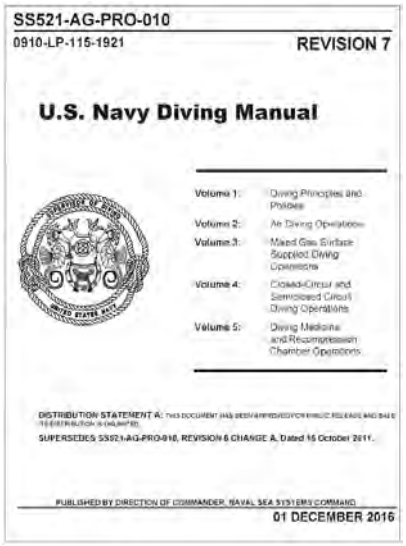
Frequently Asked Questions

The following are some of the frequently asked questions that DAN receives.

How long should a patient wait to fly after being treated for decompression sickness?

A: According to the U.S. Navy diving manual a waiting period of no less than 72 hours is given as a general guideline for patients who are completely recovered. Longer waiting periods are routinely prescribed in the Asia-Pacific region. A waiting period gives the diver time to recuperate before being exposed to the lower ambient pressure and partial pressure of oxygen found in commercial aircraft, which are usually pressurized to an altitude of between 2,000 and 8,000 feet, approximately 0.76 ATA. This does not mean that cabin pressure is always maintained at higher pressures. One study found that 10 percent of the commercial flights tested had cabin pressures exceeding 8,000 feet (Hampson et al. 2013).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REVISION 7

U.S. Navy Diving Manual

Volume 1: Diving Principles and Policies
Volume 2: Air Diving Operations
Volume 3: Mixed Gas Surface Supplied Diving Operations
Volume 4: Closed-Circuit and Semi-closed Circuit Diving Operations
Volume 5: Diving Medicine and Recompression Chamber Operations

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SUPERSEDES SS521-AG-PRO-010, REVISION 6 CHANGE A, Dated 15 October 2011.

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01 DECEMBER 2016

Differences in flight conditions may need consideration, for example an 2 hour-long direct flight versus a long-haul flight with multiple stopovers.
If the patient is not fully recuperated, and has residual symptoms, an extend-ed waiting period may be prescribed by the treating doctor. In some cases, it may be up to a week or more to allow for further resolution of symptoms. If the patient is still in treatment and needs to be transferred by the treating physicians, for example to a higher level of care, an aircraft pressurized to 1 atmosphere may be required, and the patient may still require 100 percent oxygen during the flight.
For further guidance on flying after recompression treatment, DAN medical staff are available on the DAN information line at +1 919 684 2948.

Since we rely on the local diving community to help us operate the chamber and our medical staff changes frequently over time, we have some problems in providing uniform training. Can RCAP help with this?

A: Having staff trained in a different way is a common problem when the doctor who provides training changes frequently. Training refers to operating the chamber and reacting in emergencies. When training is provided by several people using different materials and methods, there is always room for confusion, which can become a real problem in an emergency.
DAN can provide a Chamber Assistant & Chamber Operator course.

We believe our obligation goes further than a standardized course. Personalized slides and manuals are made for the and these materials will remain at the chamber for any future training (or retraining) organized by the chamber. This way we are not only able to provide training, but make sure that when new staff arrives, they get trained in the same way, with manuals and slides that show exactly what they will see in their facility.
The DAN Chamber Assistant & Chamber Operator course has already been organized at several chambers all over the world and we will continue to do so as part of RCAP.

We were treating a diver that had Type I DCS. In conversation with this diver they wanted to understand what may have caused the injury. Other divers were certain that this individual was diving too soon after flying. Is this a potential risk?

A: There are concerns with diving after flying but they do not involve concerns with nitrogen or the reduced cabin pressure. The concerns are directly related to the diver's physical condition on arrival at the dive destination. Long flights (8 hours or longer) do affect us physically through less than optimal hydration, nourishment and rest. Fatigue and lack of hydration have been suspected of contributing to the risk of DCS. They can at least confound the evaluation process and eventual diagnosis.
Allowing enough time to properly rest, rehydrate and eat is essential. This could mean waiting at least 24 hours. The more time zones crossed the greater the adjustment. Our circadian rhythm is disrupted and that can affect our cognitive processes. The diver needs to make an objective and honest assessment of their physical condition before choosing to dive. You can also contact DAN for assistance and information.

Is the in-line high pressure oxygen filter insert serviceable in the ultrasonic bath or do we replace it?

A: There are several aspects to this question:

- HP filter inserts or elements, strategically placed before high pressure regulators, may be found in separate in-line filters, or in some cases, a filter element is built into the inlet port to the regulator, or located inside the regulator itself.
- Most often these inserts are made of sintered metal: brass, bronze or stainless steel.
- Filter insets should be inspected annually for the presence of any dirt such as metal particulates, oxidation products and dust.
- If clean, then they can simply be replaced.
- If dirty, or every few years (no more than 4 years), they should be removed so that they can be cleaned.
- Filter inserts can be cleaned either by placing in an ultrasonic agitating bath, using an oxygen cleaning agent, and/or by carefully blowing in the opposite direction using high pressure medical air (oxygen clean) or even oxygen.

Frequently Asked Questions

The following are some of the frequently asked questions that DAN receives.

- Take care when opening and then removing these inserts: this will be a high-pressure line meaning that venting the line is required before starting to disassemble the filter housing or removing piping.
- When any parts in on oxygen system are disassembled, work must be done cleanly otherwise oxygen clean of the complete filter housing will be needed before reassembly.

What should we do when an injured diver presents for treatment at our facility, who has in implantable cardiac device (ICD) in place? Can we treat them?

A: The primary answer to this question does not lie with the device, but rather with the health of the diver.

