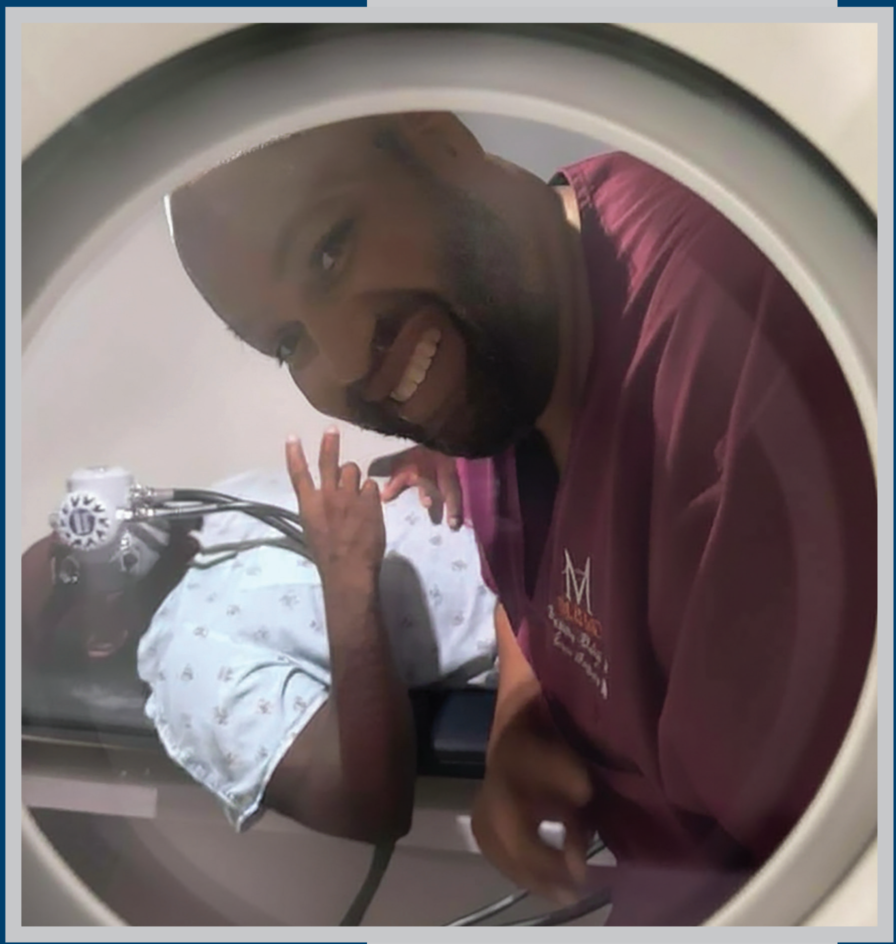
RISK ASSESSMENT GUIDE

For Recompression Facilities



Divers Alert Network®

5th Edition

RISK ASSESSMENT GUIDE FOR RECOMPRESSION FACILITIES

Fifth Edition

Author

François Burman, BSc (Engineering), MSc

Vice President of Safety Services, Divers Alert Network

Editor

Frans Cronjé, MD, MSc

Diving and Aviation Medical Examiner, Senior Researcher & Lecturer,
Hyperbaric Physician Baromedical Facility: University of Stellenbosch

Contributors

Matias Nochetto, MD, DAN
Sheryl Ann Shea, RN, CHT, DAN
Robert Sheffield, CHT, International ATMO

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Foreword

One of the greatest challenges for diving physicians world-wide can be finding hyperbaric chambers in which injured divers can be safely recompressed in a timely manner. For recompression to be timely it is logical that physicians would direct divers to the closest available chamber. However, a frequently under-appreciated consideration for physicians trying to manage time-pressured dive accident scenarios is the suitability of candidate chambers. A chamber may be available, and perhaps close, but is it ‘suitable’? Suitability is a multifaceted consideration which takes account of the diver’s condition, the qualifications and experience of staff at the chamber and any associated hospital, the medical support available, and the chamber’s safety. Chamber safety is a fundamental, non-negotiable requirement. Sick divers often have a sense that any chamber will do, but unfortunately this is not the case. History has taught us the hard lesson that poorly designed, equipped or maintained chambers can be dangerous places, but how do we know what a dangerous chamber looks like? What are the benchmarks upon which we can make this difficult judgement, and how do chamber owners or operators benchmark themselves to ensure their facilities don’t present unintended dangers?

This is where Francois Burman’s authoritative “Risk Assessment Guide for Recompression Facilities” has made its indelible mark through four previous editions, and now into its updated fifth. Burman is, in this writer’s opinion, unquestionably the world’s preeminent expert on hyperbaric technologies and safety systems. His expertise and collaboration with other experts in producing previous editions of this publication laid the knowledge foundation for the establishment of DAN’s Recompression Chamber Network; essentially a register of chambers that, as best can be judged against the guideline’s criteria, are safety-compliant and available for treating divers in locations all over the world. This has maximized DAN’s ability to rapidly provide advice about evacuation and appropriate disposition of sick divers for recompression treatment.

This guide is an invaluable resource for professionals involved in hyperbaric care of patients, no matter whether their role is technical, maintenance, medical or nursing. It is written in Burman’s typically frugal, to the point, clear style. It is eminently approachable, understandable, well researched and logically arranged. I congratulate Mr Burman and DAN for updating this guideline and continuing the extremely valuable service to the diving community that it represents.

Professor Simon Mitchell

Anesthesiologist and Diving Physician.

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RISK ASSESSMENT GUIDE
FOR RECOMPRESSION FACILITIES

General

Scope

This risk assessment guide is intended to apply to recompression facilities worldwide that are technically equipped to deliver emergency treatment to recreational scuba divers suffering from decompression illness (DCI).

The scope of this guide is focused on the technical, operational, and safety aspects of recompression facilities. Medical decisions related to the treatment of injured divers remain subject to professional medical judgment and the availability of therapeutic resources.

Traditionally, recompression treatment facilities utilize dual-lock multiplace chambers. Monoplace chamber treatment facilities were initially intended for clinical hyperbaric treatments, usually no more than 90 minutes in duration. While not ideally suited for significantly longer recompression treatments, they can be utilized where the attending physician is appropriately trained in diving medicine. These facilities are increasing in number and extent. While this guide is primarily focused on multiplace chambers, it is not intended to exclude monoplace chambers – pressurized with either oxygen or air. Where applicable, specific requirements pertaining to monoplace chamber are included.

Purpose

The primary purpose of this guide is to provide a means of assessing whether an existing facility complies with minimum safety requirements for the treatment of injured scuba divers.

In addition, it is also intended as a safety guide for the following purposes:

- to provide guidance in the acquisition of a new recompression facility; and
- to provide guidance for modifications or additions to an existing facility.

Basis

The basis for the compilation of this guide was a thorough analysis of the risks that are inherent to the following situations:

- the exposure of humans to hyperbaric pressures;
- the restrictive nature of recompression facilities;
- the fire and explosion hazards associated with hyperbaric equipment;
- the multitude of associated mechanical and physiological hazards; and
- the hazards inherent in operating potentially dangerous machinery.

Each of these risks has been considered in the light of actual quantifiable risks and of minimum measures required to mitigate, remove, or acceptably contain potentially hazardous situations.

Applicable Statutes and Regulations

The operation of pressure vessels for human occupancy, the operation of dangerous machinery, and general occupational health and safety provisions is commonly controlled by regional or national statutory or regulatory provisions.

Neither this guide nor any other single document, code of practice, or set of operating instructions can supersede the requirement to comply with such provisions. All applicable statutes, regulations, standards, bylaws, and other regulatory instruments take legal precedence over the recommendations contained within this guide.

Many countries do not prescribe safety standards. This guide, originally commissioned by International DAN, has been specifically compiled to facilitate safety assessments of recompression facilities that are located where safety standards are lacking — or as a supplement to applicable statutes and regulations.

Appendix A contains a list of the regulatory and guidance documents that were consulted in the compilation of this guide. Please note that this guide does not claim to comply either in part or in whole with any or all these documents.

Also, the listed documents typically apply to facilities that deliver a wide range of services and therapies, not just recompression services and only the issues and risks relevant to recompression facilities have been considered here.

Explanatory Notes

A risk is based on these three factors: 1) the probability that 2) an exposure to a hazard will result in 3) harmful consequences.

The risk is higher where there is greater probability that an event will occur, greater the frequency of exposure to a hazard, and/or greater the severity of the consequences.

Unless all three of these factors are present, no risk exists.

A *hazard,* by contrast, is a potentially harmful situation or agent. A *risk* results from exposure to a *hazard*.

The terms *hazar*d and *risk* tend to be used interchangeably in many documents. In this document, however, *risk* refers to the probability of an adverse event, whereas *hazard* refers to the harmful situation itself.

The process of assessing risks associated with recompression chamber (RCC) facilities commences with a review of the impact of hazards associated with RCCs. The table below provides a description of each of the potential hazards and its associated risks.

Table 1: Identified Hazards Associated with Recompression Facilities

Hazards	Potential Risks
Fire and explosion hazards. Note: Fire prevention is critical in RCCs, because fire-suppression techniques are limited in their effectiveness in the presence of high oxygen (O_2) partial pressures.	
General issues	Fire requires the presence of three elements: fuel (a combustible or flammable material), an oxidizing agent (usually oxygen [O_2]), and a source of ignition (either heat or energy). Under hyperbaric conditions, the reactivity of the oxidizing environment is greatly increased due to the elevated partial pressure of the O_2. Any leakage of O_2 into a chamber due to improper, ineffective, or ill-fitting mask/neck seals in the breathing apparatus will dramatically increase the O_2 partial pressure, especially in a chamber with a small internal volume. The flammability of materials increases as the partial pressure of O_2 increases, to the point where normally non-combustible materials may become flammable or combustible. And the partial pressure of O_2 increases as a chamber's internal pressure increases, irrespective of whether the O_2 percentage also increases or not. If the O_2 concentration in a chamber exceeds 23.5% or more (i.e., meets the generally accepted definition of an O_2-enriched atmosphere) at an elevated total pressure, flames spread rapidly. RCC fires with survivors have occurred in chambers with an O_2 percentage below 23.5%. The heat of combustion rapidly increases the pressure in any contained environment, meaning the internal pressure within a chamber can soon exceed its intended or safe working pressure. The results of a RCC fire thus include depletion of the O_2 in the chamber, the production of toxic gases and other fire by-products, the combustion of human tissue, and overpressurization of the chamber.

Hazards	Potential Risks
Sources of fuel	Note: This analysis is limited to materials generally not considered to be combustible and to materials whose combustion behavior could be dramatically different in a RCC than under normal circumstances. Many materials either require a very high temperature for ignition or do not burn in air at atmospheric pressure. Such materials include certain types of flame-resistant fabrics, silicone rubber, polyvinyl chloride, asbestos-containing paint, glass fiber, polyamides, epoxy compounds, certain asbestos blankets, and lubricants. Such materials, however, all burn vigorously in an O_2-enriched environment. Examples include the following: • Flammable anesthetizing compounds. • Human tissue, hair, oils, and fats. • Oil-based or volatile cosmetics (e.g., body oil, hair spray, sunscreen, etc.). • Loose cotton garments, such as those commonly used in hospitals; they can be totally destroyed within 20 seconds in a 100% O_2 environment. Fabrics such as loosely woven cotton (carded or combined), gauze, and thin lace, which are liable to become super-combustible if tiny air spaces between the fibers become saturated with O_2 during a RCC treatment. Even after such fabrics are relocated to an atmospheric air environment, if they are ignited, they will burn almost as rapidly as if they were still within an O_2-enriched environment, until sufficient time has elapsed for the O_2 to diffuse out of the fibers and be replaced by air.
Sources of ignition	The more obvious sources include the following: static sparks from attire made of synthetic materials, noncompliant electrical wiring, and oil-contaminated materials (which present a spontaneous heating hazard), and items introduced by patients such as lighters/matches or tobacco products, children's toys, and handwarmers. In O_2-enriched environments, the minimum energy required for ignition is much lower than is the case in atmospheric air environments. The following list is not exhaustive, but it illustrates some of the known but less obvious sources of ignition: defective electrical equipment, high-voltage monitoring or radiological equipment, heated surfaces in broken vacuum tubes or lamps (even lamps used for illuminating diagnostic equipment), hot-wire cautery or high-frequency electrocautery devices, open or arcing switches, overheated motors, brushed motors, bare defibrillator paddles, and electrical thermostats.

Hazards	Potential Risks
Mechanical hazards	
Potential energy	Even small volumes of compressed gas represent a large amount of potential energy. Should such energy be released suddenly, the effects on adjacent structures and personnel can be devastating. Such a release can occur as a result of a failure of the vessel or its piping.
Deviation from design code or standard	Such a hazard may be created if the vessel is modified in a manner contrary to the original code or the design and construction standards employed in its manufacture.
Access restrictions	Any restrictions on access into or out of a vessel can create a hazard in case of a fire or other emergency. For example, rescue or firefighting personnel could be hindered from entering a chamber to render aid or occupants could be hindered from escaping from a chamber; either instance could be life-threatening.
Visibility	Any restrictions on chamber operators' ability to see clearly into the vessel reduces their effectiveness as safety monitors.
Sealed or semi-sealed containers	Certain containers may present hazards in a RCC, as they may collapse or rupture during changes in pressure. Examples of such containers include ampoules, stoppered bottles, capped bottles (e.g., multidose vials or glass intravenous infusion sets), and pneumatic cushions used for breathing masks or for positioning patients. Any air-filled containers taken into a chamber that are not adequately vented may either collapse under pressure (possibly resulting in adiabatic heating of the contents and thus representing a fire or explosion risk) or explode upon resurfacing if the gas trapped within the container cannot escape during ascent.
Other hazards	Other risks related to mechanical hazards include the malfunction, disruption, or inoperativeness of many standard items when they are used under hyperbaric conditions. Such risks include the implosion of lamps or vacuum tubes (e.g., cathode ray tubes in medical monitors); the overloading of fans due to higher gas density; and inaccurate operation of flow meters, pressure gauges, and/or regulators.

Hazards	Potential Risks
Physiological and medical hazards Note: As noted on page 49 in the description of this guide's scope, medical considerations remain subject to professional medical judgement. The only hazards thus included in this section are those that may arise as a result of mechanical, electrical, or other safety malfunctions.	
General hazards	These include electric shock and a fouling of the atmosphere in a RCC with carbon dioxide (CO_2), carbon monoxide (CO), pyrolysis products from overheated materials, or toxic products generated during combustion (e.g., cyanide or chlorine).
Gas contamination	The inadvertent introduction into the chamber of contaminants in compressed gases may be toxic to humans. In the context of hyperbaric facilities these may include, but are not limited to, excessive concentrations of: • CO, CO_2, oil-vapor, oil, and other particulates commonly detected in compressed gas products. • Hydrocarbon (HC) and volatile organic compound (VOC) products. • Sulphur and nitrogen oxide (NOx) based combustion products.
CO_2	Should a chamber's ventilation or air exchange system malfunction or prove inadequate, CO_2 levels could rise to toxic levels due to the increased atmospheric pressure.
Rapid depressurization	A rapid release of the pressure in a chamber can lead to shock waves, noise, and/or loss of visibility due to condensation inside the chamber. Rapid depressurization may occur if the relief valve is activated due to over pressurization or due to a failure of the vessel, viewports, penetrations, or its piping.
Noise	During compression and subsequent ventilation, noise levels for the occupant can be high enough to cause discomfort or hearing damage.

Not all risks have the same consequences or need for urgent attention. It is thus deemed prudent to use a risk level (RL) rating scale, as outlined in the table below (and detailed in Appendix B):

Table 2: Risk Level and Associated Mitigating Requirements

RL	Risk Rating	Requirements
5	Very high	Attention and risk mitigation are critical and must be given the highest priority. A potentially dangerous situation may exist, with the possibility of very serious or catastrophic consequences in the event of an adverse incident. Treatment activity should stop immediately and should not recommence until effective mitigation is in place.
4	High	Attention and risk mitigation are required and must be given high priority. A serious situation may exist that could endanger people or equipment or that could seriously disrupt or jeopardize the business. Solutions or actions that may mitigate the risk should be considered, at the discretion of the *responsible person* (see below for a definition of this term as used in this guide), and they should be recorded in writing.
3	Medium	Attention to the risk is required. Eventually exposure to this risk could likely result in an incident. Outcomes could include business disruption, financial or liability consequences, injuries, or equipment damage. Mitigation of the risk should be accomplished within practical time and cost considerations.
2	Low	Attention to the risk is recommended for the optimal functioning of the facility. Risk mitigation steps already in place should be recorded in writing.
1	Very low	The risk is acceptable. Note should be taken of the risk, but either it has already been suitably mitigated, or its impact is of justifiably low significance.

These suggested risk levels have been determined through an assessment of risk as described in the Explanatory Notes on page 2. Appendix B provides an indication of the applicable risk levels, based on the quantification of relative risk.

However, risk levels may vary on a case-by-case basis, as a result of the following factors: 1) the type or nature of the facility; 2) the degree of qualified discretion allowed by national or local authorities, and 3) a determination by the *responsible person* of whether a risk is relevant.

The term *responsible person* as used in this document refers to a facility's owner, manager, or safety officer. In most countries, it is mandatory under occupational health and safety regulations to designate this person in writing.

The term *competent* as used in this document to describe an individual should in all cases be assumed to mean a person who is competent to perform or certify an activity by virtue of their training, knowledge, and experience. This applies especially to the design, manufacture, testing, inspection, installation, management, and/or operation of hyperbaric facilities or equipment.

The term *specialist* as used in this document should be assumed to include *competent* persons, professionally qualified experts (e.g., fire engineers or electrical or electronic engineers), and representatives of organizations recognized as specialists in a particular field.

Suggested Risk Assessment Process

The example on the next page illustrates a suggested method for applying the risk assessment process described in this guide.

The process begins with an assessment of the risks that affect a given RCC facility. The risks need to be identified as applicable or deemed relevant by the *responsible person*. Guidance as to the importance of each risk thus identified is offered in the form of a risk level. The actual risk level may differ, as the *responsible person* deems relevant in the situation.

This is followed by a detailed physical evaluation of the facility regarding its conformance to relevant minimum requirements. The facility's technical aspects are described in section A - Construction and Equipment; the operational aspects in section B - Administration and Maintenance. A facility's *responsible person* should describe in detail how each applicable minimum requirement has been complied with.

