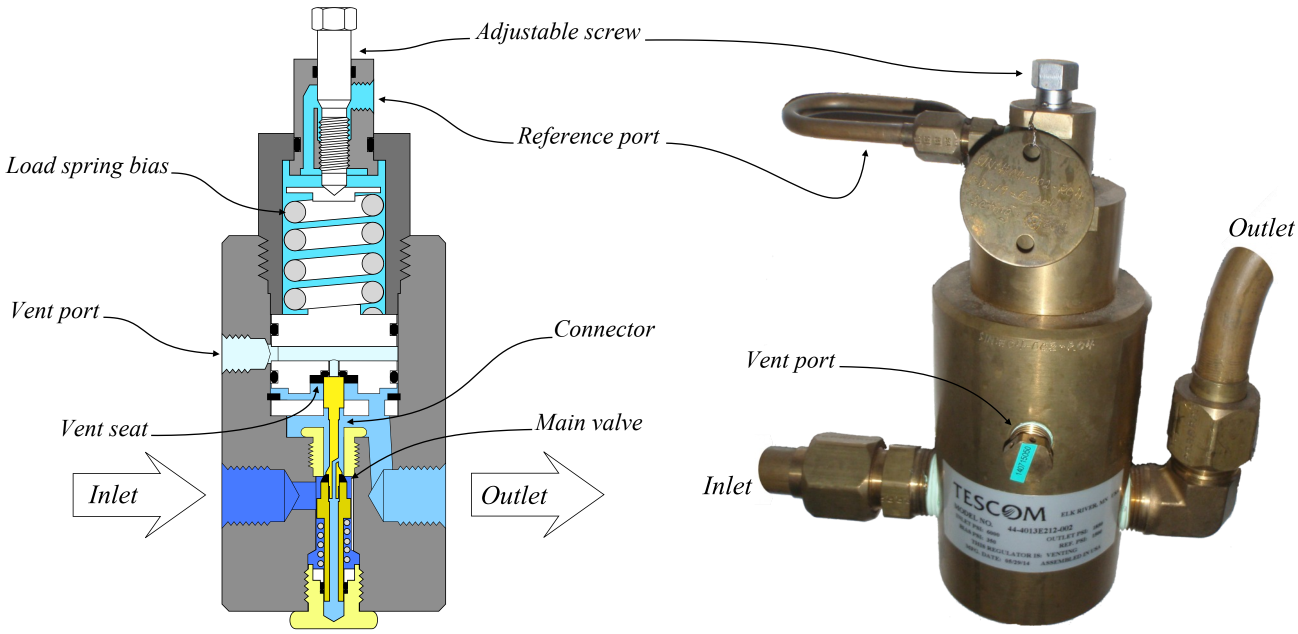


Masks with screwed connectors: Inlet (#3) & outlets (#4)

The masks must be always ready for use. Depending on the model, the supply pressure for the mask generally ranges from 5 bar to 12 bar over the ambient chamber 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 inhales, the movement of the membrane opens the inlet valve and closes the outlet valve. When the diver exhales, the movement of the diaphragm closes the inlet valve and opens the outlet valve.

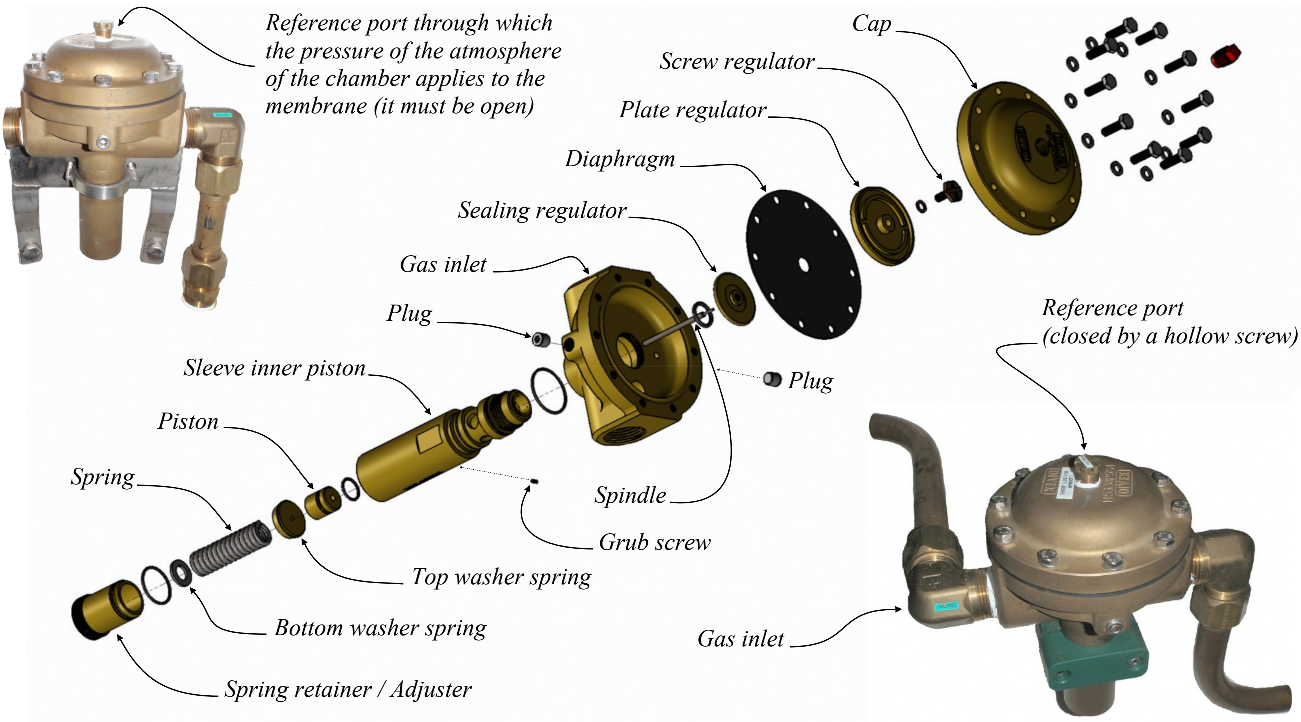


Depending on the model, the supply pressure for the mask generally ranges from 5 bar to 12 bar over the ambient chamber pressure. he gas inlet is usually provided by a piloted piston regulator which bias pressure is adjustable. As a result this regulator adjusts automatically its delivery pressure according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

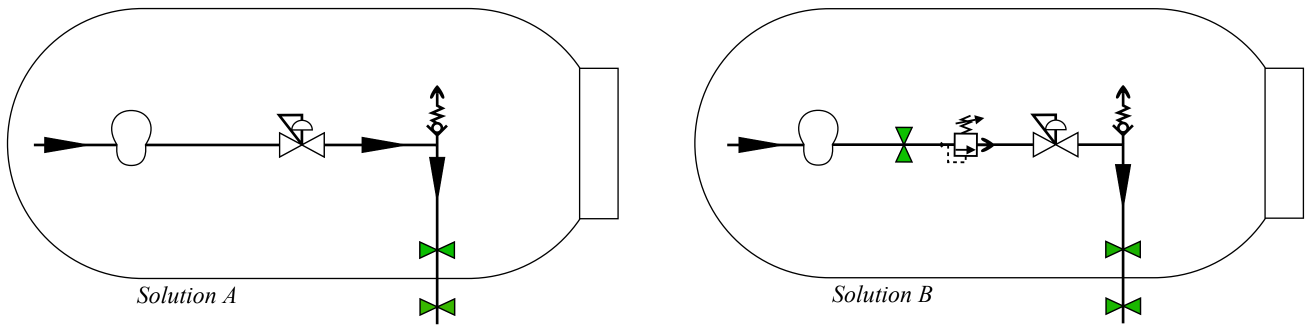


The breathed gas is recovered from the mask to the surface by the suction resulting from the differential pressure between the surface and the depth of the chamber. However, a too lofty aspiration may injure or kill the divers. For this reason, a

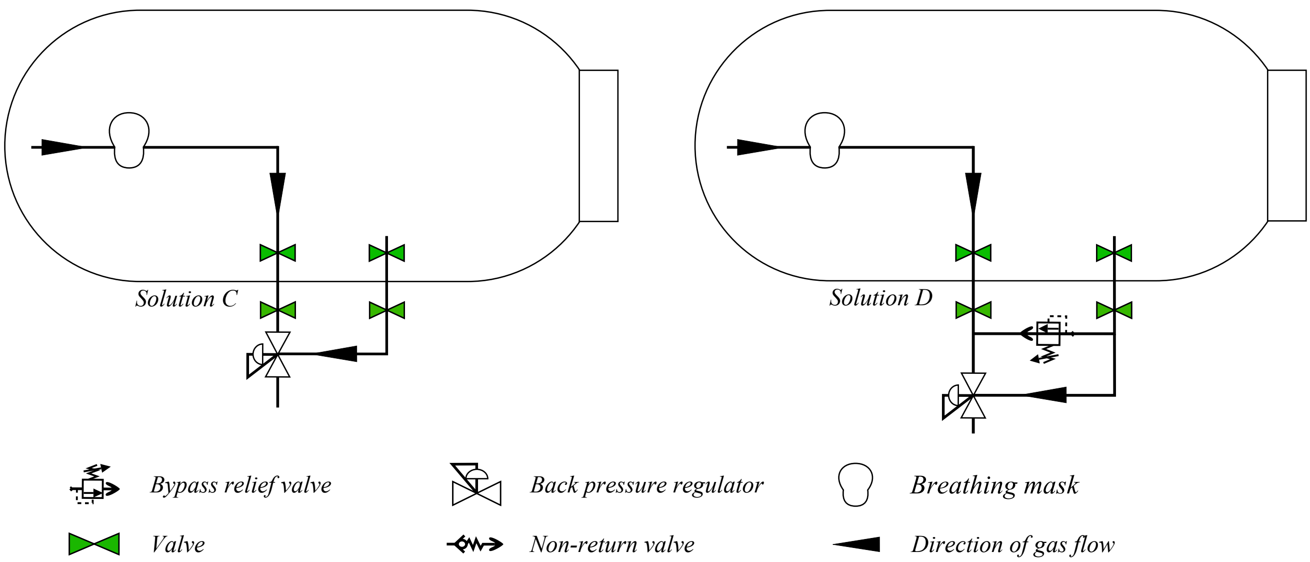
back pressure regulator is used to reduce the differential pressure to only 1 bar and limit the maximum suction to which the diver's lungs may be subjected in the event of a breathing mask mechanical failure.
The outlet from the mask is connected to the inlet of the back-pressure regulator, and its outlet is related to atmospheric pressure. The back-pressure regulator taken as an example below is designed by DIVEX.



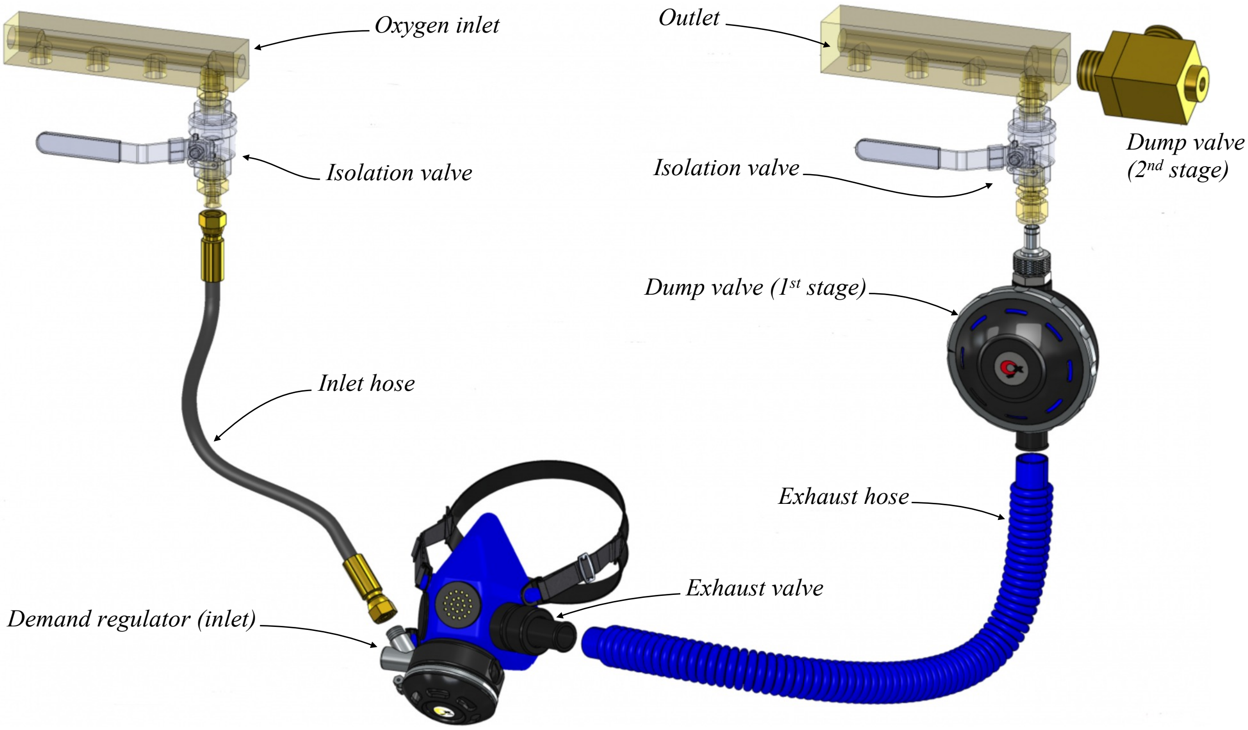
The manufacturer says that the back-pressure regulator (BPR) should be installed such that ambient chamber pressure is applied to the top of the diaphragm (through the reference port). The regulator can be installed in the chamber or outside the chamber. In the case of an installation in the chamber,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



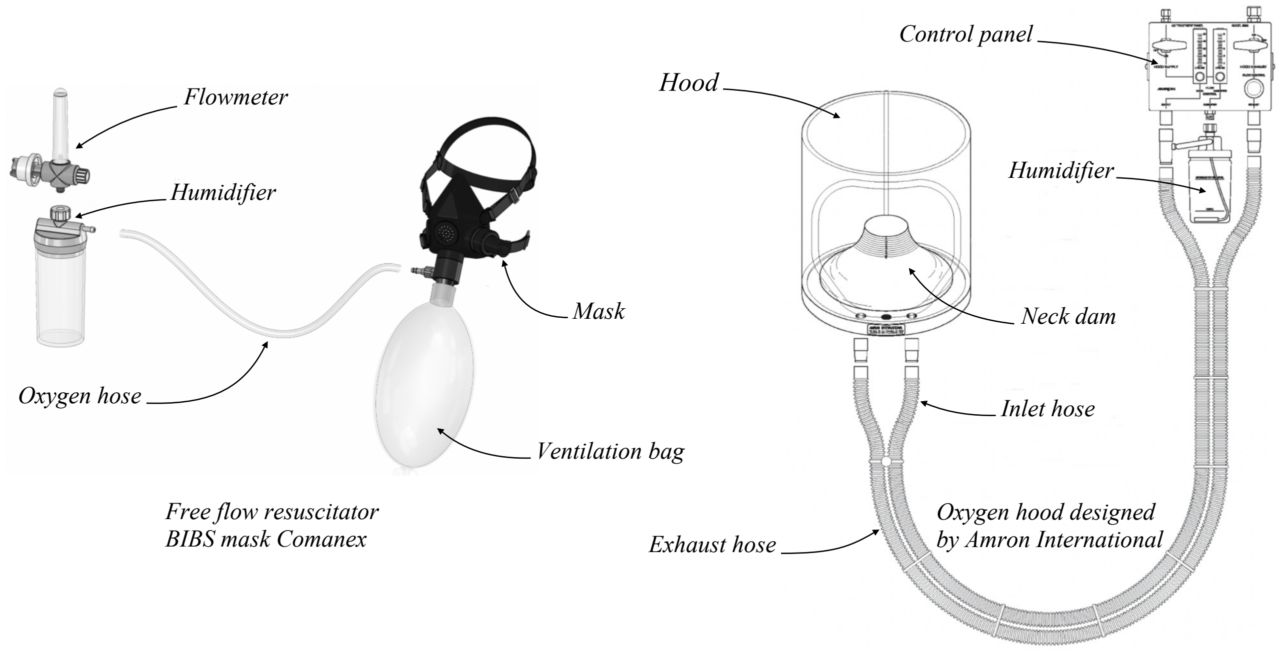
In the case that the back pressure regulator is installed outside the chamber, a tracking pressure (pilot) pipe that is connected to the inside of the chamber is fitted to reference port of the regulator *(See solutions C & D below)*. Note that such tracking pressure connection hose is also necessary for the gas supply regulator if it is installed outside the chamber.



Some manufacturers make surface-supplied Deck Decompression Chambers (DDC) with dump valves operating like back-pressure regulators. However, they cannot be installed outside the chamber. It is the case of the system below designed by Comanex where the 1st dump valve can withstand 5 bar differential pressure. The 2nd stage is added in case of more elevated differential pressure.



In addition to the standard BIBS masks described above, at least a freeflow BIBS resuscitator mask and a hyperbaric oxygen treatment hood should be provided with the diver medic kit. These devices, equipped with flow meters and humidifiers, usually require specific adaptations that should be in place in the chamber.

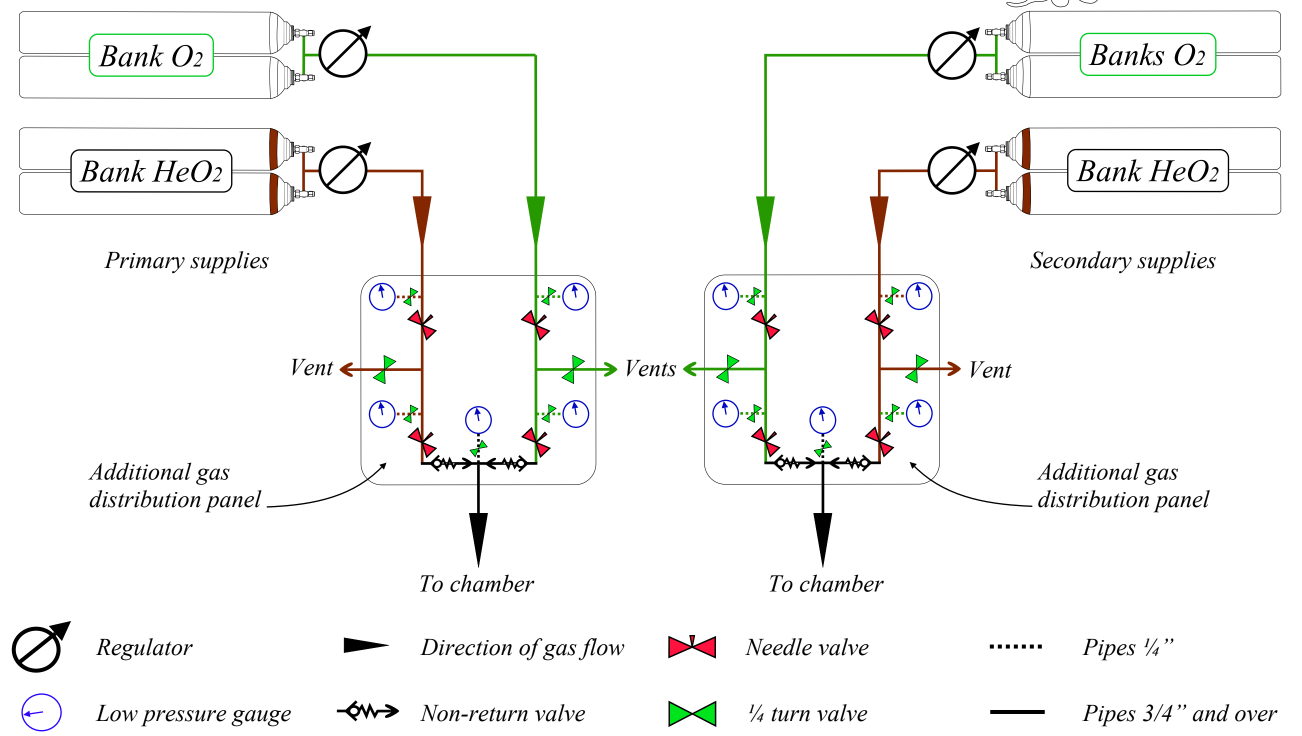


Free flow resuscitator
BIBS mask Comanex

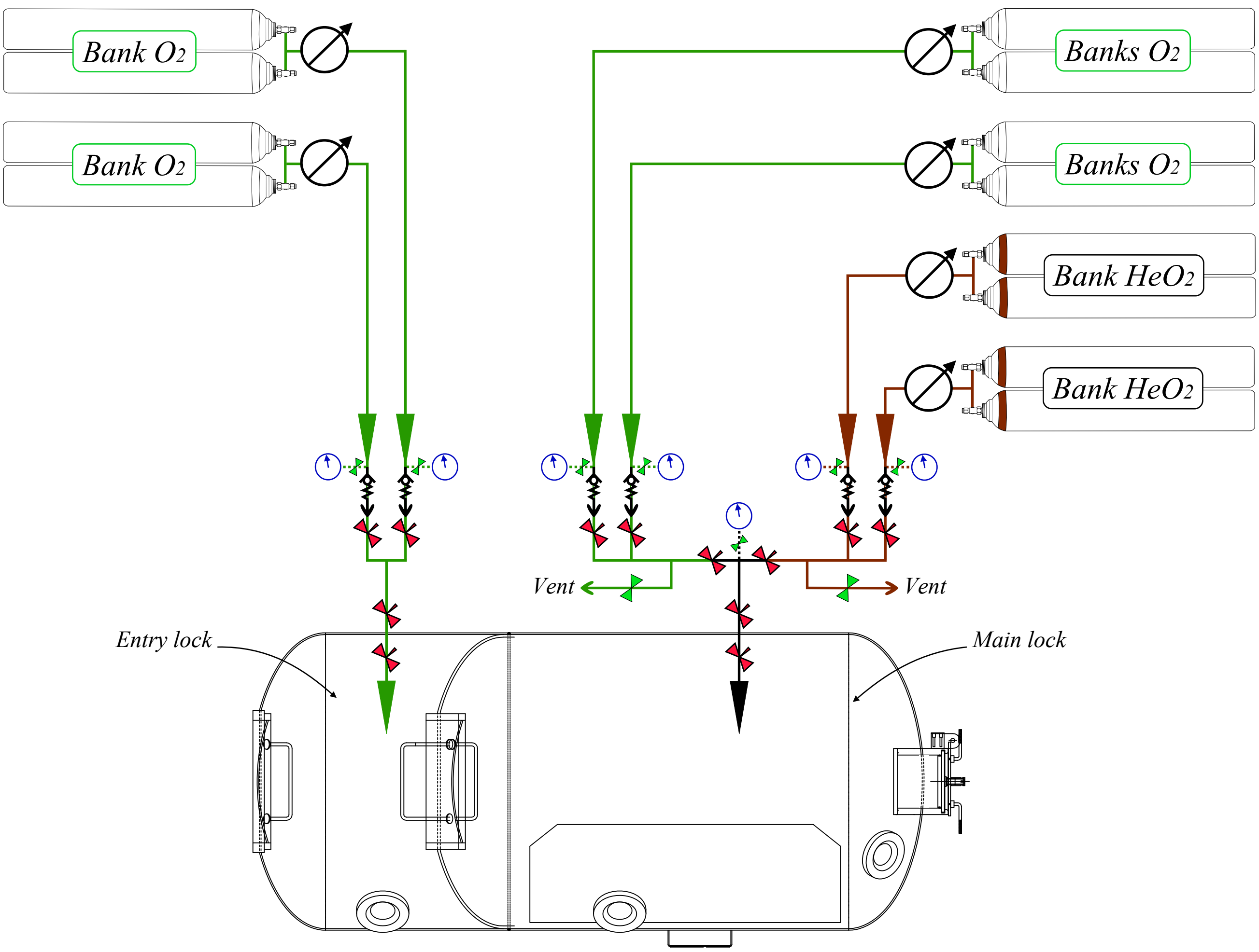
Oxygen hood designed
by Amron International

2.20.2.8 - Adaptation of the chamber for therapeutic heliox mixes use

Heliox is commonly used for the treatment of decompression accidents. For example, the table Comex Cx 30 uses heliox 50/50 between 30 m and 18 m and oxygen from 18 m to the surface. The chamber atmosphere can be air or heliox 80/20. However, most chambers are not equipped to provide oxygen and heliox therapeutic mixes simultaneously.
To implement such procedures, many diving teams connect the heliox 50/50 quads between 30 and 18 m and reconnect the oxygen between 18 m and the end of the decompression. That is generally done by the chamber operator's assistant and has the inconvenience that the chamber operator has no direct control of this operation.
Another procedure is to install additional gas distribution panels to separate the gas sources and provide oxygen or heliox to the primary and secondary oxygen supply lines. Such panels are installed near the gas sources when installing them in the chamber's control room is tricky and would require a modification of the gas distribution system of the chamber, which must be approved by a certification body. Note that the principles of isolation of oxygen lines discussed previously are to be in place to ensure that oxygen is not sent to the victim by mistake below 18 m *(see the scheme on the next page)*.
Again, the chamber operator has no direct control of this operation when these panels are outside the room.