The important question to ask is whether the diver was cleared to dive, by their cardiac specialist after the device was installed. If declared fit-to-dive with an ICD in place, then there is no reason not to treat this diver inside the chamber.

The secondary answers lie in the safety of the device and hence of the chamber.

There are no reports of any ICD having failed inside of any recompression that we are aware of. Most ICD manufactures have issued letter of confirma-tion that their devices are in fact safe to be used in a pressurized environ-ment; this included devices powered by lithium-type batteries.

The concern that the device will be subjected to elevated oxygen levels is addressed in that being implanted, it is not exposed to the chamber operat-ing environment.

Lastly, in most cases, an ICD is sterilized before leaving the factory using an autoclave. Saturated, hot steam at up to 3 ATA (20 MSW, 60 FSW, 29 psi) and typically 135°C (275°F) for between 4 – 60 minutes is used to destroy any microbes. This environment is much harsher than what is expected inside a recompression chamber.

HYPERBARIC CHAMBER TREATMENTS PACEMAKER

(IPG IMPLANTABLE PULSE GENERATOR)

DEFIBRILLATOR

(ICD IMPLANTABLE CARDIOVERTER DEFIBRILLATOR)

Medtronic has performed hyperbaric chamber testing on several pacemakers and defibrillators to determine the maximum safe pressure for hyperbaric chamber therapy. This testing was performed at selected pressures up to 165 feet of seawater or 6 Atmospheric Pressure Absolute (ATA).

These devices exhibit rate response and were chosen because they are representative of current models with respect to mechanical susceptibility to external pressure.

No loss or degradation of output operation was observed in any of the devices tested, however, rate responsive pacing began to diminish at pressures in excess of 66 feet of seawater (3 ATA) which caused the devices to pace at the programmed lower rate. The loss of rate responsive pacing was observed to be temporary; activity pacing returned at lesser pressures. It was also noted that pressures approaching 132 feet of seawater (5 ATA) began to significantly deform the titanium shield.

Following the hyperbaric chamber testing, all devices were analyzed for final functional and activity performance. Each device performed within specification.

In summary, Medtronic devices similar to the Medtronic pacemakers and defibrillators tested should operate normally up to 49.5 feet of seawater (2.5 ATA), and will begin to significantly deform at pressures near 132 feet of seawater (5 ATA). Based on results of this testing, similar Medtronic pacing devices should not be exposed to pressures in excess of 49.5 feet of seawater (2.5 ATA). It is the responsibility of the physician to determine the safety concerns for these pacemaker patients and make the final decision concerning the use of hyperbaric chamber treatments when indicated.

Although we are not aware of any reported incidences of ICD shock triggered ignition, and do not believe this to be of significant risk, it may be advisable to disable defibrillation therapies, pending further study to the contrary, while patients are undergoing hyperbaric treatments. Ensure that an external defibrillator and medical personnel skilled in cardiopulmonary resuscitation (CPR) are present while device therapies are programmed off should the patient require external rescue.

Chamber Profile:

ResortDoc, Silhouette, Seychelles

Continued from page 3

DAN will always strive to improve the safety of scuba diving and has taken this to the next step by improving the knowledge and safety at chamber facilities worldwide. Chamber doctors have access to diving medical assistance and advice via the DAN hotline at all times. With the development of the RCAP, the DAN team of doctors and medics have more confidence referring DAN members to remote chamber facilities. Proof once again that DAN is your buddy!

FAQ Frequently Asked Questions

The following are some frequently asked questions that DAN receives.

Does our chamber need both internal and external hull isolation valves?

Piping which passes through the chamber hull must have isolation (shutoff) valves to prevent uncontrolled pressurization or depressurization of the chamber, or leaks in any of the other gas lines that might affect control of the chamber environment should a malfunction occur. It is preferable to have isolation valves both on the exterior and interior sides of the hull.

This requirement is typically set for commercial and military diving systems. However, many clinical chambers are not fitted with this capability – this is especially true for monoplace chambers.

Recompression chambers used for treating injured scuba divers fall into a unique category – they treat neither fit and healthy commercial or military divers, nor sick patients who may be infirm and difficult to manage.

The key to meeting this requirement is thus the assessment of real risk.

The primary concern is loss of control if a system fails – say rapid, run-away pressurization or depressurization, a safety valve opening well below set-pressure, a bilge valve leaking, or a leak in a pressure gauge line. Without being able to isolate the line, control of the chamber and thus the safety of the occupants would be severely compromised.

Secondarily, there is the concern of an inattentive or even an absent operator on the outside. How would the inside attendant deal with such loss of control?

This means that a lack of control on the outside or the inability to control on the inside, without dual shell valves, would be very difficult to achieve.

ASME PVHO-1, the design code that most chambers are designed to, requires a minimum of an external shell valve on all gas lines into or out of the chamber. A recompression chamber must at least meet this requirement. The unlikely event of an absent, disabled or inattentive operator should be evaluated on a case by case basis, and either a policy put in place for minimum of two people to attend the outside of the chamber, or a fail-safe or dead-man's switch should be installed that will bring the chamber to the surface safely and shut off all pressurization lines.

Dual shell valves would, however, be good practice for all remote chambers with limited staffing.

Link to a real-life example of where an internal isolation valve would have mitigated a potential accident.

F. BURMAN

Dual safety valve

What is the correct pressure for our chamber safety valve to be set at?

There are a few things to consider here.

- Some hyperbaric chambers are designed for depths allowing some degree of commercial diving to be done – say up to 225 psi (± 16 ATA), and many are produced to provide up to a 165 FSW (50 MSW) for a US Navy treatment table 6A.
- The most common treatment table for a scuba diver suffering from DCS is the US Navy TT6, requiring only 29 psi (2.8 ATA). Remember also that oxygen as a therapeutic gas becomes increasingly toxic when one exceeds this pressure.
- Occasionally a facility might also use a mixed-gas treatment table, using heliox or nitrox at 100 FSW (30 MSW).
- The safety of the chamber as a pressure vessel is affected by the maximum air supply pressure that could potentially take the chamber pressure to a level above the design pressure.
- The codes require the safety valve to be set to be fully open at no greater than design pressure.
- Finally, one needs to be able to test the safety valve; preferably while still fitted to the chamber.