If compliance with national or local regulations is required, but either no such regulations exist or any regulations that do exist are considered inappropriate for a RCC facility, the *responsible person* should comply with the appropriate guidelines detailed in Appendix A, in the "System Guidance Documents" and/or "System Standards" sections.

If a *specialist* suggests that exceptions to the minimum requirements are acceptable, these exceptions should be recorded in writing, together with any motivating considerations and presented to the facility's owner or manager for acceptance and endorsement.

In preparation for a safety assessment or an external review, this process should be undertaken in writing, especially as it relates to an assessment of actual or likely risks and to compliance or noncompliance with minimum applicable requirements.

This process should also be followed when any change in the status of a facility's equipment is anticipated — i.e., prior to the modification of existing equipment or to the acquisition of new equipment. A RCC treatment facility is an integrated unit, meaning that even small changes to certain items may have a significant impact on its overall operational safety.

Examples of risk assessment

Element: Access to bilges (typically RL 3)

Step 1: Identification of risk: Is the chamber fitted with a bilge area?

If the answer to Step 1 is “yes,” then the minimum requirement is that adequate access is required to enable the area to be cleaned and disinfected regularly. A build-up of dust and/or other waste materials represents a risk of both fire and adverse health effects.

Step 2: Application of minimum requirement(s) to address, remove, or mitigate the risk.

If the answer to Step 1 is “no,” then no requirement applies.

Comments:

In cylindrical chambers, deck plates are generally used to provide more comfortable standing space, as well as drainage space for condensed moisture, spillage, and, if applicable, fluid from a fire extinguishing system.

The area below the deck plates is called the bilge area.

It is preferred that deck plates be firmly secured for grounding, stability, and noise reduction purposes. However, the plates need to be installed in such a way that they can be readily removed to permit adequate cleaning.

If the minimum requirement(s) cannot be met, the *responsible person* may exercise discretion by, for example, removing noncompliant deck plates.

The deck plate design could also be modified to allow for easier removal or lifting of the plates or alternative cleaning techniques could be considered.

In all cases where such discretion is employed, it must be recorded in writing, endorsed by the owner or manager, and filed together with the completed compliance document.

Element: Chamber room lighting (typically RL 3)

Step 1: Identification of actual risk:

Ultraviolet light may cause deterioration of the chamber acrylic windows. Direct sunlight, mercury vapor discharge, and certain types of fluorescent lighting are known sources of detrimental UV radiation.

Step 2: Application of minimum requirement(s) to address, remove, or mitigate the risk:

Chamber windows should not be exposed to direct sunlight. Where fluorescent lighting is preferred, this lighting should be selected based on an appropriate UV spectrum range (UV radiation with a wavelength above 320 nm being released at more than 30 cm (1 ft) from the lamp).

Comments:

All forms of fluorescent lighting, including the compact fluorescent lamp (CFL), produce UV radiation.

UV radiation is classified in three main ranges, based on wavelength in nanometers (nm):

UVA: ±320 – 400 nm: the least harmful and almost negligible at distances of 30 cm (1 ft) and further.
UVB: ±290 – 320 nm: in sufficient quantities, causes sunburn and cancer. It also degrades acrylic windows.
UVC: ±100 – 290 nm: the most hazardous range to humans; typically used in germicidal applications.

The glass tubes used in incandescent, fluorescent, and CFL lamps absorb almost all UV radiation. At distances greater than 30 cm (1ft), the amount of harmful UV light is negligible.

Metal vapor lamps, specifically metal halide and mercury, can produce sufficient UV light in the UVB range to degrade acrylic materials.

Where the minimum requirement cannot be met, the safety officer may exercise discretion by, for example, installing UV filters (covers, screens, and films) between the source of UV radiation and the chamber acrylic window.

In all cases, where such discretion is employed, this must be expressed in writing, endorsed by the owner or user, and preferably filed together with the completed compliance document.

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A. Construction and Equipment

Elements	Risks	RL	Minimum Requirements

A-1. General Housing

Elements	Risks	RL	Minimum Requirements
1) Applicable standards for RCC facilities	The risks associated with this hazard include fire safety, building safety, mechanical equipment safety, personnel safety, and operational safety.	3 3	a) National statutes, regulations or standards, and local bylaws or ordinances should be followed, especially as to fire safety, building, and general facility matters. b) Chapter 14 of NFPA 99 (the National Fire Protection Association code as applicable to RCCs) addresses the pertinent risks on a thoroughly integrated and comprehensive basis; it is specifically relevant to hyperbaric facilities and should be used for additional guidance. Alternatively, the application sections in any of these documents may be used: American Bureau of Shipping (ABS), Lloyd's Register (LR), Australian/New Zealand Standard (AS/NZ), EN 14931, or Canadian Standard Z275.1.
2) Room housing the RCC	The use or storage of any equipment unrelated to the chamber room could compromise the safety of the facility and impede emergency evacuation.	3	Any room housing a chamber should be large enough to ensure unrestricted access to all controls, viewports, piping systems, and for egress in an emergency. The room should be for the exclusive use of the hyperbaric operation.
3) Supporting foundations for the RCC	Inadequate supporting foundations for a RCC could cause a failure of the building's support structure, especially during on-site hydrostatic testing.	4	All foundations for a RCC should be strong enough to support the chamber during all intended operations, including hydrostatic pressure testing. (Note: This requirement may be reduced if the chamber can be removed should any welding or other repairs or modifications be required or if pneumatic pressure testing is allowed.) It is preferable to locate a chamber in a ground-floor location.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
4) Fire protection of the rooms housing the chamber & ancillary equipment	A fire in a chamber or an equipment room may endanger any or all the following: a) The facility's staff and patients, both inside and outside the chamber; b) The operators (in addition, a fire may prevent them from remaining at their posts during an emergency termination and evacuation process); c) The chamber and its ancillary equipment; d) The continued operation of ancillary equipment (thus preventing safe termination of the treatment); and/or e) In some cases, the remainder of the building.	3 3	a) Local and/or national statutes, regulations, bylaws, and ordinances pertaining to fire safety in RCCs should be followed; protection should extend not just to the room containing the chamber, but also to associated treatment areas and ancillary equipment rooms. The protection should encompass fire-extinguishing capabilities, fire-resistant construction, and isolation doors (typically, rated for 2-hour fire-resistance). Certification of compliance with such provisions should be obtained from the relevant local authority. b) An automatic wet sprinkler system remains the preferred fire-suppression option. If such a system is not deemed to be required, at least one portable fire extinguisher, preferably of the dry chemical type, should be strategically located within the room.
5) No smoking or open flame signs	Any source of open flame presents a hazard in a location where the possibilities of high O_2 concentrations exist.	4	No smoking or open flame signs should be clearly displayed both within and outside any RCC facility and a strict no-smoking policy should be enforced within the unit.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
6) Communications capabilities	Even in the event of an emergency, an operator should never leave a RCC. But without an effective communications link with outside services, an emergency would require an operator to leave the control panel, thus losing contact with and sight of the patient.	5	All RCCs should be linked to an emergency control center by means of an alarm, intercom system, or telephone.
7) Lighting (UV)	UV light with a wavelength of less than 320 nm, referred to as UVB and UVC radiation, causes deterioration of a chamber's acrylic windows. Direct sunlight, mercury vapor discharge, and certain types of fluorescent lighting are known sources of harmful UV radiation.	3	Acrylic windows in a RCC should not be exposed to direct sunlight or any form of harmful UV radiation. If fluorescent lighting is used in a RCC area, the lamps used should have a wavelength above 320 nm (referred to as UVA radiation).

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**

A-2. Design and Construction[1]

1) Design of a RCC	The utmost care must be taken in the initial design of a RCC, because once a unit is constructed and installed, structural changes to the pressure vessel are exceedingly difficult to carry out in complete safety.	3	During the design of a RCC, all aspects of the chamber's operation relevant to its intended use should be considered — e.g., internal size, layout, number of occupants, storage shelves and bracketry, and maximum working pressure. It is recommended that RCCs be rated to a working pressure of at least 20 msw (66 fsw).
2) Safety standards	The use of inadequate, inappropriate, and/or unsuitable safety standards can compromise operator, patient, and/or facility safety; can compromise the safety of the entire health-care facility; and can result in noncompliance with relevant statutes and regulations. Pressure vessels are classified as hazardous equipment.	3	a) Chambers should be designed to meet the requirements of any of the internationally accepted and applicable safety standards, as well as any relevant national statutes or regulations. Care should be taken to ensure that the selected standards are applicable to pressure vessels for human occupancy (especially regarding viewport design). The ASME PVHO-1 (American Society of Mechanical Engineers' Pressure Vessels for Human Occupation) standard, which dovetails with NFPA 99 regulations, is an accepted standard.
		3	b) In addition, an internationally accepted life-support standard should be used to determine requirements for chamber equipment, ancillary equipment, levels of redundancy, safety system equipment, and maintenance, all as applicable to the intended use of the chamber. Examples of such standards include NFPA 99, AS/NZS 2299, ABS, and LR[2].

[1] Sections A-2 through A-8 are based on the use of an air-filled, multiplace chamber. While oxygen-filled monoplace chambers do not fall within the scope of traditional recompression facilities, they do fulfill a role. These are not excluded, and additional precautions and limitations are required, as indicated where applicable.

[2] These standards are listed in **Error! Reference source not found.**.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
2) Safety standards (cont.)		4	c) All chambers, viewports, and ancillary equipment, including the installation thereof, should be inspected and certified as compliant with the relevant standard(s) by an approved inspection authority. The facility should retain a copy of the certification documents so that appropriate, regular inspections and tests can be conducted.
3) Chamber flooring	Structurally unsound flooring may distort or shift, causing patients and/or medical personnel to trip or fall.	3	Flooring should be capable of supporting all equipment, personnel, and patients consistent with the intended use of the chamber.
4) Flooring materials	Certain flooring materials present risks of fire or falls.	4 4	a) Flooring should be non-combustible. b) Non-slip surfaces should be employed.
5) Access to bilges	Restricted access to a chamber's bilge area can hinder adequate cleaning of the area, resulting in a buildup of lint, dust, and human waste thus an increased fire and health risk.	3	If deck plates are fitted in place, adequate access to the entire bilge area should be provided to make effective cleaning and disinfecting of the area possible.
6) Securing of chamber flooring	Improperly secured flooring can be unstable and electrically unbonded flooring can cause a break in electrical grounding.	3	Any flooring should be securely installed to prevent its movement and ensure electrically conductive integrity. (Note, however, that whatever method is used to secure the flooring should not restrict its removal for cleaning purposes.)
7) Paint color of RCC	Certain colors may elevate patients' anxiety and dampen internal light levels.	1	Care should be exercised in selecting paint colors for a RCC. Colors that have a calming effect and enhance internal light levels are preferred.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
8) Internal surface treatment of finish of RCC	Finishes that are chemically unstable, flammable, or otherwise unsuitable in a pressurized environment present both health and fire risks.	3	The interior of a chamber should either be untreated (e.g., if it is made of stainless steel) or be treated with a non-toxic, corrosion-inhibiting, low-flammability paint that is suitable for human occupancy and hyperbaric pressure applications. Marine grade epoxy coatings have proven to be suitable products for hyperbaric applications. Where properly applied, the combination of a zinc-based undercoat and an epoxy or polyurethane top-coat provides suitable corrosion and abrasion resistance.
9) Paint fumes	Initial off-gassing from a painted surface can present a health risk.	4	No chamber should be used within the first 72 hours after application of an internal surface treatment, unless otherwise specified in the relevant material safety data information issued by the paint manufacturer.
10) Sound proofing materials	Certain sound-deadening materials represent a risk of fire.	3	If sound-deadening materials are used within a RCC, such materials should be flame-resistant.
11) Sufficient number of viewports or access ports	Inadequate allowance for visibility and access during the initial design and manufacture of a chamber may result in impaired ability to observe patients and/or may compromise the safe installation of monitoring and treatment equipment.	3 3 3	a) The initial design of the chamber should include enough viewports and equipment access-ports for piping, equipment, and monitoring leads. b) A suitable guide is to allow for at least 50% excess capacity of access ports or penetrations. c) Internal monitoring of an RCC can be enhanced using a video surveillance system.
12) Weatherproofing of electrical access ports	If access ports and electrical penetrators have not been adequately weatherproofed, there may be a risk of electrical shock, short-circuiting, or equipment damage during activation of an internal or external deluge system and/or during cleaning.	4	All electrical circuits should be housed in weatherproof enclosures capable of withstanding a deluge from the internal or external fire protection system, the application of cleaning solutions, and any precipitation to which the chamber might be exposed.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
13) Viewport design	The design and maintenance of viewports are critical to safety and yet fall outside the scope of many international design and construction codes.	3 3	a) Viewports should be designed to meet the requirements of a safety standard that makes specific provision for nonmetallic, pressure-bearing structures. The ASME PVHO-1 code is the most widely accepted viewport standard. b) The service life requirements defined by a relevant safety standard should be followed. ASME PVHO-2 allows for a service extension based on a visual inspection by a *competent* person for use in a protected service environment.
14) Care of acrylic windows	Certain cleaning fluids and UVB or UVC radiation may cause window deterioration.	4 3	a) Care should be exercised to ensure that correct cleaning procedures are enforced. b) Chamber windows should not be exposed to direct sunlight, any other source of UVB or UVC radiation, or to any direct source of heat. The ASME PVHO-2 standard provides guidance on the care and use of acrylic windows. The acrylic inserts in light-pipes are not considered as acrylic windows.
15) Seats, bunks, and other fixtures	Fixtures and furnishings installed in a chamber may introduce into the environment flammable materials, mechanical hazards, and/or a source of electrostatic charges or discharges.	3	Seats, bunks, and other fixtures should, whenever possible, be fabricated using non-sparking and non-combustible materials, be free of sharp edges and corners, and be designed for ease of installation and removal.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
16) Pressure-relief provisions	Overpressurization of a chamber can result in a risk of mechanical damage or fire.	5	a) Relief valves should conform to the relevant construction standard and should be sized so that no situation can exist whereby gas can be introduced faster than it can be discharged.
	Inadequate venting capacity of relief valves is a hazard that can lead to overpressurization.	3	b) The reseat pressure limit should be no lower than 7% below the set pressure and this function should be tested regularly.
	Excursions to pressures above safe levels for oxygen administration can result in oxygen toxicity.	3	c) Additional safety devices should be used to prevent excursions above safe levels for oxygen administration (i.e., 3 ATA).
	Malfunctioning relief valves can compromise the safety of a chamber's occupants.	3	d) Relief valves should be fitted with isolating valves internally and externally to allow them to be shut off in the event of a malfunction. Valve handles should be wired in the open position using breakable safety wire, cable (zip) ties or tamper-evident security seals.
	A fire in an elevated oxygen contained environment may lead to an explosive increase in pressure, overwhelming the ability of the relief valve to keep pressure from rising above the chamber safe design pressure. This can lead to catastrophic failure of the pressure boundary.	4	e) In chambers intentionally operated with atmospheres containing more than 23.5% oxygen, a secondary means for pressure relief should be provided. This device should be selected to prevent chamber pressure from exceeding 200% of the maximum allowable working pressure, in the event of an uncontrolled increase in pressure. The secondary pressure relief device shall be non-reclosing, ensuring no possible increase in pressure once open.
17) Chamber pressure gauges	If either occupants or operators of a chamber are unable to read the pressure gauges, it may affect the quality of treatments as well as the safety of the occupants.	4	a) All chamber compartments should be fitted with independent pressure gauges, designed for life-support, which can be read by the chamber operator. This is usually achieved by mounting the gauges on the control panel.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
17) Chamber pressure gauges (cont.)	If gauges are incorrectly installed, controlled, and/or maintained, they may not function accurately or effectively.	4	b) Treatment locks should be fitted with internal caisson pressure gauges or at least a suitable means of informing the occupants of the lock pressure.
		3	c) All gauges should be accurate and repeatable, should have scales appropriate for the expected pressure range (i.e., with normal treatment pressure in the middle third of the readout), and should be of a size suitable for easy readability (i.e., no smaller than 150 mm [6"] in diameter). Clinical hyperbaric O_2 treatment chambers are not usually used for high-pressure treatments, which require accuracy during decompression. An accuracy of ±0.5% of the gauge's full scale or better is sufficient for chambers with treatment pressures under 3 ATA. Gauges used with pressures above this level should comply with the industry standard of ±0.25% of the full scale.
		4	d) Pressure gauge lines should not supply any other devices.
		4	e) Internal ports for gauge lines should be protected with a shield to prevent inadvertent blockages.
		3	f) All systems should be correctly cleaned prior to use and regularly checked for leaks.
		3	g) Gauges should be tested and validated at least once a year to provide assurance of proper function and accuracy.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
17) Chamber pressure gauges (cont.)		3	h) In the absence of jurisdictional requirements for regular calibration, it is considered acceptable to observe any discrepancy between two equivalent gauges fitted to the chamber. An accuracy limit of no more than 2% of full scale is considered acceptable, e.g., ± 0.4 msw over a full scale of 20 msw, or 1.4 fsw for a full scale of 70 fsw.
		3	i) Gauges should be retested more frequently than annually if: • There is any doubt about accuracy, • They are sticking, • Mechanical damage has occurred, or • Testing frequency is specified by the manufacturer or jurisdictional authority.