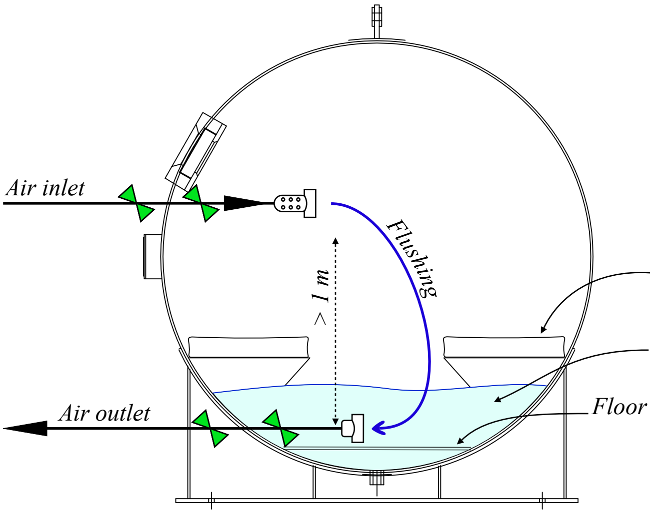
The procedures described above to adapt chambers to the use of HeO2 have the inconvenience that even though the oxygen and heliox sources are independent, the final distribution piping to the entry lock and the main lock is shared on most chambers. Thus, it is impossible to supply the entry lock with oxygen if 50/50 heliox is used. As a result, the solution to be able to employ oxygen in the entry lock when the victim breathes heliox is to provide the locks with entirely separate supply lines, as with the example below. Note that heliox supply is unnecessary in the entry lock. Of course, such organization of the supplies must be approved by a certification body.



2.20.2.9 - Elimination of carbon dioxide and oxygen in excess

Saturation diving chambers are equipped with a “hyperbaric environment regeneration system” that continuously removes the CO2 in excess in the chamber. However, installing such a system that requires complex machinery and is described on page 237 of our document "Description of a saturation diving system" is not considered suitable for surface supplied diving decompression chambers that are not designed to be used for long periods and must be easy to implement and maintain. Two systems are, however, commonly used to eliminate the carbon dioxide (CO_2) arising from the chamber occupant respiration and the oxygen in excess due to breathing masks leaks:

- Flushing is a procedure that consists of opening the air inlet and outlet simultaneously and ensuring that the depth of the lock does not vary by adjusting them. Good training is necessary to be able to do it perfectly. Some manufacturers provide automatic systems that need to be kept under close surveillance as variations of the depth may happen with some of them.
  Flushing will not be efficient if the air inlet and outlet are too close because the incoming air will be sucked first to the outlet, and there will not be air circulation in the chamber. For this reason, a minimum distance (> 1 m) is necessary between them. Also, as said in point 2.20.1.5 and commonly implemented for saturation chambers, the air inlet should be within the upper areas of the lock, and the exhaust should be at a level underneath the bunks to favor air circulation in the lock and remove first the CO2 and O2 that tend to accumulate near the floor.



- Scrubbers are also used to remove carbon dioxide. They are composed of a fan block energized by a direct current of 24 volts, to which three or four securing clips attach a perforated canister filled with soda lime. The fan block sucks and flows the chamber atmosphere through the canister. For the reasons already discussed, the scrubber should be installed within the lower parts of the lock for more efficiency. It can be positioned vertically or horizontally. Replacement cartridges in sealed bags should be immediately available at all times. Note that these devices, which are present in many chambers, are considered optional in the document IMCA D 023 and by other organizations.

Scrubber installed horizontally

Scrubber installed vertically

Three clips fan block

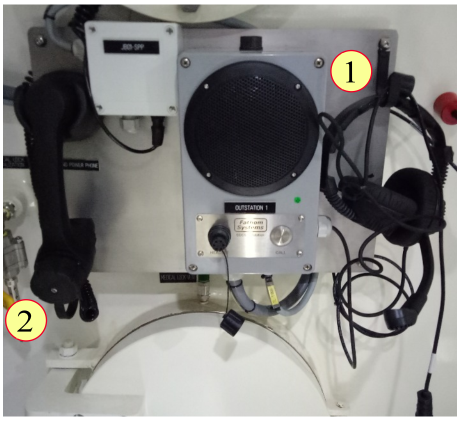
2.20.2.10 - Chamber electrical, CCTV, & communication systems

Chambers should be provided with suitable lighting to allow for the surveillance of the chamber occupants by the chamber operator. It must also allow the tender inside the chamber to operate the valves and read a document. ABS recommends at least 540 lux over bunks and in work areas. These lights and all electrical supplies are energized by a direct current of 24 volts and should be organized to be controlled by the chamber operator.

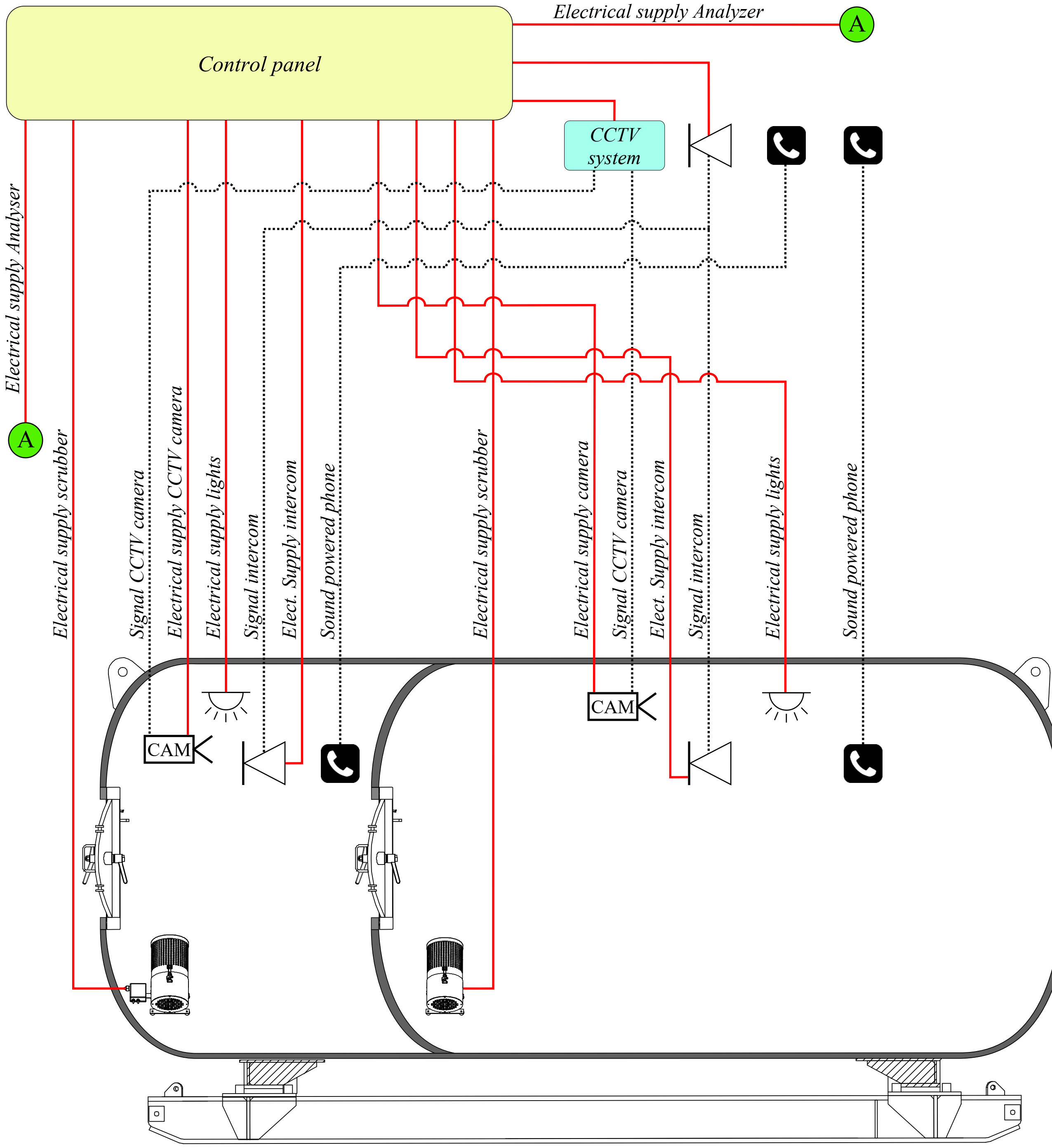
A Close Circuit Television System (CCTV) should be in place if the viewports cannot be used for watching the chamber occupants. This system is similar to the one provided to the dive control. A CCTV system may also be provided in complement of viewports. The cameras used can be underwater units that are also found in diving bells, on divers' helmets, or with Remotely Operated Vehicles (ROV). The advantage of using such cameras is that they are designed to work in harsh environments.
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.
Some chambers are also equipped with cameras mounted on the outer side of viewports.

High definition camera in housing designed by Fathom

Communications to and from the chamber operator should be provided to chamber occupants. They are composed of an intercom, and a sound powered-telephone.
The intercom system is composed of a diver communicator with two channels (one for each lock) connected to chamber loudspeakers *(see #1)*. Recent systems are equipped with a "call button" that can be used by the chamber occupants to attract the attention of the chamber operator when a conversation is required. They are also equipped with a headset that can be used by the diver medic for reporting . The system in the photo is made by Fathom.
The 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.



The electrical supplies and signals of the systems mentioned above can be summarized as follows:



Legends:

Analyser | *Intercom* | *Sound powered phone* | *Close circuit television*

Camera CCTV | *Light* | *Scrubber*

Electrical supply or signal transmission cables pass the hull through penetrators, which function to ensure the pressure vessel's seal even if the connecting wires become damaged. For this reason, certification bodies require that they are subjected to inspection by the manufacturer, who must issue a Works Test Certificate in respect of this inspection, and be arranged as follows:

- They should be designed to withstand damage from an accidental tensile load imposed on the electrical cable and prevent undue stress on the line or the penetrator connection.
- They should be organized such that the main and auxiliary power sources must not pass through the same penetrator or connection and must be spaced to prevent damaging currents.
- The supply lines passing through the penetrators must be protected by circuit breakers or fuses to prevent overload and short circuits. These circuit breakers must be located on the power source side of the hull and have the ability to operate sufficiently quickly to avoid damage to the penetrator.
- They should be labeled on both sides of the hull, so the technician can quickly identify the function of the cables they seal.
- Pressure and function tests are performed to ensure their efficiency.

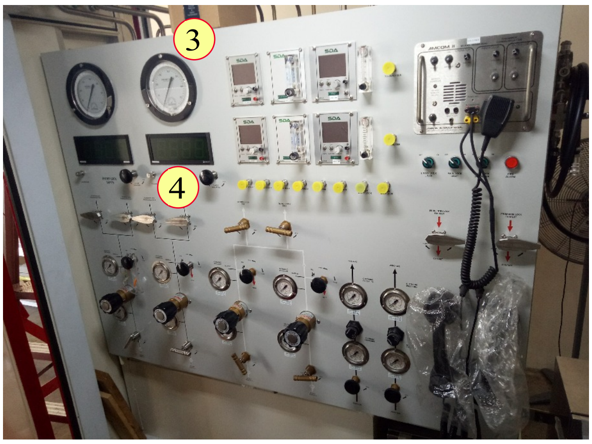
2.20.2.11 - Depth monitoring systems

Depth gauges should be provided for the chamber operator and the chamber occupants. They are of the same types as those installed on dive panels and are arranged as follows:

- A depth gauge must be available in each lock. It should be positioned within the upper part of the lock. Manufacturers usually install a bourdon tube unit of 120 to 150 mm diameter at one extremity. Like those installed on diving panels, the depth gauge should provide scale divisions of no more than 0.5 msw/2 fsw and operate in 25 to 75% of full-scale deflection.
- A depth gauge should also be installed for each lock on the chamber operator panel. Manufacturers also usually install similar bourdon tube units as in the locks (diameter between 120 and 150 mm) that must comply with the minimum scale divisions and operational percentage mentioned above, so they can be employed for managing the decompression. These depth gauges are often completed by a larger one of 200 mm and above used to control the final steps of the decompression. It is the case with the control panel on the left side below, designed by Smart dive (http://smartdives.com/). Note that this large depth gauge is often installed for the main lock only and is considered optional by certification bodies and organizations such as IMCA.

Other manufacturers provide electronic digital depth gauges in parallel with the classical 120 - 150 mm depth gauges, as they are precise enough to replace the analogical large depth gauge 200 mm mentioned above. They are of the same models as those used for diving panels, so they must allow easy reading in all conditions, display at least one decimal, and indicate the unit system used. It is the case with the control panel on the right side below, designed by Flash Tekk Engineering. Note that such an electronic device implies the use of a pressure sensor usually installed in the pressure hose from the lock to the analogical 150 mm depth gauges.

Control panel designed by Smart Dives with bourdon tubes depth gauges of 120 mm (#1) completed by a unit of 200 mm (#2)connected to the main lock.

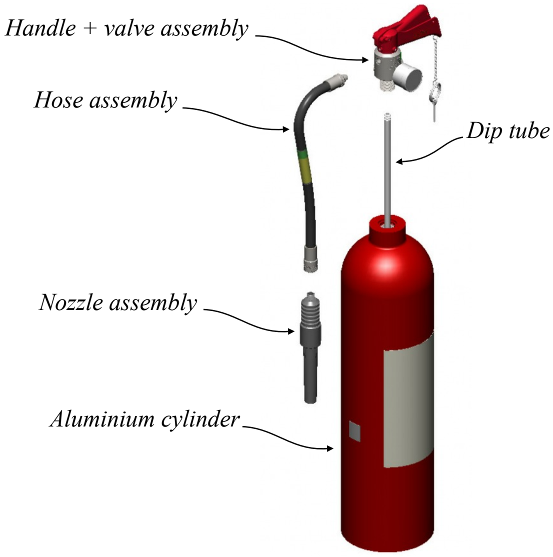


Control panel designed by Flash Tekk Engineering with bourdon tubes depth gauges of 150 mm (#3) completed by two digital gauges (#4)

2.20.2.12 - Chamber fire-fighting systems

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.
Several national regulations and classification societies impose similar rules to those recommended by NORSOK. Also, most last generation 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 deck decompression chambers 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.



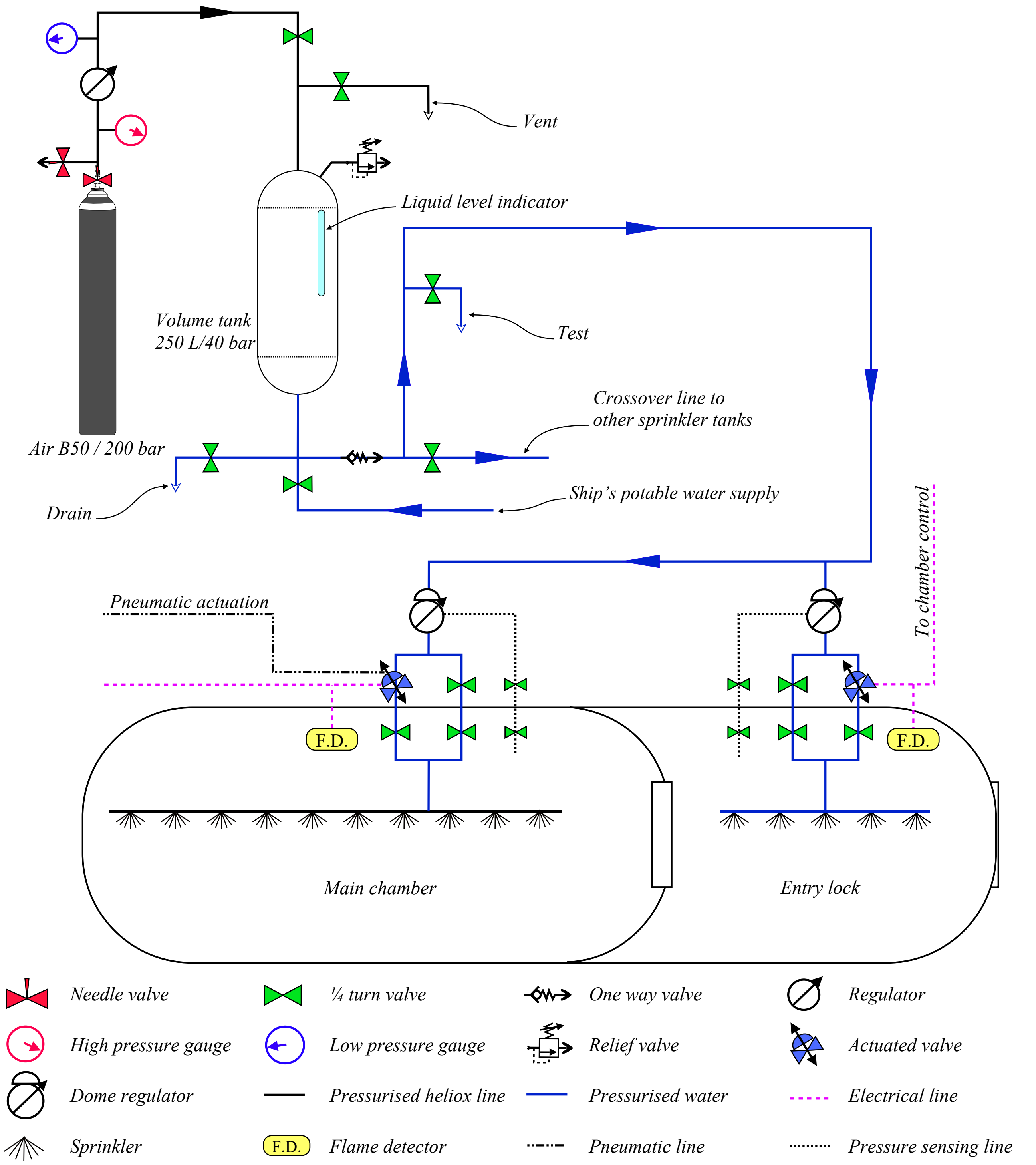
The extinguishing agent used in these extinguishers is an Aqueous Film Forming Foam (AFFF), which is suitable for fabrics, combustible solids, flammable liquids, and electrical fires up to 24 Volts. Note that its technical sheet indicates that this product is not considered harmful to aquatic organisms 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.

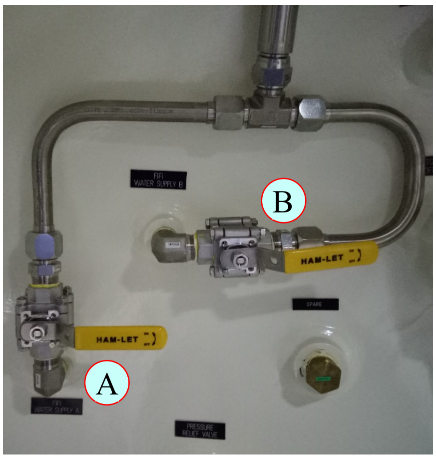
Three main systems can be used to detect a fire: Flame detectors, heat detectors and smoke detectors.

- 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.

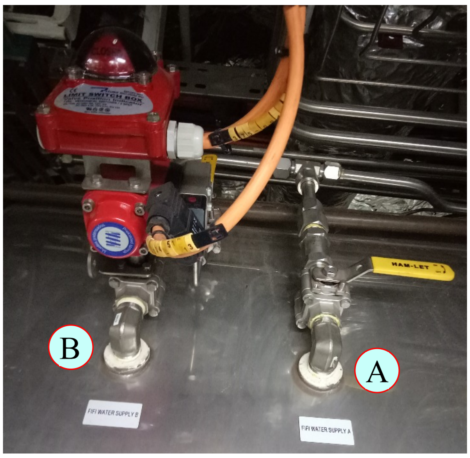
Fixed water deluge extinguishing system is highly recommended in chamber compartments that are designed for manned operations. Also, as indicated previously, these systems are mandatory in several countries.
The systems consist of water supplied to the chamber through a number of spray nozzles. In chambers 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 chamber control room and in the locks. 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 above.





Internal manual (A) & actuated (B) valves



External manual (A) & actuated (B) valves

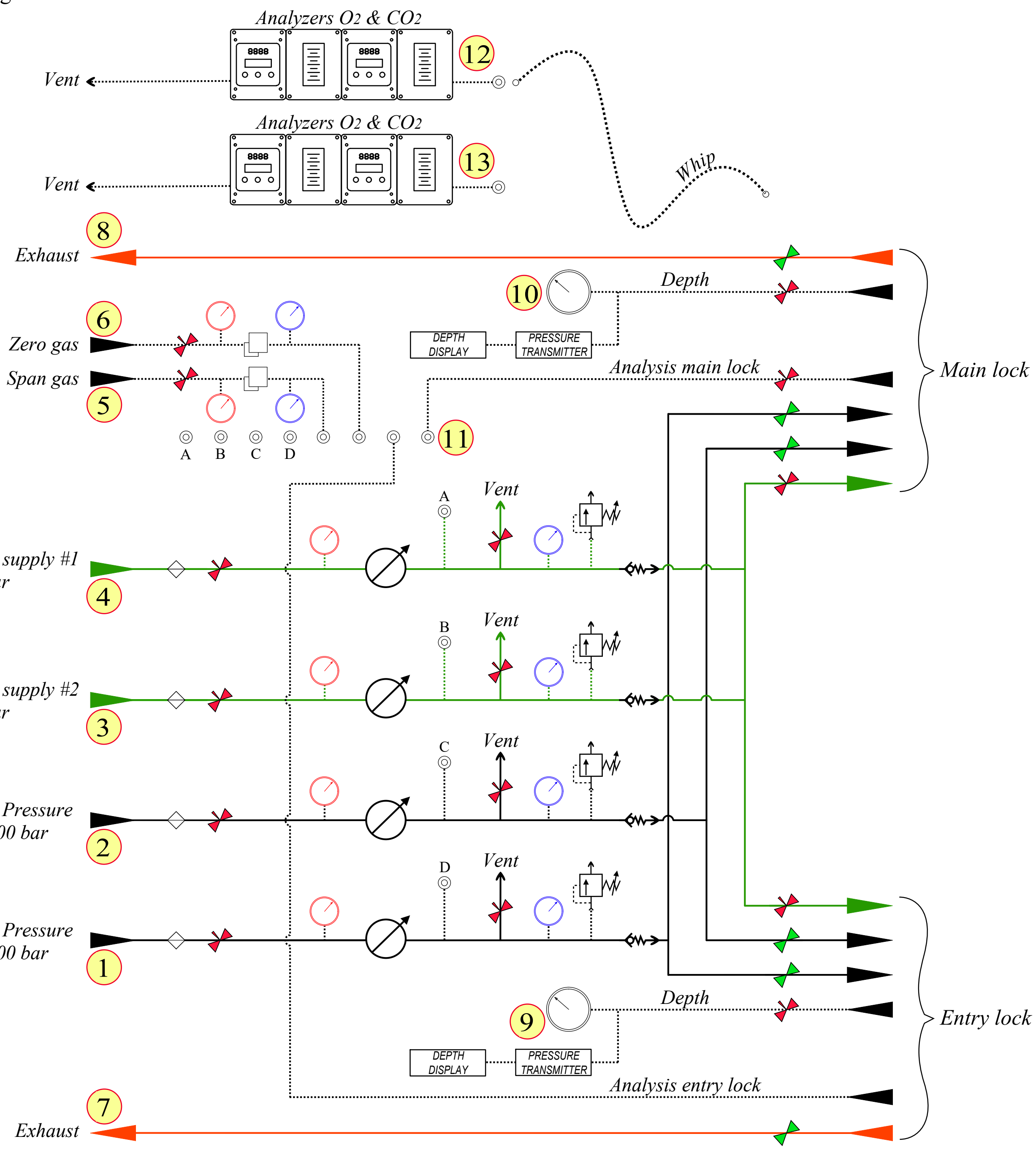
Volume tank & its pressurization sys.

2.20.2.13 - Other important elements to take into account.

In addition to extinguishing systems to combat a fire, the mattresses and positioning pads of the chamber must be designed not to ignite, withstand pressurization, and be comfortable enough for the patient (at least 60 cm width). In addition, manufacturers develop them to resist moisture and be tear-resistant. They should be installed on bunks. These bunks are usually retractable and must be designed to be perfectly secured when deployed and without potential pinch points that may injure people handling them.
The paint and accessories used for the chamber must be designed not to emit foul odours and solvent gasses that may contaminate the divers. The document US Navy NAVSEA-00C3-P1-001 *"Application procedure of formula 150 primer & formula 152 Topcoat white coating on portable or afloat recompression chamber systems"* (available on our website), provides the necessary information for a complete painting or the repair of the existing coating. Certification bodies perform off-gas testing after fabrication and completion of all outfitting, with all openings sealed. The gas samples are usually analyzed using Gas Chromatography (GC) or Mass Spectrometry (MS) methods.