Based on the typical requirements for an injured diver recompression chamber, safe practice would thus be a combination of the following:

- Install a safety valve that would be fully open at no more than 10% above the maximum, actual treatment pressure. This would prevent taking the patient to below the deepest, safe pressure, or to exceed the safe level for oxygen toxicity.
- Consider an additional safety valve, fitted with an external isolating valve, set to protect against depths exceeding oxygen toxicity levels – typically for the US Navy TT6 table. The isolating valve will allow for deeper treatments to be performed. This is easy to install using a T-piece before the existing safety valve.
- If the compressed air system can exceed the chamber design pressure if either of the two above safety valves have been isolated, then fit an additional safety valve to prevent exceeding the chamber design pressure.

Typical safety valves settings might be:

- US Navy TT6 or equivalent oxygen table, set to 72 FSW (22 MSW or 32 psi)
- Comex 30 or equivalent heliox/nitrox table, set to 108 FSW (33 MSW or 48 psi)
- US Navy TT6A or equivalent deep air table, set to 180 FSW (55 MSW or 80 psi)

FAQ Frequently Asked Questions

The following are some frequently asked questions that DAN receives.

How often do we need to oxygen clean our hyperbaric system?

To answer this question, we first need to understand what is considered as the oxygen-enrichment level at which oxygen cleaning is require from a safety aspect.

There are many different points of view in this respect. However, the generally accepted 'consensus' or 'ASTM' limit is 25% - not to be confused with the safe operating limit in an air-filled chamber of 23.5%.

The important aspect here is that the pressure of gases in the compression and gas delivery systems may well exceed 125 psi (0.86 MPa), which is the limit at which one may use ball valves in oxygen systems. This points to a clear message: we need systems free of any form of fuel in order to prevent catastrophic fires.

All gas systems that convey an oxygen-enriched mixture with more than 25% enrichment, per volume, should therefore be regarded as oxygen systems. This means that no hydrocarbons (oil especially), dust, particles or any other potential sources of fuel should be present in the complete system.

Oxygen cleaning equipment

So, what then is the cleaning frequency of an oxygen system? Here good practice states that oxygen cleaning should be done on any oxygen-enriched gas system:

1) Before the system is put into service for the first time;
2) When-ever any contamination occurs or is suspected (such as when disallowed fluids or lubricants or even oil-lubricated compressor air is used);
3) When-ever a line (pipe, hose or component) is opened without being handled in an oxygen-clean manner;
4) When-ever a replacement part or new item of equipment is installed that is not certified as oxygen-clean;
5) When-ever a system is disassembled, serviced or overhauled;
6) When-ever any brazing or welding is done on any pipe; or
7) When-ever any unauthorized work is done on any part of the system;

If none of these activities occurs, then the system should be left intact and periodic cleaning is not required. In fact, as a piping system can be complex, if all the parts are properly cleaning before initial use, we are more likely to contaminate it than to clean it effectively.

If repairs, servicing, modifications, component replacement and/or system disruptions are required, remember to work cleanly to maintain oxygen-cleanliness integrity at all times.

There is one remaining concern:

What happens when we switch from oxygen to air on our breathing systems, and then back to oxygen from air: oil-lubricated compressor air will not be free of oil unless specifically filtered for this flammable impurity. The air purity limit for oil is ≤ 0.1 mg/m^3.

If you are unsure of your air quality, then take a sample immediately after use and preferably before oxygen is put back into the system. This may contaminate your piping system from where the air enters the oxygen lines until the breathing apparatus.

We will be publishing a FAQ on how to perform oxygen-cleaning in a future edition of this newsletter.

FREQUENTLY ASKED QUESTIONS

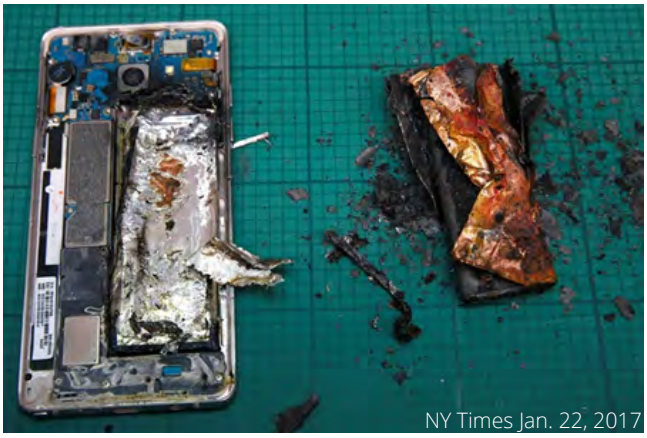
Q:Is it safe to use a lithium ion battery powered device inside the hyperbaric chamber?

A: Li-ion batteries have become the standard for most battery powered devices. In a hyperbaric chamber, we might find them in a diving light for emergencies, an otoscope, or internal analyzer units, but mostly in patient-support medical equipment, including implantable devices glucometer sensor units and pain pumps.

While we all hear the stories of Li-ion battery fires, the truth is that these are almost all as a result of either recharging issues or mechanical damage. We have not yet heard of an implantable device (such as a pacemaker) burning or exploding.

The biggest risk occurs during recharging and for this reason, one should never recharge any batteries inside the chamber. The best advice is to limit the use of any batteries inside the chamber, but where you need to use them, then consider the following additional recommendations:

- only use original equipment battery chargers for charging batteries (outside the chamber) and only use the manufacturers specific batteries: care is taken by the device manufacturer to manage recharging loads and to optimize the charge levels in the battery.
- do not leave batteries on charge overnight, for extended periods or when unattended, and do not keep Li-ion batteries at full charge levels unless you know you will need them.
- inspect Li-ion batteries regularly for any sides of damage, deformation (bulging) or leakage.