Elements	Risks	RL	Minimum Requirements
A-3. Illumination			
1) Location and design of lighting	Lighting fixtures not designed for hyperbaric applications present a serious risk of explosion, implosion, and/or fire. There are also risks if the maintenance and inspection requirements for such fixtures are not followed.	3	The preferred location for mounting RCC lights is on the outside of the chamber. However, interior use of lighting fixtures may be considered if these are: • Designed to operate under hyperbaric pressures, • Employ safe and compliant wiring, • Do not exceed the electrical parameters in section A-6. Electrical Systems, and • Certified by a *competent* design authority as suitable for use inside a RCC.
2) Elevated temperatures caused by external lights	If external lights are used in conjunction with viewports, excessive surface temperatures can compromise the integrity of the viewport acrylic lens material.	4	Lighting fixtures should be designed in accordance with the requirements of a suitable standard that includes provisions regarding viewports. The temperature rating of the specific window material should be considered during the design of fixtures.
3) Sealing materials for internal lights	The elevated surface temperature of internal lighting fixtures can cause pressure increases that may lead to a premature failure of the lights' seals. This constitutes a risk of both fire and structural failure.	3	Gasket and o-ring materials in such applications should be fire-resistant, appropriately temperature-rated, and designed and selected to accommodate movement due to thermal expansion.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
4) Internally installed lights, including portable medical examination lights	Electrical resistance lights are a source of heat and if they are not suitably protected when used inside a RCC, there is a risk that they may provide sufficient energy for ignition.	 4 4 3 3 2	Internal lighting fixtures in a RCC should meet the following requirements: a) They should have an external operating surface temperature of less than 85°C (185°F); b) They should be rated for a pressure of at least 1½ times the chamber's maximum working pressure; c) They should be located away from areas where they may be physically damaged; and d) They should be designed for such applications and that fact should be certified by a *competent* design authority. It is recommended that high-intensity local task lighting be provided using through-hull fiber-optic devices.
5) Portable medical examination lights	Portable lighting fixtures carry an additional risk that they may shatter or explode if they're dropped or accidentally damaged.	4	All externally powered portable lighting units should be of a self-contained, vented, and shatterproof design. The design should be in accordance with a recognized and applicable standard and certified as such.
6) Emergency lighting	An illumination failure in a chamber without adequate backup lighting can lead to risks for both patients and medical personnel. In addition, any emergency responders will be hampered in their ability to act, leading to additional risks.	3 3	a) Chambers should be fitted with enough lighting fixtures so there is suitable redundancy if one fixture fails. If a chamber has sufficient viewports, external room lighting may be sufficient to provide backup illumination. b) Lighting power circuits should be connected to the chamber's emergency power supply.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**

A-4. Gas Supply Systems, Ventilation, and Air Conditioning

1) Air pressurization system	Insufficient air capacity for nonroutine or emergency treatments can compromise patient care during inadvertent power breaks that affect the compressor.	5	a) Air compressors and storage vessels should be designed with sufficient capacity to complete a maximum-duration medical treatment, including pressurization, and to supply the maximum, continuous ventilation demand.
	Excessive moisture can affect the ability of filtration systems to work effectively.	3	b) Compressed air systems should be fitted with after-coolers to ensure that excess condensate is removed prior to storage.
	Condensed moisture can also influence control valves and result in accelerated corrosion in storage vessels.	3	c) It is recommended that automatic drains be fitted to all filter housings.
	In addition, environmental particulates above a certain size can result in damage to the compressor's gas flow path.	2	d) Compressors should be fitted with inlet filters capable of removing airborne particles no larger than 10 μm in size.
2) Piping systems	Certain piping materials are not suitable for hyperbaric facilities due to impurities and/or corrosion considerations.	4	a) In most cases, only copper, brass, or stainless-steel alloys should be used for supply systems to a RCC. Materials for RCC exhaust systems should be O_2-compatible but are not otherwise restricted.
	Undersized piping systems can affect patients and facility staff by prolonging treatments unnecessarily, restricting extraction of patients during emergencies, and generating excessive noise.	3	b) Supply piping systems should be designed to deliver and maintain compression rates between the ideal of 18 msw/min (60 fsw/min) and a minimum of 2.4 msw/min (8 fsw/min). The industry average is 10 msw/min (33 fsw/min).
		3	c) Exhaust systems should be capable of bringing the chamber from 20 msw (65 fsw) to surface pressure in no more than 6 minutes.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
2) Piping systems (cont.)	Venting systems can cause injuries to patients if inlets are not suitably screened.	4	d) All exhaust inlets, relief valves, depth monitoring inlets, sample inlets, and other suction inlets inside the chamber should be fitted with anti-suction-injury devices.
		2	e) All fluid/gas shell penetrations should be fitted with internal and external isolating valves, as close to the penetration as possible, to allow the fluid/gas flow to be shut off in the event of a malfunction.
		4	f) Chambers should be configured with an escape valve device or capability, so that occupants can override the controls in the event of operator failure and return the chamber to surface pressure.
	The use of high-pressure supplies can result in the overpressurization of piping and/or other components, beyond their rated levels. Inadvertent overpressurization can also occur if the control equipment fails or if the operator fails to control pressures correctly.	3	g) Chambers should be pressurized using regulated, low-pressure gas. Note: High-pressure gas supplies, i.e., those greater than > 4 MPa (580 psi), should be reduced as close to the source as practical.
		3	h) All pressure-reducing regulators should be fitted with downstream pressure-relief devices to protect any piping and/or other components that are rated for lower pressures.
	Dirt particles are a known source of the failure of regulators to maintain constant downstream pressure.	4	i) The inlets on all pressure-reducing regulators should be fitted with suitably sized particle filters (< 5 µm) to prevent dirt or debris from entering the sensing ports and causing downstream regulator creep.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
2) Piping systems (cont.)	System designs that rely on operator attentiveness to prevent certain actions — including back-filling of storage vessels at different content levels, reverse-pressure or -flow situations (especially on systems with diaphragms and/or sensing equipment), and venting through unintended flow paths — can compromise supplies, lead to an inaccurate assessment of available gases, and/or result in the failure of pressure-control equipment.	3	j) The piping of supply systems should be fitted with nonreturn (check) valves to prevent the following actions: • inadvertent back-filling of storage vessels; • exposure of regulators and/or other components to reverse-pressure situations if they were not designed for such applications; and • venting through self-venting ports on pressure-reducing regulators.
	Inappropriate or inadequate cleaning procedures can result in premature component failure or the introduction of toxic vapors into the chamber and can increase the risk of fire.	3	k) All air-system components and piping should be suitably cleaned prior to their first use.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
2) Piping systems (cont.)	Due to more frequent connection & disconnection and/or an intrinsically weaker structure, flexible hoses are more prone to failure due to mechanical deterioration, surface abrasion, material age- or environmentally related degradation, and cracking and weakening of end fittings. Any such damage can result in unrestrained hoses whipping around and/or rapid and even catastrophic failure, with associated; • expansion-related damage, • permanent hearing loss, and • trauma or injury.	3	l) In selected cases, the use of flexible hoses for RCC supply systems is acceptable, subject to all the following criteria: • Be kept to a minimum, except for low pressure lines; • Preferably be restricted to short lengths: <1 m (3 ft) where used for HP, i.e., >4 MPa (580 psi) gas applications; • Be fitted with restraints (anti-whip devices) on both ends; • Be suitably rated and appropriately certified for the system design pressure; • Be consistent with cleanliness requirements and compatible with the gas they transport; • Be connected without any stress on joints and couplings; • Be assembled without kinks or sharp bends; • Be adequately protected from external mechanical damage; • Not pose a trip hazard; • Be used only where adequate provision has been made for the regular inspection of the condition of all flexible hoses; and • Shut-off valves should be located as close to the end fittings as is practical.
		3	m) Consideration may be given to the use of a check valve in a flexible hose connected directly to a chamber, as a buffer in the event of a line break. Check-valves or the ability to prevent backflow, should be an inherent part of the design of a chamber's control panel.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
3) O_2 supply volumetric or capacity considerations	Correct volumetric considerations are essential for providing effective treatments, as well as preserving the health care facility's other requirements.	3	The system should be designed to ensure that the required volume of O_2 is available to provide for the full duration of the longest likely treatment provided. As a guideline, a supply system should be based on the product of maximum number of occupants, each breathing at least 64 actual lpm (2.3 acfm) at depth (in ATA), for the complete treatment cycle for the maximum intended number of treatments between refilling periods.
4) O_2 supply and exhaust systems	An inadequate supply of therapeutic O_2 can compromise a treatment regimen and thus negatively affect the outcome for the patient.		The design of a chamber's supply and exhaust systems should meet the following criteria:
		3	a) Be capable of ensuring a supply pressure of at least 0.35 MPa (50 psi) above the chamber's pressure to each outlet as otherwise required by the selected breathing apparatus;
		3	b) Be equipped with emergency isolation valves, preferably fitted close to the shell;
		3	c) Include sufficient capacity to permit treatments to be completed prior to refilling;
		3	d) A secondary (reserve) supply of O_2 should be available if the main supply is interrupted;
		3	e) Ensure that high-pressure supplies conform to the guidelines for a safe and controlled supply;
	Leakage of exhaled O_2 into the chamber presents a fire risk.	4	f) Ensure that the exhaust system is fitted with an effective overboard dump system, which automatically adjusts to the treatment pressure; and
	The uncontrolled exhaust of exhaled gas (O_2 or air) from the breathing apparatus could lead to a significant risk of suction injury.	4	g) It should ensure that the exhaust system has been designed to restrict or control the flow between the patient and ambient pressure.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
5) Cryogenic supply system	Inadequate maintenance, poor housekeeping, and/or lack of regular inspection of the cryogenic supply system presents a risk of fire, supply interruption, and/or facility damage.		If a RCC has a cryogenic supply system, it should conform to all applicable statutes and regulations, should be controlled and managed by a *competent* gas supply company, and should be properly maintained, at a minimum with respect to the following factors:
	Even if the filling and maintenance of the system are handled by an outside vendor, a RCC's owners and managers still bear responsibility for ensuring the integrity, safety, and availability of the system.	3	a) Security of the site, to prevent unauthorized access or interference with the system;
		3	b) Routine monitoring of fire hazards, such as removal of under or overgrowth, overhead electrical supply lines, or burnable materials (including waste matter), stored in the immediate vicinity of the system;
		4	c) Placement and integrity of adequate warning signs and emergency instructions;
		3	d) Regular inspections (at least prior to each treatment session) of the cryogenic storage area, including monitoring of liquid/gas storage levels, system pressures, control positions, equipment condition, and site security; and
		3	e) Appropriate and regular maintenance by an appointed, *competent* gas supply company.
6) O_2 purity standards	Impure or contaminated O_2 is both a health- as well as a fire risk.	4	a) Medical O_2 requires a purity level of at least 90% unless national regulations dictate otherwise. Under no circumstances should a RCC use O_2 that is not either piped from a cryogenic source, supplied from high-pressure cylinders certified as containing medical-grade $O_{2,}$ or provided using a suitable medical O_2 generator.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
6) O_2 purity standards (cont.)		3	b) If a RCC cannot be guaranteed of a suitably pure supply of O_2, the supply to the chamber should be analyzed by one of these means: • Continuously while online; • At the discretion of a *competent* person, who should substantiate in writing the requirements for the frequency of the analysis; or • At the very least, whenever supplies are changed over or refilled.
7) O_2 piping	Compressed O_2 represents a risk of fire and other effects of its stored energy.		O_2 piping should be designed and installed according to the following minimum requirements:
		4	a) Only *competent* and thoroughly trained individuals should install, clean, or work on O_2 piping systems;
	Inappropriate or inadequate cleaning procedures can result in premature component failure or the introduction of toxic vapors into the chamber and can increase the risk of fire.	4	b) If copper tubing is brazed, it should be continuously purged with nitrogen (N_2) during the brazing process to prevent the formation of hazardous copper oxides;
		4	c) All O_2 supply lines should be cleaned in accordance with an approved O_2 cleaning procedure;
	Certain materials are not suitable for use with O_2.	4	d) Only O_2-compatible materials should be used (publications of the ASTM [American Society for Testing and Materials], CGA [Compressed Gas Association] and ASME/PVHO contain lists of approved materials);
	In the event of a fire, the O_2 supply to the chamber would intensify the fire.	4	e) An O_2 shut-off valve should be installed at the point where the O_2 enters the room;
	Rapid-acting valves are a potential source of adiabatic heating during opening and closing.	4	f) Quick acting ball valves should not be used to isolate lines containing O_2 at pressures > 0.86 MPa (125 psi);
		3	g) The pressure in any O_2 supply lines to the chamber should be visible from the control panel;

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
7) O_2 piping (cont.)	The use of high-pressure supplies can result in overpressurization of piping and other components not designed for elevated pressures. High pressures can also be introduced inadvertently if control equipment fails or if an operator fails to control pressures correctly.	3	h) O_2 supplied at pressures > 0.86 MPa (125 psi) should be reduced at their source or, if that is impractical, at the chamber control station;
		3	i) All pressure-reducing regulators should be fitted with downstream pressure-relief devices to protect piping and other components rated for lower pressures;
		3	j) The discharge from any safety-relief device(s) should be connected to an exhaust line piped into a safe open space (i.e., it should not terminate near a source of heat, an ignition source, or a hazardous area);
	Dirt particles are a known source of the failure of regulators to maintain constant downstream pressure.	4	k) The inlets on all pressure-reducing regulators should be fitted with suitably sized particle filters (≤ 5 µm) to prevent dirt from entering the sensing ports and causing downstream regulator creep;
	System designs that rely on operator attentiveness to prevent certain actions — including back-filling of storage vessels at different content levels, reverse-pressure, or reverse flow situations (especially on systems with diaphragms and/or sensing equipment) and venting through unintended flow paths — can compromise supplies and lead to an inaccurate assessment of available gases and/or result in the failure of pressure-control equipment.	3	l) O_2 supply systems should be fitted with nonreturn (check) valves to prevent the following actions: inadvertent back-filling of storage vessels; exposure of regulators and/or other components to reverse-pressure situations if they were not designed for such applications; and venting through self-venting ports on pressure-reducing regulators;
		3	m) Following installation and at prescribed maintenance intervals, all O_2 piping should be tested for leaks (caution should be exercised when using testing solutions that are flammable or not O_2-compatible); and
		3	n) Only special, dedicated tools should be used for O_2 service (i.e., they should be clean and non-sparking).

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
8) Conditioning of chamber air	Uncomfortable temperatures within a chamber can compromise the patient's condition and may increase the percentage of O_2 in the chamber. Uncomfortable conditions can also heighten patients' anxiety levels, cause medical problems, and affect the control of static electricity.	2	Chambers should be maintained at a temperature under 30°C (86°F) and a relative humidity between 50% and 70%. This may be achieved with ventilation using suitably-conditioned air. Alternatively, suitably designed and approved chamber environmental conditioning units may be used.
9) Ventilation requirements	Inadequate ventilation can have an impact on patients' conditions, allow a buildup of O_2 and/or CO_2, and affect the temperature and humidity in the chamber. Such conditions increase the risk of fire and/or toxic gas levels, as well as of other risks associated with elevated temperature and humidity. Such risks exist during all stages of chamber operation, including pressurization, a constant-pressure state, and depressurization.	3	a) A minimum ventilation rate of at least 64 actual lpm (2.3 acfm) per chamber occupant is required (*actual* flow implies the rated flow at the chamber's ambient pressure and temperature). This rate may be reduced if CO_2 levels are monitored continuously or if patients are breathing O_2 using an overboard dump system, providing that O_2 levels remain below 23.5%. <u>Note</u>: The ventilation rate may need to be increased above this recommended level if no overboard dump system is installed or if the overboard dump is not effective, in order to keep O_2 levels below 23.5%.
	Poorly placed inlet and exhaust points may also result in inadequate circulation and ineffective removal of unwanted gases.	3	b) Inlet and exhaust points should be positioned to ensure effective air circulation, facilitate the removal of unwanted gases, lower the internal temperature of the RCC, and reduce humidity levels.
		2	c) Stable conditions may be maintained using metabolic O_2 injection and scrubbing to remove CO_2 and odor levels. <u>Warning</u>: Under no circumstances should a chamber's interior O_2 level be allowed to exceed 23.5%.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
10) Internal breathing apparatus	Toxic, nonbreathable, and harmful gases constitute a serious hazard for occupants of a chamber. An ineffective supply of therapeutic gas can compromise the quality of the treatment and affect the outcome for the patient.	4 4 4 4 5 4	Each occupant should be provided with an individual breathing apparatus. The apparatus, including its supply system, should be designed to meet the following criteria: a) It is available for immediate use at all times; b) It is independent of the chamber atmosphere; c) It can be used simultaneously by all occupants; d) It is fully functional at all chamber operating pressures; and e) In the event of a fire, the supply can be switched to air (or a suitable, normoxic mixture).
11) External self-contained breathing apparatus	In the event that the air in the vicinity of a chamber becomes fouled by smoke or other combustion products, the chamber operator may (due to the complexity of the treatment then in process) be unable to depressurize the chamber and evacuate the occupants to safety. In such a case, the operator faces the risk of breathing the fouled air unless an external self-contained breathing apparatus is available.	4	An independent source of breathing air or a suitable filtered breathing apparatus should be available for use by essential chamber personnel in the event that the air in the vicinity of the chamber is rendered toxic, is fouled or otherwise becomes unbreathable. Suitable eye protection to shield chamber personnel from combustion products should be incorporated into the breathing apparatus.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
12) Sources of air for a chamber	Toxic, flammable, or fouled air can be introduced into a chamber's air source by means that may be beyond the control of the facility's owner or manager.	5	Compressor intakes should be located so that toxic, flammable, or fouled air cannot be introduced into a chamber's system. (Typical sources of fouling include vehicular activity, internal combustion engines, other mechanical equipment, and building exhaust outlets.) Warning signs should be posted at the locations of all compressor intakes.
13) Handling of air for a chamber	Unsuitable or malfunctioning air-handling equipment can contaminate the air supply to a chamber. Contamination with oil or other HCs presents a particular hazard in O_2-enriched environments.	4	The air supplied to a chamber should be monitored as detailed in section A-7. Communications and Monitoring, subsection 8, Chamber air-supply monitoring (see page59). Efforts should be made to ensure that all known causes of contamination are eliminated by following correct maintenance procedures and by conducting regular inspections of compressor seals, air purification devices, and compressor intakes and filters.
14) Compressor air intake	Inappropriately located and/or inadequately sized air-intake piping can lead to excessive air intake resistance or a starving of the compressor. This may result in reduced air output and pressure, overheating, excessive oil consumption, and damage to the compressor.	3 3	a) The introduction of any form of resistance to the flow of air, including remote location of a modified inlet filtration system without instruction or approval from the compressor manufacturer, should be avoided. b) Any extension of an intake hose should account for the added flow resistance.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
14) Compressor air intake (cont.)		3	c) As a general rule these criteria should be followed: • The internal diameter of an intake hose should be increased by at least 6.35 mm (¼") for each 3 meters (10 feet) of extension, applied to the complete length of the hose; • If 90-degree bends or other similar flow restrictions need to be used, the internal diameter of the complete intake hose should be increased by 6.35 mm (¼") for each bend and no more than four bends are recommended; • Provision should be made at the connection to the existing compressor intake to drain any condensate that might accumulate in the hose and run into the compressor intake; • The inlet to the extension hose should be covered with mesh to prevent insects or debris from being drawn in and the opening should also face downward to avoid any direct rain from entering the hose; • The use of any form of filter at the inlet to the extended hose should be avoided; and • The manufacturer's requirements and recommendations, if available, always take precedence.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
15) Use of an oil-lubricated compressor	If a chamber is served by an oil-lubricated compressor, a failure of the air-treatment package, inadequate maintenance procedures, or a failure of the compressor system could introduce oil and/or other HCs into the chamber's air supply. This presents a major risk of fire, especially in an O_2-enriched environment.	3 3 3	a) If a chamber is served by an oil-lubricated compressor, it should be fitted with an air-treatment package specifically designed to produce breathing air (Appendix C). b) Air-treatment packages on oil-lubricated compressors should preferably be fitted with automatic safeguards to ensure either that contamination cannot occur or, if it does, that the air-supply system will shut down before the contamination can reach the chamber. c) Oil-lubricated compressors and associated air-treatment packages should be diligently monitored and maintained.
16) Redundant air-supply capability	A failure of a chamber's air-supply system, especially during a life-threatening emergency treatment, can seriously compromise the patient's condition and the efficacy of the treatment.	3	a) Air-supply facilities should consist of two or more individual systems, each with sufficient capacity to maintain the required flow rates on a continuous basis. This requirement may be met by using one large compressor, typically with a low-pressure (LP) rating, and one standby compressor, typically with a high-pressure (HP) rating, which can be used to fill an adequately sized high-pressure storage tank. Other acceptable options include two low-pressure compressors, two suitably sized high-pressure compressors, or a large supply of stored air.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
16) Redundant air-supply capability (cont.)		4 3	b) At least one system should meet the pressurization and ventilation requirements of the full duration of any intended treatments. The standby system should have the capacity to provide for the full duration of the longest table used for treatments of life-threatening conditions, for example a U.S. Navy Treatment Table 6 (USN TT 6) with full extensions. c) Each compressor should be supplied from a separate electric branch circuit.
17) Sound attenuation	A chamber environment contains numerous acoustic factors that serve to magnify noise levels.	3 3 2 4	a) Mufflers should be used to reduce noise to the levels required by national regulations, or at least below 85 dB(A). b) Noise levels during maximum flow situations, including emergency ascents, should be considered and verified. c) Reverberation should be reduced through the use of baffling panels. d) If noise levels cannot be effectively reduced (such as during pressurization), personal ear protection should be provided to all chamber occupants.
18) Power-operated or automatic chamber control system	Automatic control systems may provide better control and allow the operator to focus on the patient rather than the controls. In the event of any system failures, the chamber and the occupants may be placed at risk from rapid ascent or descent. This could also affect occupants being locked in the chamber.	4	The chamber operator must have the means to override or deactivate the control system to manually control the chamber. This should include descent, ascent, and ventilation rates, as well as maintaining the chamber at constant treatment pressure. Isolation valves and an emergency escape valve should be available for the inside tender in a chamber.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**

A-5. Fire Protection

Note: A fire within a hyperbaric chamber presents a potentially fatal and catastrophic situation.