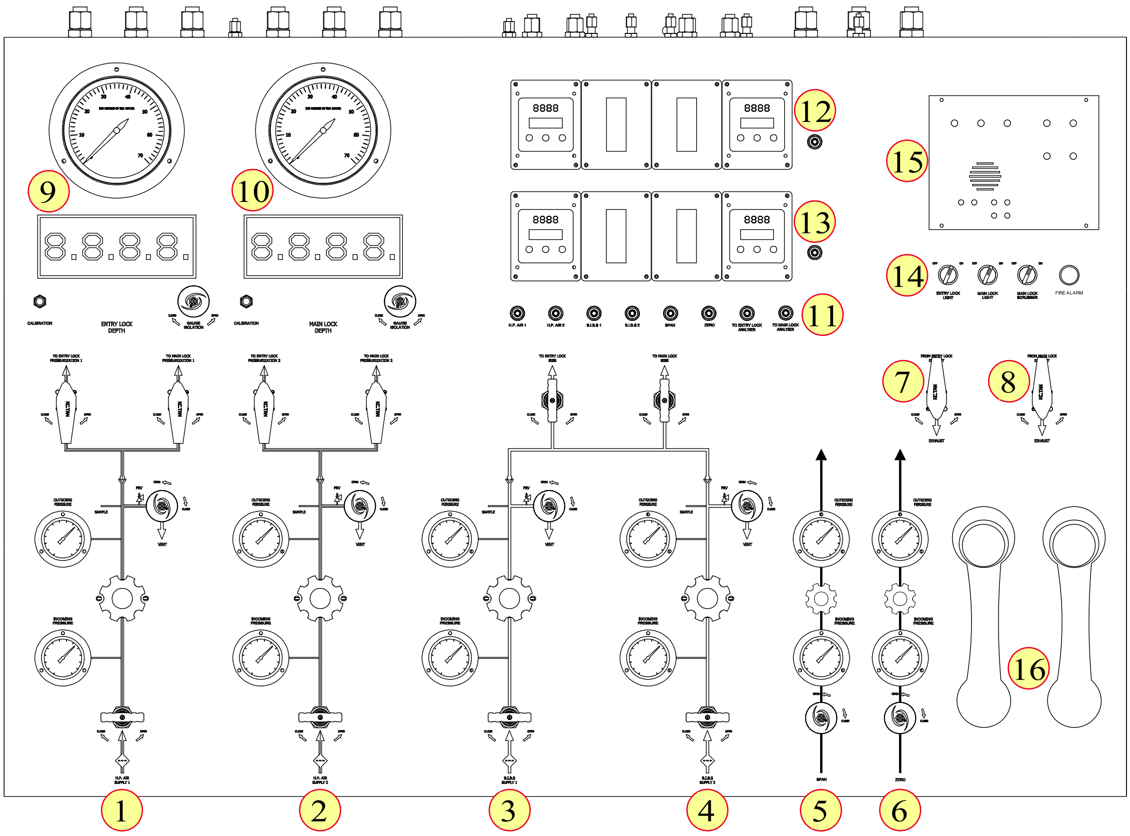
2.20.2.14 - Operator's control panel

The chamber operator must be able to control the entry lock and the main lock simultaneously. For this reason, certification bodies require that the elements for the control of the chamber are grouped. As a result, they can be arranged on the chamber's hull between the two locks or a separate panel installed near the dead-end extremity of the chamber or in another room. Note that these separate control panels are usually designed to allow the operator to sit.
The panel taken as a reference below is the unit designed by Flash Tekk Engineering already taken as an example in point 2.20.1.11 "Depth monitoring systems". Note that as a difference from the scheme used to explain the general supplies of a chamber in point 2.20.1.5, this panel is supplied by two HP lines at 200 bar and two oxygen lines at 40 bar. Its gas lines are organized as follows:



Needle valve	*¼ turn valve*	*One way valve*	*High flow regulator*
High pressure gauge	*Low pressure gauge*	*Relief valve*	*Quick connector*
Regulator	*Air supply lines ¾"*	*O2 supply lines 1/2"*	*Pipes ¼"*
Exhaust line	*Whip analysis*	*Direction of flow*	*Vent line*

The supply and exhaust lines described on the previous page are arranged on the panel with electrical and communication devices as follows. Note that the video system is not integrated with this panel. The reason is that the video system is not mandatory if the operator can monitor what happens in each lock through the viewports. Also, many manufacturers separate the video system from the other functions of the panel.

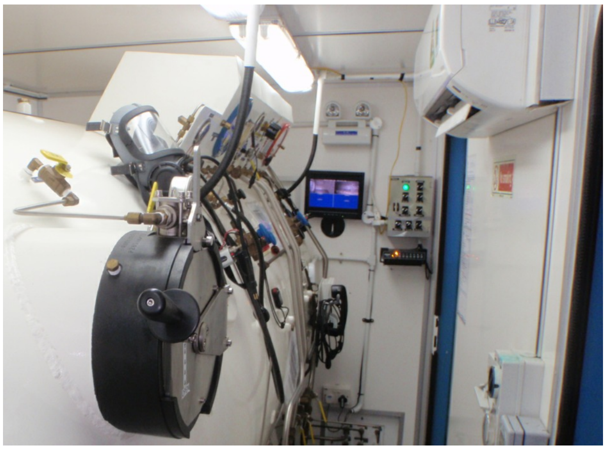


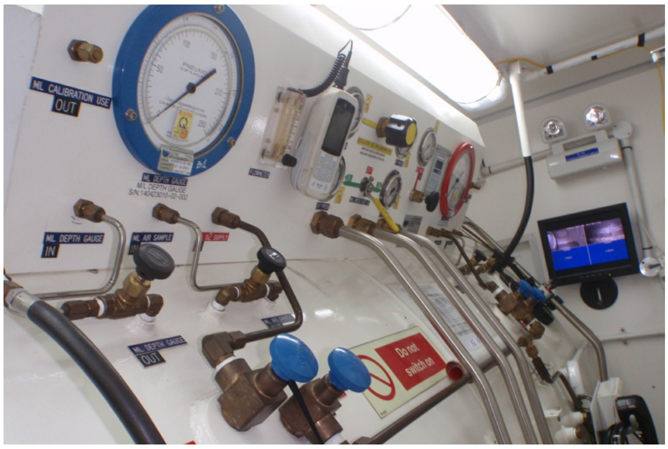
- The pressurization lines #1 & #2 are supplied by two separate HP banks, as indicated in the drawing in point 2.20.1.6. Piston regulators regulate pressure to 11 bar maximum (Pressure indicated for the relief valve). Two separate distribution lines are available for each lock.
- The BIBS supplies #3 & #5 are also from two different banks, as explained in point 2.20.1.6. The oxygen or heliox mix is pre-regulated at the source, and the final regulation is performed on the panel. As mentioned in point 2.20.1.8 "Adaptation of the chamber for therapeutic heliox mixes use", a shared line is used to distribute the oxygen in both locks. As a result, oxygen cannot be used in the entry lock when heliox treatment gas is ongoing. The connection of the oxygen in place of heliox can be made as discussed in this previous point.
- The commands of the exhaust lines #7 (entry lock) & # 8 (main lock) are positioned at the opposite side of the pressurization valves, so they cannot be confused with them. They are close enough to allow the chamber flushing procedure mentioned in point 2.20.1.9.
- Calibration gasses lines # 4 (span gas) & # 6 (zero gas) are included in this panel. They can be connected to the analysers using dedicated whips to be inserted in quick connectors. Note the series of quick connectors #11 below the analyzer blocks #12 & #13 (O2 + CO2) comprises the analysis ports of the air supply lines, the oxygen/heliox supply lines, the main lock atmosphere, the entry lock atmosphere, and the calibration gasses. This arrangement allows for calibrating analysers and checking the gas online and the atmosphere in the lock simultaneously. It is commonly used on saturation systems and, unfortunately, rare with surface-supplied decompression chambers, although all gasses provided to the chamber should be analyzed online.
- Two gauge ensembles (# 9 entry lock & #10 main lock), already described in point 2.20.1.11, are provided. The digital gauges are more precise than those using bourdon tubes, which are used as secondary units.
- The electrical supplies are grouped on the right side of the panel, above the exhaust valves (See #14). They consist of the entry and main lock light switches, the switch for the scrubber (only one scrubber is provided in the main lock), and the fire alarm.
- A diver communication set with one line for each lock (# 15) is provided. Note that they can be replaced by communication sets allowing to phone from inside the chamber, such as the one designed by Fathom.
- Two sound-powered telephones (see #16) are also provided. One is for the entry lock and one for the main lock.

Other mandatory element devices should be in the proximity of the control panel:

- Most competent bodies say that communications with the dive control should be in place if the chamber is in a separate room and is to be used while diving is taking place.
  However, we consider that communications with the dive control have to be installed as there may be situations when the chamber has to be activated while the diving supervisor has to manage the divers in the water. Nothing is published by these competent bodies regarding the nature of these communications. However, like those shared with the DP operator, they should be designed to allow discussion without continuously pressing a button, so the operator can manage the chamber while receiving instructions from the diving supervisor.
  A backup that could be a radio has to be provided.
- There should be communications with the other parts of the vessel, such as the bridge, the diving superintendent's office, and the OCM's office. They are mandatory with most clients and not mentioned by many competent bodies. A phone or an intercom is considered acceptable. The reason is that the people operating the chamber room should be able to be called at all times by the people managing the boat and the project. Note that when the chamber is in the same room as the dive control, it is accepted that these communications are shared.
- A lot of clients require that a satellite phone is provided in the chamber room to contact the doctor and company management. Some vessels are equipped with phone systems that allow connecting cabins and offices to the onboard satellite phone system. Note that systems working through the onboard internet are not accepted for the initial call as they may not be activated by the correspondent onshore. They can be used later when activated and if working correctly. Cell phones can be used onshore but are not considered suitable offshore except if emitters are installed that allow communications at all times.
- Fire and general alarms should be provided. They must be designed such that they can be muted. This alarm is shared with the dive control system if the chamber is installed in the same room.

Sufficient lighting should be provided above the control panel. 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. For this reason lights are usually positioned above the control panel *(see below)*.





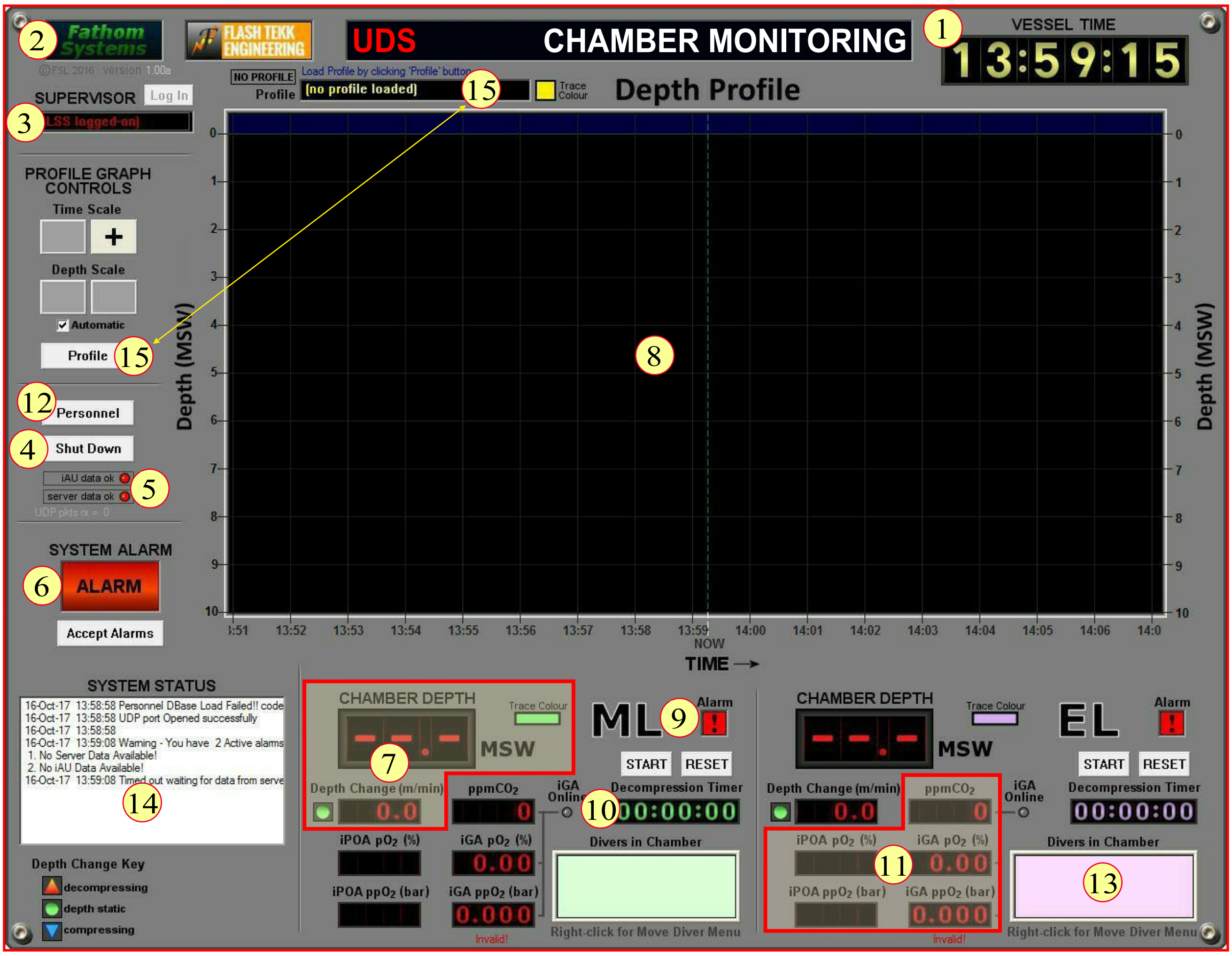
2.20.3 - Diver Monitoring System (DMS)

The Diver Monitoring System (DMS) described in this point complements the one discussed in point 2.19, " Communications, surveillance, recording, alarms, and electrical supplies". It is made by Fathom and installed on a system designed by Flash Tekk engineering.
As already explained in point 2.19.5, such systems are gradually adopted in the diving industry as they allow for better control of the ongoing operations and are mandated with some standards, such as NORSOK U100. As these standards are to be applied in Norway, companies working in this country are required to use such equipment. The part of the system dedicated for the chamber is designed as follows:

A "Client" PC is provided for each decompression chamber. This client PC is located in the dive control's electrical cabinet, and a monitor is mounted on each chamber next to the control panel so that the chamber operator can easily consult it during operations.
Fathom company says that the chamber operator, called "LSS/Chamber supervisor" in their manual, does not need to interact frequently with the software during normal operational activities, except when adjusting alarm settings, moving divers from the system, or logging on or off the system. Thus, the main activity of the chamber operator is monitoring the decompression and occasionally "moving" the divers in or out of the chamber's locks.

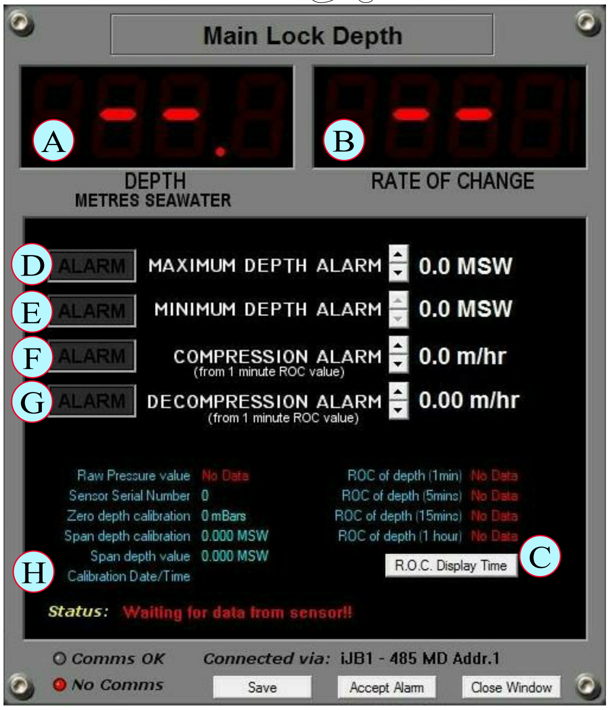
The chamber operator (chamber supervisor) must log on to the system to track his name in the assigned "chamber operators" list. That is achieved by clicking on the "Supervisor Log In" button *(see #3 in the scheme on the next page)*. He is is then prompted to enter his password before login is permitted.
Note that "LSS" stands for "Life Support Supervisor". Nevertheless, such a function that consists of directing several "Life Support Technicians" in charge of the chambers of a saturation diving system is too elevated for air or nitrox diving operations where the "chamber operator" is usually a diver qualified for this task.
The screenshot on the next page shows a typical display presented to the "chamber operator".

- Main display description:



Note that the description of some elements are similar to those for the diving supervisor workstation.

1. Vessel time display:
   It shows the time reference used onboard the vessel and used for recording data. As already explained in point 2.19.6, this time is adjusted for regional time-zone and daylight-saving policies against the "Coordinated Universal Time", also known as "Greenwich Mean Time or GMT". It is the time used on the vessel bridge for all vessel time operations.
2. Fathom systems logo:
   Clicking the Fathom Systems Logo on the top of the display opens a page that indicates the software version, copyright, and Fathom Systems phone number that can be contacted in case of an emergency.
3. Chamber operator (Chamber Supervisor) Identification:
   This display window shows the name and ID number of the chamber operator. Pressing the "Log In"/"Log Out" button allows the chamber operator to log in and out of the system.
4. "Shutdown":
   This button shuts down the Chamber Room client display software.
5. Data Link Status Indicators
   These indicators show the status of the data links to the Server and iAU. The following colours are used to make their status visible: Green means that the connection is good, amber indicates that the link is faulty or intermittent, and red means no connection is established.
6. Alarm indicator:
   The alarm indicator is grey when the conditions are within limits, and the signal is normally transmitted. It is illuminated red when a depth or analysis alarm condition is outside limits, or the signal is faulty. The alarm indicator flashes until the supervisor accept the alarm (via the Alarm settings window).
7. Main Lock & Entry Lock Depth & ROCO displays:
   There are two large digital depth readouts for each of the compartments in the chamber. These displays are generated from the signals from the digital depth transducers.
   Colour-coded digital displays provide the rate of change of depth of each compartment in MSW/hour.
   A dynamic symbol adjacent to the depth change digital displays shows whether the chamber lock depth is getting deeper (compressing), shallower (decompressing), or static. This indicator input is taken from the calculated rate of change of depth value.
   Clicking on either the "Chamber Depth" display or "Rate of Change" display brings up the chamber depth dialogue box for the corresponding chamber, as shown on the next page.



A. Depth Display:
Shows current chamber depth in meters seawater, received from the chamber pressure transmitter.

B. Rate of Change Display:
It shows the rate of change of the depth calculated over a period of pressure transmitter readings.

C. Time base for the rate of change calculation:
It is set by pressing the "R.O.C. Display Time" button which cycles through 60 s, 5 min, 15 min and 1 hr with each button press.

D. Maximum Depth Alarm:
Sets a depth above which an alarm is displayed. It is done using the up/down arrows.

E. Minimum Depth Alarm:
Sets a depth below which an alarm is displayed. It is also done using the up/down arrows.

F. Compression Alarm:
Sets a rate above which an alarm is displayed. It is based on a 1 minute rate of change time base.

G. Decompression Alarm:
Sets a rate above which an alarm will be displayed. It is based on a 1 minute rate of change time base.

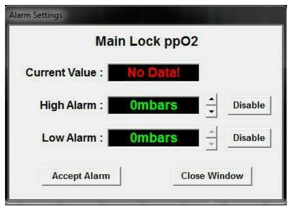
H. Sensor Status and Information
The lower half of the dialogue is dedicated to displaying additional detailed information.
"Status" indicates whether data are available from the pressure transducer
"Raw Pressure Value" indicates the raw data value received from the sensor
"Zero Depth Calibration" displays the sensor pressure which has been calibrated to correspond to zero bar
"Span Depth Calibration" is the sensor depth at the last calibration, based on the previous calibration.
"Span Depth at Calibration" is the actual depth at last calibration, measured using a pressure calibrator.

8. Depth Profile Display:
This large graphical display shows a real-time plot of the main lock and entry lock depth signals against Time. This display is updated automatically and provides a depth graph (on the Y-axis) against Time (on the X-axis). The display uses colour-coded traces to represent each of the following depth sensor signals: The main lock depth is green, and the entry lock is purple.
The data shown on this display are held local to the chamber room display application, with 12 hours being retained in the client PC memory. Data older than 12 hours is discarded, so the Report Generator application should be used if a review of older data is required.
The depth profile is scaled vertically in metres of seawater (MSW). The depth scale used for the depth profile display can be manually adjusted with the increase and decrease buttons. When the automatic mode is selected, the depth is scaled automatically to include the most profound depth encountered for the duration of the current display.
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 trend horizontal display.
The time scale used for the Depth Profile display can be manually adjusted with the increase and decrease buttons.

9. Depth alarm:
The display is grey when the alarm conditions are within limits and healthy. The display is illuminated red when there is an alarm or the chamber's critical parameters are outside limits or is faulty. The alarm indicator flashes until the chamber operator accepts the alarm (via the alarms configuration window for the particular sensor).

10. Decompression timer:
A decompression timer is provided. It is like a stopwatch with start/stop/reset commands.

11. Gas analysis readings:



Percentages O_2, pp O_2 and ppm CO_2 readings are shown for each chamber lock. They are mirrors of the readings from the gas analysers. Note that the manufacturer says that they are not to be considered the primary gas analysers, and the values to take into account for critical decision are those of the primary analysers. Clicking on the percentages O_2 & pp O_2 displays brings up the alarm dialogue for the corresponding sensor.
The alarm levels can be set using the up/down arrows and enabled/disabled using the corresponding button.

12. "Personnel":
Pressing this button opens the personnel database editor.

13. Diver Location Window (chamber):
A display window is provided for each chamber lock that shows the names of the divers inside them. Clicking the window brings up a dialogue box allowing adding and removing the divers in the chamber.

14. System Status Window:

This window displays a log of events and errors. No errors should be displayed under normal conditions.

15. Chamber Depth Profile:
    A depth profile can be displayed on the “Depth Profile” graph. Clicking the “Profile” button opens a window that allows creating dive profiles and loading, editing, and saving them on the server. The loaded dive profile is shown in a text box above the depth profile.

- Alarm management:

The “chamber operator” may be alerted when a system parameter enters an alarm condition such as:

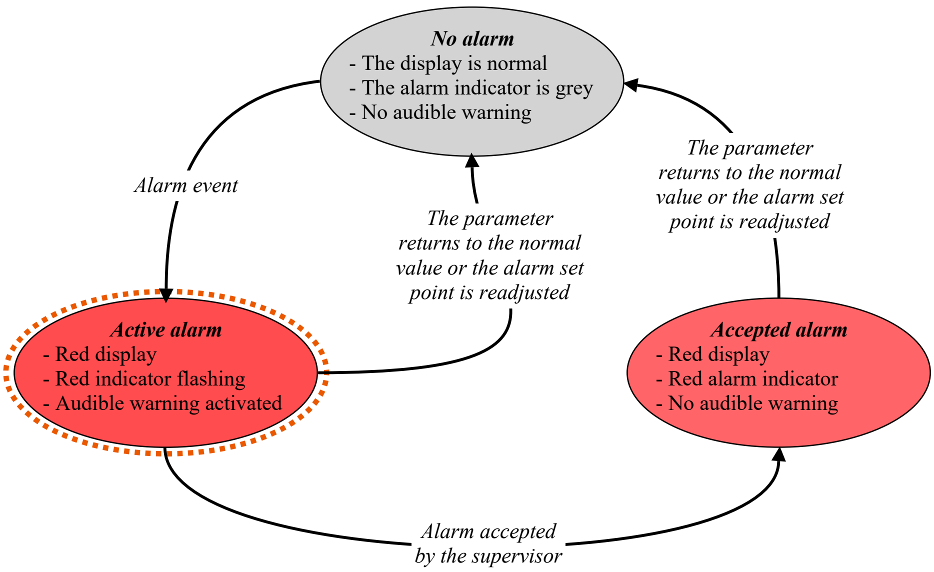
- Depth alarms for Chamber Locks (High and Low alarms)
- Rate of Change of Depth alarms (Compression alarms/decompression alarms) for each chamber lock.

As for the terminal in the dive control, this alarm status results in:

- The digits of the element affected turning red
- The alarm indicators are illuminated red and flashing
- An audible warning generated every 10 seconds
- In case of a system error or fault alarm is generated, the display changes to a row of red dashes.
- A description of the problem is published in the status box that can normally be opened by clicking on “show status” *(see #14 in the scheme of the monitoring screen)*.

Remember that the active alarm must be accepted by the supervisor to stop the indicator from flashing and the audible warning from being repeated *(see #6 in the scheme of the monitoring screen)*.
Clicking on the red numeric display of the parameter in the alarm state opens the “alarm settings window” for the particular sensor.
Once accepted, the alarm indicator remains illuminated red and the digital parameter display remains red also.
When the alarm returns within the set point(s), the display returns to its normal display colour and the alarm indicator returns to grey.

The alarm processes can be summarized as follows:



- Closing the chamber client display:

The chamber operator clicks "Shut Down" to close the "chamber client" display. Like many computers, that opens a message of confirmation asking to confirm the intention to quit the program.
When this application is shut down, the data are still being logged by the server, so the only problem with shutting down the “dive control client” is that all the stored depth profile data (up to 12 hours) will be lost, as this data is not preserved between sessions (however, the logged information for this period is still stored on the server).
The chamber operator doubles click on the desktop icon to restart the application.

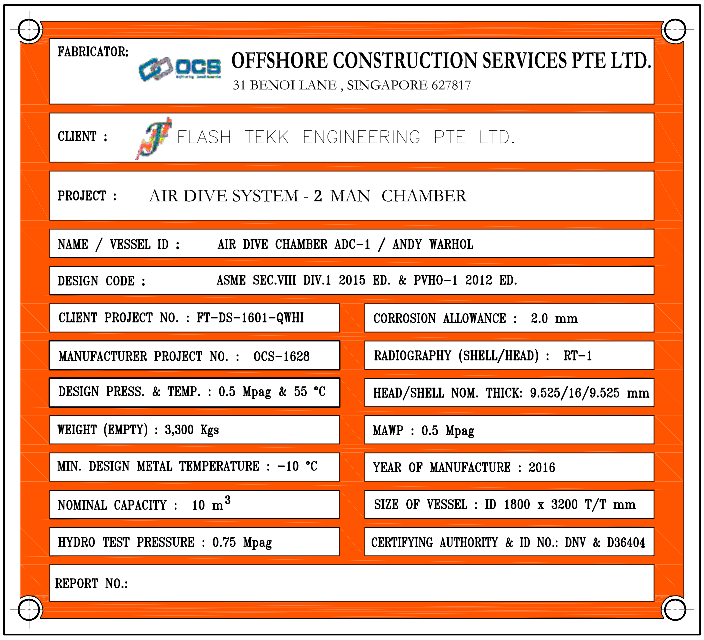
- Operation when the Data Server is Unavailable:

A warning is displayed if the data server is unavailable. Additionally, if a function is selected, that requires interaction with the server, such as, for example, personnel movements, a message is presented to the chamber operator informing that the server is not available.