- never tamper with parts of the battery, especially not the casing
- ensure that the battery leads, contacts and housings are always secure.
- develop, implement and practice an emergency action plan for any form of Li-ion battery fire: water will not extinguish a Li-ion fire; these fires will need foam, carbon dioxide or dry chemical extinguishers to extinguish them, so the best course of action is to lock the device out immediately you detect any abnormal heat, smoke, smell or suspected failure, but most of all...
- never take high energy devices (those that consume more power) into the chamber, such as cell phones, iPads, laptop computers or personal medical devices that use rechargeable li-ion batteries.

Disposable coin-size batteries are not regarded as unsafe, but where possible, these should be checked before each treatment, to ensure there has been no damage and that the batteries are secure. You may wish to read the full article "Use of Lithium-Ion Batteries in Hyperbaric Chambers", either for free or for a 1 hour CHT or nurse CE credit, on the International ATMO site:
https://learn.hyperbaricmedicine.com/activities/use-of-li-ion-batteries-in-hyperbaric-chambers-1-0-hour/

Finally, please feel free to reach out to the RCN team if you have questions such as what devices might be acceptable, or how to mitigate the risk if a high-energy device is required inside the chamber.

FREQUENTLY ASKED QUESTIONS

Q: How often do I need to calibrate my chamber depth gauges?

A: This question is asked frequently, and some confusion exists with how it needs to be done. There is more to just 'calibration' though, so let us break this down into a few respective parts.

1. We all use the term 'calibration' but in reality, all we can really do to test the gauge accuracy is zero the gauge and then compare the readings with some form of master, or pre-calibrated gauge. Let us therefore accept the word 'checking' rather than 'calibration', which will indicate if the gauge works and reads correctly.
2. Accuracy is a relative term. For deep diving, which decompression must be done very carefully, the standard requirement is ±0.25% of full scale. For a 0 – 450 fsw (0 – 130 msw) gauge, this would imply that each reading needs to be within ±1 fsw (±0.3 msw). However, for the treatment of injured divers to typically no more than 100 fsw (30 msw), this degree of accuracy is not required to ensure the best outcome. Here an accuracy of ±0.5% of full scale is accepted practice.
3. The frequency of testing depends on a variety of factors, such as the actual location and situation. Here are the guidelines:
   a. In the event of any visible discrepancy between different gauges reading the same pressurized compartment (say the Caisson and main lock gauges); or
   b. In the event of any gauge malfunction, such as not returning to zero, sticking, hunting around the expected pressure level; or
   c. In the event of any mechanical damage, such as the gauge being dropped or something striking the gauge; or
   d. Where regulatory requirements dictate (some countries and some operating standards have specified requirements;
   e. The original manufacturer's instructions; or failing any of these
   f. At least once a year. This is the general international standard; the ASME PVHO-2 standard for example requires annual testing.
4. The final consideration is how to check gauges. Here we have a few options.
   a. Comparing all the gauges fitted to the chamber: at least the treatment (main) lock and the transfer (entry) lock gauges; the Caisson gauge if fitted; or
   b. Using a master, calibrated gauge to check each depth gauge at a pre-selected set of pressures going up and down in pressure; or
   c. Removing the gauge and sending it to an accredited laboratory. However, unless this is required by the inspection authority, this is not the best way to do this as the transporting and then re-installing of the gauge can lead to changes in the readings. The ASME-PVHO-2 standard accepts the first option, as long as it is done thoroughly and recorded.

FREQUENTLY ASKED QUESTIONS

Q: We have some rust in our bilge area. Can we fix this ourselves and what should we be concerned about?

A: A chamber would need to have suffered significant neglect before corrosion becomes a major concern; small on-site repairs should be safe and easy to do yourselves.

A decision to perform local paint repairs has two aspects to it: when corrosion damage is too extensive for a local repair by anyone other than a pressure vessel fabricator or repair service, and what should you do when you discover rust.

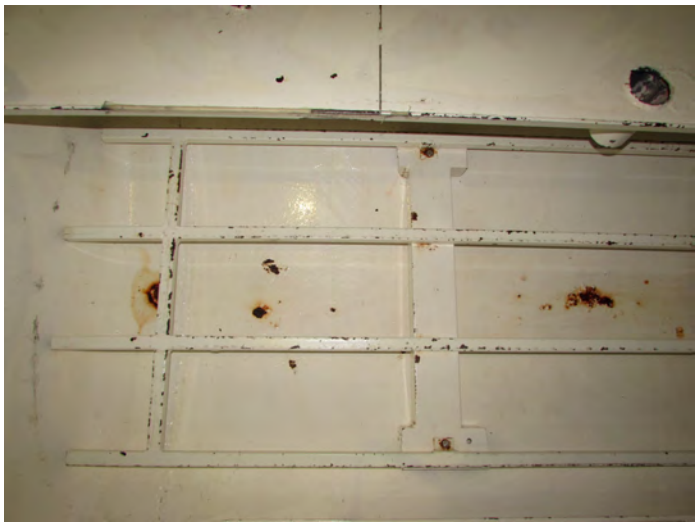
Steel pressure vessels are usually designed with at least some degree of corrosion allowance, and this is almost always the case where the designer understands the likelihood that moisture can accumulate in hidden places – such as in a bilge. A corrosion allowance is often noted on the nameplate.

In addition to this, the depth of any corrosion is actually less significant than the extent – a small area can withstand a few millimeters of local pitting; an extensive area could well mean that local repair is not possible.

As a guideline, small areas (say less than 12 mm or ½ inch in diameter or length) could allow for material thinning of up to ¼ of the plate thickness or say 1 – 2 mm.