It is normally required that hyperbaric chambers used for medical treatments have a deluge fire-suppression system together with a secondary system, such as a handline or a portable hyperbaric extinguisher.

However, apart from O_2-fueled fires, most fires within a chamber can be effectively extinguished using a manual fire extinguishing system.

It is normal practice for diving chambers to be equipped with portable, water or wet-foam fire extinguishers.

At the discretion of the facility's medical director and/or *responsible person*, a handline or portable fire extinguisher, available in at least the treatment lock and rated for the maximum treatment depth, may be acceptable.

It is essential that continuous environmental oxygen levels be carefully monitored.

In the event of any indication of a fire, reaction times to shut off any oxygen supplied to the BIBS, provide occupants with regular breathing air, access and deploy the handline or portable extinguisher, and decompress the chamber, should be regularly assessed through drills.

Deluge systems in oxygen-filled monoplace chambers are generally regarded as impractical.

Elements	Risks	RL	Minimum Requirements
1) Unsuitable means of fire extinction	Certain generally accepted methods of extinguishing a fire are not suitable or effective within a hyperbaric, O_2-enriched environment.	5	a) Fire blankets, CO_2 extinguishers, and other fire-extinguishing devices that rely on air exclusion are either unsafe or ineffective in an O_2-enriched environment and thus should not be installed in or carried into a chamber.

Note: The following section applies primarily to a water-based deluge system with a secondary system being either a handline or a portable extinguisher. The sections relevant to all fire protection systems should still be assessed and complied with.

Elements	Risks	RL	Minimum Requirements
2) Component failure	Component failure can affect the integrity of a fire-suppression system.	5	The design of all fire-suppression systems should be such that failure of components will not compromise the effective functioning of the other system.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
3) Immediate activation of certain functions	The activation of certain safety-related functions should not be left to the operator during emergency situations. Without immediate reactions to such an event, the lives of occupants and the safety of the entire facility could be placed at extreme risk.	 4 4 4 3 3 4	On activation of either a deluge system or a handline system, the following should occur immediately: a) Isolation of all O_2 supplies to the chamber's interior and activation of an oil-free breathing air supply (or normoxic gas) in the place of O_2; b) Instruction to the occupants to immediately put on their breathing apparatus; c) Visible and audible indication of an alarm situation at the operator's console, plus signaling to the nearest fire department; d) Disconnection of all internal, ungrounded electrical power systems, excluding those that are intrinsically safe[3]; e) Activation of emergency lighting and communications, if applicable; and f) Based on severity and where the situation can be safely assessed: • Surfacing of the chamber as rapidly as the situation requires; and • Performance of any special activities within the chamber.
4) Fire alarm	The chamber operator should not be expected to have to contact fire and/or emergency services manually if an adverse incident occurs either within the chamber or in its immediate vicinity.	4	A fire alarm and/or emergency signaling device should be located at the operator's console, so the operator can easily and directly signal either a telephone operator at a nearby health-care facility or the nearest fire department. A direct alarm/monitoring system automatically coupled to the fire department is even better.

[3] The term *intrinsically safe* implies that a device, item of equipment, or a wiring circuit, cannot release enough energy to ignite a flammable vapor or atmosphere, especially when present in an oxygen-enriched environment (O_2 > 23.5%).

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
5) Fire-suppression system's power supply	A power failure could completely compromise the activation and effective functioning of the fire-suppression system.	5	All fire-suppression system components and controls should be powered from the RCC facility's emergency power system or from the chamber's independent backup power reserve.
6) Water deluge system	Unless the deluge system is properly designed, there is a risk that its coverage and/or function may be ineffective under the range of pressures and situations found within a hyperbaric environment.	5	a) A fixed water-deluge system should be installed in all manned locks, excluding locks used solely for transfer purposes.
		5	b) The system should be designed to function effectively and simultaneously in all treatment locks, even at different pressures.
		5	c) The system should perform as specified across the full operating pressure range of the chamber.
	Fire deluge tanks are not usually fitted with the means to determine the actual water level. The required pressurized space above the water implies that the vessel cannot simply be filled to the top.	3	d) A suitable water-level indicator should be installed and preferably displayed at the chamber console.
	Any rust or other particles and flakes may clog the spray nozzles or cause the activation valve to seize shut. Typical screen hole diameters are 3.2 mm (⅛ inch) *, which is sufficient to allow water to flow if partially clogged or pressure is reduced. * This is the Underwriters Laboratories (UL) requirement for fire line strainers.	3	e) A suitable water filter (strainer) should be installed as close to the outlet of the water-supply system and always before the deluge activation valve. Strainers that allow for regular opening and inspection should be selected. Where the water supply system is contained in a stainless steel or suitably lined corrosion-product free vessel, and where any form of particle deposits (e.g., limescale), are not present, this requirement may be dispensed with.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
7) Location of activation controls	Response time during an emergency has a direct effect on the success of the outcome.	3 3	a) Activation and deactivation controls should be installed at the operator's console and inside each manned lock. The number and location of control stations required inside each lock are dependent on the lock size and are subject to the *responsible person*'s discretion. b) All controls should be designed to prevent their inadvertent activation but not cause a delay if activation is required.
8) Deluge activation time	The speed with which a deluge system is activated in the event of a chamber fire has a direct effect on the success of the outcome.	4	Deluge valves should open within one second of the activation signal. Water should be delivered from the sprinkler heads no longer than three seconds after the activation signal.
9) Adequate deluge system coverage (based on NFPA 99)	Inadequate or incomplete coverage reduces the effective extinguishing capability of a deluge system.	4 4	a) The deluge system should be designed so that the number and position of the sprinkler heads achieve the following effects: • Uniform spray coverage; • An *average* spray density at *floor level* of no less than 82 lpm/m^2 (2 gpm/ft^2); and • An actual coverage of no less than 41 lpm over any floor area larger than 1 m^2 (1 gpm over any area larger than 1 ft^2). b) The design should account for the fact that the increased density of air in a hyperbaric atmosphere causes increased resistance to water droplet movement, which in turn reduces the effective spray angle — thus necessitating a greater number of sprinkler heads.

<table>
<tr><th colspan="4">A. Construction and Equipment</th></tr>
<tr><th>Elements</th><th>Risks</th><th>RL</th><th>Minimum Requirements</th></tr>
<tr><td>9) Adequate deluge system coverage (based on NFPA 99) (cont.)</td><td></td><td>5</td><td>c) The system should be tested after it has been installed as well as after any modifications are made, preferably across the full range of operating pressures to confirm that it functions as designed.</td></tr>
<tr><td colspan="4"><u>Warning</u>: Conventional deluge systems may be found in many diving systems but are not necessarily appropriate for combating the high-temperature, rapidly propagating O_2-fueled fires that can occur in a RCC facility that delivers regular hyperbaric oxygen treatments.

<u>Definition</u>: The term “floor level” in the context of a horizontal, cylindrical chamber is taken to mean either the area one-quarter diameter below the chamber’s center line (which equates to 87% of the chamber diameter) or the area at actual floor level, whichever is greater.

<u>Note</u>: European Standard EN 16081 (see Appendix D, Reference 14) provides an alternative approach to designing a deluge system.

According to this standard, specific flow or pressure parameters are not required. Instead, the system is qualified by means of a so-called hot test, wherein temperatures at certain positions on dummies that have been set on fire in a pressurized chamber must be reduced to specific levels within a specified period of time.

Flow, pressure, and duration parameters are not specified.

It is the opinion of the author that this is a more suitable design approach, as the ability of the deluge system to extinguish a fire rest with the system’s designer and manufacturer.</td></tr>
<tr><td>10) Deluge system water capacity</td><td>Insufficient water capacity, especially if all spray nozzles are operating simultaneously, can compromise the effective extinguishing capability of a deluge system.</td><td>4</td><td>a) The system should be designed with sufficient water capacity to maintain the required flow, which is determined as the product of 82 lpm per m^2 over the actual floor area in m^2 (2 gpm/ft^2) in each chamber lock for at least 1 minute.</td></tr>
<tr><td></td><td>Excessive amounts of deluge water could present a drowning risk where chamber occupants have fallen to the floor or failure of essential equipment due to flooding.</td><td>4</td><td>b) The maximum water capacity should be determined by the capacity of the chamber’s bilge or drainage system, so as not to flood equipment or, in extreme cases, drown a patient who may have fallen to the floor.</td></tr>
<tr><td></td><td>In the event that the deluge water is depleted, driving gas may enter the chamber, causing an increase in chamber pressure.</td><td>3</td><td>c) The driving gas supply should shut off prior to water being driven out of the deluge supply tank.</td></tr>
<tr><td>11) Reserve supply pressure</td><td>Insufficient reserve supply pressure can render the deluge system ineffective in the event of a power failure.</td><td>4</td><td>The deluge system should have sufficient stored pressure to operate for a minimum of 60 seconds without electrical power.</td></tr>
</table>

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
12) Handline or portable extinguishing systems	Contained fires can be extinguished using handlines or portable extinguishers, avoiding the disruptive effects of a deluge system.	3 3 3 3	a) Each treatment lock should be fitted with at least a handline or a portable extinguisher. b) If a treatment lock is designed for only one or two patients and is fitted with a single handline, the handline should reach the entire interior of the chamber safely, including the bilge, if applicable. c) Transfer locks fitted out to treat patients should be fitted with at least a handline or a portable hyperbaric fire extinguisher. d) If bilge access panels are installed, handlines should be long enough to extinguish fires in the bilge area.
13) Handlines	Inadequately sized or rated handlines can fail during use, which both causes a physical hazard and compromises their effectiveness.	3 4	a) Handlines should have a minimum internal bore of 12 mm (½"). b) All handlines and portable extinguishers should have a rated working pressure greater than the pressure for which the supply system is designed.
14) Handline activation	Cumbersome, awkward, or poorly located handlines can impair response times.	4	Handlines should be readily accessible and activated using individual, quick-opening valves located within each chamber lock.
15) Dual valves	Leaking activation valves can present problems inside a chamber for electrical equipment, patients, etc.	3	All handlines should also be fitted with individual isolation valves that are placed in accessible locations outside the chamber and are sealed in the open position with frangible safety wire seals.
16) Water supply pressure and/or flow	Inadequate pressure and/or flow in the water supply will impair the effective functioning of handlines.	4 4	a) The pressure of any handline water supply should be at least 0.35 MPa (50 psi) higher than the chamber pressure at all times. b) The system should be capable of delivering at least 19 lpm (5 gpm) per handline at maximum chamber pressure.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
17) Regular function testing	Deluge systems that are not regularly maintained and function tested can fail upon use. Seals, controls, pressurization devices, etc. can stick or jam due to creep, embrittlement, or deterioration.	4 4 4	a) Deluge, portable extinguishers, and handline systems should be function tested at least every six months, with their full and effective function confirmed. b) If a bypass system is installed, the design of the system's test mode should be such that the system resorts to normal operating mode by default after the test. c) Full testing, including the discharging of all the water (or alternate extinguishing media), should be conducted once a year. Water vessels should be drained and inspected, and water strainers opened, inspected, and where needed, cleaned. This requirement does not replace the need for full function and performance testing after a system's initial installation and after any subsequent modifications.

Note: Bypass systems make regular testing easier, as the interior of the chamber does not need to be deluged.

Care should be exercised in the selection of a bypass system, so that the potency of the full flow path can be assessed.

Lines may become blocked over time, reducing the supply of water to individual sprinkler heads.

It may be preferable to design a bypass so that full flow is achieved but the water is captured by means of flexible pipes leading down to the bilge (preferably into suitable containers).

It is also still advisable to measure the system's flow (volume per unit of time) to ensure that full flow is achieved, in accordance with the system's design.

The duration of the sprinklers' operation will depend on the system's design but should generally be no less than 60 seconds.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**