2.20.4 - Chamber identification

The chamber must have been designed and built to a recognized international standard and be fit for human occupancy. IMCA D 023 says that it must be the case for any unit manufactured after the 1st of July 2014. However, similar standards have been in force for a long time with other organizations.
This standard and the number of occupants the chamber is designed for must be easy to find. They are usually indicated with complementary information that allows tracing the construction process of the device on an identification plate that is generally installed on a leg or the body of the pressure vessel. As an example, the plates installed on the chambers Flash Tekk engineering give 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



Note that the elements indicated on the ID plate must be documented. Also, the chamber cannot be used if the identification plate, usually riveted to its support, is missing. For this reason, people auditing the chamber should ensure it is in place and that it is the original one. Thus, that the plate corresponds to the pressure vessel considered. Note that not perfectly centered holes indicate that the ID plate has been reinstalled or is not the original one. In this case, the reason for the reinstallation must be documented and approved.
In addition to the above, the number of occupants the chamber is designed for is frequently required to be painted on it. This indication is usually made above the entry. It must correspond to the number of occupants indicated on the ID plate and in the documentation issued by the manufacturer and the certification body.

2.20.5 - Maintenance

The maintenance of the chamber should be performed according to the recommendations from the manufacturer and equipment suppliers. Also, those of IMCA D 023 remains among the most suitable and most used. They should be implemented when they are more stringent than the manufacturer's, or these recommendations are missing.

Part of the chamber	Items	Visual external + function test , calibration	Visual internal + external + gas leak test at max. Working pressure	Internal + external+ overpressure test or replacement procedure	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	Pipework	6 months	2 years		

Part of the chamber	Items	Visual external + function test , calibration	Visual internal + external + gas leak test at max. Working pressure	Internal + external+ overpressure test or replacement procedure	Other
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	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 IMCA recommends inspection at a minimum frequency of 6 months. However, when the system is in use, this frequency should be increased for many elements of the pipework and should be those indicated in points 2.16 & 2.18. It should be the same for the analysers described in point 2.17 and the communications and monitoring systems described in point 2.19.
Based on the above, the following suggested daily, weekly, and monthly maintenance should be taken into account during the operations if the recommendations from the manufacturer's manual are less stringent or do not mention them.

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:

- The O-rings should be verified and re-greased with a film of silicone grease if necessary.
- The 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 lighting and scrubbers.

After the diving project or every 6 months:

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

2.21 - Control rooms, workshops, and compressor rooms.

2.21.1 - Purpose

Depending on whether the diving system is built in the vessel or portable, the control rooms and workshops are specific rooms of the ship or shipping containers arranged for various functions and certified by an competent official body.

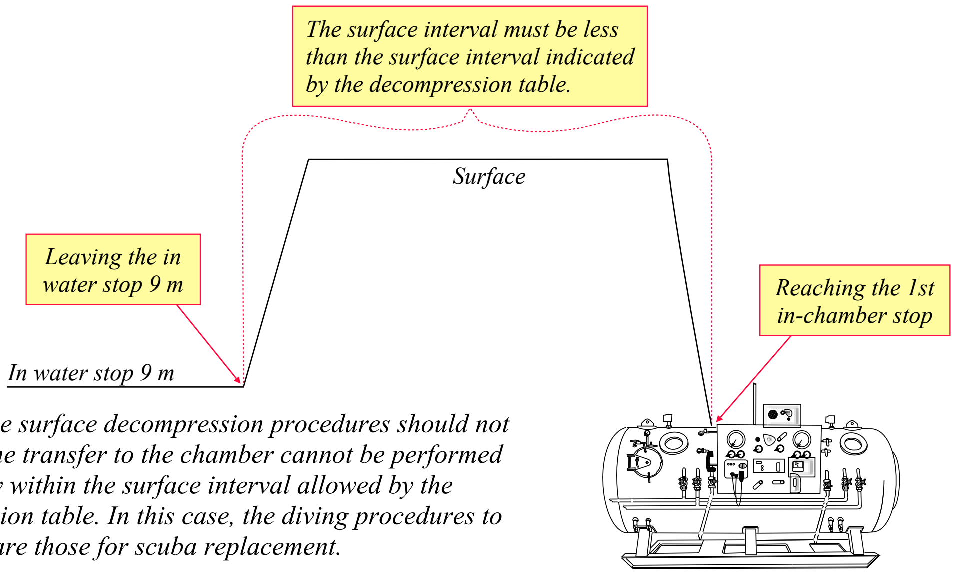
- Control rooms are designed to accommodate the gas distribution panel to divers with the communication and monitoring systems that allow the supervisor to control the dive. The decompression chamber is sometimes installed in the same room as the systems to control the dives or in a separate room which must be linked to the dive control by a dedicated wired communication system.
- Workshops are rooms where maintenance and on-site repairs are performed. They are also dedicated to the storage of equipment and spare parts.
- Compressor rooms are designed to accommodate compressors and sometimes gases other than oxygen that must be stored on deck or in a ventilated place.

These rooms must be designed to protect people working in them from external weather conditions, be provided with suitable firefighting and alarm systems, and equipped with respiratory systems that allow the supervisor and technicians to terminate a dive and then evacuate safely to the muster point in case of a fire or an abandonment of the ship.

2.21.2 - Dive control and chamber control rooms.

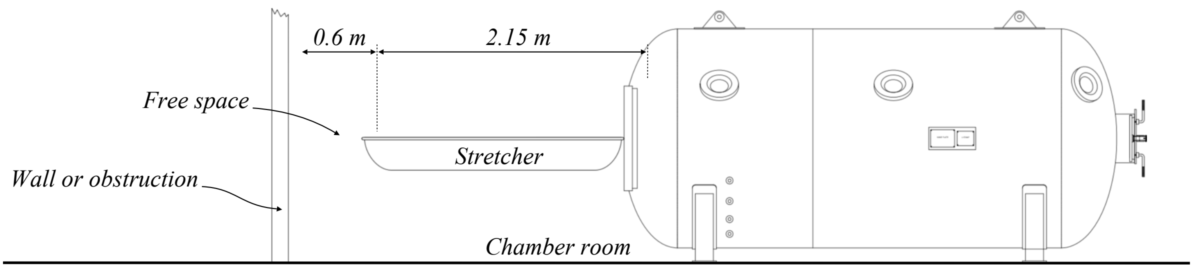
Dive control rooms and chamber control rooms are usually installed in direct proximity to the launching station.

- The dive control should be positioned so the diving supervisor can view the launching station. If that is not possible, and as already mentioned in previous points, cameras should be provided to allow him full monitoring of what happens on the launching station, particularly with the Launch and Recovery Systems (LARS). Several cameras are usually necessary for this purpose to avoid dead angles and loss of vision due to the blinding of cameras during sunrise and sunset. It must be considered that the ship's position and orientation will change during the operations, so the affected cameras will not always be the same. It should also be taken into account that the deck lighting may also disturb cameras.
- The chamber should be positioned so that a diver performing surface decompression can be transferred to it within the planned interval surface of the table. Remember that this interval starts when the diver leaves the stop 9 m to the time he is back under pressure in the chamber. This interval should be less than 7 minutes with DCIEM tables and 3 minutes with COMEX tables. Organizing for transit on the deck of less than 1 minute is recommended to be able to control unforeseen events.

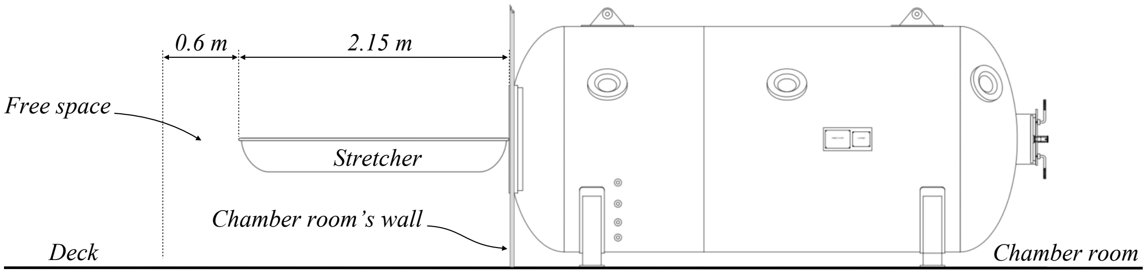


Note that the surface decompression procedures should not be used if the transfer to the chamber cannot be performed comfortably within the surface interval allowed by the decompression table. In this case, the diving procedures to implement are those for scuba replacement.

In addition, there must be sufficient room to position the stretcher with a casualty at the entrance of the entry lock. The document "Hyperbaric Facility Design Guidelines", from the Undersea and Hyperbaric Medical Society says that if the door of the entry lock is situated in the room where the chamber is accommodated, there should be a minimum space of 60 cm (24") between the extremity of the stretcher and the wall or the closest obstruction when the stretcher is positioned at the entrance of the entry lock, ready to transfer the casualty into the chamber (see below). Note that the average length of a stretcher is 2.15 m.



Many chambers are organized so that the door of the entry lock is on deck so that it is not necessary to enter the room where the chamber is installed to transfer into it. Nevertheless, even in this case, the rules for access with a stretcher must be the same.



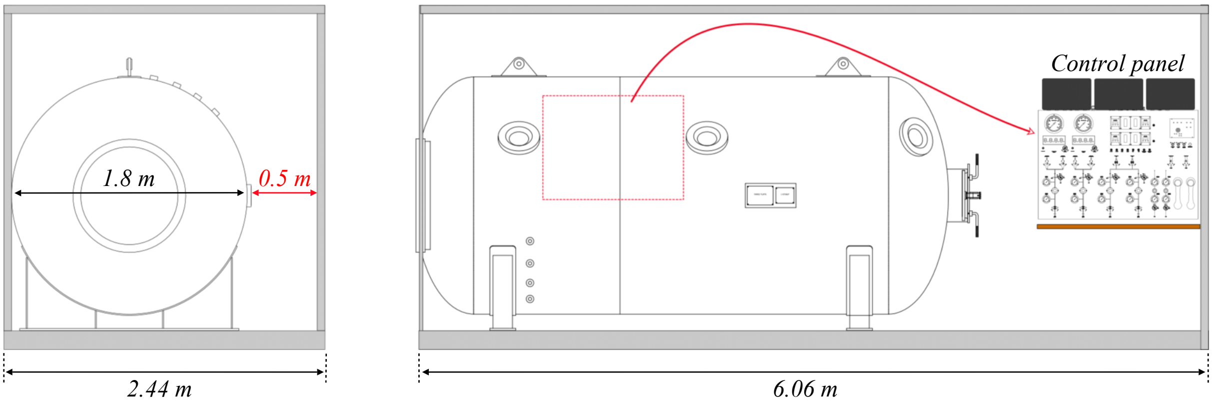
If the access to the chamber is on deck, there must be a window or a door allowing the chamber operator to monitor the transfer of the diver or the casualty into the entry lock. A camera should be installed near the entrance if there is no window.

The rooms must be designed to protect the personnel from weather conditions and falling objects. Also, they should be comfortable enough to allow the supervisors and chamber operators to perform their duties safely and comfortably.

- The temperature inside the room must be controlled to be comfortable for the occupants 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. Also, it is recommended that their entrance door is sealed and waterproof if it opens to the deck.
- 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.
- The personnel must have easy 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. The systems for muting audible alarms should be easy to visualize and operate. Also, comfortable chairs should be provided so people can rest during their shift. Regarding this point HSE organizations recommend the following:
    - The chair must be stable enough not to trip over, even though the vessel is facing rough weather conditions. A circular or five-point-of-contact base is recommended when it is not fixed to the floor. If the chair is fixed to the floor, rails should be provided to adjust its distance from the control panels (like those used with Dynamic Positioning systems).
    - The seat height should be adjustable. Additionally, the seat pan should ideally have a feature that allows it to tilt backward and forwards and should have a rounded front edge to reduce pressure on the backs of the thighs. Backrests should be designed so that they support the lower back. It is suggested to provide adjustable systems.

Additionally, the diving supervisor spents a lot of time watching monitors. To avoid eye and neck strain, they should be positioned such that they are not too close and not set such that the supervisor is obliged to look at them from an uncomfortable angle.

When the control panel of the chamber is installed on its side, the chamber operator is obliged to work standing. That obliges to plan for turnover with several operators to reduce fatigue and ensure that the panel is constantly monitored in case long decompressions have to be performed. The Undersea and Hyperbaric Medical Society recommends a free space of at least 90 cm (36") between the panel and the wall or the closest obstruction. Unfortunately, considering the IMCA and NORSOK rules *(see in point 2.20.2)*, new chambers installed in containers cannot comply with this recommendation. In this case, installing the control panel at the extremity or in a separate room is more suitable. Also, a panel positioned at the extremity allows the operator to sit while operating the chamber.



- An ambient atmosphere oxygen analyser with visual and audio alarms must be provided in any control room where gasses are distributed to divers, to ensure that there is no accumulation in the room. Note that the models used for this purpose are specific because provided with a module that insures air circulation to the sensor. Thus, the oxygen analysers used on gas panels are not suitable for this purpose. It is preferable to position the air inlet of the analyser near the floor as oxygen is heavier than air.
- Remember that oxygen and mixes considered pure oxygen must be regulated down at the source (the quad) to a maximum of 40 bar (600 psi) and not be introduced in the room at a pressure above this value.
- The exhaust and vent lines of the dive and chamber panels must be organized to vent on deck.
- As indicated in the previous point regarding the design of decompression chambers, a satellite phone must be provided in the chamber room to communicate with the diving medical specialist appointed by the company. However, cell phones can be used if the operation is onshore or close to the shore and the network is stable. Note that new systems such as the Fathom communications systems described previously allow direct phone communication to the doctor (who is not on site) from inside the chamber.
  Also, communications to the bridge and the terminal of the system that allows a doctor who is remote in his office to visualize the essential information of a patient in the chamber at the same time a medical intervention is practiced is not made mandatory by organizations such as IMCA and IOGP. Still, we recommend it as the problem to solve by the doctor will be similar, and when a medical table is started, the treatment under pressure can be longer than first expected.

Fire fighting systems and means of escaping should be provided in all control rooms.

As an example, IMCA D 023 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 023 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 systems are protected with the 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 powerful fire pumps is installed in the dive control. As an example, the UDS Lichtenstein is equipped with two pumps allowing 140 m3/h each. The operating panel, control unit, and power supply of this system are contained in a central cabinet on the bridge.
However, most transportable surface supplied diving 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.

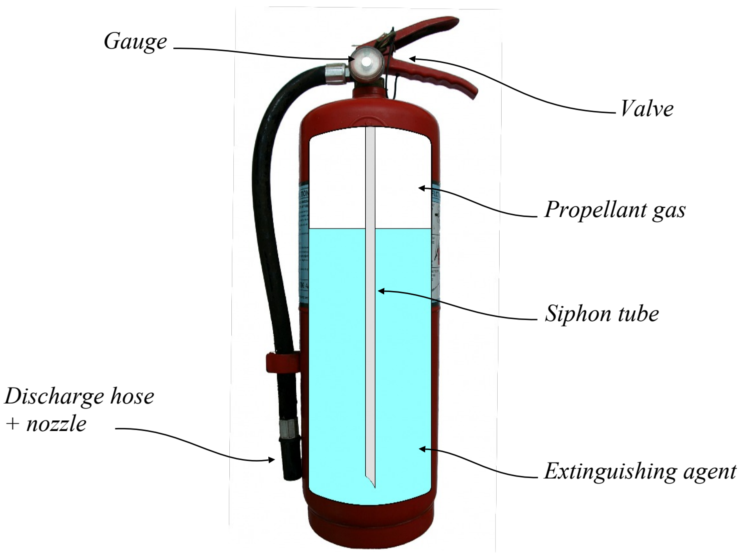
- Foam:
  Fire extinction is normally achieved by the use of fresh or salt water, because of its good cooling characteristics. However, with oil, which has a lower specific gravity than that of water, effective extinction can best be achieved by smothering the burning fuel with foam, thus cutting off 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 diving 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.

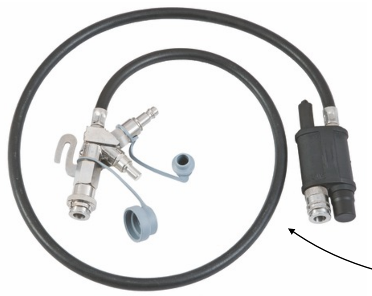
Extinguishers are the most common portable fire extinguishing devices in dive controls. The reason is that they are easy to use and can be stored near the strategic points without the need for a specific installation.
Note that there are two main types of extinguishers:

- “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 most certification bodies say 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.
Most safety organizations say that emergency breathing apparatus fitted with communications must be available for the diving supervisor, the chamber operator, and the diving technician if relevant so that they can terminate a dive in a smoky or polluted atmosphere. Note that such apparatus should also be provided to the winch operator and the tenders on deck. 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)*.



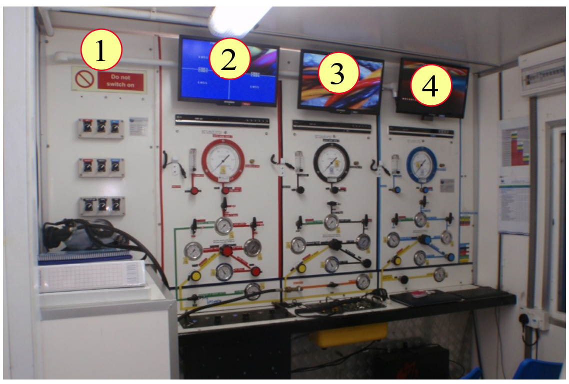
Automatic Switch Over Valve

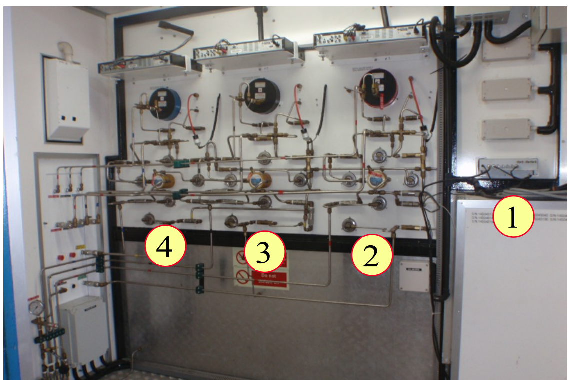
Note that the breathing apparatus must never be connected to a compressor as the air intake may be in a polluted area. For this reason, the air provided must be from a gas reservoir only.
In addition to the emergency breathing apparatus, several escape sets should be provided to allow the not essential 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.

IMCA D 023 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.

The control rooms should be organized such that the piping and electrical connectors of the dive panels are accessible for maintenance and repair. Thus access to the back of the control panels is to be provided.

- That can be organized such that panels installed on a bulkhead can have their back accessible in an adjacent room, such as in the pictures below.





- Hatches should be provided when the panels are installed on a wall of the room which is not a separation bulkhead to provide access from the external of the room. It is often the case with dive controls organized in portable containers. The hatches must be waterproof and approved by a certification body. These hatches must always be accessible.
- When the control panels are installed in cabinets, there should be a space of approximately 70 cm between the back of the cabinet and the wall to allow the technician to intervene comfortably.
- Exception: Some certification bodies do not require specific means of access to the back of panels that can be quickly removed and changed, such as the small individual diving panels described in point 2.18.2. In this case, it is considered that such panels are very light and that removing them is as simple as opening a hatch.

2.21.3 - Workshops and tool storage rooms

A lot of electronic devices are used on modern surface-supplied diving systems. Their repair and storage must be done in optimal conditions and in a place exempt from various dirt that may pollute or damage them. Also, computers are commonly employed to manage the spare parts store, maintain the Planned Maintenance System (also called "Periodic Maintenance System"), write reports, and send messages. For this reason, the rooms dedicated to such activities should be designed similarly to control rooms.

- Their temperature and hygrometry should be similar to those of control rooms, so a temperature between 19 and 25 Cº and a hygrometry between 40% - 30%. Also, like control rooms, their entrance door should be sealed and waterproof if it opens to the deck.
- The lighting should be sufficient to read procedures and perform delicate repairs, so 300 Lux in all areas of the room and a minimum of 500 Lux near the worktables and desks.
- Firefighting systems exactly similar of those of control rooms should be provided.
- General alarms should be provided in the room or clearly audible from it.
- Phone communication with the dive control, the diving superintendent and the offshore construction manager, and the bridge should be in place.
- A breathing apparatus allowing the technician on duty to support the diving supervisor terminating the dive in a smoky or polluted atmosphere (some essential diving equipment may be damaged) and then escape to the muster station should be stored in a visible place.
- Suitable storage boxes should be provided, and the room must be organized such that the technician in charge can lock it to protect the items and data stored in it from theft.

Storage rooms dedicated to equipment not affected by temperature variations do not need to be provided with air conditioning and isolation. However they must be designed to protect these items from the other weather aggression, fire, and theft.

- Their entrance door should be waterproof if it opens to the deck.
- They should be provided with lighting of 300 Lux minimum.
- The general alarm should be audible inside them.
- Their fire fighting systems should be organized in the same manner as the control rooms. It is not required to provide escape masks in them, but they should be provided at the direct proximity such as in the access corridor, or on deck.
- Suitable storage boxes should be provided, and the room must be organized such that the technician in charge can lock it to protect the items and data stored in it from theft.

The substances hazardous to health should be stored in specific rooms separated from other storage areas.

- “Substance hazardous to health” covers substances such as:
    - Products containing chemicals that can react alone or with other chemicals
    - Products that can emit fumes, dusts, vapours, mists, asphyxiating gases, biological agents (germs).
    - Products that are corrosive or highly pollutant.

  Thus, paints, solvents, acids, oils, etc. that are commonly used for the maintenance of the diving system.
- Boats are usually equipped with specific storage rooms for this purpose that are adequately ventilated and provided with a deluge or a water mist system that is part of the firefighting system of the boat, in addition to adequate extinguishers and fire fighting lance at their direct proximity. Portable containers should be provided with similar firefighting arrangements.
- Several rooms are to be used in case of potential chemical reactions if some substances are stored in direct proximity.

Radioactive substances are not used in diving systems. However, they may be used with inspection tools. They must be stored in specific containers that are isolated in a particular part of the deck that is classified “no go zone” for other personnel than those in charge.

2.21.4 - Compressor and gas storage rooms

It is not an obligation to install compressors and store gases in a specific room. Many models of compressors are designed to work in the open air, specifically those driven by diesel engines. However, many companies prefer using electrically powered compressors secured in a specific room that may also contain HP air cylinders.

The advantage of installing compressors in a dedicated room is that they are protected from unfavorable weather conditions, which allows operating and maintaining them more comfortably and increases their durability. For these reasons, compressors of built-in systems are usually installed in a dedicated room inside the ship.
In addition, when installed in a dedicated container, the compressors of portable systems are protected from small falling objects and inappropriate handling during the mobilization. Also, these rooms are usually designed with permanently installed electrical supplies, pipework, and gas panels equipped with quick connectors to energize the system and easily and quickly fit gas distribution hoses to the dive control and the chamber room.

Regarding the gases that are stored in the compressor room, please remember that oxygen and mixes considered as pure oxygen must be stored in open and well-ventilated areas that are clear of any fire hazard. For this reason, only air is stored in the compressor room.

The compressor room should be designed as follows:

- The lighting should be sufficient to read procedures and perform maintenance tasks, so 300 Lux in all areas of the room and a minimum of 500 Lux near those where reading gauges and documents and performing maintenance tasks is required. Note that waterproof lights are needed. Also, these lights and the electrical system are to be classified as ATEX if nitrox or oxygen compressors are to be used (ATEX are EU directives describing the minimum safety requirements for workplaces and equipment used in explosive and flammable atmospheres).
- The room must be adequately ventilated to avoid heat accumulation and favor the refrigeration of compressors. Thus, large openings that can be closed by dedicated hatches are usually provided near the lower and the upper parts of the room. A forced ventilation system using pulsed fresh air can also be used. This air circulation must be increased when nitrox or oxygen is compressed, so the ventilation should be sufficiently efficient to make oxygen accumulation impossible. Openings with louvers that can be closed by hatches in bad weather conditions are suitable means of ventilation commonly used.
- An ambient atmosphere oxygen analyzer with visual and audio alarms must be provided when oxygen or nitrox mixes compression is performed. These analysers are of the same models as those used in control rooms. However, the model selected should have an alarm that can be heard when compressors are running.
- Compressors, gas cylinders, and other items must be secured to the walls or the floor of the room. Also, the air inlets of compressors should be located within the upper parts of the room, above 2 m in height.
- The fire fighting systems of built-in compressor rooms usually consist of the boat's fire detection and deluge or water mist system. In addition, extinguishers and fire fighting lance are provided in their direct proximity. Mobile compressor rooms that accommodate only air compressors can be provided with only portable systems. However, a deluge or a water mist system with the fire alarm system linked to the vessel's bridge must be installed in those designed to accommodate nitrox and oxygen compressors.
- General alarms should be provided in the room or clearly audible from it.
- Phone communication with the dive control, the diving superintendent and the offshore construction manager, and the bridge should be in place.
- As said in the introduction, the compressor room should be approved by a certification body for the compressors and gas cylinders installed in it. Of course, this certification includes the types of gasses intended to be compressed and stored. As a result, a room certified

As said previously, mixes with more than 22% oxygen must not be stored in a closed room, but 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.
It must be noted that storing oxygen in adequately ventilated containers, so that gas accumulation inside the room is impossible, is acceptable. However, a recognized certification body must accept the container design.