However, several of such pits in a concentrated area (typically 150 mm or 6 inches in diameter or length) where the corrosion exceeds 1 mm could be of concern. In this case, one would need to approach a professional shop or design engineer to evaluate whether local repair would be possible. A door or viewport flange can sustain more significant damage as long as this is not on the sealing surface.

So, the important thing is to inspect your vulnerable areas regularly and when you notice either 'crusty' bubbles, red oxide weeping from a bubble, or simply clear rusting, you should take action as soon as possible. Rust is generally a slow process, but one would want to conduct inspections at least monthly.



Reparable rust spots in the chamber bilge

Where you notice or suspect corrosion, use a scraper or some other hand instrument to probe the area. Do not use force and certainly do not grind out or use other machine tools to remove corrosion. Once you are able to determine the extent and it appears to be light (less than say 1 mm), use sanding paper or a sanding machine to clean up any rust and the adjacent area at least 25 mm (1”) from any corrosion. Make sure to go down to bare metal. ‘Feather’ the paint where it borders on the bare metal – meaning, lightly sand so that there is no clear ridge between remaining paint and the bare metal.

Clean the area thoroughly, preferably with a solvent or some form of rust converter, and please be very careful when using any flammable liquids in confined spaces – only take a wettened rag into the chamber and not any of the liquid. It is important to remove all forms of oil, dust, debris or fingerprints.

Reparable rust spots in the chamber bilge

As soon as the area is dry, apply a suitable paint or etch primer. Then allow this to dry and if at all possible, use a fan to circulate the area. Follow the primer instructions as to when it should be suitably dry.

To improve the appearance, you can lightly sand the primed paint to remove any brush marks or raised areas. Be sure to then clean this area as before.

Finally, you can apply the topcoat in one or more layers. Once again, lightly sand the area after each coat has been applied if you wish to make the paint look as pleasing as possible.

Allow to dry thoroughly (usually 72 hours or until ‘dry-to-service’) and be sure that there is no strong or unpleasant odor remaining.

Finally, observe the freshly painted areas after the first few treatments to ensure that there are no bubbles being formed due to any form of oil, dirt or fingerprints that will prevent a firm bonding of the paint to the underlying surfaces.

These minor repairs will be as good as the paint on a new chamber as long as you are sure to remove all the previous corrosion, clean thoroughly between coats, and allow to dry properly between each coat.

The next question will likely be what paint that can be used for these repairs?

You can enquire from a reputable chamber manufacturer or check with the paint supplier, or failing this, any marine application two-part epoxy or two-part polyurethane paint, with a low VOC (volatile organic compound) content and that does not ignite, burn, support combustion or release flammable vapors when subject to fire or heat once applied should be good. You can contact us at RCN@dan.org if you have any paint-related questions.

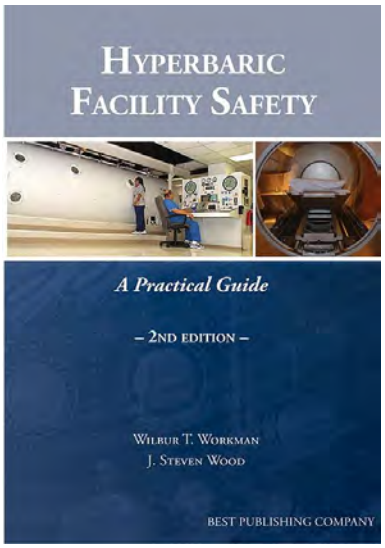
FREQUENTLY ASKED QUESTIONS

Q: Our unit is new and we have so many things to think about. Could you please share with us the 10 most important things that we should focus on from a safety perspective? Our hospital has asked to demonstrate that we are a safe facility.

A: This is a very valid question and has been asked on several occasions.

While there are perhaps 100 things if not more that even the most basic facility will need to consider, we can prioritize these based on a score obtained from a simple risk assessment tool. It is all about frequency of exposure, probability that an incident could lead to an accident, and what the likely consequences could be.

Using actual on-site assessments of 150 facilities around the world, here are the 10 primary risks based on their risk score. You may be surprised by some of these findings.



Second edition of the Workman seminal publication

1) Safety drills not practiced - an emergency action plan may fail if it is not carried out promptly and correctly. We try to avoid accidents from happening, but they do happen.

2) Alternative breathing gas for operator not provided – remember that in the event of a fire or contaminated chamber environment, it will take time to get the chamber to the surface. The operator must have a safe and non-oxygen enriched gas throughout the process.

3) Emergency operating and medical procedures undocumented - if it is not recorded, then it does not exist! Even if they are perhaps not entirely correct, at least you will be following something.

4) Maintenance system absent, inadequate, or inappropriate – you cannot expect to have no equipment failures, which usually occur at a critical time if you do not take care of your facilities.

5) Leak testing not done – oxygen leaks introduce a fire risk; sensing lines may lead to under-reading of the depth gauge or inaccurate chamber environment oxygen level measurements.

6) Air supply analysis or quality control lacking – you cannot see, smell, feel, or taste most contaminants in breathing gas. It is only through a carefully considered air quality and analysis control system that you can be more assured of safety.

7) Particle filters before regulators absent – most high-pressure regulator failures are caused by dirt and particulates lodging on the sensing surface of the regulator valve. The downstream pressure will not remain constant and either the breathing device will fail, or the regulator safety valve will pop and likely cause the operator to panic.

8) Standard operating procedures not documented – how can you demonstrate effective and safe practice if everyone relies on what they think is best? If it is not recorded……it does not exist.

9) Oxygen cleaning procedures not in place – while oxygen cleaning is not required on a regular basis - except in the event of contamination, suspected contamination, or a lack of confidence in how maintenance was done - when it is required, you will need to have at least a basic oxygen cleaning procedure in place. This might be as simple as a procedure for selecting and then monitoring an external cleaning service provider.