A-6. Electrical Systems

1) Electrical regulations	The presence of electrical wiring and equipment within RCCs presents several critical risks, including fire. It is essential to precisely follow local electrical regulations during construction and/or renovation of a RCC, as they are devised to meet local operating and supply conditions.	4	NFPA 70, the National Electrical Code, contains applicable regulations that have been considered by the NFPA 99 committee. All electrical work on a RCC should adhere to either this code or, at a minimum, to local electrical regulations applicable to alternating current (AC) distribution, wiring, and grounding.
Warning: Electrical equipment that must be installed in or brought into a RCC should be limited to a maximum voltage of $24V_{DC}$. All the precautions detailed below should still be followed because even low-voltage switches can induce sparks with enough energy to ignite certain materials under normal conditions. Note: A hyperbaric chamber is considered a Class 1, Division 2 location for the purpose of specifying electrical system components. That means it is a location in which flammable vapors may be present but are normally confined within closed systems or in which ignitable concentrations of such substances are limited by ventilation. In other words, a hyperbaric chamber is considered a Class 1 location not because of its O_2-enriched atmosphere but because of the presence of flammable vapors (e.g., from alcohol swabs or medical dressings), combined with the presence of combustible materials (including human skin, dust, or lint).			
2) Location of service equipment, switchboards, distribution boards, and/or control panels	Switching for all forms of electrical power can produce sparks that contain more than sufficient energy to ignite a flammable material.	4	All electrical service equipment and high-voltage equipment (i.e., above 24 V_{DC}) should be located outside of the chamber.
3) Energized electrical equipment built into O_2-piped consoles	The combination of leaking O_2 piping and energized electrical equipment creates a risk of fire.	4	If control consoles contain both O_2 piping and electrical equipment, the electrical equipment should be totally enclosed, constantly ventilated, or the enclosed console space should be either ventilated or monitored for excessive O_2 concentrations.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
4) Location of switches, circuit breakers, line fuses, relays, ballasts, transformers, motor controllers, and/or power supplies	Switching for all forms of electrical power, even on low-power lines, can produce sparks. Energy-storage devices can produce sparks when they're switched or rapidly discharged. Sparks are a known source of ignition.	4 4	a) No switching devices and no power sources should be installed within a RCC. b) Power supplies for equipment inside a RCC should be installed outside the chamber, according to the following criteria: • For alternating current (AC) power, an ungrounded isolated power supply (IPS) should be used; and • For direct current (DC) power, an appropriately shielded transformer providing ungrounded power and including suitable protection (a fuse, trip switch, or circuit breaker) to protect against any current overload should be used.
5) Electric motors	Electric motors, including both conventional commutating motors as well as brushless motors, are a source of sparks and/or localized high temperatures.	4	Fan motors should be mounted outside of RCCs. Motors specifically designed and certified for use within hyperbaric environments may be considered (e.g., for CO_2 scrubbers or non-invasive blood pressure monitors), with the written approval of the safety officer. Acceptable motors include explosion-proof motors, purged or gas-filled motors, and brushless DC motors that can be demonstrated to be localized heat-source–free and arc-free. Bearing surfaces in brushless DC motors should not contain any hydrocarbon-based lubricant.
6) Protection from a water deluge	Electrical equipment that is exposed to immersion or flooding by either external or internal sprinkler and/or deluge systems can fail. Patient outcomes and safety procedures can thereby be affected.	5	All critical electrical equipment should be protected from the effects of water-based fire-suppression systems. If that is not possible, any equipment critical to safety should be able to function long enough to allow patients to be decompressed if necessary.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
7) Reserve power supplies	If critical equipment fails due to a building or municipal power failure, the health and safety of chamber occupants can be compromised if lighting and communications systems fail. The chamber environment may become hazardous while monitors are down, patient monitoring equipment may fail, safety equipment may be rendered inoperable, and the chamber may not be able to be safely decompressed.	4 5 4	a) All critical equipment — including chamber lighting and emergency lighting, communications equipment (including emergency communications, if applicable), alarm systems, fire detectors, fire-suppression systems, chamber pressure controls and monitors, patient monitors, infusion pumps and ventilators, and environmental monitors — should be connected to either a health-care facility's emergency electrical system or, preferably, an independent reserve supply facility. b) If automatic controls are used to control chamber pressure, pressurization, and depressurization, power to these controls should be maintained for sufficient time to complete a treatment or at least to depressurize the chamber safely. Alternatively, a full manual set of controls can be provided. c) Emergency or back-up lighting to the facility should be provided.
8) Reserve gas supplies	Failure of compressed air systems and/or O_2 supply systems due to a power outage can compromise the chamber environment (due to insufficient ventilation) and can endanger patient safety (e.g., due to ventilator failure, O_2 supply interruption, etc.).	4 4 4	a) If only low-pressure compressors are used, at least one compressor should be connected to an emergency power system. b) Stored high-pressure (HP) air supplies may be used to alleviate such a situation; however, the amount of stored air should be such that a treatment can be safely concluded without compromising the patient's safety. c) Stored HP O_2 may be used as a backup for liquid oxygen (LOX) supplies.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
9) Integrity of control and alarm systems	Power outages, especially those due to spikes or variations in voltage, can compromise the function of control systems and alarms. This may lead to improper deluge activation, false alarms, loss of chamber pressure control, etc.	4	Chamber control and alarm systems should be so designed that hazardous conditions cannot occur during power variations, interruptions, or restoration.
10) Chamber wiring and/or equipment	Inappropriate electrical wiring and unsuitable electrical equipment can present a risk of fire and explosion, electrocution, or implosion in a chamber environment. Contact with electrically-live components can affect the human body in the following ways: • Tetanization or the involuntary contraction of affected muscles, which can make it difficult to let go of a live component. ¶ • Breathing arrest, due to involuntary contraction of the muscles that control the lungs, which can alter normal respiratory processes. ¶ • Ventricular fibrillation or the superposition of an external current with physiological currents leads to uncontrolled contractions and this induces alterations of the cardiac cycle. ¶	3 3 3 3 3 3	a) The requirements for Class 1, Division 2 locations should be followed, as a general rule, for any electrical wiring and equipment located in a chamber. However, it is not a requirement that chambers be classified as Class 1 locations. b) NFPA 70, Article 500, provides guidance on selecting equipment and designing wiring for chamber environments. c) Only the minimum amount of electrical equipment deemed necessary for patient care (as determined for each treatment) should be permitted inside a chamber. A chamber should not be used to store electrical equipment not required during treatment. d) All equipment intended for use within a chamber should be tested and approved for such use. e) Conductive surfaces of all electrically powered equipment should be grounded to the chamber shell. f) Standard medical industry equipment should not be altered for use inside a chamber unless such alterations are sanctioned by the original manufacturer or by a *competent* authority.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
10) Chamber wiring and/or equipment (cont.)	• Burns, due to heating caused by current passing through the body. ‡ ¶ AC power ‡ AC or DC power (Joule effect)	3	g) The chamber's O2 level should be continually monitored, and alarms should be sounded when this level rises above 23.5%.
		3	h) Where electrical equipment is required for use inside the chamber and has not been approved for hyperbaric use by either the chamber or the equipment manufacturer, an appropriate risk assessment should be conducted and approval endorsed by the safety officer and medical director.
		3	i) Where the requirements of the risk assessment deem there to be a fire risk, or where the required voltage exceeds 24 V (AC or DC), the electrical portions of such equipment should be purged using an inert gas or oil-free air.
		3	j) Advice from a competent electrical design authority should be sought to ensure safety and compliance with these requirements.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
11) Requirements for monoplace chambers, or chambers intentionally pressured with more than 23.5% oxygen	Reduced volume chambers (less than 2 m^3 or 70 cf), whether filled with air or any oxygen-enriched mixture, and chambers containing more than 23.5% oxygen, regardless of whether constant ventilation is used, are more susceptible to the risk of fire.	5	All internal electrical equipment, wiring and connections should be limited and comply with the following requirements: a) Electrical parameters for all circuits should be limited to now more than 28 V_{DC} (communications or sensors only) or 3 V_{DC} (power supply), and 4 W. b) No surface temperatures anywhere in or on the equipment should exceed 60°C (140°F). c) Wiring should not be exposed to any flammable materials or occupants. d) Circuitry, including batteries where applicable, should be sealed or isolated from the chamber environment. e) Equipment should be free of any hydrocarbons or volatile, flammable compounds. f) Wiring connections should be securely locked. g) Lighting should be provided from outside the chamber. The only exception to these requirements should be for electrical components that are intrinsically safe* or comply with the Class 1 requirements according to NFPA 70, Article 500. *Refer to the footnote on page 38.
12) Insulation of conductors	Uninsulated conductors represent a source of sparks. The composition of insulating material may also present an environmental hazard if it's exposed to heat or fire.	 3 3	All conductors used inside a chamber should be insulated using flame-resistant material. a) Ground conductors encapsulated within equipment or wiring that is an integral part of approved equipment do not require insulation. b) Wiring, which is an integral part of equipment approved for use inside a chamber, does not need to meet the flame-resistance classification.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
13) Permanently installed wiring methods	Inadequate wiring methods can generate heat, shorting, and/or burn-through, which can cause sparking or ignition.	3 3 4	a) Fixed wiring should comply with the requirements of Class 1, Division 2. This does not imply a requirement for intrinsically safe* wiring. *Refer to the footnote on page 38. As a minimum, fixed wiring should be installed protected from damage. b) Where fixed conduits, boxes, and enclosures are used, they should provide protection against the ingress of dust, humidity, and water or other fire suppression media. Note: This is similar protection to an IP65 enclosure, except for the need to withstand significant differential pressures. c) Decisions regarding the suitability of wiring methods should be made by a *competent* person.
14) Sealing and drainage of conduits and enclosures	Activation of a deluge system can introduce water into unsealed enclosures. This can lead to premature failure of electrical wiring and components.	3	Requirements regarding sealing and drainage are detailed in NFPA 70, Article 501-5 and should be followed. Drainage points should be identified such that collected fluids can be removed.
15) Flexible cords used with portable equipment	The interruption of any powered circuit, even for low voltages, can produce a spark.	 3 4 3 3	Cords used with portable equipment should meet the following criteria: a) Be of a type approved for extra-hard utilization; b) Be connected to terminals in a secure and approved manner; and c) Be supported in such a manner that no tension exists on the terminal connections. d) Be fitted with an on-off power switch outside the chamber, unless compliant with 17) below, and the plug on the cord should not be used to interrupt power.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
15) Flexible cords used with portable equipment (cont.)			The only exception to these rules applies to cords normally supplied with portable devices that are rated at less than 2 A, where such cords are securely fastened and protected from accidental damage or inadvertent disconnection of the connector.
16) Receptacles and plugs	Interruption of any powered circuit can produce sparks sufficient to ignite a flammable agent. Unsecured and ungrounded connections are a source of possible shock and arcing. Drenching from a deluge system can cause short circuits in unprotected connectors.	 4 3 3 3 3 3	All plugs and receptacles should meet the following criteria: a) Be of an approved type and both water- and pressure proof; b) Be grounded via a grounding conductor; c) Be fitted with an interlocking mechanism to prevent withdrawal or insertion inside the chamber while energized; d) Be fitted with a locking mechanism or be supplied with a label warning against unplugging them while they are under load; and e) Be capable of conducting ungrounded power between the external supply and the device on this inside; and f) Be secured and protected against accidental damage by chamber occupants.
17) Internal switches	Switches are a potential source of sparking.	4	It is recommended that all switches be located outside the chamber. If internal switches are used, they should meet one of the following criteria: • They should be waterproof (at least IP 65), but care should be taken where housings require venting to chamber pressure; or • They should either be housed in an enclosure so that no sparks can reach the chamber atmosphere or be rated as intrinsically safe*.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
17) Internal switches (cont.)			Switching with a capacity of less than 25 mW (e.g., piezo switches) is excluded from these restrictions. *Refer to the footnote on page 38.
18) Monitoring of equipment temperature ratings	Hot surfaces can be a source of ignition, especially within RCC environments.	4	No equipment installed or allowed in a RCC should have any exposed surfaces that can exceed a temperature of 85°C (185°F). Note: This temperature threshold is based on the ignition temperatures of materials commonly found inside RCCs, the potential for fault conditions in O_2-enriched atmospheres, and consideration for the safety of chamber occupants.
19) Exposed live electrical parts	Exposed live (energized) electrical parts can be a source of shocks and/or sparks in the event of an electrical fault.	4	No exposed electrical parts (excluding patient monitoring leads) should be present in a RCC unless they have been certified as being intrinsically safe*. *Refer to the footnote on page 38.
20) Use of low-voltage, low-power equipment	Low-voltage and low-power equipment can produce sparks. Of even greater concern is the potential for overheating under fault conditions.		All sensors and signaling, alarm, communications and remote-control equipment used or intended for use within a RCC should meet the following requirements:
		4	a) Equipment should be isolated from AC power (also known as mains power) by either the power supply circuit design, opto-isolation, or other electronic isolation methods;
		4	b) The design of chamber speakers should be such that all electrical circuitry and wiring are enclosed, and their rating should not exceed 28 V_{rms} and 25 W except where compliant with 19) above. Alternatively, the following equipment configurations are considered acceptable:
		3	a) Equipment listed as intrinsically safe* for use in Class 1, Division 1, Group B locations; or

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
20) Use of low-voltage, low-power equipment (cont.)		3 3 3	b) Equipment that is totally enclosed and constantly purged by means of an independently supplied, O_2-compatible air source that automatically de-energizes if the air supply fails; or c) Equipment that is hermetically sealed, filled with inert gas, positively pressurized, and fitted with an automatic de-energization device that trips if the initial pressure (i.e., when sealed) changes by more than 10%; or d) Equipment that has been approved for use by a *competent* authority and that has the written permission of the safety officer. *Refer to the footnote on page 38.
21) Portable and patient-care devices	The risks associated with the use of electrical medical equipment in a RCC include current leakage, unvented batteries, off-gassing of batteries, sparking, heat-generation, and/or explosion or implosion due to inadequate venting.	 3 3 4 4	In addition to the limitations noted above (i.e., a surface temperature of less than 85°C [185°F], an operating voltage of 28 V_{DC} or less, and adequate certification and/or testing for use within RCC environments), any patient-care devices used within a chamber should meet the following minimum requirements: Be designed and certified as safe for patient-care applications (e.g., per NFPA 99, Chapter 10); a) Electrical and mechanical integrity should be continuously monitored under the facility's maintenance program; b) Devices that utilize O_2 should be designed so that O_2 cannot accumulate in electrical sections under any conditions; and c) Devices have been successfully tested for proper performance over the chamber's full operating pressure range.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
22) Use of portable battery-operated electrical or electronic equipment	Any sources or users of electrical power can generate sparks and/or heat. In addition, batteries are a source of toxic and/or flammable gases under fault or heavy-load conditions.		All such equipment — including permanently installed sensors, communications devices, and signaling, alarm, or remote-control equipment — should meet the following criteria:
		4	a) Batteries should be fully enclosed and secured within the equipment enclosure;
		5	b) Batteries should be compatible with the chamber's maximum operating pressure and be of a sealed type that does not off-gas during normal use;
		5	c) Batteries should not be charged while they are inside the chamber;
		4	d) Batteries should not be changed while the equipment is located inside the chamber;
		4	e) Rechargeable lithium-ion batteries should be examined prior to each use for any signs of mechanical damage, overheating, or leaking.
		4	f) The equipment's electrical rating should not exceed 12 V_{DC} and 48 W (28 V_{DC} and 25 W for communications).
23) Chamber grounding	Inadequate grounding compromises the effective functioning of a chamber's IPS as well as of any intrinsically safe* equipment, grounded power supplies in terms of protection from electrocution, and control of static electricity in any chamber designed to operate at O_2 levels above 23.5%. *Refer to the footnote on page 38.	3	The chamber should be connected to the building ground point and not to the electrical system earth wire. In addition, the resistance between the chamber and the electrical supply system earth wire should be less than 1 Ω (ohm). Note: Where the resistance between the chamber and electrical ground is more than 1 Ω, this indicates a bonding problem. This should be corrected as it may introduce an electrocution risk between neutral and ground wires.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
24) Patient grounding	Static electricity is a known cause of hyperbaric fires. A static charge can generate in several ways, including the presence of unsuitable clothing or bedding, excessive movement of occupants, relative humidity below 40%, and the lack of a path to ground between occupant and any grounded surface.	5	Where a monoplace chamber is being used, or any chamber where the atmosphere is intended to be above 23.5%, all chamber occupants should be grounded to the chamber using a dedicated personal grounding wire. The grounding wire should be fitted with a 1 MΩ (megaohm) resistor. Refer to the Warning note at the end of section B-1.
25) Internal equipment surface grounding	While all internal electrical devices must be powered using ungrounded power, it remains possible that stray voltages, electrical faults, induced surface (electrostatic) charges, and circuit-board current leakage can result in the flow of current between conductive equipment housings/casings and the grounded chamber.	3 4	a) Conductive housings of all internal electrical devices should be grounded to the chamber at all times. The exceptions to this apply to: • communications systems that are required to be grounded independently from the chamber; and • internally battery powered equipment. b) No electrical system may use the chamber or any conductive internal surfaces as a ground or return conductor.
26) Line isolation monitoring.	The use of any alternating current (AC) electrical devices inside a chamber represents additional sparking and electrocution hazards, due to the chamber serving as a potential ground path to neutral. While the use of an ungrounded IPS reduces this risk, medical life support equipment may require continuous function despite any leakage to ground.	4	All AC electrical circuits inside a chamber should be supplied from an ungrounded IPS equipped with a line isolation monitor (LIM).

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
27) Protection of equipment outside the chamber	A failure of critical electrical equipment outside the chamber in the event of flooding by a deluge system compromises the safety of chamber occupants.	4 3 4 3	a) All equipment that must remain functional for the safe completion of a treatment after activation of a deluge system should be adequately waterproofed. b) Any conduits should be waterproof and, as applicable, equipped with drains. c) All electrical circuits should be protected so that flooding by water does not constitute a further hazard. d) All electrical equipment should meet national regulations.
28) Ground fault circuit interrupters (GFCI)	Any potential contact between personnel or equipment and live AC conductors are a known source of electrocution, ignition, or equipment failure. In addition, the chamber and associated equipment are connected to building ground, introducing additional potential for an electrical grounding path.	3	Any electrical power system providing current to external electrical devices or to chamber internal electrical devices should be fitted with a GFCI. An earth leakage circuit breaker (ELCB), or a residual current circuit breaker (RCCB), provides similar earth-leakage protection, and is usually located in the facility's electrical panel (distribution box), rather than at the power outlet. Care should be taken to ensure that these devices are installed in the wiring circuits that provide power to the chamber systems.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**

A-7. Communications and Monitoring

Warning: Ordinary communications equipment is not suitable for use within a chamber due to the potential for sparking from switches and arcing from microphones, both of which represent a distinct risk of fire.

Communications and monitoring equipment are mandatory for the safe operation of a chamber; therefore, such equipment must adhere to special provisions.

Note: Requirements for electrical systems, including those that supply communications and monitoring equipment, are detailed in section A-6. Electrical Systems (page 44).

Compliance with those requirements is mandatory to ensure safety.

Requirements for fire detection and protection, as distinct from communications and monitoring, are detailed in section A-5. Fire Protectionn.

Elements	Risks	RL	Minimum Requirements
1) External communications equipment	Electrical equipment — including power amplifiers, output transformers, and monitors — is capable of producing electrical discharge.	5	All such equipment should be installed for use only outside a chamber.
2) Internal communications equipment	Low-voltage and low-power equipment can produce sparks. Of even greater concern is the fact that it is capable of overheating under fault conditions.	4	The requirements detailed in A-6 Section 18) Use of low-voltage, low-power equipment (page 52) should be followed.
3) Communications between operator and occupant(s)	A breakdown in communications between the operator and the occupant(s) of a chamber can incur risks involving chamber operation, fire, occupant safety, and/or the outcomes of the medical therapy that is in process.	5	a) A continuous, clearly audible communications link between the operator and all RCC locks should be in place whenever the chamber is in use. b) It is further recommended that the following be in place:
		3	• A multi-channel system with discrete (closed-circuit) operator-attendant circuits for discussion of sensitive patient issues; and
		3	• A sound-powered telephone or emergency communications system (e.g., surveillance microphones).
		4	c) Communications channels between the locks and the control panel should be kept open at all times.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
4) Individual patient communication devices	Individual patient microphones are contained within the O_2 delivery system and are therefore exposed to 100% oxygen — and thus may represent a direct source of ignition.	5	Where used, oxygen mask or hood microphones should be approved as safe at the rated pressure and in 100% oxygen environments.
5) O_2 monitoring	O_2 levels above 23.5% can increase flame propagation exponentially and are classified as highly dangerous. If diluent gases are introduced, O_2 levels below the safe partial pressure for a specific chamber pressure can result in a hypoxic environment. Chambers that are large (i.e., a diameter greater than 1.8 m [6 ft]), a treatment lock longer than 3 m (10 ft), that are designed for more than six occupants) or that are designed with restricted interior air flow (i.e., limiting the immediate dilution of gases) may retard the ability of O_2 analyzers to indicate the actual average O_2 levels present in the environment.	5 3 5	a) O_2 levels should be monitored at all times. Visual and audible alarms should indicate O_2 concentrations above 23.5% or below 19.5%. b) Monitoring should preferably occur at two or more treatment lock locations, especially in larger chambers, with one sample point located near the ventilation outlet or the chamber's exhaust point. c) Warning: Chambers should not be operated with interior O_2 levels above the safe limit of 23.5%.
Note: Treatments associated with commercial diving operations may require O_2 percentages below 19.5%. Since such treatments will be performed only under the direct supervision of a suitably qualified medical practitioner or life-support supervisor, the determination of allowable minimum levels in such cases is left to the discretion of the supervising individual and accepted and safe diving practices.			
6) CO_2 monitoring	CO_2 levels can build up during a long treatment involving little or no ventilation. High CO_2 levels are dangerous and can potentiate O_2 toxicity. CO_2 intoxication can be insidious and thus difficult to discern.	3	If ventilation is not (or cannot be) used, CO_2 levels within the chamber should be monitored continuously. Visible and audible alarms should indicate CO_2 concentrations above the safe surface equivalent value (SEV) of 0.5% (5,000 ppm_v) relative to the treatment depth. SEV = CO_2 (% or ppm_v) x pressure in ATA.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
7) Combustible gas monitoring	Where flammable gases are used within a chamber, any leak or compromised gas-discharge circuit will create an immediate explosion hazard.	5	Flammable gases should not be used in a chamber.
8) Chamber air-supply monitoring	There are two possible sources of contamination of the chamber's air supply — contaminants in the ambient air and those added by the gas-compression equipment. If oil-lubricated compressors are used or if compressor intakes are positioned in areas that could be polluted by motor vehicle exhausts, toxins, oil vapor, or other HC contaminants can be rapidly introduced into the chamber's air supply. Toxic gases such as carbon monoxide (CO) can compromise the health of chamber occupants. Oil vapors and other VOC and HC contaminants represent a known fire risk in an O_2-enriched environment. Any air used in a piping system that is also used to convey O_2 requires additional attention due to the elevated fire risk.	4 4 2 5	a) All compressors should be fitted with suitable air-treatment packages capable of producing air safe for breathing purposes. b) Air should be sampled for possible contaminants (CO_2, CO, H_2O, oil, and particulates) at least every six months. c) Automatic safeguards should be considered where volatized HCs and CO could be present, especially where oil-lubricated compressors are used. d) The required minimum specifications for breathing air are detailed in Appendix C and can be summarized as follows: O_2 — 20% to 22% H_2O — Based on actual supply (storage) pressure (see Appendix C) CO_2 — < 500 ppm_v CO — < 5 ppm_v HCs — < 0.5 mg/m^3 for liquids (oil); < 25 ppm_v for methane (CH_4) Particles — < 0.5 mg/m^3 for particles > 5µm Odor — Nil

<table>
<tr><th colspan="4">A. Construction and Equipment</th></tr>
<tr><th>Elements</th><th>Risks</th><th>RL</th><th>Minimum Requirements</th></tr>
<tr><td>8) Chamber air-supply monitoring (cont.)</td><td></td><td>5</td><td>e) The required minimum specifications for HCs in medical air or O_2-compatible air (OCA), for use in RCCs whose built-in breathing system (BIBS) may be supplied with breathing air, are detailed in Appendix C and can be summarized as follows:

HCs < 0.1 mg/m^3 of liquids (oil)
< 25 ppm_v of CH_4

Note: The maximum limits for water vapor in compressed air for HP cylinder storage are as follows:

< 62 ppm_v (50 mg/m^3) for pressures between 4 - 20 MPa (580 - 2900 psi); and

< 44 ppm_v (35 mg/m^3) for pressures between 20 - 30 MPa (2900 - 4350 psi).</td></tr>
<tr><td colspan="4"><u>Note</u>: Prior to deciding on a suitable location for a compressor intake, it is recommended that the air be sampled at the intake location at a time when maximum impurities are expected to be present.