- Large ventilation openings should be provided at the top and the bottom of the room (remember that oxygen is heavier than air) so that the air circulation is sufficient to avoid gas accumulation even though the container is closed. Openings with louvers are suitable means of ventilation commonly used.
- The electrical supply and lighting should be classified as ATEX.
- The container should also be provided with a deluge or a water mist firefighting system with the fire alarm linked to the vessel's bridge and approved by a certification body. Portable systems should also be provided.

2.21.5 - Specifications of containers accommodating elements of portable diving systems

Shipping containers are large steel boxes of standard sizes that are internationally recognized, initially designed to safely transport cargo by road, train, and boat. The standardization of the sizes and corner fittings allows a container to be manipulated and piled up with others without modification of the lifting and storage systems, whatever the country. This standardization also allows discharging a container to a trailer or a wagon or the opposite, reducing handling to a minimum. Three standard sizes, initially calculated in feet, are commonly employed.

Usual name	*Length*		*Width*		*Standard height*	
	External	*Internal*	*External*	*Internal*	*External*	*Internal*
10 ft container	*9 ft 10 in (2.99 m)*	*9 ft 3 inches (2.84 m)*	*8 ft (2.44 m)*	*7 ft 8 inches (2.35 m)*	*8 ft 6 inches (2.59 m)*	*7 ft 10 inches (2.39 m)*
20 ft container	*20 ft (6.06 m)*	*19 ft 4 inches (5.9 m)*	*8 ft (2.44 m)*	*7 ft 8 inches (2.35 m)*	*8 ft 6 inches (2.59 m)*	*7 ft 10 inches (2.39 m)*
40 ft container	*40 ft (12.2 m)*	*39 ft 6 inches (12.04 m)*	*8 ft (2.44 m)*	*7 ft 8 inches (2.35 m)*	*8 ft 6 inches (2.59 m)*	*7 ft 10 inches (2.39 m)*

The weights and maximum cargo loads of these containers are given below. Note that the maximum gross weight of 40 ft and 20 ft containers is the same. Also, ISO provides several designations for these container lengths with a few height variations. However, most containers in service have a standard height of 8 ft 6 inches (2.59 m)

Usual name	*Internal volume*	*Empty weight*	*Max cargo load*	*Max. gross weight*	*ISO designations*	*Heights ISO designations*
10 ft container	*561 ft³ (15.1 m³)*	*2,870 lbs (1,300 kg)*	*22,040 lbs 10,000 Kg*	*24,910 lbs (11,300 kg)*	*1D & 1DX*	*ID: 2.59 m IDX: 2.59 m*
20 ft container	*1170 ft³ (33.1 m³)*	*4920 lbs (2230 kg)*	*62,080 lbs 28,250 kg*	*67,200 lbs (30,480 kg)*	*1CC, 1C, & 1CX*	*1CC: 2.59 1C: 2.438 m 1CX: < 2.438 m*
40 ft container	*2386 ft³ (67.6 m³)*	*8201 lbs 3720 kg*	*58,999 lbs 26,760 kg*	*67,200 lbs (30,480 kg)*	*1AAA, 1AA, 1A, & 1AX*	*1AAA: 2.86 m 1AA: 2.59 m 1A: 2.438 m 1AX: < 2.438 m*

Containers have been adopted to accommodate diving and ROV systems for a long time. However, there are things to take into account to employ them legally and ensure that those installed on small vessels will fulfill their function even though they are submitted to rough weather conditions.

- Shipping containers are initially designed with a structure as light as possible to allow transportation of a maximum cargo load without being outside the maximum gross weight. Thus reinforcements are provided at strategic points, and the walls are considered part of the structure. For this reason, the installation of hatches and other modifications of the walls cannot be undertaken without the approval of a certification body.
- Shipping containers are initially designed to be transferred in ports or inland using specific lifting systems and are not intended to be transferred at sea. For this reason, a diving system installed in standard shipping containers cannot be moved when the vessel is at sea as they are not designed to withstand the dynamic forces arising from such operations. Thus that can be done only when the ship is alongside the jetty. Also, they are not provided with lifting padeyes, and installing such handling points is typically impossible or will require numerous modifications that must be certified. For this reason, it is recommended to use “offshore containers” that are reinforced units designed to transfer cargo at sea and equipped with suitable lifting points.

Offshore containers have the same sizes as shipping containers. However, they are built according to IMO's circular MSC/Circ.860. Also many manufacturers and certification bodies refer to the European standard EN 12079. However, many other national standards have been published.
IMO MSC/Circ.860 says that offshore containers should be designed to fulfill the following requirements:

- Approving competent authorities should base their approval of offshore containers both on calculations and on testing, taking into account the dynamic lifting and impact forces that may occur when handling in open seas.
- Offshore containers should be fitted with special pad eyes, suitable for the attachment of purpose-built slings connected with shackles. Where ISO corner fittings are mounted in conjunction with pad eyes, these corner fittings are not intended for lifting offshore.
- In order to facilitate handling in open seas, offshore containers should be pre-slung. Such slings should be permanently attached to the container and considered to be part of the container. The dynamic forces which occur when handling containers in open seas will be higher than those encountered during normal quay-side handling. This should be taken into account when determining the requirements for slings on offshore containers by multiplying the normal safety factor for slings by an additional factor. The fact that light containers will be

subject to relatively higher dynamic forces than heavier containers should also be taken into account. Minimum material requirements for impact toughness should be specified when high strength steel is used in e.g. chains, links and shackles.

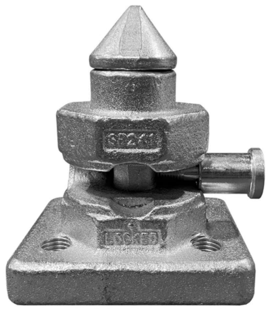
- Since offshore containers may not always be secured on supply vessels, such containers should be designed so as to withstand 30º tilting in any direction when fully loaded. Cargo may normally be assumed to be evenly distributed with the centre of gravity at the half height of the container, but on containers for dedicated transport (e.g. special bottle rack containers for gas bottles in fixed positions) the actual centre of gravity should be used.
- Protruding parts on an offshore container that may catch on other containers or structures should be avoided. Doors and hatches should be secured against opening during transport and lifting. Hinges and locking devices should be protected against damage from impact loads.
- Strength calculations should include lifting with the attached lifting sling and any other applicable means of handling (e.g. lifting with fork lift trucks). Impact loads on the sides and bottom of containers should also be considered in these calculations and impact properties should be included in the requirements for structural steel materials. However, calculations, including static equivalency of point loads in combination with the tests as set out in paragraph 13 should normally be considered sufficient.
- Containers are sometimes temporarily used on floating or fixed offshore installations as storage space, laboratories, accommodation or control stations, etc. When used this way, the container will also be subject to the regulations applicable for the offshore installation in addition to transport related requirements based on these guidelines.

IMO MSC/Circ.860 also requires the following regarding the maintenance of offshore containers:

- 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 and any other official approval or data plates on a single base plate.
- The inspection plates on offshore containers should commonly show the date of the last inspection, unlike Safety Approval Plates on containers subject to the International Convention for Safe Containers (CSC), which are marked with the date when the first periodic examination is due and in the case of containers covered by a Periodic Examination Scheme (PES), with the date by which the subsequent examination is scheduled.

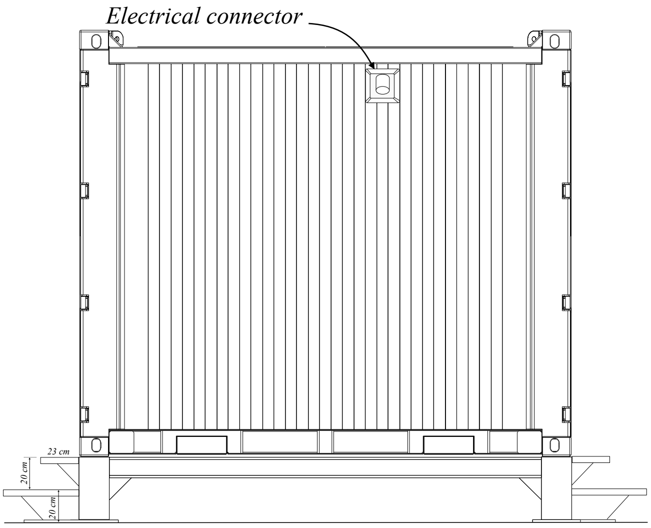
Note that, as already indicated for the LARS, the structure of the container must not be damaged during the transfer and the mobilization. Thus, welding sea fastenings on the structure of the offshore container is prohibited. Nevertheless, it is commonly considered suitable to fasten the container with wedges welded on the floor that imprison the container using the ISO corner fittings. Note that this procedure creates tripping hazards that must be signalled. Another solution is to weld or bolt an ISO fitting connectors to the deck and secure the container on them as it is done on container carriers.

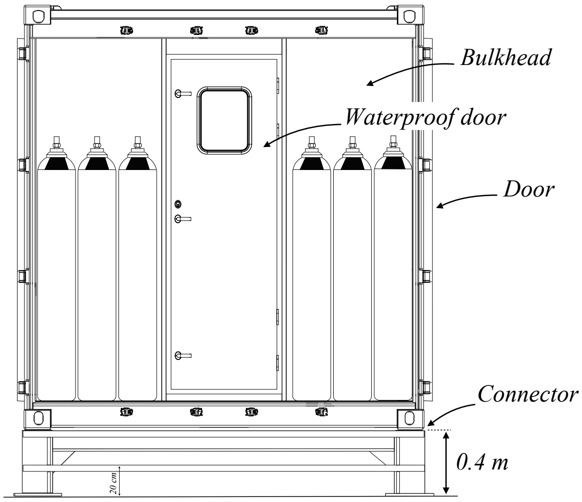
Welded wedge securing an ISO fitting



ISO fitting connector

The portable diving system may be installed on a deck that can be under the waves during rough weather conditions. In this case, despite the seals of the container doors, the waves often make sea water enter into containers.
For this reason, installing the containers approximately 40 cm above the deck is recommended to enable the waves to pass underneath. Installing containers in such a way also allows the bottom of the containers to be ventilated and thus makes them less prone to corrosion.





Prefabricated frames, as in the drawing above, are preferable to individual legs because their dimensions are adapted to each container, which simplifies their installation. In addition, they offer more stiffness and can be reused indefinitely. Of course, they should be approved by a certification body.
It is also recommended to position the electrical supplies and equipment of containers to their highest parts so that these items are not affected in case of flooding. Also, containers used as dive controls should be isolated by a waterproof door in addition to the doors of the container.

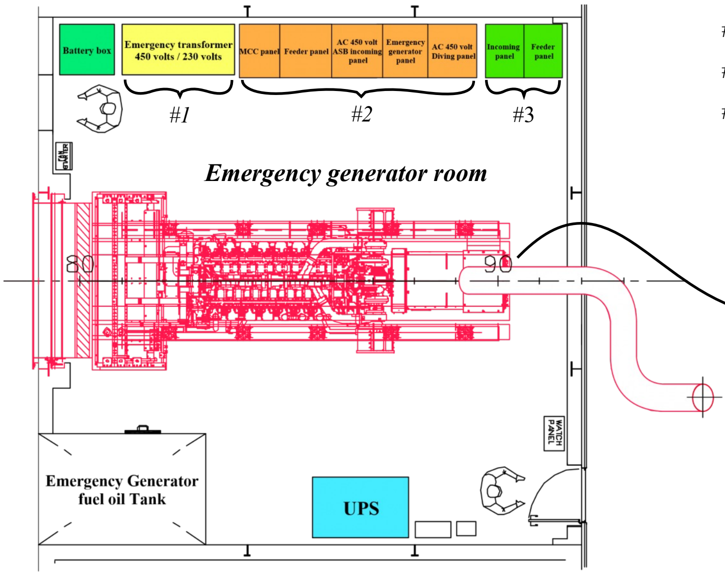
2.21.6 - Protection of control rooms against harmful and explosive gasses

There should not be diving operations in areas where emissions of harmful and explosive gasses are likely. However, the boat may be exposed to such conditions by accident, and some country rules, certification bodies, and clients require that control rooms of dive systems operating within the 500 m limit of offshore installations are protected against intrusion of harmful and explosive gasses. It must be noted that modern dive and chamber control rooms accommodate electrical and electronic equipment that can emit sparks and that an unexpected release of explosive and harmful gases may happen despite the isolations and other precautions implemented on many installations diving teams are working along.
The isolation system is similar to those designed for ROVs, already described in Book #2. It provides a pressurized area that prevents external gasses and dust intrusion into the control room and sensitive zones. Thus, the internal pressure of the room is maintained above a predetermined minimum pressure, which is commonly 0.5 mbar. That should be achieved with the lowest possible flow of gas. An alarm is fitted to the system if the pressure falls below a predetermined level (usually between 0.50 and 0,25 mbar). The enclosure must be tested to ensure that it withstands 1.5 times its normal working pressure for 2 minutes without distortion.

2.22 - Generators

2.22.1 - 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.



#1: Transformer 450 volts / 230 volts

#2: Switchboard 450 volts AC

#3: Panel 230 volts AC

V16 diesel 2065 hp + Dynamo 1540 kW

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.

2.22.2 - 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 should be secured against becoming loose due to vibration.

2.22.4 - 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.

2.22.5 - 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 in addition to the name of the manufacturer and the traceability code.

2.22.6 - 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 ≤ P ≤ 560*	*5*	*1.3*	*9.2*	*0.54*
B	*75 ≤ P < 130*	*5*	*13*	*9.2*	*0.7*
C	*37 ≤ P < 75*	*6.5*	*1.3*	*9.2*	*0.85*
Stage 2 - Compression engines (diesel)					
E	130 ≤ P ≤ 560	3.5	1	6	0.2
F	75 ≤ P < 130	5	1	6	0.3
G	37 ≤ P 75	5	1.3	7	0.4
D	18 ≤ P < 37	5.5	1.5	8	0.8

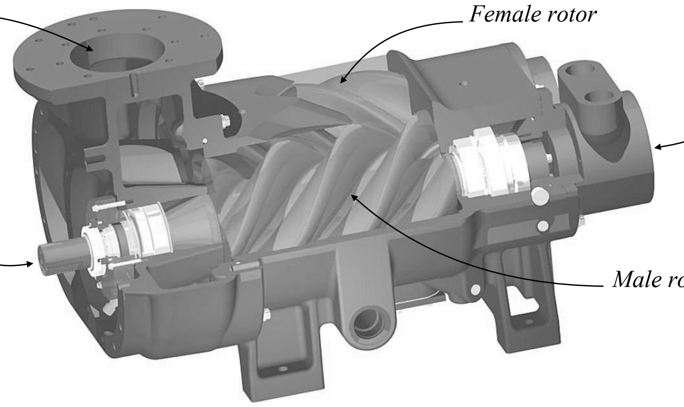
2.22.7 - Other hazards

- 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.

2.23 - Industrial air compressors

2.23.1 - Purpose and description

Industrial air compressors are used to energize the pneumatic winches of some Launch and Recovery Systems. They are also used to power the transfer pumps used to fabricate mixes and transfer oxygen, in addition to various tools such as airlifts and pneumatic tools used on the deck.
Industrial compressed air can be provided by the compressors of the ship, or by portable units when the systems in place on the vessel are insufficient. These machines are designed to provide air at average pressures between 10 - 14 bar for the majority of the models in service, but which can be up to 24 - 25 bar for some models. The volumes of air delivered vary from 1 m³ / min to 23 - 25 m³ /min. Most built-in machines are driven electrically, and majority of mobile industrial compressors are powered by diesel engines.
Industrial air can be compressed by reciprocating piston compressors with a design similar to those used for breathing air and described in point 2.12.1 “Reciprocating piston air compressors”. However, even though piston compressors allow to to obtain pressures above 300 bar, they are limited in volume of air delivered compared to screw compressors that cannot deliver such elevated pressures, but have been adopted by most industries because they can deliver large volume of air at the pressures mentioned above that are the pressures used by the tools they are designed to energize.
These compressors consist of two screw male and female rotors in place of pistons and give a continuous pulsating-free discharge. Two shafts usually activate the rotors: One is the driving shaft which is part of the male rotor, and the other is the driven shaft which is part of the female rotor. The driving shaft is connected to the driven shaft via timing gears, so both rotors rotate at the same speed. The driving shaft is powered by an electric motor or a thermal engine. The two rotors are enclosed in an airtight casing. They rotate at high speed and, for this reason, provide high throughput.



Note that screw compressors are often used to supply Pressure Swing Adsorption (PSA) Oxygen generators. A specific filtration is added to provide oxygen compatible air. Some models of screw compressors are oil free.
EN 1012 and EN ISO 4414 are applicable to compressors and compressor units having an operating pressure greater than 0,5 bar and designed to compress air, nitrogen or inert gases.

2.23.2 - Selection and installation of the associated components

The components and piping should be selected and installed in accordance with the manufacturer's recommendations. It is recommended that components and piping made in accordance with recognized international standards should be used. These components should be selected or specified so that the users are safe when the compressor is used. They should operate within their rated limits. Designers and installers should focus on their reliability, and the hazards they can create in case of failure or malfunction should be considered.

- If used, rigid piping should be mounted to minimize stresses; they should be protected against foreseeable damage and should not restrict access for adjustment, repairs, or replacement of components. The piping should not be used to support features that can impose undue loads. These excessive loads can arise from component mass, shock, vibration, and pressure surges.
- The flexible air supply hoses should conform to EN ISO 2398 “Rubber hoses, textile-reinforced for compressed air. specification”. They must be regularly checked and changed if necessary.
- Ropes should be installed along the air hoses, and be secured to them at least every 20 cm. The aim of this system is to keep the hoses in one piece and prevent the whipping in case of rupture of the hose under pressure.
- “Hose arresters” should be installed at each coupling to prevent whipping in case of a connection failure *(see the picture on the side).*

- The coupling used should conform to a recognized standard and to the maximum pressure delivered by the compressor.
- The flow rate through piping should not create hazards due to temperature change or pressure drop. Variations in the flow rate should be minimized by avoiding sudden changes in internal diameters of piping.
- The length of the piping/hose between actuators and their directional control valves should be kept to a minimum to optimise the response time. Also, the number of connections should be kept to a minimum.
- Installation of flexible hose assemblies should:
    - Have the minimum length necessary to avoid sharp flexing and straining of the hose during the component

operation. Flexible hoses should not be bent with a radius smaller than the recommended minimum bending radius.
    - Minimize torsional deflection of the hose during the installation and use, e.g. as the result of a rotating connector jamming.
    - Be located or protected to minimize abrasive rubbing of the hose cover.
    - Be supported, if the weight of the hose assembly could cause undue strain.
- Piping/hoses should be identified or located in such a manner that it is not possible to make an incorrect connection that can cause a hazard or malfunction.
- The manifolds should be rigidly and securely mounted, and should not malfunction due to distortion when operated within the intended range of operating pressures and temperatures. Mechanically and manually operated valves should be installed so that they cannot be damaged by foreseeable operating forces.
- Rigid pipes or/and rubber hoses across access ways should not interfere with the normal use of the access way. They should be located either below or well above the floor level and in accordance with site conditions. The hoses/pipes should be readily accessible, rigidly supported, and where necessary, protected from external damage.
- Exposed openings in pneumatic systems and components, in particular tubes and hoses, should be protected during transportation either by being sealed or by being stored in an appropriately clean and closed container. Male threads should be protected. Any protective device used should be of the type that prevents reassembly until it is removed.

2.23.3 - Isolation from energy sources

The system shall be designed and constructed so that components and controls are located where they are easily accessible for use, adjustment and maintenance without causing hazard. Also, it should be designed to facilitate positive isolation from energy sources. That can be done by:

- Isolating the supply with a suitable shut-off device, which should be lockable, and shall be accessible without causing a hazard, or isolating and dissipating pressure from the system with a suitable shut-off device(s) having a pressure-release feature, which can need to be lockable;
- Releasing or supporting mechanical loads when the system is depressurized.
- Protection from the electricity: The precautions indicated for the electrical generators should apply to electrically powered compressors.

2.23.4 - Protections similar to those in force with generators *(see point 2.22)*

The precautions for the hazardous areas (zone 0, zone 1, zone 2), harmful gas emissions, protection from moving and scalding parts, and the prevention of fire hazards are those previously described for generators in point 2.22.

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3 - Maintenance of the diving system

3.1 - Organize a reliable surface supplied diving system

3.1.1 - Purpose

Diving 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, 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:

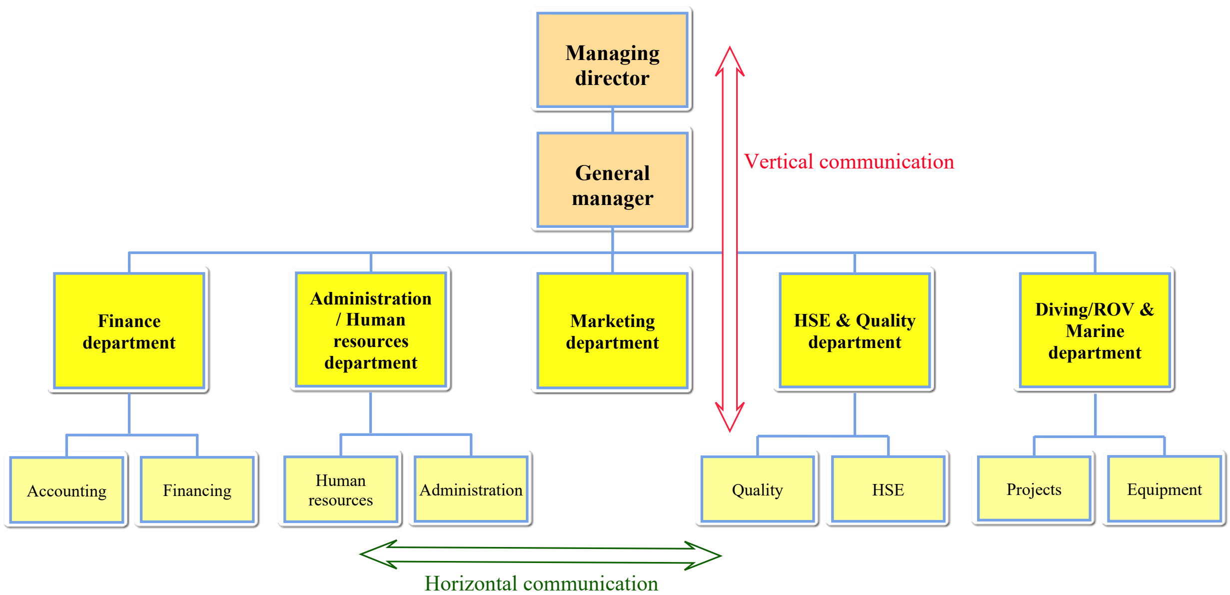
- The solving of breakdowns of systems during the operations.
- The preventive maintenance of systems in use and stored.

As a result, the maintenance of diving 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 diving 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 helmet maintenance 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 diving systems that are computerized require specific competencies that were not asked for in the past.
For these reasons, the owners of the last generation diving 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 Planned 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 diving 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.

Another option often implemented by companies is to rent the system. The advantage of renting a system is that its owner 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 some clients, particularly some members of the "International association of Oil & Gas Producers (IOGP)", request that the diving 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 diving 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 diving 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

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 surface supplied diving 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, wet bells,						
Hull	X	X	X		X	X
Basket & wet bell structure	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
Bell & basket 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 pipework (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 divers (If used for heliox diving)						
Compressors			X	X	X	X
Scrubbers			X	X	X	X
Filters				X	X	X
Gas receivers & volume tanks	X		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
Umbilicals						
Bell umbilical			X	X	X	X
Bell umbilical winch	X			X	X	X
Diver umbilicals			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 (usually not present)				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.

- 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 diving system 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	Extremely 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 can 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 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 such as D 023, D 037, or D 040 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 behaviour, 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 4.3.1.