10) Operator checklists inadequate or lacking – many operators become complacent as the awareness of risk diminishes with time and when start-up and shut-down procedures become too familiar. Remember that that the risk does not change – it is as dangerous on the first day as it is years later. Documented and recorded checklists, followed consistency and with full attention, will prevent most system-related accidents from happening.

While some of these may come as a surprise, all of these have a significant impact on the safety status of your facility. None of these are difficult to put in place, demonstrate when requested to do so, or present in the event of an incident.

FREQUENTLY ASKED QUESTIONS

Q: What gas quality standard applies to hyperbaric chambers compressed using air?

A: There are several international standards that apply to breathing air quality and the first step is to determine which of these may apply to your facility. There is no single universal standard for hyperbaric chambers, but a few countries do provide acceptable quality levels for use under their national compliance system.

Assuming that your region does not have a hyperbaric air quality standard, your best approach is to see if there is anything governing surface breathing air (e.g., for breathing in spray paint booths or gas tanks), underwater breathing air (typically for commercial diving), low pressure air, high pressure air (e.g., for firefighters), and oxygen compatible air.

Most standards focus on elements such as carbon dioxide (CO_2), carbon monoxide (CO), oil (mist or vapor), volatile hydrocarbons (e.g., methane), moisture (water), particulates, and odor. There is no one standard that addresses all of these, and yet most of these may have a detrimental effect on your chamber occupants.

Many standards are based on high pressure air where elements such as moisture are relatively easy to remove, and one concern is freezing up of regulators. This is not the same for low pressure air (gas supply pressures for recompression chambers are typically less than 220 psi or 15 bar).

The sensible approach is to determine what is safe for recompression chamber treatments, considering fire, equipment, and physiological hazards. Also remember to perform a detailed assessment of where your compressor intakes are located to determine whether there are any potential contaminants that don't appear on any national breathing air standard.

DAN has researched this topic extensively, analyzed the effects of contaminants on the hyperbaric environment,

and determined what is safe for all concerned with the facility.

The recommendations below are entirely achievable where compressors and filters are properly maintained, and where air intakes are secured against ingress of any other hazardous compounds.

	HP Air	LP Air	OCA
CO_2	500 ppm_v	500 ppm_v	500 ppm_v
CO	5 ppm_v	5 ppm_v	5 ppm_v
Moisture	50 mg/m^3	160 mg/m^3	50 mg/m^3
Oil (VOC)	0.5 mg/m^3	0.5 mg/m^3	0.1 mg/m^3
Odor	Slight	Slight	None
Other THC	25 ppm_v	25 ppm_v	25 ppm_v

Determining odor is subjective, however, any indication of an irritant, harsh, or otherwise unpleasant smell is not acceptable. There should in fact be no smell in the compressed air.

The limits shown above would meet all international specifications and are certainly as safe as breathing air can be.

If you use your regular compressed air system to provide air-breaks, or to provide air to the BIBS in an emergency, the air needs to be free of any oil – this is what we refer to as Oxygen Compatible Air (OCA). The concern is that oil or other volatile products are a potential source of fuel, and mixing this with pure oxygen increases the chance of a fire in the system

If your only option is the regular air you use to pressurize your chamber, it is important to pay attention to the compressor servicing and filter change-out requirements, together with regular air analysis. Oil is usually undetectable in a well-maintained compressed air system.

When receiving air quality test results, do not only look for the pass or fail outcome; observe the trends where one element is increasing over time. This is an early warning sign that something is not right.

We are also often asked how often air quality tests need to be performed. Many regions will provide minimum requirements such as 3-, 6-, or 12-month air testing.

What is more important is to consider your risks and the likelihood of contamination when making this decision. In the event of any suspected contamination, changes in the environment, strange odors, or where the air quality levels fail during subsequent tests, action should be taken to ensure that the situation is back under control.

So, unless you have an online, real-time analyzer, remember that your spot checks only tell you want was in the air at the moment you took the sample. It does not provide any assurance that the situation will be the same immediately after a sample is drawn.

FREQUENTLY ASKED QUESTIONS

Q: What lubricants and sealants are appropriate for use in a hyperbaric facility?

A: All sliding or rotating surfaces, and including threaded joints, require a lubricant – whether to simply reduce friction, or to reduce the amount of heat generated by friction. Worn threaded joints, or where there are small leaks that develop over time, can be mitigated using a suitable sealant.

Oxygen is not a flammable gas, but when combined with a volatilized fuel and an ignition source ignition, the potentially devastating results are well publicized. In a hyperbaric environment we have all of these elements: oxygen, heat sources and materials that burn much more easily, especially where oxygen is above 21%.

Hydrocarbon-based cylinder valve fire

We therefore need to take great care when selecting materials, components, instruments, machinery, and gas control equipment, all of which may need some form of lubricant or sealant at some stage.

To ensure that we remain safe regardless of what sort of equipment, lubricant or sealant may be needed, it is best to limit the types of products used to avoid confusion, and especially to maintain control over what may come into contact with oxygen-enriched environments.

At the very minimum, no hydrocarbon-based products (greases, oils, sealants) should be allowed into a hyperbaric facility, and especially where surfaces are in contact with oxygen – even in small amounts.

Compatible Lubricants

Available information, pricing and availability are often limiting factors when it comes to what can be procured by a facility. Compressors and other rotating machinery outside the actual hyperbaric chamber may well be lubricated using products that we do not want to come into contact with oxygen.

In this discussion we will focus on pressure control equipment, seals, threaded joints, and any sliding surface likely to come into contact with elevated levels of oxygen, including inside the chamber.

We will also use the term ***grease*** to indicate a lubricant used on sliding, mating, or sealing surfaces.

The primary purpose of a grease is to reduce friction. When tightening two threaded surfaces, we have two hard surfaces in close contact. A grease will ensure that the tightening effort is used to achieve the required seal compression or tightness, rather than being used to overcome

friction between the perhaps slightly damaged threads.