At the discretion of the responsible person, a hyperfiltration system (which ensures CO levels of < 2 ppm_v and oil content levels of < 0.1 mg/m^3) may replace the requirement for continuous monitoring, as long as filter replacement schedules are strictly followed.

Periodic sampling of such air (i.e., every six months) remains a requirement.</td></tr>
<tr><td>9) Commercially supplied gases</td><td>It is possible to procure certified gases that have not been analyzed.

Commercially supplied gases may contain contaminants in particulate form which present a fire risk in the piping systems and an explosion risk in the chamber.</td><td>3

3</td><td>a) The responsible person should ensure that any commercial companies supplying certified gases have an adequate quality control system.

Random sampling is strongly recommended to ensure quality.

b) Piping systems used to transfer gases from commercially supplied cylinders or containers should be fitted with particulate filters rated at ≤ 10µm (fine particles).

This does not replace the requirement to use particulate filters rated at ≤ 5µm at pressure regulator inlet ports.</td></tr>
</table>

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**
10) Visual monitoring of the chamber interior	If a dangerous or emergency situation develops, inadequate surveillance of the chamber interior from the operator's normal position can compromise the operator's response and thus the occupant's safety.	3	It is standard practice in the industry to employ closed-circuit TV monitoring or video surveillance if direct visual monitoring of the chamber interior is not possible from the operator's normal position.

A. Construction and Equipment			
Elements	**Risks**	**RL**	**Minimum Requirements**

A-8. Other Equipment and Fixtures

1) Permanently installed furniture	Ungrounded permanent furniture and other fixtures electrically isolate occupants, thus • enhancing the buildup of static electricity (a potential cause for concern in chambers with an O_2 concentration of more than 23.5%); and • reducing the effective functioning of a chamber's electrical protection and safety systems.	3	All permanently installed furniture should be electrically grounded.
2) Exhaust systems	The risks associated with inadequate exhaust systems include increased noise, back-pressure, and O_2 concentrations at the O_2 overboard dump system's outlet.	3	a) Exhaust should be piped outside the building to a location that is clear of nearby hazards and where re-entry of exhaust gases back into the building is unlikely.
		3	b) Exhaust piping should be sized such that the resistance to exhaust flow is minimized and the surfacing time for the chamber from 3 ATA to the surface is less than 6 minutes.
		3	c) Exhaust exit locations should be clearly identified with signage that prohibits smoking or any open flames in the immediate vicinity.
		3	d) Exhaust outlets should be protected against entry of birds, insects and other creatures, debris, and precipitation. Screens or mesh materials with openings of no more than 3.2 mm (0.125") should be used. Outlets should be positioned to reduce the opportunity for rain/snow to enter the system.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**

B-1. Procedural Requirements

Note: This section is not intended to provide exhaustive detail regarding administrative requirements for RCCs.

It is assumed, at a minimum, that RCCs will be managed by suitably qualified personnel who will follow all applicable local and national statutes and regulations.

The additional minimum requirements listed here are intended to offer some degree of further guidance to ensure a basic level of chamber safety.

Attention to detail is the most important precept in mitigating the risks associated with a RCC; that axiom should be stipulated in the facility's operating procedures, and all administrative and maintenance personnel should be regularly reminded of it.

Warning: RCCs are medical devices, so their operation must be overseen by a medical director. In addition, diving systems fall under the relevant nation's occupational health and safety regulations, requiring operation by competent technical staff. Military installations are often governed by a different set of regulations, which may or may not exclude any civilian liability.

Elements	Risks	RL	Minimum Requirements
1) Standards	Minimum standards are required to ensure effective and safe operation of the facility.	4	a) RCC services that meet the needs of injured divers and other patients, as determined by the nature of the facility, should be available for use either at all times or within a reasonable notification period.
		4	b) Facilities should be organized, integrated, staffed, and directed commensurately with the scope of the services offered.
		3	c) The scope of services (medical and technical) should be clearly defined. This is essential to allow for proper transfer and referral of patients.
		2	d) The facility's patient-support capabilities (e.g., ability to administer IV infusions or ventilator support, to take vital signs, or to use a defibrillator) should be appropriate for the level of service provided.
2) Personnel	The administration of hyperbaric therapy must be done by *competent* and thoroughly trained staff to ensure patients'	4	a) RCC facility staff should be suitably trained and competent, appointed in writing, provided with clear responsibilities, and delegated with the appropriate authority.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
2) Personnel (cont.)	safety, the efficacy of treatments, and the responsible practice of medicine.	4 3	b) A qualified dive medicine practitioner should remain in close proximity during chamber treatments and be available to respond to any medical emergency. c) In addition, a suitably qualified safety officer should be appointed. The safety officer, who may also be a supervisor or chamber operator, should be involved in all aspects of planning, regulations, and use of the facility.
3) Responsibility	The safety of a hyperbaric facility is affected by the conditions and practices in and around the unit, as well as, if applicable, in the health-care facility in which it is located. If responsibility for those conditions and practices is not clearly assigned, it can put the safety of the chamber at risk.	4 3	a) The ultimate responsibility for the care and safety of a RCC's patients and personnel lies with the owner and/or manager of the RCC facility. This person or organization should ensure that rules, practices, and conduct regarding safety throughout the facility are effectively and formally delegated to *competent* and *responsible* people. b) In all cases, staff should follow regulations pertaining to the use of such facilities as mandated by relevant authorities.
4) Policies	Policies that fail to integrate and account for the sometimes-conflicting requirements detailed in national, regional, and municipal statutes and regulations and in international guidelines and industry-specific equipment instructions can seriously compromise operational safety (e.g., there can be variation in matters such as the allowable oil-vapor content in compressed air or the allowable voltage in a confined space).	3	An integrated set of policies — mandating compliance with all applicable national, regional, and municipal statutes and regulations, especially those regarding the use of equipment — should be established and enforced by suitably *competent* and experienced personnel.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
5) Operating procedures	Inadequate, unproven, and informal operating and safety procedures can present a serious risk to the safe operation of a hyperbaric facility, under both normal and emergency conditions.	3	Internationally accepted, qualified, and proven procedures should be established, implemented, and continuously monitored.
6) Implementation and compliance	Procedures that have not been correctly implemented or that are not followed and/or staff that have not been trained to understand and follow procedures, are likely to result in mistakes and/or oversights that can endanger the safety of both patients and staff.	5 3	a) A facility's owner, manager, or, where delegated, medical director is responsible for ensuring that all staff receive appropriate training, follow operating and safety procedures, and are *competent* to effectively fulfill their respective responsibilities. b) The owner or manager should ensure that periodic audits are conducted of the facility's operating and safety management systems.
7) Regular inspections of the chamber	If chamber operators fail to conduct regular pre- and post-treatment inspections of the chamber, risky situations could arise (e.g., patients taking hazardous items into the chamber, etc.).	4	A set of comprehensive pre- and post-treatment checklists should be established as part of the treatment log. This will ensure that the operator is reminded to perform the necessary safety, cleaning, and system checks before and after every treatment.
8) Patient transport and referral procedures	A failure to establish procedures for when and how a patient is transferred elsewhere could place the patient at risk and could open a facility to liability.	4	Procedures should be established regarding when and how to transport emergency cases to or from the hospital, if the RCC is not attached to a full-service medical facility. Self-standing or independent RCC facilities should not undertake stabilization or extended care of emergency cases.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
9) Rules and regulations	A lack of adequate training, discipline, contingency planning, or adherence to procedures represents a risk to the facility, patients, and staff. Lack of sufficient responsible and trained staff also represents a risk.	4	a) Clear rules and regulations for the operation of the facility, including the use of emergency equipment, should be established.
		5	b) All staff should be thoroughly trained in the implementation of these rules and regulations; such training should include regular follow-up sessions, hands-on training, and regular emergency and fire drills.
		5	c) Treatments should be performed only under the direct supervision of qualified personnel who have appropriate training and experience.
		5	d) The chamber operator should remain physically present at the chamber console throughout every treatment, irrespective of any emergency that may occur.
		4	e) The owner, manager, medical director, or safety officer of the facility should ensure that discipline is maintained at all times. They are also responsible for contingency planning and training.
		5	f) All staff should be thoroughly trained and experienced in the use of emergency equipment and the execution of emergency procedures.
		4	g) The owner or manager should establish minimum staff qualifications, experience levels, and staffing levels based on the nature and size of the RCC facility, as well as the type of treatments normally provided. As a minimum, there should always be at least two staff members outside the chamber.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
10) Proper documentation	Proper documentation for all hyperbaric treatments is necessary to avoid the legal ramifications that could arise from delivering unauthorized, unsuitable, or ineffective treatments.	 4 3 3 3 3	These are the essential requirements for properly documenting a hyperbaric treatment: a) Completed indemnity and acknowledgement forms (i.e., patient consent). b) Chamber operator checklist. c) Patient records. d) Patient treatment log. e) Operational treatment log.
11) Training	Inadequately trained personnel, irrespective of their functions and responsibilities, can compromise the safety of patients, staff, or the facility. They may react inappropriately during either normal operations or emergency situations.	5	a) All staff should be thoroughly trained to levels recommended by national regulations and should be drilled in all appropriate operational and emergency procedures as established by the *responsible person*. Thorough and internationally accredited training — such as those endorsed by any of the following - should be used to ensure that only competent personnel operate the facility and its equipment: • European Baromedical Association (EBAss) • Hyperbaric Technicians and Nurses Association (HTNA) • National Board of Diving and Hyperbaric Medical Technology (NBDHMT) • Southern African Undersea and Hyperbaric Association (SAUHMA) • Undersea and Hyperbaric Medical Society (UHMS) Alternatively, thorough on-the-job training by competent and qualified instructors, endorsed by the appointed medical practitioner, documented, and attested through examination may suffice.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
11) Training (cont.)		3	b) Trainees and other personnel without the requisite hours of practical experience should function only under the direct supervision of an appropriate technician, doctor, or other qualified staff member.
		3	c) The safety officer, in conjunction with a medical doctor, should establish the requirements for refresher training, especially for staff who are not engaged in providing treatments on a regular basis. The types of such training include the following: • Formal qualifications (see section B-3. Medical Staff Qualifications) Unless specified otherwise by a governing body, refresher training should occur at least every two years. • Facility-specific training, including operational and emergency procedures: The frequency of such refresher training should be based on the frequency with which the staff member performs treatments and the number of drills held within a 12-month period. Refresher training is required where staff members have not performed any treatment activities within the previous 12 months. In any case, refresher training should be conducted at least every two years.
12) Direct heat sources	The presence of open flames, smoking materials, and/or heated objects represents a serious hazard in a RCC environment.	5	Any object that could be a source of heat that could trigger the chamber's fire detection system (if it has one), or that could degrade acrylic windows should be specifically banned from RCC facilities — either within the chamber or in its immediate outside vicinity.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
13) Flammable gases or liquids	Flammable gases or liquids, especially in environments with elevated O_2 levels, represent a serious risk of fire, even after the completion of a treatment.	5	a) All flammable gases and liquids, including those contained in cigarette lighters and chemical hand warmers, should be forbidden inside the chamber, as well as near the intake to the facility's compressor(s).
		4	b) Alcohol-based pharmaceuticals should be permitted only if they are medically necessary, have been authorized by the health-care professional treating that specific patient, and have the specific consent of the facility's safety officer. The quantities of such products should be limited to an extent such that only an insignificant amount of flammable vapor could be released into the chamber environment. In addition, O_2 monitoring procedures should be strictly followed and all sources of electrostatic spark discharge should be eliminated.
14) Overcrowding	Overcrowding around the chamber and/or the presence of nonessential personnel represent a risk to safe operations and patient privacy, as well as to the management of emergency situations.	3	Nonessential personnel should be kept out of all treatment areas. People accompanying patients should be restricted to designated waiting areas.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
15) Textiles, toiletries, and/or footwear	Certain fabrics represent a serious risk in hyperbaric environments, especially in the event of a fire. For example, synthetic materials tend to retain O_2 in their closed-cell construction, creating a concentrated source of O_2. Nylon undergarments can burn into the skin at high temperatures. Loose-fitting garments can incur the following risks: • They can make it difficult to determine whether patients are carrying hazardous items with them; • They can compromise the wearer's safety in the event of a fire because they may retain trapped gas, expose skin, and/or interfere with a deluge system's operation; and/or • They can catch on equipment or protuberances. The use of fabrics such as blankets, sheets, or drapes in a chamber represents additional fuel in the event of a fire. Certain personal toiletries or cosmetics represent a risk of fire. Shoes that contain steel nails in the soles represent a risk of sparks and thus fire, especially in chambers with aluminum deck plates.	3 3 3 4 2 2 3 4	a) Procedures should be in place to ensure that patients wear only approved garments, as close to 100% cotton as is possible. Silk, wool, and synthetic materials should be specifically banned. b) Although most medical dressings do not pose a significant risk, the risk of fire (source of fuel or ignition) should be assessed to determine acceptability for use inside the chamber. c) Garments should cover as much of the patient's skin as possible. d) Flammable hair sprays, hair oils, skin oils, and cosmetics should be banned for all operating personnel as well as all patients. e) If possible, any other fabrics used in a chamber should be treated with flame-retardant compounds or should be inherently flame-resistant. f) It is important to note that flame-retardant compounds often require regular reapplication, especially after washing. The instructions of the compound's manufacturer should be closely followed. g) As a general rule, patients should be prevented from wearing their own shoes in the chamber. h) Where this rule must be waived, the staff should ensure that no steel items are present in their shoes, which may create sparks on aluminum deck plates.

B. Administration and Maintenance

Elements	Risks	RL	Minimum Requirements

Warning: Where a chamber is intentionally compressed using a gas containing more than 23.5% oxygen, the risk of static ignition increases exponentially. This risk increases in the case of monoplace or reduced volume chambers - less than 2 m^3 (70 cf), even with constant ventilation. The following additional requirements apply to such chambers.

a) All occupants should be grounded to the chamber using a suitable electrostatic grounding system, with a resistance of no more than 100 MΩ (1 x 108 ohms)4.

b) Where a grounding device is attached to an occupant, such as a wrist strap, protection against potential electrocution is generally built into the device, with a resistance of no less than 1 MΩ (1 x 106 ohms).

c) Occupant grounding should be checked and the result recorded prior to every chamber excursion.

Note: In addition to observing the requirements above, RCC owners and safety officers may want to consider the following recommendations to assist in further reducing risks, including the extent of potential injuries or the ability of staff to control the introduction of hazardous materials into the chamber:

a) Provision of dedicated garments, supplied by the facility, to patients before all treatments.

   Ideally, such garments will be snug-fitting cotton scrubs.

b) Cleaning of any patients who have been contaminated with oil or grease (such as accident victims) before they put on the facility-supplied treatment garments.

c) Assurance that the supplied garments either have no pockets or have had their pockets sewn shut.

[4] Grounding resistance values are suggested in NFPA 77: Recommend Practice on Static Electricity, 8.2.3 of the 2024 edition.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**

B-2. Emergency Procedures

1) Procedures for handling emergency situations	It is often not possible for operating or attending staff to react effectively in an emergency unless they have received adequate training and support. Emergencies may be operational or technical in nature or may involve medical issues for patients or staff. Medical issues in patients are dealt with in subsection 2 below and in staff in subsection 3 below.	5	It is imperative that every RCC establish and document emergency procedures to ensure the safe completion of treatments and the safe evacuation of patients and staff in the event of an emergency as well as the effective handling of any potential emergency situation. The following are among the emergency situations that should be covered: • Loss of primary air and/or O_2 supply; • Loss of back-up air and/or O_2 supply; • Contamination of air and/or O_2 supply; • Rapid increase or decrease in chamber pressure; • Fire inside or outside the chamber; • Fire inside or outside the compressor and/or gas storage areas; • Loss of power; • Failure of any chamber systems (lighting, communications, etc.); and • Activation of the deluge system (either accidentally or intentionally).