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:

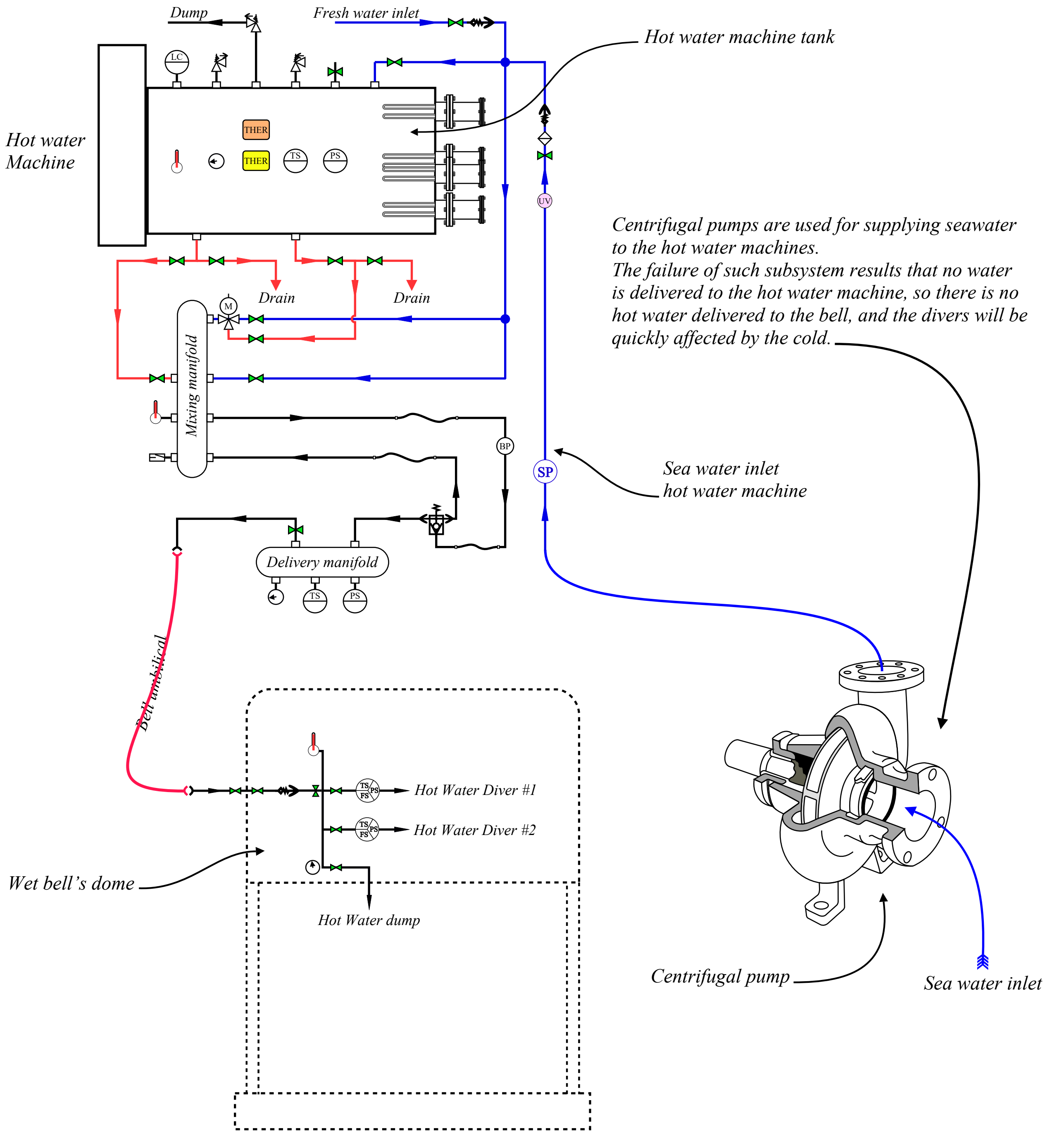
- The worksheet records the following elements:
  - Identification of the system
  - Function and operating mode
  - Failure mode identified and the cause of this failure
  - The effects of the failure
  - Critical analysis
  - Mitigation and notes
- The FMEA management of change sheet indicate the following 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.

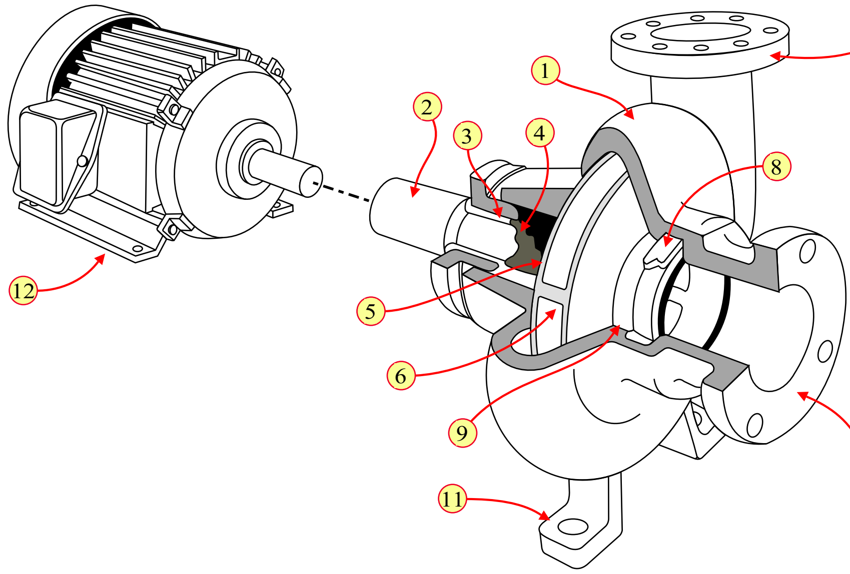
3.3.5 - Failure Mode Effect Analysis forms adapted to dive systems

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 4.3.3, It is necessary to give a limit, because an FMEA can yield a great deal of information relating to failure behaviour 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 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 Table 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 diving 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 023, D 037 & D 040 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 or the document selected, 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 4.1.2.2, 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 4.1.2.3, the use of external service providers is usual for the maintenance of 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 4.1.2.3.

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 diving system, 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

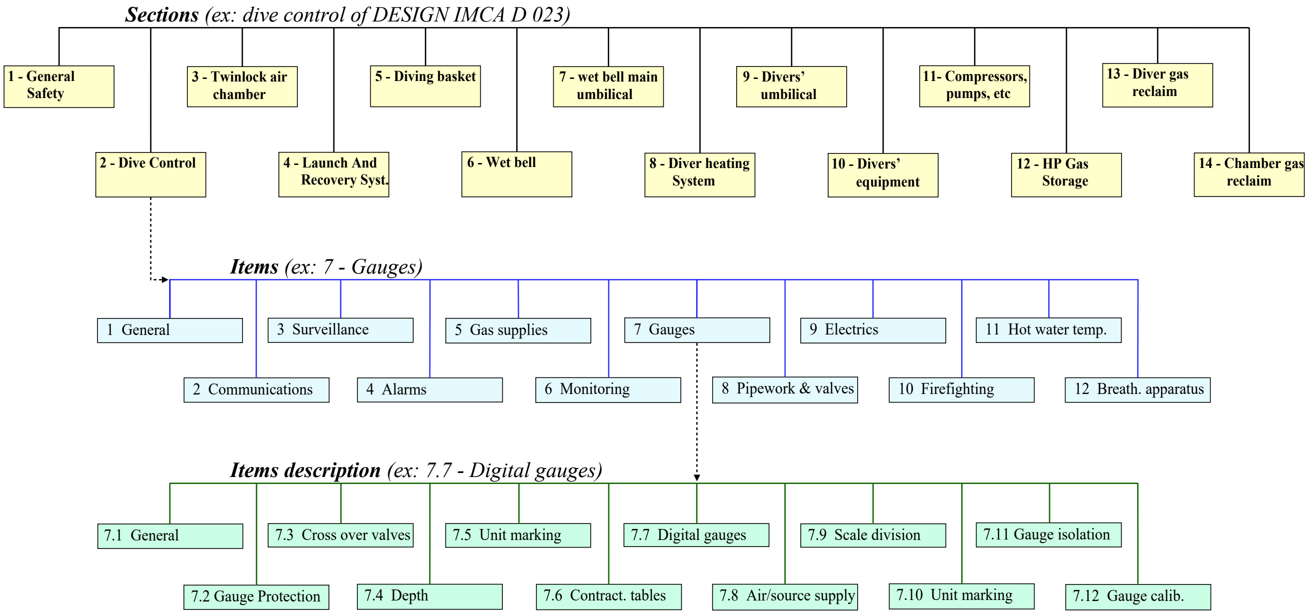
Reference numbers are the identification system most used. It usually allows to indicate where the element is installed, and its function and model. These reference numbers must be listed and also indicated in a reference document.
To locate the exact position of the elements, a precise scheme/drawing 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 audit 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 DESIGN documents. 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 Notes (DESIGN) are organized as follows:

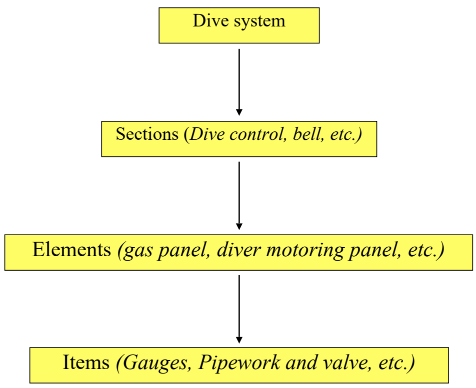


With this method of referencing, the items (as an example, the gauges) are grouped by function in the dive control. As an example, the gauges are all listed in the same file where the role and situation of each of them are to be indicated.

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:

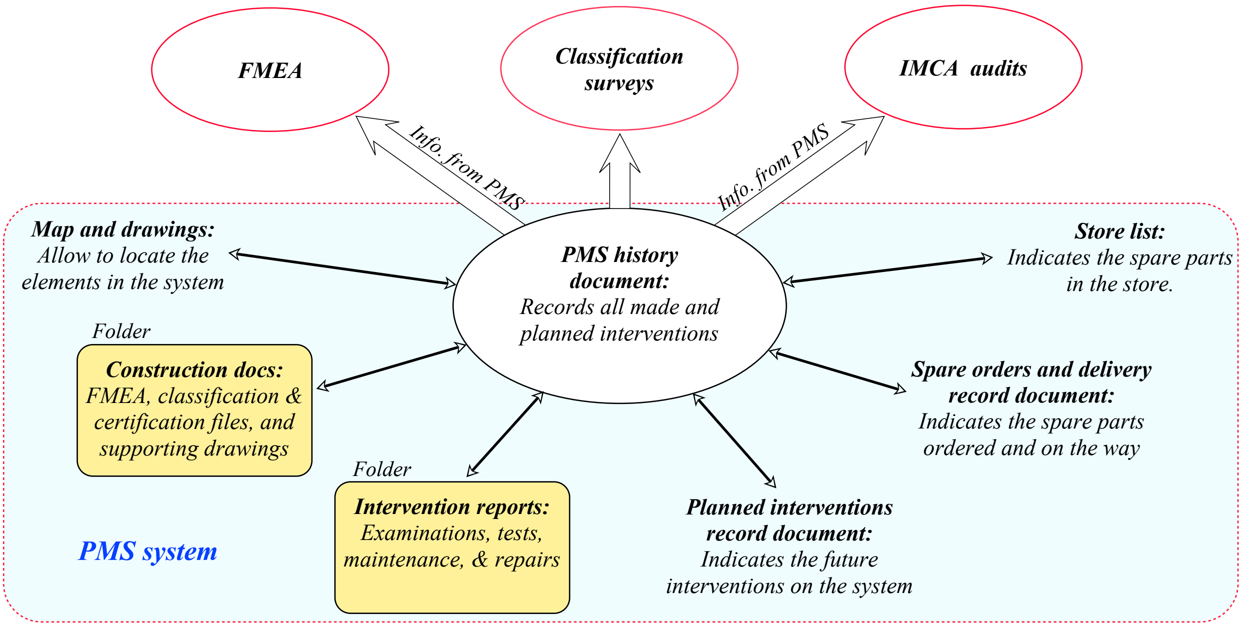
- Make sure that each item is precisely located and easy to find. If necessary photos can be used.
- Give a reference number or code to each item
- Write a glossary of acronyms or codes that are used
- Write a list of the items that are represented on the schemes/drawings and indicate where to find their 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 4.4.1 & 4.4.2, it is mandatory that the planned Maintenance System provides a history of the interventions performed on the system. Also, as discussed in point 4.3 "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 4.4.3.2 may become complicated to implement with companies using several diving 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

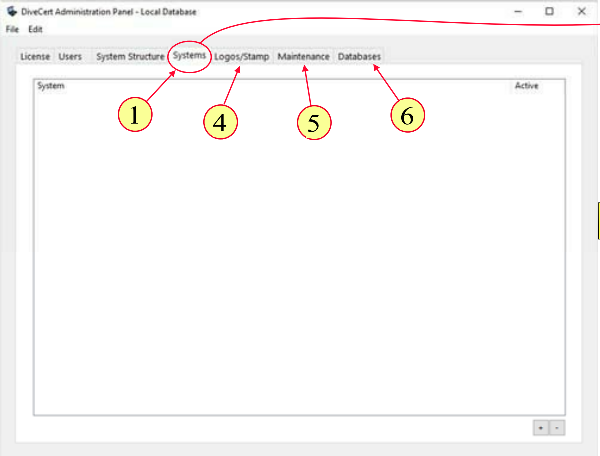
DiveCert is a certification, asset management, and planned maintenance software system, specifically designed for the diving industry by Namaka subsea that is designed to work with “Microsoft Windows” and “Apple OSX” operating systems. This software is designed to eradicate issues in the planned maintenance System and preparing IMCA audits efficiently. It is based on the following IMCA guidelines:

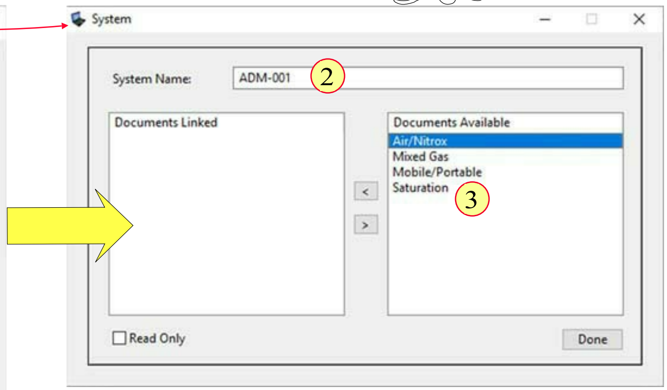
- IMCA D 018 - “Code of practice for the initial and periodic examination, testing and certification of diving plant and Equipment”
- IMCA D 023 - “Diving Equipment Systems Inspection Guidance Note for surface orientated (air) diving systems”
- IMCA D 024 - “Diving Equipment Systems Inspection Guidance 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)*





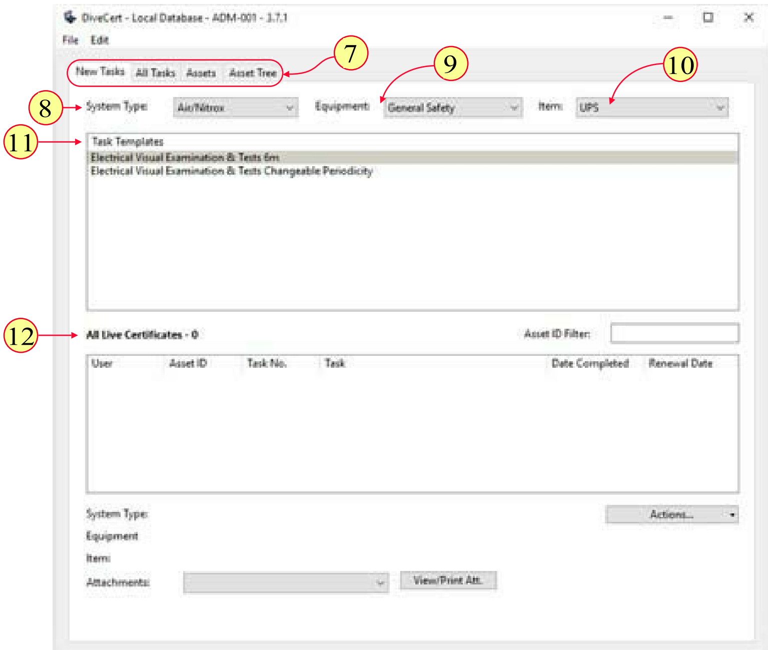
When the window "System" is opened, the operator can give a name to the dive system by highlighting the 'System Name' and retyping the name he desires *(See #2),* and select the type of system among the documents types *(see #3)*

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)*.



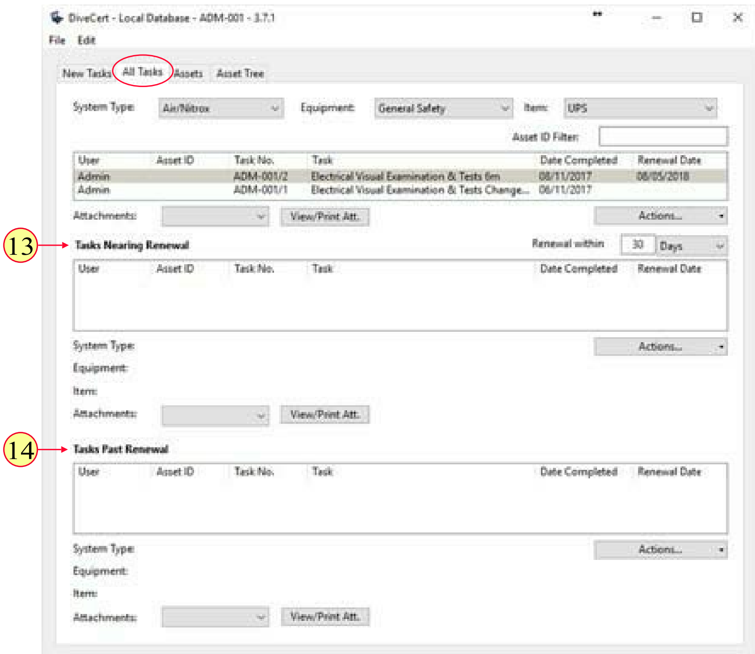
Two menu are visible when the tab "New Tasks" is selected:

- "Task Templates" *(see # 11)* displays the different task templates available.

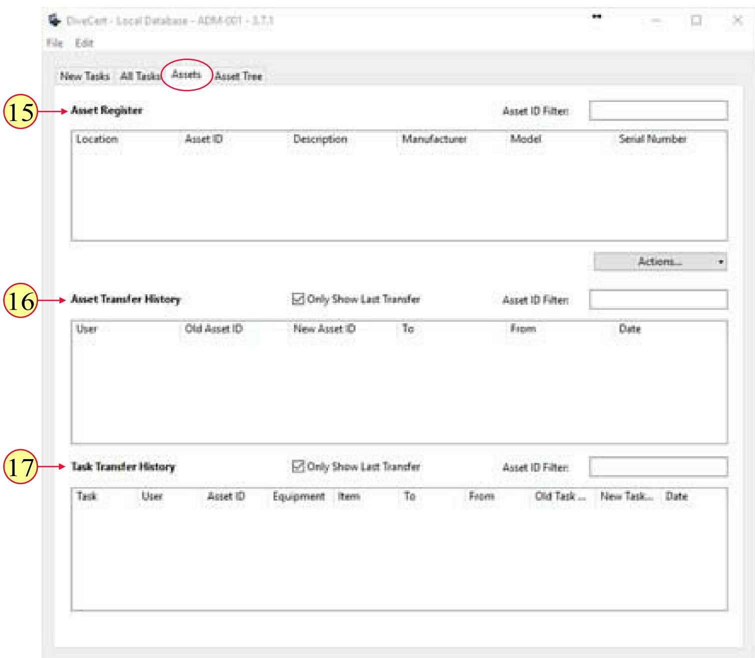
- "All Live Certificates" *(see # 12)* displays the current system live certificates, date completed, and renewal dates. This function of this section is the reviewing of live documents. Clicking the "Actions" button opens options such as:
    - "Print": Printing out a single selected certificate.
    - "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)*.

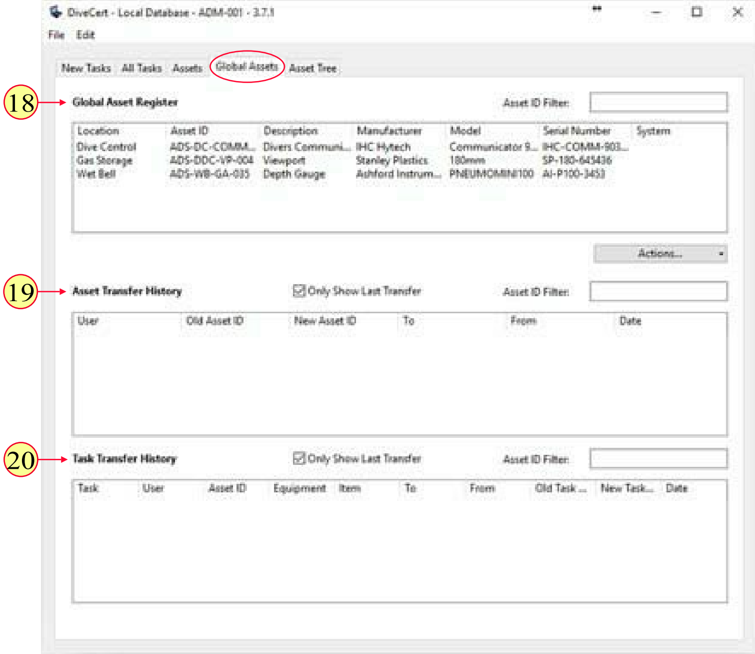


Clicking on “Asset” tab opens a window that shows the assets for the system the user has logged into. This panel allows to see the “Asset register” *(see #15)*, “Asset transfer history” *(see #16)*, and “Task transfer history” *(see #17).It* is accessible to all users that are limited by the privileges given by the software administrator.



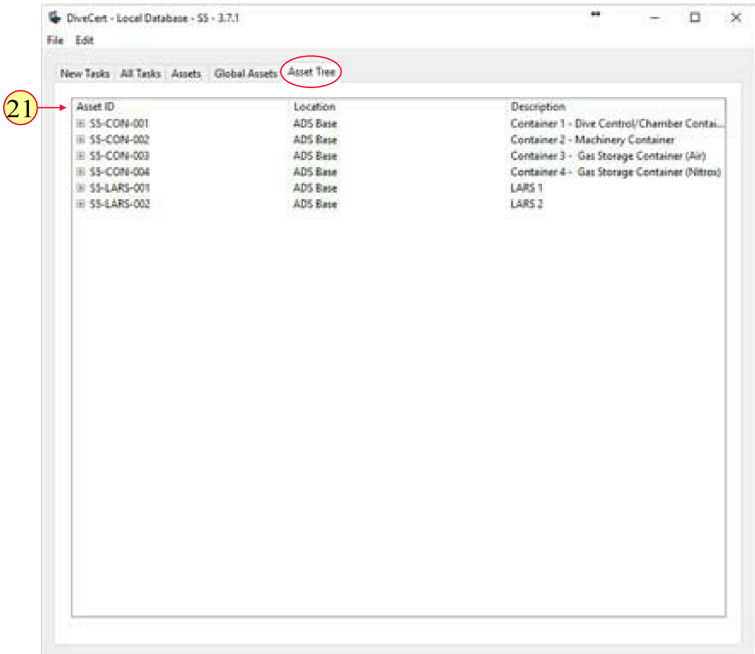
- “Asset Register” shows all the system asset identifications and descriptions, filtering the system assets can be achieved easily by using the Asset identification filter if required.
- “Asset Transfer History” shows the logs that are automatically performed when transferring an asset. The program identifies 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.

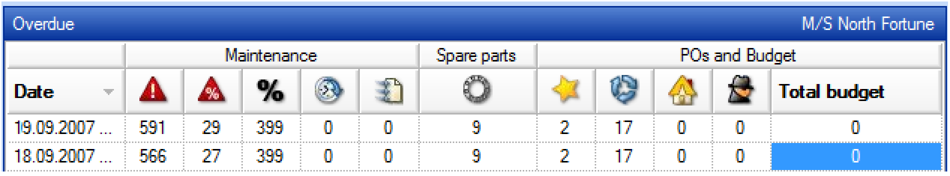
Note that Namaka Subsea provides online technical support and can organize training

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.

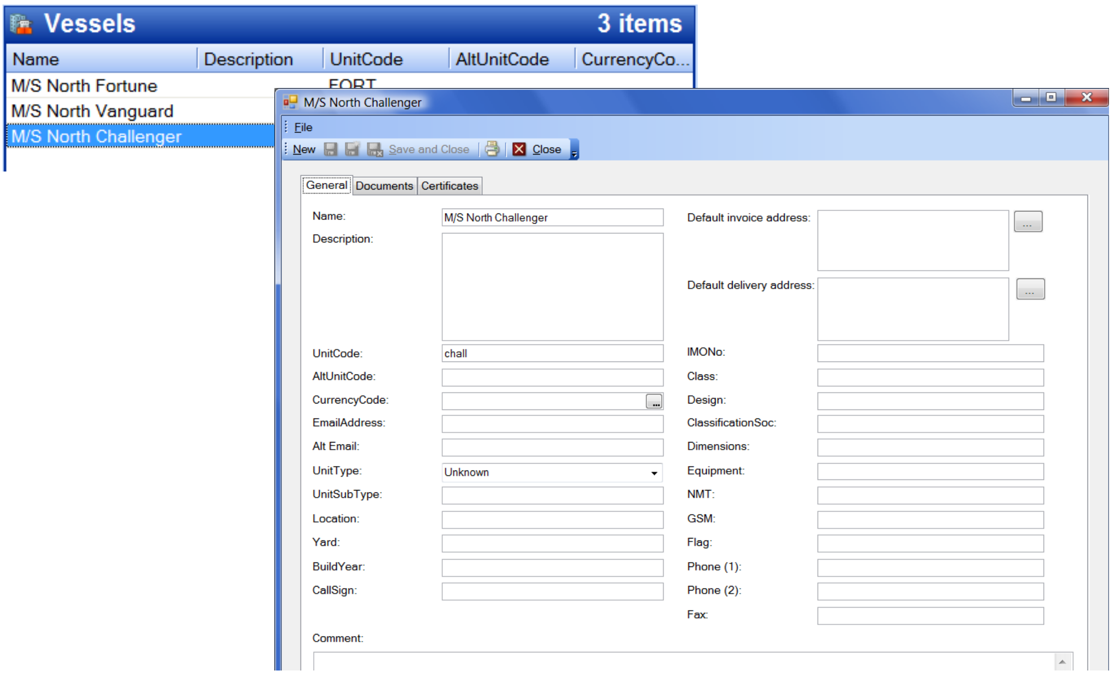
- 1 - “Fleet” module gives an overview of the entire fleet through the nine following tools:

- 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.