It can be used to ensure sliding surfaces, like the interlock mechanism, to retract smoothly and effective.

There are a few additional advantages to a grease that effect choice, such as:

- Acting as a barrier between two surfaces of different metals or materials, to protect them from sticking together, or seizing.
- Providing a minor degree of protection against surface corrosion caused by the environment.
- Preserving materials, such as seals (flat and o-ring type), and keeping them flexible.
- Assisting with affixing seals and minor parts during assembly, and
- Allowing a small amount of movement in repositioning of seals during assembly, as well as while in operation.

However, greases have no strength properties, and while they offer some temporary ability to stop very small leaks, they are not sealants. Eventually the grease will be forced out.

There are many greases that are stable in oxygen at atmospheric pressure and up to at least 10 bar (145 psi). These include products used to lubricate door seals, hinges, interlocking and locking mechanisms. Where regular lubrication is needed, one would prefer to use a less expensive product. Silicone-based products are a good example of inexpensive and readily available greases.

Oxygen adds another dimension to the selection, as clearly any product used needs to remain stable in oxygen, and more importantly, not produce flammable vapours at low temperatures. If a chamber occupant touches a door seal before entering the chamber, and the grease is then left on a surface in the chamber, in elevated levels of oxygen, this could potentially present a problem.

Then finally, operating, or environmental pressure needs to be considered. This is especially important with regard to seats and seals in high pressure control equipment.

Product specification sheets, technical data sheets or application instructions do not always provide the answers needed. Some additional homework may be needed, especially when examining products that are affordable and available.

The first column in the table below shows greases that can be used for general purpose applications in oxygen-enriched environments up to 100 bar (1450 psi) – be diligent in checking the actual pressure ratings. The second column shows greases compatible with oxygen up to the stated pressures.

To the best or the author's knowledge, all of these products have been used in either hyperbaric or diving applications where oxygen is of concern. However, this does not automatically apply any endorsement of any listed product. One still needs to do some additional checking to ensure the grease is appropriate and also that it is compatible with the relevant materials – metals and synthetic or rubber-based products.

Oxygen-enriched gases ≤ 100 bar/1450 psi	High pressure gas > 100 bar/1450 psi
Castrol Braycote 601 EF & 803 EP	Carbaflo OX-250 (Fuchs) (240 bar)
Dow Corning 111 & 112	ChristoLube MCG 111 (LTI) (690 bar)
Dow Corning Molykote 55, P-1900	Du Pont Krytox NRT 8908 (350 bar)
Gleitmo (Fuchs) 593 OX (60 bar)	Fluorolube GR 362 (aka Tribolube 71)
Loctite Krytox (Henkel) RFE grease	Fomblin (Solvay) RT 15 (345 bar)
OC-7 (MPT Industries) (100 bar)	Gleitmo 599 (400 bar)
OC-9 (MPT Industries) (100 bar)	Halocarbon MT-3I (690 bar)
Parker Super O-Lube	Klüberalfa YV 93-302 (360 bar)
Rhodorsil Paste 408	LOX-8 grease (Fluoramics) to 200 bar
Turmotemp II/400-OX (100 bar)	Turmoxygen LCO 25,27 (300 – 450 bar)

Acceptable lubricants for use in hyperbaric systems

There are two take away messages here:

- It is easier to use only one grease in a facility for all applications. This avoids any potential for confusion. If the argument against this is cost, review your use of the grease, as it is a common mistake to use far too much to achieve the same result. One should be very

sparing with the use of greases; it only requires a thin layer to reduce friction.

Compatible Thread Sealants

This part of the discussion mirrors what we described above, with the primary difference being the function and application of sealants.

The primary purpose of a sealant is to ensure a seal where mating surfaces are not ideal – perhaps caused by a degree of movement required during temperature changes, perhaps minor thread wear especially on tapered threads, perhaps just small surface aberrations. However, these products are only intended to seal minor leaks.

There are a few additional advantages to a sealant that may affect choice, such as:

- Preventing threaded joints from loosening.
- Providing some friction reduction between threaded surfaces during assembly.
- Acting as a barrier between two surfaces of different metals or materials, to protect them from sticking together, or seizing.
- Providing a minor degree of protection against surface corrosion caused by the environment and where the sealant covers these surfaces.

There are three important notes here:

- Threads must be clean and free of burrs or other imperfections that can cause damage during assembly,
- Thread sealants have no load bearing (strength) capability – they cannot replace a damaged thread.
- They should not be used together with a lubricant.

Damaged threads

Thread sealants are available in a variety of forms:

- Lead seal capsules and 'tinned' threads, used for heavier duty tapered thread applications.
- PTFE (Teflon) cones, used for clean applications where tapered threads are used.
- Thread sealants (liquid or paste).

Lead-dipped sealant

Teflon cone

Once again, products are selected based on price and availability, technical compliance, compatibility with the sealing surfaces, and stability in oxygen.

The table below includes a range of oxygen-compatible sealants and their respective environmental pressure ratings.

To the best or the author's knowledge, all of these products have been used in either hyperbaric or diving applications where oxygen is of concern. However, this does not automatically apply any endorsement of any listed product.

Product	Rating
Formula-8 (Fluoramics)	690 bar (10,000 psi)
Oxy-Tite (La-Co Industries)	180 bar (2,600 psi)
Loctite sealant for O_2 systems	< 30 bar (435 psi)
OC-3 (MPT Industries)	150 bar
OC-5 (MPT Industries)	690 bar (10,000 psi)

Sealants acceptable for use in hyperbaric systems

The final, important notes to this section include:

- All previous sealant product must be effectively removed – clean surfaces are needed for effective bonding.
- Careful note must be taken of drying time.
- Sealants…. Seal! They are not intended to serve as primary lubricants.

What then about PTFE (Teflon) Tape?