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
2) Procedures for handling patient medical emergencies	Medical emergencies must be dealt with promptly to avoid fatalities and to prevent disabilities.	5	It is imperative that every RCC establish and document emergency procedures to ensure that patient medical emergencies can be managed appropriately. The following are among the situations that should be covered: • CNS O_2 toxicity seizure; • Pulmonary O_2 toxicity; • Omitted decompression; • Cardiac emergency/arrest; • Pulmonary barotrauma/pneumothorax; • Ear/sinus barotrauma; • Claustrophobia/anxiety; or • Uncooperative or aggressive patients. Additional emergency procedures for potential situationally based emergencies such as hypoglycemia, urinary retention, and trauma should be considered.
3) Procedures for handling staff medical emergencies	Medical emergencies in staff should be dealt with in a standardized manner to prevent illness or injury that could result in disability or render the staff member unable to manage occupants of the chamber. Occupational injuries and diseases carry an additional legal risk for RCC owners and managers, and emergency procedures should consider any specific legal requirements that may apply.	5	It is imperative that every RCC establishes and documents emergency procedures to ensure that staff medical emergencies can be managed appropriately. Many of the situations listed under patient medical emergencies above also apply to staff; these are among additional situations that should also be covered: • Sharps injuries; • Exposure to an infective fluid; • Occupational injury (e.g., barotrauma) or occupational disease (e.g., hearing loss or skin conditions); • Omitted decompression; and • DCI.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**

B-3. Medical Staff Qualifications

1) Dive medicine practitioners	The ability to administer and monitor hyperbaric medical treatments requires specific knowledge, training, and experience. Patients can present with a range of responses and side effects, and numerous other medical complications or situations can also arise. Furthermore, if the patient is located in a sealed, pressurized chamber, the practitioner may need to either manage a medical incident in a hands-off manner or deliver care within the confines of the pressurized chamber.	 4 3 4 4	A RCC's dive medicine practitioner should hold the following minimum qualifications: a) Registration as a medical practitioner according to relevant national regulations; b) Completion of dive medicine training endorsed by relevant national regulations or by a recognized international hyperbaric and/or dive medicine association; c) Current basic life support (BLS) certification (with advanced cardiac life support [ACLS] certification recommended); and d) Confirmation of being medically fit to enter a chamber while it is under pressure.
2) Chamber operators	Medical complications and emergencies may require specific and quick action in order to mitigate risk for the patient. Appropriate knowledge, training, and experience are required if a chamber operator is to make decisions regarding pressure control, ventilation, monitoring, and/or termination of a treatment.	4	No one should operate a hyperbaric chamber unless they are a suitably qualified chamber operator with appropriate training endorsed by relevant national regulations or a recognized international hyperbaric and/or dive medicine association.
3) Chamber attendants	The chamber attendant is typically the only person with direct, immediate access to patients during treatments. Proper medical training, experience, and competence are essential to enable attendants to manage patients appropriately and to follow	 3 3	Chamber attendants should hold the following minimum qualifications: a) Appropriate training endorsed by relevant national regulations or by a recognized international hyperbaric and/or dive medicine association; b) Current BLS certification; and

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
3) Chamber attendants (cont.)	instructions from the medical practitioner, who is typically stationed outside the chamber.	3	c) Confirmation of being medically fit to enter a chamber while it is under pressure.

B-4. Patient Care

1) Staffing levels	The operation of a RCC is complex under normal as well as emergency conditions and thus requires a minimum complement of qualified staff. Operators may need to leave the control panel at times – such as to use the bathroom. History has shown that accidents have happened during the time that chambers have been left unattended.	5 4	No chamber should be left without an operator in control at any point, even momentary The following minimum staffing levels should be maintained at all times: a) A medical practitioner who is qualified to deliver hyperbaric oxygen therapy. b) A chamber operator; c) At least one chamber attendant, and d) An assistant chamber operator or support person, available in case the operator needs to leave their post to check equipment, use the bathroom, or due to an emergency.
2) Medical supervision	Professional expertise is required to deal with the side effects and complications of treatments and with the possibility that advanced care, life-support services and complicated interventions might be called for. Failure to provide proper medical supervision can thus compromise a patient's health or life.	3	A qualified dive medicine practitioner should be available at all times during all treatments and should supervise treatments in accordance with international requirements for medical supervision.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
3) Patient medical screening	Significant physiological risks exist for patients with contraindications if they are placed under hyperbaric pressure, especially if they are also administered O_2-enriched gases. Patients may also have psychological and/or social issues that can affect their health and safety and/or the outcome of their treatments.	4	Every patient should be screened by a qualified dive medicine practitioner before being accepted for treatment. The screening should include confirmation of the appropriateness of the treatment, the lack of any contraindications, and an assessment of the patient's physical and psychological status.
4) Patient orientation	Patients who are unaware of the hazards associated with RCCs could inadvertently bring prohibited items or materials into a chamber. If patients are not well informed about the process, they may experience anxiety which could cause them to panic or at the least experience additional stress.	3	Patients should receive an orientation to the facility, as well as to all relevant policies and procedures before their treatment begins. The orientation should emphasize safety precautions related to fire and pressure hazards (e.g., prohibited items and materials).
5) Patient records and procedures	Failure to comply with national requirements regarding patient records can put a facility in legal jeopardy.	3	Patient medical records should be kept up to date and confidential, with individual files kept on each patient. Any relevant national regulations regarding patient records should be followed.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
6) Basic emergency medical equipment available	If a patient experiences distress while in the chamber, it may be necessary to render immediate care either inside the chamber or immediately upon extracting the patient from the chamber. Furthermore, some RCC facilities do not have ready access to hospital emergency departments. The lack of equipment to manage such situations can compromise patients' health or lives.	3	Medical equipment suitable to manage any foreseeable emergencies, consistent with the RCC's advertised scope of services, should be available, maintained, and readily accessible.

B-5. Equipment

1) Approved equipment	The use of noncompliant or unapproved equipment, instruments, and devices represents a risk of explosion, implosion, and/or fire.	4 5	a) Only equipment that is specifically compliant with the requirements of this document or that has been specifically assessed and approved for use within a RCC should be used in a chamber. b) All other equipment should be expressly prohibited from being taken into a chamber. This includes high-energy devices, photographic flashes, lasers, tablets, and cellular phones.
2) Defective equipment	Defective equipment can compromise safety and hamper emergency responders.	4	Defective equipment and equipment suspected of being defective should be withdrawn from use and repaired to the satisfaction of the delegated safety officer prior to being returned to the chamber.
3) Flammable items	Flammable items and substances include the obvious possibilities, as well as less obvious items like paper and lubricants, all of which represent a risk of fire.	5	Flammable items should be kept to an absolute minimum inside RCCs. Newspaper should be expressly prohibited, due to the volatile inks used by some papers.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
4) Temperature ratings	Equipment with unsuitable temperature ratings can cause a fire or explosion.	4	All equipment intended for use in a chamber should strictly follow the chamber's temperature rating requirements. This matter requires vigilance by staff.
5) Compatibility with O_2 equipment	Many items, if ignited within a pressurized, O_2-enriched environment, are not self-extinguishing.	4 3 3	a) Only approved, dedicated O_2 containers, control mechanisms, interconnecting hoses and fittings, valve-seat materials, and lubricants should be used in a chamber. b) International guidelines for determining the suitability of materials for O_2 compatibility should be followed. c) Static conditions and impact conditions are both applicable. ASTM and NFPA guidelines for designs using O_2-compatible materials should be followed.
6) O_2 cleaning procedures	Contamination of O_2 equipment presents a risk of fire or explosion.	3	All O_2 equipment — including fittings, connections, gas handling equipment, etc.- should be O_2 cleaned prior to use in a chamber. O_2 cleaning requires special considerations, and only approved procedures should be used.
7) O_2-compatible lubricants	HC-based lubricants are a known source of fuel in an O_2-enriched environment.	4	Only O_2-compatible lubricants should be used inside a chamber.
Warning: Devices with o-rings, gaskets, bearings and moving parts may utilize HC-based lubricants, that are unacceptable for use in a chamber. Sealing and bearing surfaces should be carefully examined for the type of lubricant used. Where a HC-based lubricant is in evidence, or when in doubt, the surfaces should be oxygen-cleaned and an O_2-compatible– lubricant applied.			
8) Use of light metals	Light metals (e.g., cerium, magnesium, and magnesium alloys) are capable of burning in air.	5	Any combustible light metals such as magnesium should be prohibited from being used within a chamber, unless located within a patient (implanted) and assessed as sufficiently safe by the safety officer.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
9) Radiation exposure	X-rays or gamma radiation can degrade acrylic windows. This risk is especially applicable if the source of radiation is located outside the chamber and the radiography is delivered through the viewport.	3	a) If acrylic windows are exposed to any form of high-energy radiation, facility owners and managers should be aware that the service life of the window will be drastically reduced. The maximum allowed absorbed dose is 40 kilogray (kGy) (4 mega rad [Mrad]). Exposure to X-rays or gamma radiation reduces window service life to three years.
	Direct sunlight is also a known source of harmful UV and infrared radiation capable of degrading acrylic windows.	3	b) Exposure to harmful UV or infrared radiation (e.g., from direct sunlight) also reduces the service life of acrylic windows. In such cases, ASME PVHO-2 requires strict adherence to a maximum service life of 10 years.

B-6. Handling of Gases

1) Compressed gas standards	The storage and handling of compressed gases and the installation and cleaning of O_2 and related piping systems, involve serious risk of fire and/or explosion.	3	a) The CGA Handbook of Compressed Gases provides minimum safety guidelines. Similarly, European, Asian, and Australian industrial gas associations provide guidance documents. The sections relevant to the storage and handling of all gases (e.g., compressed air, O_2, N_2) should be followed within all RCC facilities.
		3	b) CGA G-4.1, Cleaning Equipment for Oxygen Service, provides minimum safety guidelines for cleaning O_2 piping systems. This document or an alternative deemed appropriate by the *responsible* person should be followed.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
1) Compressed gas standards (cont.)		3	c) ASTM G-93-96, Standard Practice for Cleaning Methods and Cleanliness Levels for Materials and Equipment Used in Oxygen-Enriched Environments, provides further guidance on cleaning O_2 piping systems.
2) Procedures for handling gases	Compressed gases represent a risk of both fire and explosion.	4	Only qualified staff should be permitted to operate or work on gas-handling equipment.
3) Liquefied gases	Liquefied gases boil off rapidly and can change the composition of a chamber's atmosphere.	5	No gases stored in a liquefied state should be taken into a RCC.
4) Flammable gases	Flammable gases represent a severe risk of fire.	4	No flammable gases should be stored in or near a RCC facility or near any compressor intake(s).
5) Storage of gases	Large quantities of stored gas, especially O_2, elevate the risk in the event of a fire, especially if the storage containers are not regularly inspected for leaks, etc.	3	a) The amount of O_2 stored in or around a RCC should be kept to the minimum required to complete treatments and to deal with emergency situations.
	Pressurized containers also represent a risk of explosion.	5	b) Pressurized containers should be taken into a RCC only if they are approved for such use, such as emergency gas supplies.
6) Use of non-flammable gases	Even non-flammable pressurized gases present risks unless sufficient control systems are in place.	3	Non-flammable gases required for use in a chamber should be piped into the facility. Shutoff valves accessible to staff members should be located at the points of entry to the room housing the chamber.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**

B-7. Maintenance

1) Regular testing and calibration of equipment	Inadequate maintenance of O_2-handling equipment, chamber controls, and safety equipment can result in equipment failure, representing risks for both operators and occupants.	3 3	a) The safety officer should be responsible for ensuring that all equipment is regularly checked and serviced. b) Pressure-relief valves, gauges, and analyzers should be calibrated at least annually.
2) Labeling of gas outlets	Inadequate labeling of O_2-system components, especially outlets, risks them not being identified during emergencies.	3	All essential controls on an O_2 system, especially gas outlets, should be clearly labeled. It is also imperative that the gases delivered at every labeled outlet are checked prior to their first use (by reviewing the attached certificate[s] of analysis or, preferably, by continuous gas analysis).
3) Replacement parts	The use of nonstandard spares and replacement parts can result in premature equipment failure.	3	The safety officer should be responsible for ensuring that only manufacturer-authorized components are used during both initial installation and subsequent maintenance of all equipment.
4) Authorized work	All installation, repair, and modification work to hyperbaric chambers and their associated equipment directly affects the safe function of the units.	3 3	a) The safety officer should ensure that only *competent* personnel perform repair and maintenance work and that all such work is performed according to the provisions of both legal requirements and the equipment manufacturers' manuals. b) All equipment should then be fully tested and the results logged after any repair or maintenance work is performed.
5) Maintenance logs	A lack of operating and/or maintenance logs precludes adequate control of maintenance procedures, potentially resulting in premature equipment failure.	2	The safety officer should sign off on all maintenance procedures and ensure that logs of all operating and maintenance procedures are maintained.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
6) Cleaning of filters	Blocked or partially blocked filters reduce efficiency of chamber operation, provide a risk where rapid decompression may be required, and may introduce dirt and contaminants should filters fail as a result of excessive loading.	3 3 3	a) The chamber gas supply inlet filters should be cleaned or changed at least annually. b) Inlet filters for regulators, flow controls, and the exhaust system require annual maintenance. c) Manufacturers' recommendations should be adhered to at all times.
7) System maintenance	Inadequate and/or incomplete maintenance can result in deterioration of systems below a level of optimal safety and readiness and/or failure of systems to a degree that could affect operational safety.	3	Adequate and effective systems maintenance requires that the following elements be addressed: a) Initial installation, repairs, additions, and modifications to all equipment should be evaluated by *competent* personnel who have been appointed by the safety officer. This evaluation should include testing under pressure.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
7) System maintenance (cont.)		3	b) The safety officer should ensure that a comprehensive preventative maintenance process is in place. It should include the following elements: • Periodic testing of all safety-related equipment (e.g., gauges, valves, meters, fire extinguishers and deluge systems, warning systems, etc.); • Checks of O_2 piping systems for leaks; • Checks that gas flows remain unobstructed; • Checks of all automatic drains (to ensure that no condensate is discharged, that drain valves have no blockages, and that filter elements are not saturated); • Replacement of filters, lubricants, and coolants; • Checks of fluid levels (e.g., lubricants, coolants, etc.); • Adjustment of regulators, sensors, safety valves, and switches; • Correct and effective activation of safety systems (e.g., deluge system, electrical alarms, emergency power system, backup gas supplies); • Checks of electrical connections and terminations, wiring, switches, chamber and equipment grounding, and function of electrical safety devices (ELCB, RCCD, GFIC, LIM); • Analysis of gases; • Checks of viewports, pressure boundaries, calibrations, and statutory testing status; and • Recording of all periodic tests in the maintenance log, which should be scrutinized regularly.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
7) System maintenance (cont.)		2	c) A documented corrective maintenance process should be established. It should include the following elements: • Full cause-and-effect recording of all system failures and breakdowns; • Logging of corrective actions; A hold on further pressurization of the chamber while it is occupied until the issue has been resolved and the resolution has been approved by the safety officer; and • Regular audits by the safety officer.
		2	d) A suitable, dedicated maintenance area, equipped with dedicated tools and instruments, is required to enable personnel to effect repairs, replacements, and cleaning with minimum downtime.
8) Systems cleaning procedures	Ineffective or incomplete cleaning of hyperbaric piping and gas storage systems can introduce dangerous substances into the systems, posing a risk of fire or toxic contamination.	3	a) After initial installation, repairs, or modifications of any gas supply or control systems, a cleanliness certificate should be issued that meets the satisfaction of the safety officer.
		3	b) The placement of suitable filters at positions such as the O_2 or air inlet should be considered as appropriate.
	A failure to thoroughly clean chambers and their associated equipment on a daily basis can result in the spread of transmissible diseases.	3	c) Suitable cleaning procedures should be documented and should be certified as effective by the safety officer prior to being implemented. These procedures should preferably include objective inspection and testing instructions.
		3	d) Suitable, noncorrosive antiseptics and detergents should be used to clean all surfaces at the end of every treatment day.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
8) Systems cleaning procedures (cont.)		3 3	e) Caution is required in cleaning certain components (e.g., windows and fire-resistant materials) to avoid degradation of the material or a reduction in its fire-resistant properties. f) Safe and comprehensive protocols should be established regarding issues such as protective clothing, disposal of cleaning containers, disposal or cleaning of contaminated linens, inspection of chambers after they have been cleaned, and adequate ventilation both during cleaning and prior to treatments.
Warning: Trichloroethylene, methylene chloride, and other compounds hazardous to health are not recommended as a cleaning compound in RCCs. Not only are they hazardous to individuals who use them, but some cleaning fluids also react with CO_2-absorbent chemicals, forming a toxic and explosive volatile compound.			
9) Approved lubricants or consumable materials	Many common and accepted lubricants and consumable materials are not safe for use within a hyperbaric environment, especially in the presence of high concentrations of O_2.	4 2 2	a) The criteria by which materials are judged to be safe for use in a hyperbaric environment should include the following: • Suitably pressure-rated and O_2-compatible; • Nontoxic; • Nonreactive with system elastomers and other similar materials; • Noncorrosive; and • Effective and easy to apply or use. b) Materials should be clearly identified for their intended use and should be packaged to keep out contaminants. c) Lubricants should be used sparingly and should not be used to correct equipment flaws (e.g., on nonsealing joining surfaces or to compensate for a poor fit). All excess lubricants should be removed prior to the use of the equipment.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**

B-8. Electrical Safeguards

1) Testing	Any electrical faults or failures of a chamber's protective equipment presents considerable risk to the safety of the operating environment.	4	All electrical circuits, GFCIs, and line insulation monitors (LIMs) should be tested before each treatment session, to ensure that they are functioning normally and that no live conductors are grounded. The devices are usually located in each power circuit. ELCBs and RCCBs, usually located in the distribution boards, should be tested at least monthly. Chamber grounding should be tested periodically, as determined by the facility planned maintenance system.
2) De-energization of equipment	A failure to de-energize electrical equipment during a fire, especially in facilities with a sprinkler or deluge system, can be exceedingly dangerous, due to the risk of electrical shock and even death if water comes in contact with an electrical fire.	5	Any electrical equipment in a RCC that is not life-critical should be de-energized prior to the activation of a sprinkler or deluge system (unless it is adequately waterproofed).