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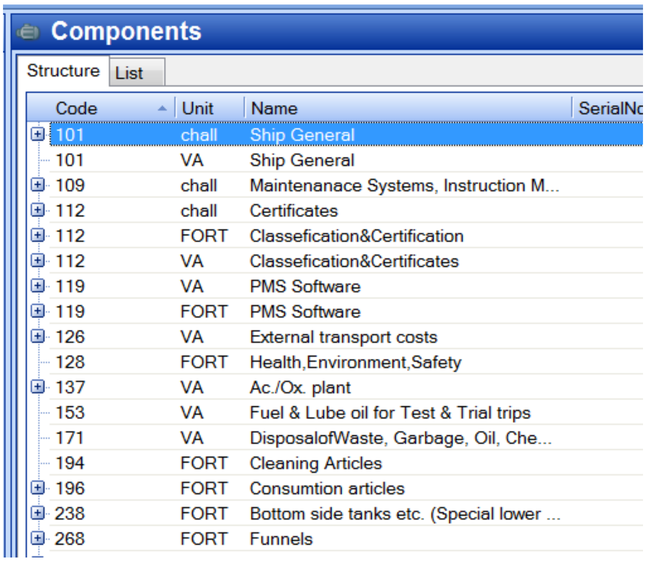
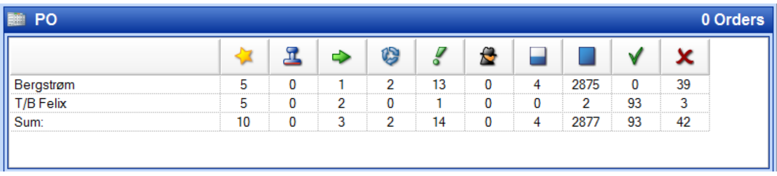
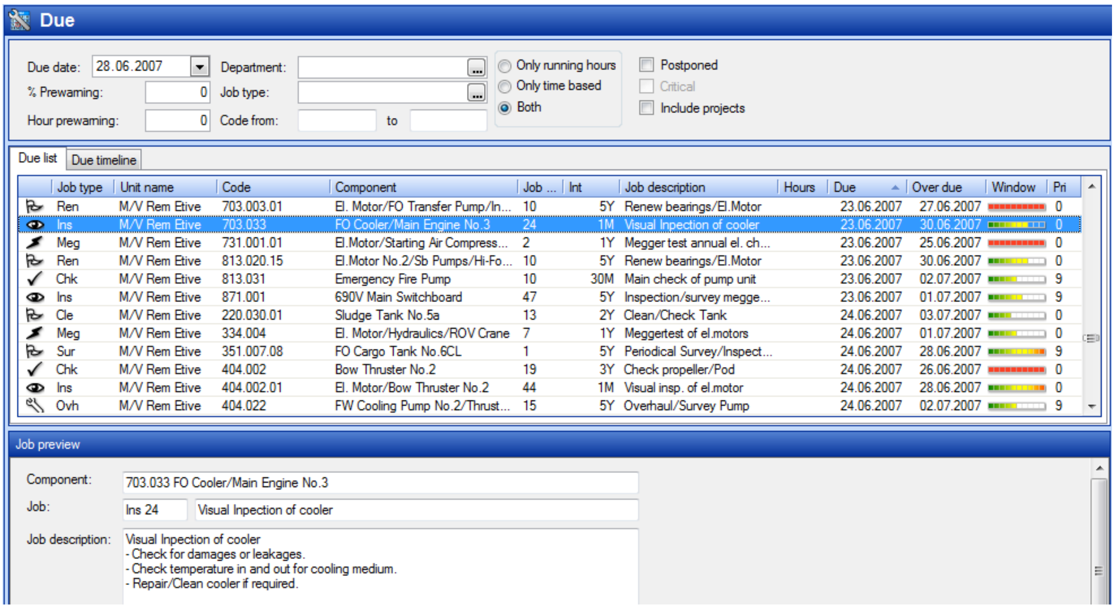
- Components: Show the components and systems of all vessels across the fleet.



- "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.

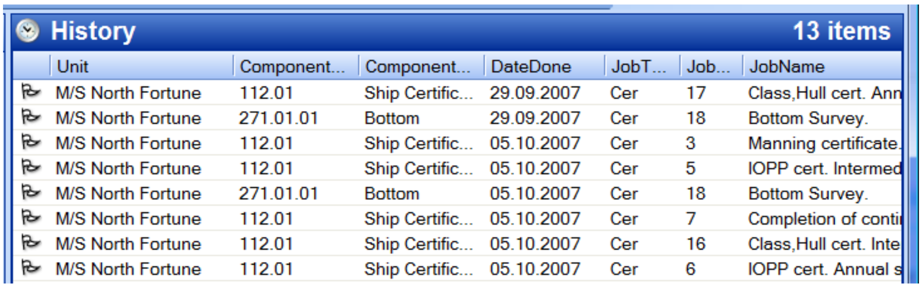


- Due: Gives an overview of scheduled jobs such as:
  - Checking jobs.
  - Annual survey, certificate renewal, service, check/clean components jobs.
  - Visual inspection type jobs
  - Lubrication and oil change jobs
  - Megger test jobs *(The Megger test is a method of testing making use of an insulation tester resistance meter that will help to verify the condition of electrical insulation)*.
  - Overhaul jobs

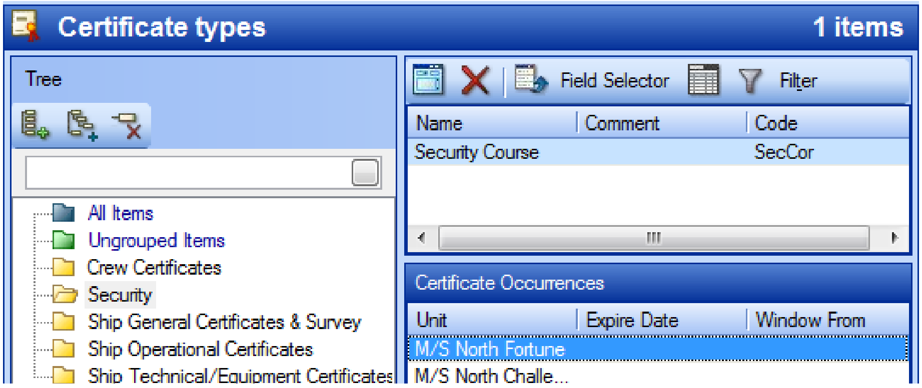


Hyperlink Table of contents

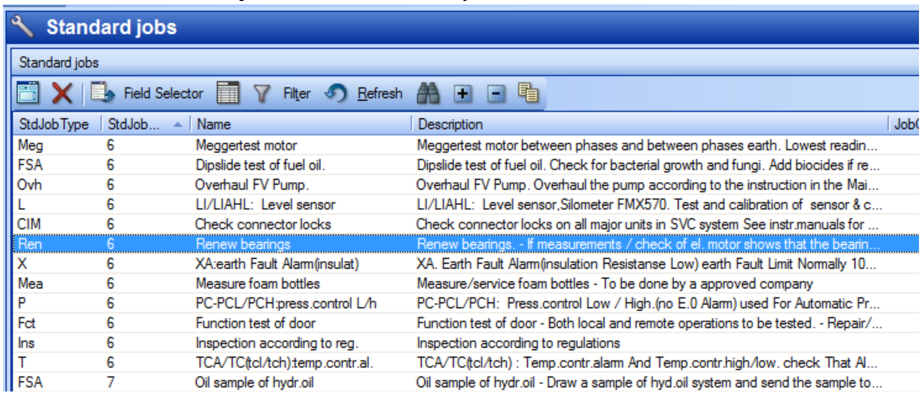
- History: shows all jobs that have been done on components on all vessels within the fleet.



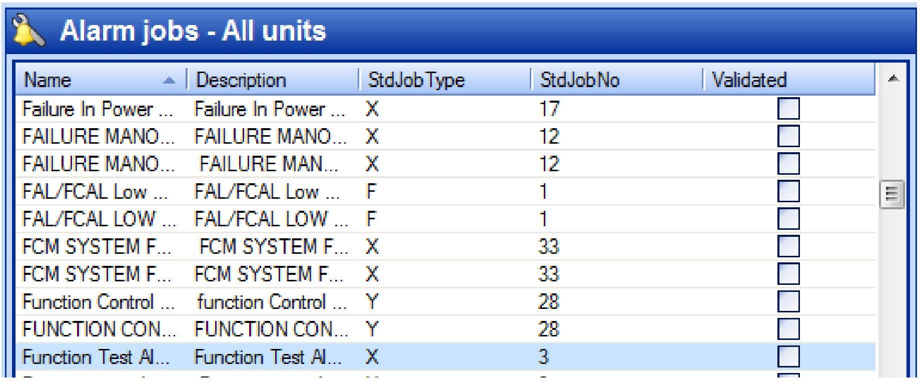
- Certificates overview: Shows an overview of the certificates within the fleet.



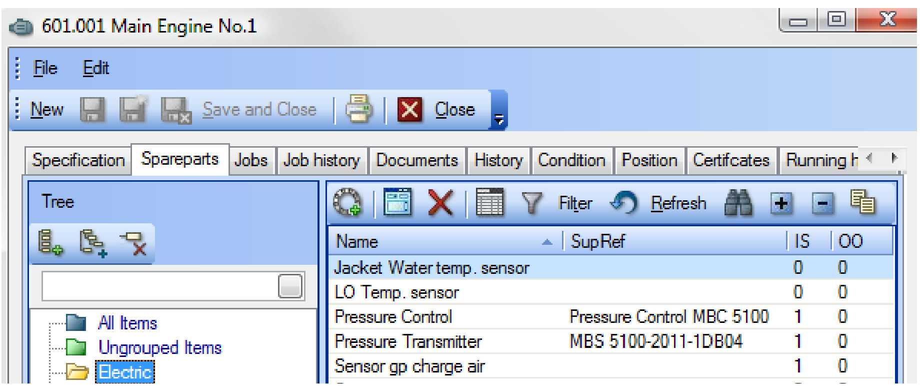
- Standard jobs: Shows all standard jobs defined on the system.



- Alarm jobs: Shows all alarm jobs set in the system



- Stock: Shows stocks across the fleet.



- 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.

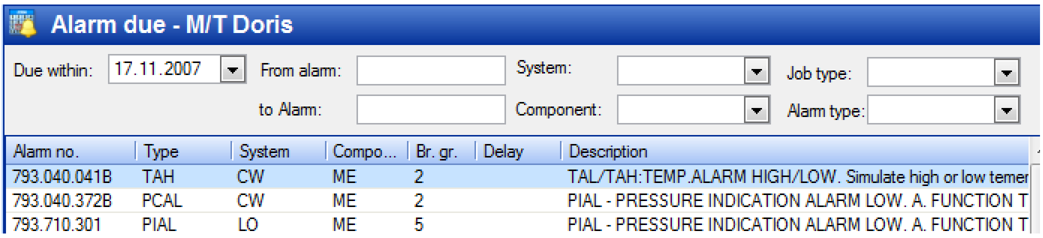
Due list | Due timeline

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:

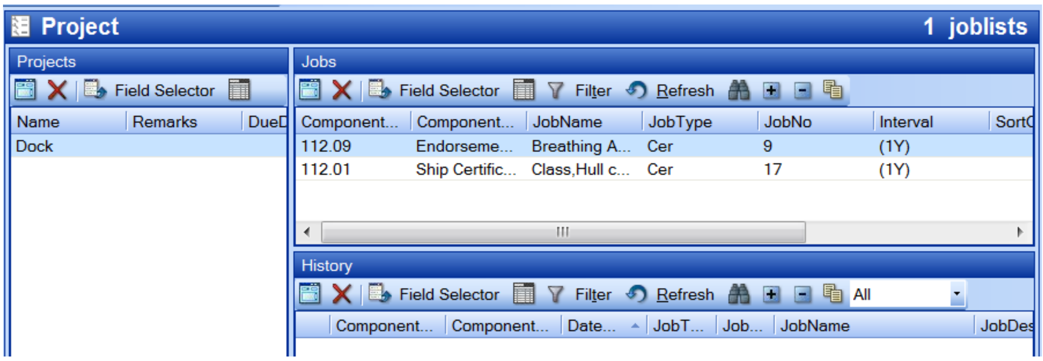
- search for jobs
- indicate due job work details
- organize and check the interval between two interventions
- automatically withdraw spare parts from the stock if the job always require the use of particular spare parts.
- designate the person in charge and the crew for the job, and enter an estimate 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.

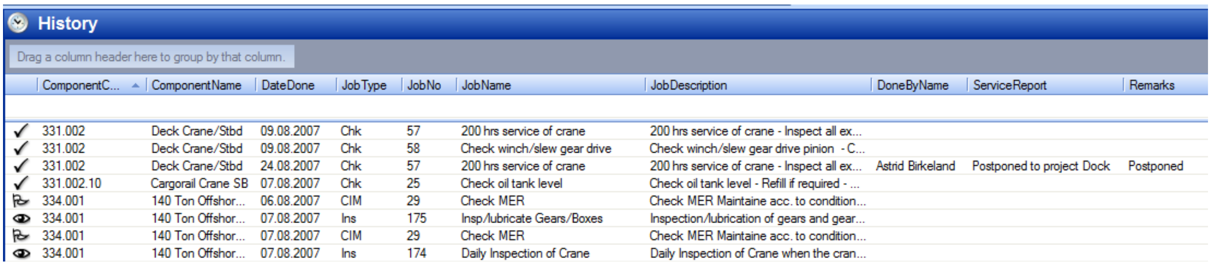


This program provide tabs that open windows that give details about the alarm, and allow to close the job.

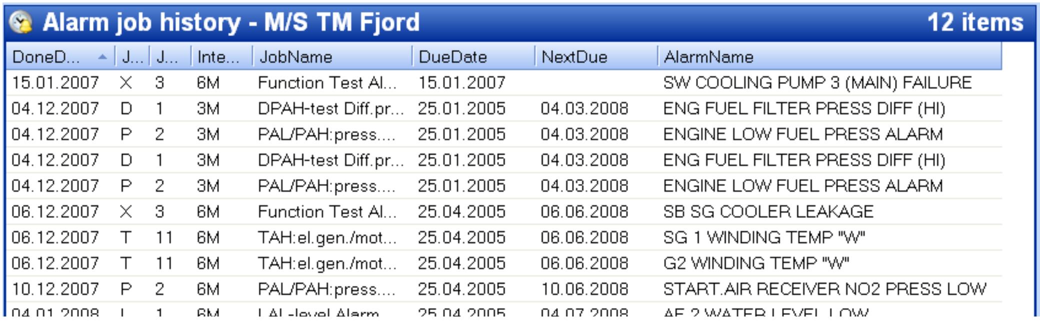
- "Project" is a function that allows the user to collect and group different jobs. If the user wants to postpone tasks until the vessel is going to dry dock, it is possible to create a project and delaying the job to this project.



- "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.



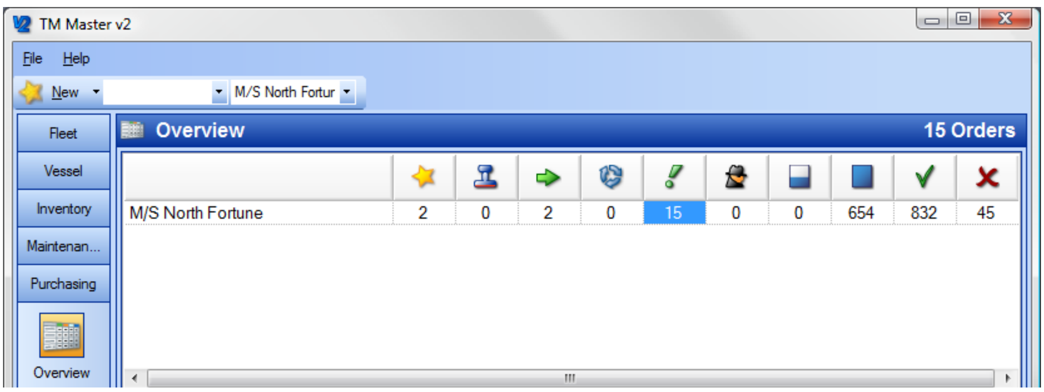
- "Alarm job history" is a function that shows the tests that have been done on alarms.



- "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.



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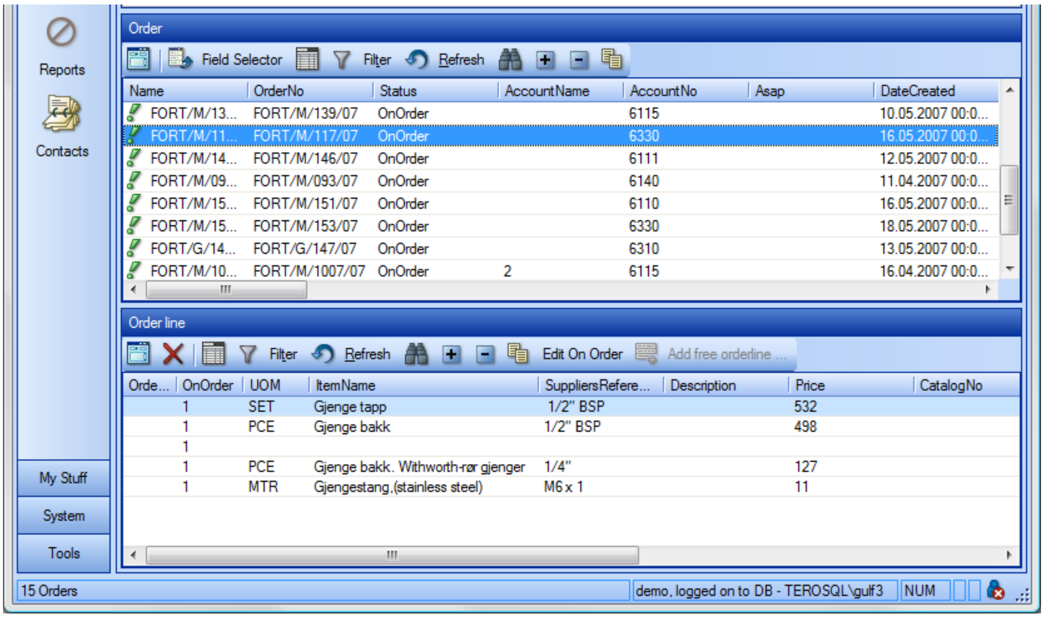
This window provides the following information:

- 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.
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 4.4.3.1, 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.

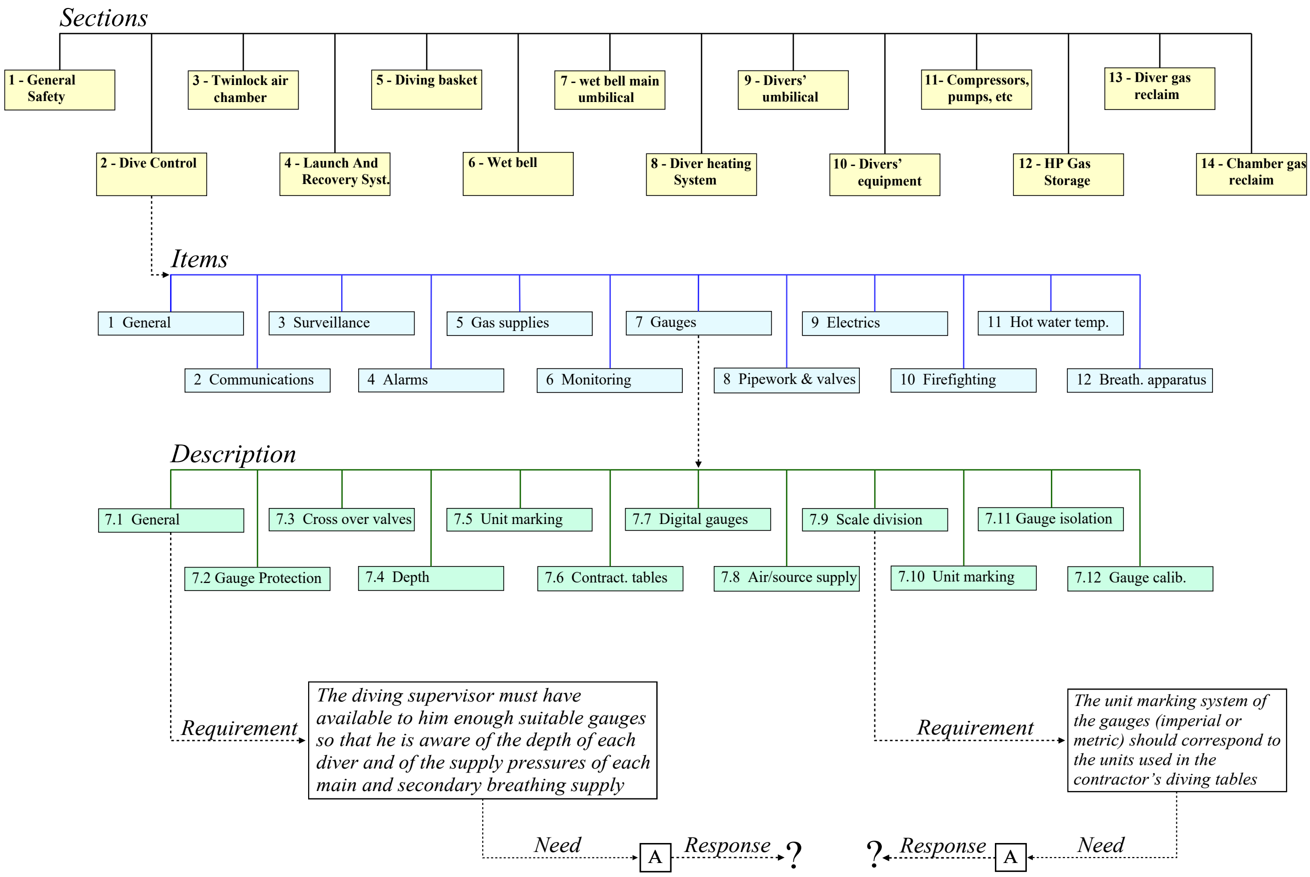
It is recommended that items not required for a particular system are not deleted but rather are marked as "not applicable". This will ensure that the tables in the various sections look similar to a master copy of the blank document, which may make it easier for a subsequent person to check.

- 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.

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 4.5.1.2, 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 4.1.2.3 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.