The most universally used product for both lubricating and sealing actions is PTFE. In fact,

PTFE is used as a base product in most lubricants and sealants we use.

However, when it comes to tape form, is PTFE a lubricant or a sealant?

To answer this, we need to consider the primary functions of PTFE tape, and that is to reduce friction, and thereby to enable an effective seal, using an additional seal such as an o-ring or flat elastomeric washer.

- It does appear to resolve very minor leaks, although in reality all it does is hide them temporarily.
- It does serve as a barrier between two dissimilar metals to reduce corrosion or materials, to protect them from sticking together, or seizing.
- It does serve to reduce friction in tapered joints, enabling deeper engagement and effecting a better thread surface to surface seal.
- It is available in oxygen-compatible form.
- It does not serve as a sealant for parallel threads that require an o-ring or other soft material to make the seal.
- It has no strength or repair properties for damaged threads.

Teflon is therefore primarily a lubricant and not a sealant. Its primary function is to reduce friction and ensure that the primary seal can do its job effectively.

FAQ

Q: Do patients in multiplace chambers also require grounding?

A: In the light of the chamber fire in Michigan earlier this year, where we read that the facility failed to use grounding straps to discharge static electricity, does this mean all chamber occupants should be grounded? (CBS New article)

This is a very valid question, and one that requires both reference to NFPA 99 as well as some explanation.

NFPA 14.3.1.6.3.2 (2024 edition) states "In Class A and Class B chambers with atmospheres containing more than 23.5 percent oxygen by volume, electrical grounding of the patient shall be ensured by the provision of a high-impedance conductive pathway in contact with the patient's skin."

Let's start by explaining how chambers for human occupancy are classified. It has nothing to do with the gases used for pressurization. A Class A chamber is a multiple occupant chamber, referred to as multiplace; a Class B chamber is a single occupancy chamber, referred to as monoplace.

In any chamber where the intention is for the chamber environment to have an oxygen content of more than 23.5%, all occupants shall be grounded. This requirement does not include chambers with treatment gases that are supplied and dumped through a close-circuit BIBS system.

In practice, we very rarely see any multiplace chambers pressurized with oxygen-rich gases, except for Perry Sigma II, which allows for two patients inside the chamber, which can be pressurized using oxygen. In this case, both patients need to be grounded.

It is essential to note that a static electrical charge on an occupant, especially in an environment with very low humidity, can reach 10,000 to 15,000 volts (10 kV to 15 kV). When discharged, the energy is more than sufficient to ignite materials with low ignition energy characteristics that may be inside a chamber. These could include cotton fluff (lint) and dust. We specifically exclude any flammable vapors inside the chamber, but dust and fluff from clothing and bedding may well be present.

Grounding a patient in a chamber with an internal environment of more than 23.5% (where we pressurize the chamber using oxygen enriched gas) is an essential safety requirement, and grounding of both the occupants and chamber itself must be ensured at all times.

https://panamericahbo.com/products/chamber-accessories/

FAQ

Q: We have an old recompression chamber that was donated by a UK organization back in 1985. The wiring from the old chamber electrical power supply system has red, black and green wires leading to the plug that goes into the wall socket.

Our new communications system has black, grey, and green-yellow wires. Our new chamber cooling system has yellow, blue and green-yellow wires. Our new analyzer has brown, grey and green wiring. The replacement compressor, which is a used unit, has brown, orange, grey and bare copper wires.

Some of these items had plugs that we had to remove, to replace with plugs suitable for our wall power outlets.

This is so confusing, and while we are waiting for an electrician to help, we wondered if you could help with understanding what the correct colors should be.

A: This is a great question, as many of our RCN facility members have chambers which are built in one country, have been retrofitted with equipment coming from other countries, and then installed in yet another country – which can make the wiring configurations confusing.

While we can provide you with the best information we are aware of, you will need to consider the age of your equipment, as even within some countries, changes have been made.

With some luck, much of the world as we know it will eventually adopt the IEC (International Electrotechnical Commission) color coding. However, there may be a few countries that do not migrate over.

The table on the next page contains most of what you need to know, but we do need to clarify your compressor requirements.

As the replacement compressor has 4 wires, this tells us that the compressor uses what is known as a two-wire single phase configuration. Often domestic hot water heaters and stoves use this method of providing more and better-balanced power, such as 240 volts (V) in the USA (where it is usually 110 V), and 240 V in many other countries even though the normal domestic supply is also 240 V. Yes, this is confusing. Anyway, in the table we have provided for up to 3 live (hot) wires, in the event someone requires up to 3 phase power.

This resource chart is for educational purposes only. Please be sure that only a qualified electrician does the work for you. and please consult the instructions!

Electrical wiring color codes applicable to some diving regions. For countries in Asia, some such as Indonesia use the USA configuration, others the UK code, with variations. The Philippines use a very different code according to their electrical code requirements.

FAQ

	IEC Europe	USA, Mexico	UK, Malaysia, Maldives	India	China	Australia, New Zealand
Live 1	Brown	Black (Brown)	Brown (Red)	Red	Yellow	Brown (Red)
Live 2	Black	Red (Orange)	Black (Yellow)	Yellow	Green	Black (White)
Live 3	Grey	Blue (Yellow)	Grey (Blue)	Blue	Red	Grey (Blue)
Neutral	Blue	White (Grey)	Blue (Black)	Black	Blue or Black	Blue (Black)
Earth	Gr-Ye	Green	Gr-Ye	Green, Gr-Ye	Green, Gr-Ye	Gr-Ye

Notes:
Colors in parenthesis apply to the old color scheme for that country or region. Most countries commenced with transitioning from 2000 onwards, so as a general rule, equipment older than 25 years would likely still retain the old wiring color configuration.

Some countries may also allow the green, or green with yellow stripe (Gr-Ye) wiring to be replaced by a bare copper wire

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