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**

B-9. General Safeguards

1) Furniture	Furniture that is inadequately grounded, that has loose joints, and that contains ferrous metals can result in fire (due to static discharge, buildup of a static charge, and sparking from ferrous metals).	2 3 5 3	a) Furniture should be periodically inspected, especially as to its grounding and insulation and the integrity of its joints. b) Unless it is unavoidable, furniture inside a chamber should not be moved during treatments. c) Metals that exhibit sparking potential on impact should not be used on load-bearing furniture. For example, oxidized ferrous metals should never be used for chair-leg tips in a chamber, as they could produce high-temperature sparks if they strike a surface such as aluminum deck plates. d) Only O_2-compatible, nonflammable lubricants should be used on casters and bearings inside a chamber. This should be confirmed by regular inspection.
2) Materials containing rubber	Rubber materials deteriorate rapidly in an O_2-enriched environment, resulting in reduced mechanical strength.	3	All rubber-bearing materials should be regularly tested in accordance with established periodic maintenance requirements, especially at points of kinking. This is especially applicable to rubber with a high carbon content.
3) Fire-suppression equipment	Failure of any fire-suppression equipment jeopardizes the ability of the system to effectively extinguish a fire.	4 4	a) All fire-suppression controls, including switches, valves, and monitoring equipment, should be visually inspected prior to every treatment session. b) Semiannual inspections should be conducted of all fire-extinguishing media and of the functioning of the system.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**

B-10. Housekeeping

Elements	Risks	RL	Minimum Requirements
1) Tidiness	Cluttered and untidy facilities present a safety hazard in terms of operational control, especially in emergency situations.	3	The owner or manager should ensure that operating areas are kept free of unnecessary equipment, that nonessential equipment is stowed away, and that essential equipment is at hand.
2) Cleanliness	Any buildup of flammable materials, such as grease, dirt, lint, and dust, represents a risk of fire.	3 3	a) It is essential that a RCC be kept meticulously free of grease, dirt, lint, dust, and other undesirable materials. b) The person tasked with daily cleaning should be thoroughly briefed as to the dangers of uncleanliness.
3) Diseases & contamination	The lack of and/or inadequate, daily cleaning of the chamber and equipment may cause transmission of diseases and spread of contamination.	3 3 3	a) A suitable, non-corrosive disinfectant (e.g., quaternary ammonia-based) should be used to clean all surfaces following each treatment day. b) Due caution is required in cleaning certain hyperbaric components, e.g., fire-treated bedding and mattresses, to avoid degradation or a reduction in fire-resistant properties. c) Safe and effective protocols should address issues such as protective clothing, disposal of cleaning containers, disposal or cleaning of contaminated linen, inspection of chamber after cleaning, and adequate ventilation during cleaning and prior to treatments.
4) Acrylic cleaning procedures	The visibility and life span of acrylic materials can be reduced by: • Abrasion – reducing visibility; • Surface damage – reducing life span; and • Degradation due to chemical incompatibility – reducing visibility and life span.	4 3 2	a) Antiseptic and cleaning compounds should be specifically certified as being suitable for acrylic windows. b) Due caution is required in cleaning acrylic components to avoid mechanical damage. c) A soft, lint-free cloth should be used to clean the acrylic window.

B. Administration and Maintenance			
Elements	**Risks**	**RL**	**Minimum Requirements**
5) Standby conditions	During extended periods of down-time (i.e., the chamber is not being used), there may be less attention paid to housekeeping, with the corresponding danger of non-compliance with facility safety procedures.	3 3 2	a) Only properly trained personnel should be allowed to clean the facility. b) The entry of unauthorized personnel into the facility should be prevented. c) The facility should preferably be kept secured (locked) at all times.

Abbreviations

"	inch(es)
Ω	ohm
A	ampere
ABS	American Bureau of Shipping
AC	alternating (electrical) current
acfm	actual cubic feet per minute
ACLS	advanced cardiac life support
AS/NZS	Australian/New Zealand Standard
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	atmospheres absolute (101,325 Pa or 14.7 psi)
BIBS	built-in breathing system
BLS	basic life support
CO_2	carbon dioxide
CO	carbon monoxide
°C	degrees Celsius (temperature)
CFL	compact fluorescent lamp
CGA	Compressed Gas Association
CH_4	methane
DAN	Divers Alert Network
dB(A)	A-weighted decibel (a measure of the relative loudness in air as perceived by the human ear)
DC	direct (electrical) current
DCI	decompression illness
DT	dew point temperature (measured at sea level/1 ATA and expressed in °C or °F)
EBAss	European Baromedical Association
ECHM	European Committee for Hyperbaric Medicine
EIGA	European Industrial Gas Association
ELCB	earth leakage circuit breaker (detects current leakage to ground; provides similar protection to a GFCI and an RCCB)
EUBS	European Undersea & Baromedical Society
°F	degrees Fahrenheit
fsw	feet of sea water
ft	foot
gpm	gallon per minute (Imperial; 1 gpm = 3.8 lpm)
GFCI	ground fault circuit interrupter (detects current leakage to ground; provides similar protection as an ELCB or a RCCB)
H_2O	water
H_2S	hydrogen sulfide
HC	hydrocarbon

HP	high pressure (in context of this publication, assumed as > 1.5 MPa/225 psi for air and inert gases; > 0.86 MPa/125 psi for O_2)
HTNA	Hyperbaric Technicians and Nurses Association
IP	ingress protection
IPS	isolated power supply (also referred to as an isolated power system) provides electrical isolation between input and output circuits and provides separate ground paths)
ISO	International Organization for Standardization
kGy	kilogray (a unit of absorbed radiation dose, defined as 1 Joule/kilogram: 1 kGy = 1 kJ/kg)
LIM	line isolation monitor (also line insulation monitor; used to detect ground leakage in ungrounded electrical systems)
LOX	liquid oxygen
LP	low pressure (in the context of this guide, assumed as < 1.5 MPa/225 psi for air and inert gases; < 0.86 MPa/125 psi for O_2)
lpm	liters per minute
LR	Lloyd’s Register
m	meter
MΩ	megaohm (1 million ohms)
MPa	megapascal (10^6 pascal)
Mrad	megarad (a unit of absorbed radiation dose with 1 Mrad = 10 MGy)
msw	meters of sea water
µm	micrometer (10^{-6} m)
mA	milliampere (0.001 A)
mg/m^3	milligrams per cubic meter (0.001 g/m^3), measured at normal temperature and pressure
mm	millimeter (0.001 m)
mW	milliwatt (0.001 W)
min	minute
nm	nanometer (10^{-9} m)
NBDHMT	National Board of Diving and Hyperbaric Medical Technology
N_2	nitrogen
NFPA	National Fire Protection Association
NOx	nitrogen oxide
O_2	oxygen
OCA	oxygen-compatible air
Pa	pascal
ppm_v	parts per million by volume
psi	pounds per square inch
PVHO	pressure vessels for human occupancy
RCC	recompression chamber
RCCB	residual current circuit breaker (detects current leakage to ground; provides similar protection as a GFCI and an ELCB)
RL	risk level
SAUHMA	Southern African Undersea and Hyperbaric Medical Association

SEV	surface equivalent value (expressed in percentage or %)
SO_2	sulphur dioxide
TT	treatment table
UV	ultraviolet light (light spectrum immediately below visible light; wavelength range 10 – 400 nm)
UHMS	Undersea and Hyperbaric Medical Society
UL	Underwriters Laboratories
USN	United States Navy
USP	U.S. Pharmacopoeia
VOC	Volatile Organic Hydrocarbon
V_{AC}	volts alternating current
V_{DC}	volts direct current
V_{rms}	root mean square voltage
W	watt

Appendix A
Applicable Regulations and Guidelines

System Standards

1. Australian/New Zealand Standard (AS/NZS) 2299.1.2015, *Occupational Diving Standards — Standard Occupational Practice*, 2015.
2. American Society of Mechanical Engineers (ASME) PVHO-1, *Safety Standard for Pressure Vessels for Human Occupancy*, 2023.
3. American Society of Mechanical Engineers (ASME) PVHO-2, *Safety Standard for Pressure Vessels for Human Occupancy: In-Service Guidelines* (guidelines for PVHO acrylic windows), 2019.
4. Canadian Standard Z275.1, Hyperbaric operations and work in compressed air environments, 2023.
5. European Standard EN 14931:2006, *Pressure Vessels for Human Occupancy (PVHO). Multi-place pressure chambers for hyperbaric therapy. Performance, safety requirements, and testing*, 2006.
6. European Standard EN 12021:2014, *Respiratory equipment. Compressed gases for breathing apparatus*, 2014 (including November 2014 corrections).
7. European Standard EN 16081:2013, *Hyperbaric chambers — Specific requirements for fire extinguishing systems — Performance, installation, and testing (Austrian standard)*, 2013.
8. National Fire Prevention Association (NFPA) 99, *Health Care Facilities Code*, chapter 14 ("Hyperbaric Facilities"), 2024.

International Classification Society Rules

1. American Bureau of Shipping (ABS) 7: *Rules for Building and Classing Underwater Vehicles, Systems and Hyperbaric Facilities*, 2018.
2. Lloyd's Register (LR): *Rules and Regulations for the Construction and Classification of Submersibles and Diving Systems*, 2019.

Additional Guidance Documents

1. American Society for Testing and Materials (ASTM) G-93-96, *Standard Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments*, 1996.
2. Australian Standards (AS) 4774.2-2019, *Work in compressed air and hyperbaric facilities*, Part 2: Hyperbaric oxygen facilities, 2019.
3. Compressed Gas Association (CGA) G-7.1-2018, *Commodity Specification for Air*, 7th edition, 2018.
4. Compressed Gas Association (CGA) G-4.1, *Cleaning Equipment for Oxygen Service*, 7th edition, 2018.
5. Compressed Gas Association (CGA) P-45-2018, *Fire Hazards of Oxygen and Oxygen-Enriched Atmospheres*, 2nd edition, 2018.
6. European Industrial Gases Association (EIGA) 33/18, *Cleaning of Equipment for Oxygen Service*, 2018.
7. National Fire Protection Association (NFPA) 70, *National Electrical Code*, 2017.
8. Naval Sea Systems Command, *US Navy Diving Manual*, Revision 7A, 2018.

Appendix B
Determination of Risk Levels

As referred to in the Explanatory Notes (see page 2), a *risk* is based on three factors. A risk may be quantified by calculating the product of the *probability* (the likelihood that an adverse event will occur), the *exposure to a hazard* (quantified by frequency of exposure), and the potential *harmful consequences* (quantified by the severity of those consequences, should they occur).

In all cases, a realistic assessment should be made of the actual quantification of each of these three factors to arrive at a realistic worst-case scenario.

A Likert scale provides a suitable means of allocating scores to each factor; the probability of fire, mechanical and health risks should be considered for each hazard assessed.

A score is thus computed as the product of each of the three factors, such that 5 x 5 x 5, or 125, is the highest possible score.

The three tables below offer relevant descriptions for the quantification of *probability*, frequency of *exposure* and *harmful consequences*.

Table 3: Factor Score Values

Probability/likelihood of an adverse event occurring					
Fire and/or explosion		**Mechanical hazards**		**Health and/or medical hazards**	
Combustion definite	5	Failure definite	5	Event definite	5
Combustion expected	4	Failure expected	4	Event expected	4
Combustion possible	3	Failure possible	3	Event possible	3
Combustion unusual	2	Failure unusual	2	Event unusual	2
Combustion unlikely	1	Failure unlikely	1	Event unlikely	1

Exposure to the hazard	
Continuous: throughout a shift	5
Daily: about twice a day	4
Weekly: about twice a week	3
Monthly: about twice a month	2
Annually: about twice a year	1

Severity of the outcome	
Catastrophic: e.g., death, life-threatening injury, destruction	5
Severe: e.g., significant injury, facility no longer available	4
Serious: e.g., reduced ability to treat or treatment quality	3
Significant: e.g., minor damage/injury, additional staff needed	2
Noticeable: e.g., inconvenience, additional work required	1

It is possible to have no exposure to a hazard and thus no consequences. In such a case, there is no risk.

If a risk encompasses more than one of the probability/likelihood risk categories (i.e., fire and/or explosion, mechanical hazards and health and/or medical hazards), each category should be assessed separately (*probability* x *exposure* x *harmful consequences*) and the highest score should be used.

The next table provides empirically derived guidance regarding the determination of an overall risk level, based on the scoring of *probability*, *exposure,* and *harmful consequences*; the associated risk rating; and the requirement for mitigation based on the urgency of avoiding the consequence(s).

Table 4: Risk Level and Associated Mitigation Requirements

Score	RL	Risk Rating	Requirements
> 100	5	Very high	Attention and risk mitigation are critical and must be given the highest priority. A potentially dangerous situation may exist, with the possibility of very serious or catastrophic consequences in the event of an adverse incident. The treatment activity should stop immediately and should not recommence until effective mitigation is in place.
60–99	4	High	Attention and risk mitigation are required and must be given high priority. A serious situation may exist that could endanger people or equipment or that could seriously disrupt or jeopardize the facility. Solutions or actions that may mitigate the risk should be considered, at the discretion of the *responsible person* and they should be recorded in writing.
20–59	3	Medium	Attention to the risk is required. Eventual exposure to this risk could result in an incident. Outcomes could include business disruption, financial or liability consequences, injuries, or equipment damage. Mitigation of the risk should be accomplished within practical time and cost considerations.
10–19	2	Low	Attention to the risk is recommended for the optimal functioning of the recompression facility. Risk mitigation steps already in place should be recorded in writing.
< 10	1	Very low	The risk is acceptable. Note should be taken of the risk, but either it has already been suitably mitigated or its impact is of justifiably low significance.

Appendix C
Guidance on Chamber Air Specifications

Introduction

A great deal of confusion exists over the so-called minimum specifications for breathing air. This is partly because breathing air is often stored in high-pressure form, requiring additional corrosion considerations and therefore mandating uncomfortably dry air. However, the major debate centers on the safety issues associated with the presence of hydrocarbons and with the definition of oil-free air.

National standards for air purity (based on acceptable impurity levels) exist in most countries. However, these standards are not necessarily appropriate for the O_2-enriched environments found in medical hyperbaric chambers; this necessitates a review of the international standards that are applicable.

The NFPA 99 standard covers requirements for air that is both O_2-compatible and medically safe. The resulting standard is classified as medical air by the U.S. Pharmacopoeia (USP), together with additional restrictions.

Although some national standards require stricter control of (H_2O), these limits are based on storage-cylinder corrosion considerations rather than patient considerations or O_2-safety considerations.

The following two specifications both allow a greater amount of H_2O to be present (based on the many international diving standards for surface-supplied air) in air up to 4.0 MPa (580 psi). It is important to note the additional requirements for air compressed to higher pressures in order to avoid the risk of regulator freeze-up.

Breathing Air Specifications

The required minimum specifications for breathing air — if the intended application excludes any mixing to achieve O_2 enrichment above 23.5% and if the air will not be piped into any system that could be used to convey O_2-enriched mixtures or pure O_2 (such as for the BIBS) — are as follows:

Table 5: Common Air Quality Element Maximum Limits

<table>
<tr><th>Element</th><th colspan="4">Requirement</th></tr>
<tr><td>Oxygen</td><td colspan="4">20% to 22%</td></tr>
<tr><td rowspan="8">H_2O</td><td colspan="4">Compressed air for HP cylinder storage should meet the requirements of:
< 50 mg/m^3 (62 ppm$_v$) or DT -46°C (–51°F) for cylinder pressures 4 – 20 MPa (580 – 2900 psi).
< 35 mg/m^3 (44 ppm$_v$) or DT -49°C (-56°F) for cylinder pressures 20 – 30 MPa (2900 - 4350 psi).
< 25 mg/m^3 (33 ppm$_v$) or DT -51°C (-60°F) measured at the compressor outlet.
Air supplied to the chamber downstream of all pressure reducing regulators (i.e., LP air) need only meet the following requirements, except for applications where the air passes through pneumatic controls*.
* In these cases, a 62 ppm$_v$ (-46°C/-51°F dew point) limit may be required.</td></tr>
<tr><td colspan="4">Recommended limits for breathing air at up to 580 psi (40 bar or 4.0 MPa)</td></tr>
<tr><td>Supply pressure MPa (psi)</td><td>Max H_2O content* mg/m^3 (ppm$_v$)</td><td>Supply pressure MPa (psi)</td><td>Max H_2O content* mg/m^3 (ppm$_v$)</td></tr>
<tr><td>0.5 (73)</td><td>290 (361)</td><td>2.5 (360)</td><td>65 (81)</td></tr>
<tr><td>1.0 (145)</td><td>160 (199)</td><td>3.0 (435)</td><td>55 (68)</td></tr>
<tr><td>1.5 (220)</td><td>110 (137)</td><td>4.0 (580)</td><td>50 (62)</td></tr>
<tr><td>2.0 (290)</td><td>80 (99)</td><td colspan="2">*Measured at 1 ATA & 20°C (68°F)</td></tr>
<tr style="display:none"></tr>
<tr><td>CO_2</td><td colspan="4">CO_2 to be less than 500 ppm$_v$ (required where breathing pressures may exceed 1 ATA).</td></tr>
<tr><td>CO</td><td colspan="4">CO to be less than 5 ppm$_v$</td></tr>
<tr><td>Oil: breathing air</td><td colspan="4">Less than 0.5 mg/m^3 of liquid hydrocarbons (oils).
• Liquid oil content is defined as a level of condensed hydrocarbons, measured in mg/m^3 at normal temperature and pressure.
• If a chamber uses oil-lubricated compressors, irrespective of the filtration system employed, the incoming chamber air supply should be monitored downstream of the filters for oil content.
Less than 25 ppm$_v$ of gaseous hydrocarbons (e.g., methane).</td></tr>
<tr><td>Oil: medical air</td><td colspan="4">Non-detectable or less than 0.1 mg/m^3 of liquid hydrocarbons (oils).
• Liquid oil content is defined as a level of condensed hydrocarbons, measured in mg/m^3 at normal temperature and pressure. The lowest detectible level is 0.1 mg/m^3.
• If a chamber uses oil-lubricated compressors, irrespective of the filtration system employed, the incoming chamber air supply should be monitored downstream of the filters for oil content.
Less than 25 ppm$_v$ of gaseous hydrocarbons (e.g., methane).</td></tr>
<tr><td>Particulates</td><td colspan="4">Concentration of particles to be < 0.5 mg/m^3 for particles greater than 5 µm in size.</td></tr>
<tr><td>Odor</td><td colspan="4">None.</td></tr>
<tr><td>Other VOCs</td><td colspan="4">Total VOCs excluding CH_4 to be less than 5 ppm$_v$.</td></tr>
<tr><td>Others</td><td colspan="4">H_2S, SO_2 to be less than < 1 ppm$_v$. NOx to be less than 2ppm$_v$.</td></tr>
</table>

Appendix D
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