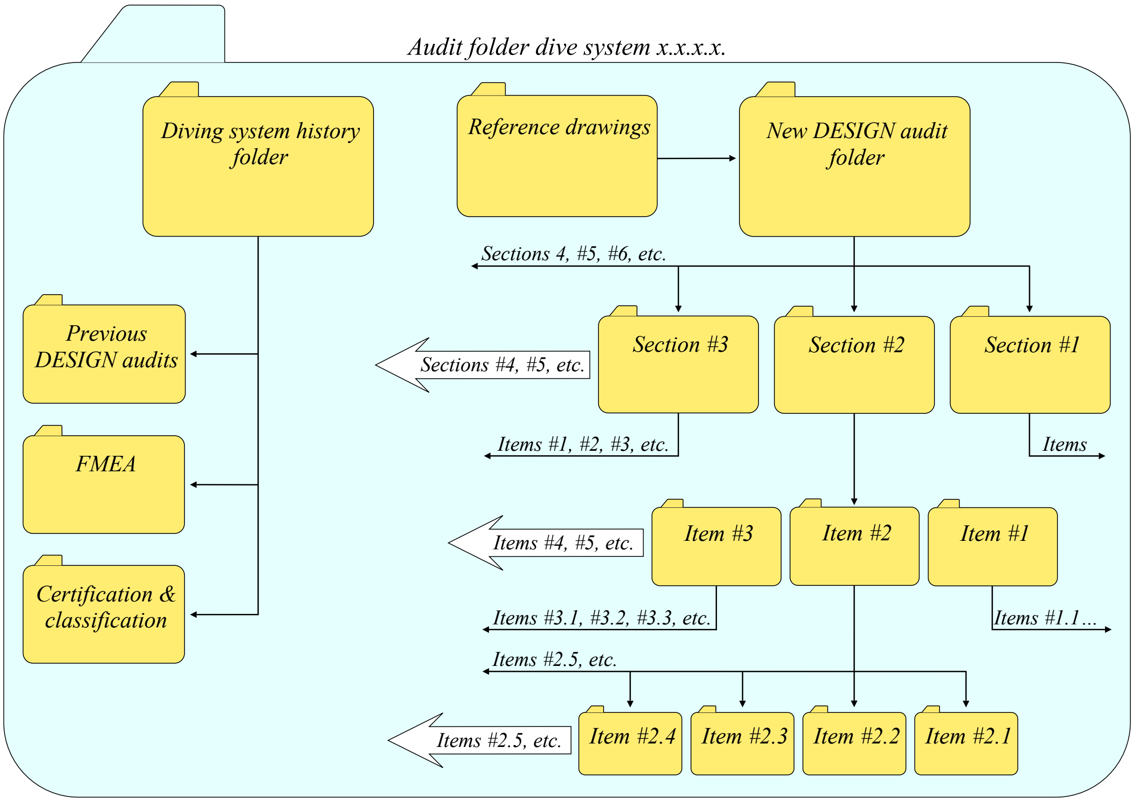
IMCA also indicates that when a disagreement occurs on the audit findings between the auditors and the diving contractor that cannot be resolved on-site, such problems are usually addressed internally by senior management within the organizations with further dialogue and resolution. However, such a 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 4.5.1.3.
    - 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 023, D 037, and D 040 must be used as support by the supervisors and the diving technicians to check the diving 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 023 - Certifications list

Section	Item # & 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
General safety	1.1 - Classification (If classified)				
General safety	4.5 - Sea Fastening (Design)				At system installation
General safety	4.6 - Sea Fastening				At system installation
General safety	7.6 - Electrical Power	6 months			
General safety	9.3 - Medical kit DMAC 15	6 months (Medic)			
Dive control	2.13 - Communications	6 months (1;2;4)			
Dive control	6.3 - Analysers	6 months (1;2;4)			
Dive control	7.12 - Gauges (calibration)	6 months			
Dive control	8.8 - Pipe works & valves	6 months	2 years	When new	
Dive control	8.12 - Relief valves	6 months	2 ½ years		
Dive control	Oxygen cleaning pipe works and regulators	6 months (2,3,4)	6 month is a minimum: The frequency of oxygen cleaning must be organised according to the working conditions		
Dive control	9.3 Electrics	6 months			
Dive control	10.2 & 10.3 - Portable fire fighting system	6 months			Manufacturer specifications
Dive control	10.2 & 10.4 - fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
Dive control	10.6 - Automatic fire detection	12 months			
Dive control	12.3 to 12.5 - Emergency breathing apparatus	6 months (1;2;4)	2 ½ years (3;4)	5 years (3;4)	
Chamber	1.6 - Communication	6 months (1;2;4)			
Chamber	2.7 & 2.7 - Pressure vessel	6 months	2 ½ years		
Chamber	3.5 to 3.9 - Viewports	6 months	2 ½ years	5 years (3;4)	10 year old max.
Chamber	4.2 & 4.3 Portable fire fighting	6 months			
Chamber	10.2 & 10.4 - fixed fire fighting system	Visual: 6 months Test: 12 months			
Chamber	10.6 - Automatic fire detection	12 months			

Section	Item # & 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
Chamber (external)	5.6 - Electrical penetrators certification				Permanent cert. (3;4)
Chamber (external)	5.16 & 5.17 Medical lock pipework	6 months	2 years		
Chamber (external)	5.19 - Pressure relief valves	6 months (1;2;4)	2 ½ years (2;4)		
Chamber (external)	5.21 - Electrical testing	6 months (2;3;4)			
Chamber (external)	5.23 & 5.24 - Valves & pipe works	6 months	2 years		
Chamber (internal)	6.13 - Communication	6 months (1;2;3)			
Chamber (internal)	6.14 - BIBS	6 months (1;2;4)			
Chamber (internal)	6.22 - Sanitary system (if installed)	6 months			
Chamber (internal)	6. 28 - Fire fighting	6 months			
Chamber (internal)	6.30 - Gauge calibration	6 months (2;3;4)			
Chamber (internal)	6.32 - Scrubber	6 months			
Chamber (internal)	6.35 & 6.36 - Valves & pipe works	6 months	2 years		
Chamber (internal)	6.37 - Electrical equip. and cables	6 months (2;3;4			
Chamber (control panel)	7.12 & 7.13 - Pipe works, valves , regulators	6 months	2 years		
Chamber (control panel)	7.15 - Gauges calibration	6 months (2;3;4)			
Chamber (control panel)	7.17 - Analysers	6 month (1;2;4)			
Chamber (control panel)	7.19 & 7.20 - relief valves	6 months (1;2;4)	2 ½ years (2;4)		
Chamber (control panel)	8.4 & 8.5 - BA sets	6 months (1;2;4)	2 ½ years (3;4)	5 years (3;4)	
LARS	2.13 & 2.14 - Main winch testing	6 months		12 months (2;3;4) (+ dynamic 1.25 SWL)	12 months (2;3;4) (NDE critical areas)
LARS	3.3 - Lubrication main wire (by pressure)				6 months
LARS	3.5 to 3.7 - Main wire testing	6 months	12 months	12 months	
LARS	4.1 - 2nd lifting system: Basket/bell recovery demo.				12 months
LARS	4.17 & 4.18 - 2nd recovery winch testing	6 months		12 months (2;3;4) (+ dynamic 1.25 SWL)	12 months (2;3;4) (NDE critical areas)
LARS	4.21 - Lubrication secondary wire (by pressure)				6 months
LARS	4.23 to 4.25 - secondary wire testing	6 months	12 months	12 months	
LARS	6.7 - Hydraulic system test.	6 months (2;3;4)			
LARS	6.8 - Intercooler	6 months (2;3;4)			
LARS	6.10 - Hydraulic oil analysis or replacement				12 months (2;3;4)
LARS	Relief valve (Hydraulic)	6 months	2 ½ years		

Section	Item # & 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
LARS	7.6 & 7.7 - Pneumatic hose	6 months	2 years		
LARS	8.7 - Electric winch: Electrical testing	6 months (2;3;4)			
LARS	9.2 - Communication	6 months (1;2;4)			
LARS	10.2 & 10.3 - Overall testing of LARS	6 months (2;3;4)		12 months (2;3;4) (+ dynamic 1.25 SWL)	12 months (2;3;4) (NDE critical areas)
LARS	11.3 & 11.4 - Portable fire fighting system	6 months			Manufacturer specifications
LARS	11.3 & 11.5 - fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
LARS	11.7 - Automatic fire detection	12 months			
LARS	13.3 - Breathing apparatus	6 months (1;2;4)	2 ½ years (3;4)	5 years (3;4)	
LARS	7.6 & 7.7 - Pneumatic hose	6 months	2 years		
LARS	8.7 - Electric winch: Electrical testing	6 months (2;3;4)			
LARS	9.2 - Communication	6 months (1;2;4)			
LARS	10.2 & 10.3 - Overall testing of LARS	6 months (2;3;4)		12 months (2;3;4) (+ dynamic 1.25 SWL)	12 months (2;3;4) (NDE critical areas)
LARS	11.3 & 11.4 - Portable fire fighting system	6 months			Manufacturer specifications
LARS	11.3 & 11.5 - fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
LARS	11.7 - Automatic fire detection	12 months			
LARS	13.3 - Breathing apparatus	6 months (1;2;4)	2 ½ years (3;4)	5 years (3;4)	
Diving basket	1.3 Documentation showing the designed SWL	Note: Only for basket manufactured after 1 January 2014			Permanent
Diving basket	1.3 & 1.14 - Load test	6 months		6 months (2;3;4)	
Diving basket	2.6 to 2.8 - Emergency cylinder	6 months	2 years (3;4)	4 years (3;4)	
Diving basket	2.9 - Pressure gauge emergency cylinder	6 months			
Diving basket	2.11 & 2.12 - Pipework	6 months	2 years		
Diving basket	2.13 & 2.14 - Hoses	6 months	2 years		
Diving basket	2.16 & 2.17 - Relief valve regulator	6 months (1;2;4)	2 ½ years (2;4)		
Diver heating system	5.3 & 5.4 - Portable fire fighting system	6 months			Manufacturer specifications
Diver heating system	5.3 & 5.5 - fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
Diver heating system	5.7 - Automatic fire detection	12 months			
Diver heating system	6.1 - Hot water system	6 months			
Diver heating system	6.3 & 6.4 - Pipework	6 months	2 years		

Section	Item # & 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
Diver heating system	6.5 - Gauges	6 months			
Diver heating system	6.6 - Electrical	6 months (2;3;4)			
Diver heating system	6.7 to 6.9 - Pressure vessels	6 months	15 months (3;4)	5 years (3;4)	
Diver heating system	6.11 & 6.12 - Relief valves	6 months	2 ½ years (2;3;4)		
Divers umbilical	3.1 - Electrical components	6 months (2,3,4)			
Divers umbilical	3.2 - Hose components	6 months	2 years	Hydro test When 1st installed	
Divers umbilical	Oxygen cleaning	6 months (2,3,4)	6 month is a minimum: The frequency of oxygen cleaning must be organised according to the working conditions		
Divers personnel equipment	1.7 - Helmet	6 months (1,2,4)	**Note:** Inspection and test 12 month according to manufacturer recommendations		12 months
Divers personnel equipment	2.5 to 2.7 - Bail outs	6 months (2;4)	2 years (3;4)	4 years (3;4)	
Divers personnel equipment	2.8 to 2.10 - Composite bail outs	6 months (2;4)	2 years (3;4)		5 years (hydraulic proof pressure test)
Divers personnel equipment	3.6 - Whips & connectors	6 months	2 years		
Divers personnel equipment	3.8 - Indicating gauges	6 months			
Divers personnel equipment	3.9 to 3.11 - Pipework	6 months	2 years		
Divers personnel equipment	Oxygen cleaning all equipment	6 months (2,3,4)	6 month is a minimum: The frequency of oxygen cleaning must be organised according to the working conditions		
Compressors	3.3. & 3.4 - Portable fire fighting system	6 months			Manufacturer specifications
Compressors	3.3. & 3.5 - fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
Compressors	3.6 - Automatic fire detection	12 months			
Compressors	4.3 - Test automatic stop safety device	6 month (1;2;4)			
Compressors	4.5 - Explosion protection air compressors if $O_2 \geq 25\%$	6 month (1;2;4)			
Compressors	4.7 - Analysers	6 month (1;2;4)			
Compressors	4.8 - Relief valve	6 months (1;2;4)	2 ½ years (2;4)		
Compressors	57 to 59 - Pipework	6 months	2 years	When 1st installed (3;4)	
Compressors	6.2 & 6.3 - Receivers	6 months (2;3;4)	2 ½ years (2;3;4)		
Compressors	7.2 - Electrical testing	6 months (2;3;4)			
Compressors	8.1 - Operational testing	6 months			
Compressors	8.2 - Delivery rate	6 months			
HP and gas storage	2.1 to 2.3 - Cylinders	6 months	2 ½ years (3;4)	5 years (3;4)	

Section	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
HP and gas storage	2.4 to 2.7 - Pipework & valves (with internal cleanliness)	6 months	2 years	When 1st installed (3;4)	
HP and air storage	2.8 & 2.9 - Lifting equipment (slings, quads…)	6 months (2;3;4)		12 months (2;3;4)	
HP and air storage	2.10 - Relief valves	6 months (1;2;4)	2 ½ years (2;4)		
HP and air storage	3.3. & 3.4 - Portable fire fighting system	6 months			Manufacturer specifications
HP and air storage	3.3. , 3.5 & 3.6 - fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
HP and air storage	3.7 - Automatic fire detection	12 months			

IMCA - Diving Equipment Systems Inspection Guidance Note (DESIGN) D 037 - Certifications list

Section	Item # & 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
Dive control	Portable fire fighting system	6 months			Manufacturer specifications
Dive control	Fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
Dive control	Automatic fire detection	12 months			
Dive control	1st aid	6 months			
Dive control	Emergency breathing apparatus	6 months (1;2;4)	2 ½ years (3;4)	5 years (3;4)	
Dive control	Communications	6 months (1;2;4)			
Dive control	Analysers	6 months (1;2;4)			
Dive control	Gauges	6 months			
Dive control	Valves and pipe works	6 months	2 year		
Dive control	Oxygen cleaning pipe works and regulators	6 months (2,3,4)	6 month is a minimum: The frequency of oxygen cleaning must be organised according to the working conditions		
Dive control	Electrical equipments	6 months (1;2;4)			
Dive control	Relief valves	6 months	2 ½ years		
Chamber general	Communication	6 months (1;2;4)			
Chamber general	Fire fighting	6 months			
Chamber general	1st aid	6 months			
Chamber external	Pressure hull	2 months	2 ½ years	5 years (3;4)	
Chamber external	Viewports	6 months	2 ½ years	5 years (3;4)	10 year old max.
Chamber external	Light and cables	6 months (2;3;4)			

Section	Item # & 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
Chamber external	Pressure relief valves	6 months (1;2;4)	2 ½ years (2;4)		
Chamber external	Valves & pipe works	6 months	2 years		
Chamber internal	Viewports	6 months			
Chamber internal	Valves & pipe works	6 months	2 years		
Chamber internal	Communication	6 months (1;2;3)			
Chamber internal	Lights and cables	6 months (2;3;4			
Chamber internal	BIBS	6 months (1;2;4)			
Chamber internal	Sanitary system (if installed)	6 months			
Chamber internal	Fire fighting	6 months			
Chamber internal	Depth gauge	6 months (2;3;4)			
Chamber internal	Scrubber	6 months			
Chamber internal	Heating / cooling system	6 months			
Chamber Control panel	BA sets	6 months (1;2;4)			
Chamber Control panel	Gauges	6 months (2;3;4)			
Chamber Control panel	Analysers	6 month (1;2;4)			
Chamber Control panel	Pipe works, valves , regulators	6 months	2 years		
LARS	Main winch testing	6 months		12 months (2;3;4) (+ dynamic 1.25 SWL)	12 months (2;3;4) (NDE critical areas)
LARS	Lubrication main wire (by pressure)				6 months
LARS	Main wire testing	6 months	12 months	12 months	
LARS	lifting system: Basket/bell recovery demo.				12 months
LARS	2nd recovery winch testing	6 months		12 months (2;3;4) (+ dynamic 1.25 SWL)	12 months (2;3;4) (NDE critical areas)
LARS	Lubrication secondary wire (by pressure)				6 months
LARS	Secondary wire testing	6 months	12 months	12 months	
LARS	Hydraulic system test.	6 months (2;3;4)			
LARS	Intercooler	6 months (2;3;4)			
LARS	Hydraulic oil analysis or replacement				12 months (2;3;4)
LARS	Relief valve (Hydraulic)	6 months	2 ½ years		
LARS	Pneumatic hose	6 months	2 years		

Section	Item # & 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
LARS	Electric winch: Electrical testing	6 months (2;3;4)			
LARS	Communication	6 months (1;2;4)			
LARS	Overall testing of LARS	6 months (2;3;4)		12 months (2;3;4) (+ dynamic 1.25 SWL)	12 months (2;3;4) (NDE critical areas)
LARS	Portable fire fighting system	6 months			Manufacturer specifications
LARS	Fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
LARS	Automatic fire detection	12 months			
LARS	Breathing apparatus	6 months (1;2;4)	2 ½ years (3;4)	5 years (3;4)	
Wet bell general	Structure and lift points (visual examination)	6 months (2;3;4)			
Wet bell general	Load test + MPI of lifting points	12 months (2;3;4)			
Wet bell general	Buoyancy test			When new & during load tests (3;4)	
Wet bell gas cylinders	Cylinder	6 months	2 years (3;4)	4 years (3;4)	
Wet bell outfitting	Gauges	6 months		When installed (3;4)	
Wet bell outfitting	Pipework	6 months	2 years (3;4)	When installed (3;4)	
Wet bell outfitting	Relief valve	6 months (1,2,4)	2 ½ years (3;4)		Manufacturer set. 1st inst. (2;3;4)
Wet bell outfitting	Electricals	6 months (2;3;4)			Manufacturer set. 1st inst. (3;4)
Wet bell Main umbilical	Hose components	6 months	2 years	When installed (3;4)	
Wet bell Main umbilical	electrical components	6 months			
Wet bell Spare umbilical	Hose components	6 months	2 years	When installed (3;4)	
Wet bell Spare umbilical	electrical components	6 months			
Diving basket	1.3 Documentation showing the designed SWL	Note: Only for basket manufactured after 1 January 2014			Permanent
Diving basket	1.3 & 1.14 - Load test	6 months		6 months (2;3;4)	
Diving basket	2.6 to 2.8 - Emergency cylinder	6 months	2 years (3;4)	4 years (3;4)	
Diving basket	2.9 - Pressure gauge emergency cylinder	6 months			
Diving basket	2.11 & 2.12 - Pipework	6 months	2 years		
Diving basket	2.13 & 2.14 - Hoses	6 months	2 years		
Diving basket	2.16 & 2.17 - Relief valve regulator	6 months (1;2;4)	2 ½ years (2;4)		
Hot water system	Portable fire fighting system	6 months			Manufacturer specifications

Section	Item # & 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
Hot water system	Fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
Hot water system	Automatic fire detection	12 months			
Hot water system	Hot water system	6 months			
Hot water system	Pipework	6 months	2 years		
Hot water system	Gauges	6 months			
Hot water system	Electrical	6 months (2;3;4)			
Hot water system	Pressure vessels	6 months	15 months (3;4)	5 years (3;4)	
Hot water system	Relief valves	6 months	2 ½ years (2;3;4)		
Divers umbilicals	Electrical components	6 months (2,3,4)			
Divers umbilicals	Pressure Function test	6 months	2 years	Hydro test When 1st installed	
Divers personnel equipment	Helmet	6 months (1,2,4)	**Note:** Inspection and test 12 month or according to manufacturer recommendations		12 months
Divers personnel equipment	Bail outs	6 months (2;4)	2 years (3;4)	4 years (3;4)	
Divers personnel equipment	Composite bail outs	6 months (2;4)	2 years (3;4)		5 years (hydraulic proof pressure test)
Divers personnel equipment	Whips & connectors	6 months	2 years		
Divers personnel equipment	Indicating gauges	6 months			
Divers personnel equipment	Pipework	6 months	2 years		
Compressors	Portable fire fighting system	6 months			Manufacturer specifications
Compressors	Fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
Compressors	Automatic fire detection	12 months			
Compressors	Test automatic stop safety device	6 month (1;2;4)			
Compressors	Explosion protection air compressors if $O_2 \geq 25\%$	6 month (1;2;4)			
Compressors	Analysers	6 month (1;2;4)			
Compressors	Relief valve	6 months (1;2;4)	2 ½ years (2;4)		
Compressors	Pipework	6 months	2 years	When 1st installed (3;4)	
Compressors	Receivers	6 months (2;3;4)	2 ½ years (2;3;4)		
Compressors	Electrical testing	6 months (2;3;4)			
Compressors	Operational testing	6 months			
Compressors	Delivery rate	6 months			

Section	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
Compressors	Gas purity	6 months (1;2;4)			
HP and gas storage	Cylinders	6 months	2 ½ years (3;4)	5 years (3;4)	
HP and gas storage	Pipework & valves (with internal cleanliness)	6 months	2 years	When 1st installed (3;4)	
HP and air storage	Lifting equipment (slings, quads…)	6 months (2;3;4)		12 months (2;3;4)	
HP and air storage	Relief valves	6 months (1;2;4)	2 ½ years (2;4)		
HP and air storage	Portable fire fighting system	6 months			Manufacturer specifications
HP and air storage	Fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
HP and air storage	Automatic fire detection	12 months			
General safety	Classification (If classified)				
General safety	Sea Fastening (Design)				At system installation
General safety	Sea Fastening (welds)				At system installation
General safety	Electrical Power	6 months			
General safety	Hydraulicl Power	6 months			
General safety	9.3 - Medical kit DMAC 15	6 months (Medic)			

IMCA - Diving Equipment Systems Inspection Guidance Note (DESIGN) D 040 - Certifications list

Section	Item # & 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
General safety	1.1 - Classification				Permanent
General safety	4.5 - Sea Fastening (Design)				At Installation
General safety	4.6 - Sea Fastening (Installation)				At installation
General safety	6.1 - Marine audit IMCA M 189 small diving vessel				Before mobilization
General safety	7.3 - 1st aid kit DMAC 15.3	6 months (1,2,3)			
General safety	7.6 - Oxygen set in the small vessel	6 months	2 ½ years (4; 4)		Visual internal + test max working pressure: 5 years
Small vessel	3.5 - Emergency electrical power	6 months			
Control position	2.8 - Test communications	6 months			
Control position	4.3 - Analyser	6 months			

Section	Item # & 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
Control position	5.12 - Gauges calibration	6 month (2;3;4)			
Control position	6.8 - Valves & Pipework	6 months	2 years		
Control position	6.11 - Relief valves	6 months	2 ½ years (2; 3; 4)		
Control position	7.4 - Electrical testing	6 months			
Control position	8.1 - Breathing apparatus	6 months	2 ½ years	5 years (leak test at max working pressure)	
Diver’s umbilical	3.1 - Electrical components	6 months			
Diver’s umbilical	3.2 - Hose components	6 months	2 years (2; 3; 4)		
Diver’s personal equipment	2.7 - Helmets	6 months			Manufacturer’s recommendations : 12 months
Diver’s personal equipment	3.5 - Bail out (steel)	6 months	2 years (3; 4)	4 years (3; 4)	
Diver’s personal equipment	3.8 - Bail out (composite)	6 months	2 years (3; 4)	5 years (3; 4) (Hydro test to the pressure marked on cylinder)	
Diver’s personal equipment	4.6 - Whips and connectors	6 months	2 years		
Diver’s personal equipment	4.8 - Gauge	6 months			
Diver’s personal equipment	4.9 - Pipework	6 months	2 years		
Diver’s personal equipment	4.13 - Relief valve testing	6 months (1;2;4)	2 ½ years (2;4)		
Diver’s personal equipment	5.3 - Harness				Discarded after 5 years in service
Diver’s personal equipment	5.3 - Harness				Discarded after 10 years after fabrication
Gas storage	2.1 - Cylinders (Steel)	6 months	2 years (3; 4)	4 years (3; 4)	
Gas storage	2.4 - Cylinder (composite)	6 months	12 months	5 years (3; 4) (Hydro test to the pressure marked on cylinder)	
Gas storage	2.7 - Pipework testing	6 months	2 ½ years	When new	Internal cleanliness
Gas storage	2.11 - Relief valves	6 months	2 ½ years (2; 3; 4)		
Chamber	1.6 - Communication	6 months (1;2;4)			
Chamber	2.7 & 2.7 - Pressure vessel	6 months	2 ½ years		
Chamber	3.5 to 3.9 - Viewports	6 months	2 ½ years	5 years (3;4)	10 year old max.
Chamber	4.2 & 4.3 Portable fire fighting	6 months			

Section	Item # & 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
Chamber	10.2 & 10.4 - fixed fire fighting system	Visual: 6 months Test: 12 months			
Chamber	10.6 - Automatic fire detection	12 months			
Chamber (external)	5.6 - Electrical penetrators certification				Permanent cert. (3;4)
Chamber (external)	5.16 & 5.17 Medical lock pipework	6 months	2 years		
Chamber (external)	5.19 - Pressure relief valves	6 months (1;2;4)	2 ½ years (2;4)		
Chamber (external)	5.21 - Electrical testing	6 months (2;3;4)			
Chamber (external)	5.23 & 5.24 - Valves & pipe works	6 months	2 years		
Chamber (internal)	6.13 - Communication	6 months (1;2;3)			
Chamber (internal)	6.14 - BIBS	6 months (1;2;4)			
Chamber (internal)	6.22 - Sanitary system (if installed)	6 months			
Chamber (internal)	6. 28 - Fire fighting	6 months			
Chamber (internal)	6.30 - Gauge calibration	6 months (2;3;4)			
Chamber (internal)	6.32 - Scrubber	6 months			
Chamber (internal)	6.35 & 6.36 - Valves & pipe works	6 months	2 years		
Chamber (internal)	6.37 - Electrical equip. and cables	6 months (2;3;4			
Chamber (control panel)	7.12 & 7.13 - Pipe works, valves , regulators	6 months	2 years		
Chamber (control panel)	7.15 - Gauges calibration	6 months (2;3;4)			
Chamber (control panel)	7.17 - Analysers	6 month (1;2;4)			
Chamber (control panel)	7.19 & 7.20 - relief valves	6 months (1;2;4)	2 ½ years (2;4)		
Chamber (control panel)	8.4 & 8.5 - BA sets	6 months (1;2;4)	2 ½ years (3;4)	5 years (3;4)	
Compressors	3.3. & 3.4 - Portable fire fighting system	6 months			Manufacturer specifications
Compressors	3.3. & 3.5 - fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
Compressors	3.6 - Automatic fire detection	12 months			
Compressors	4.3 - Test automatic stop safety device	6 month (1;2;4)			
Compressors	4.5 - Explosion protection air compressors if $O_2 \geq 25\%$	6 month (1;2;4)			
Compressors	4.7 - Analysers	6 month (1;2;4)			
Compressors	4.8 - Relief valve	6 months (1;2;4)	2 ½ years (2;4)		
Compressors	57 to 59 - Pipework	6 months	2 years	When 1st installed (3;4)	

Section	Item # & 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
Compressors	6.2 & 6.3 - Receivers	6 months (2;3;4)	2 ½ years (2;3;4)		
Compressors	7.2 - Electrical testing	6 months (2;3;4)			
Compressors	8.1 - Operational testing	6 months			
Compressors	8.2 - Delivery rate	6 months			
Compressors	8.3 - Gas purity	6 months (1;2;4)			
HP and gas storage	2.1 to 2.3 - Cylinders	6 months	2 ½ years (3;4)	5 years (3;4)	
HP and gas storage	2.4 to 2.7 - Pipework & valves (with internal cleanliness)	6 months	2 years	When 1st installed (3;4)	
HP and air storage	2.8 & 2.9 - Lifting equipment (slings, quads…)	6 months (2;3;4)		12 months (2;3;4)	
HP and air storage	2.10 - Relief valves	6 months (1;2;4)	2 ½ years (2;4)		
HP and air storage	3.3. & 3.4 - Portable fire fighting system	6 months			Manufacturer specifications
HP and air storage	3.3. , 3.5 & 3.6 - fixed fire fighting system	Visual: 6 months Test: 12 months			Manufacturer specifications
HP and air storage	3.7 - Automatic fire detection	12 months