NFPA 99B

Standard for Hypobaric Facilities

2002 Edition

NFPA, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
An International Codes and Standards Organization

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Hypobaric Facilities

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This edition of NFPA 99B, *Standard for Hypobaric Facilities*, was prepared by the Technical Committee on Hyperbaric and Hypobaric Facilities, released by the Technical Correlating Committee on Health Care Facilities, and acted on by NFPA at its November Association Technical Meeting held November 10–14, 2001, in Dallas, TX. It was issued by the Standards Council on January 11, 2002, with an effective date of January 31, 2002, and supersedes all previous editions.

This edition of NFPA 99B was approved as an American National Standard on January 31, 2002.

Origin and Development of NFPA 99B

In 1965, when the then Subcommittee on Hyperbaric Facilities was appointed, several hospitals were employing hypobaric therapy to treat respiratory diseases. Additionally, NASA and the U.S. Air Force were working with hypobaric chambers for space and air flight. The name of the Subcommittee was then changed to Hyperbaric and Hypobaric Facilities, and the initial version of a document on this subject was prepared. A tentative standard on the subject, NFPA 56E-T, was adopted at the 1971 Annual Meeting. In May 1972, the document was adopted as an official standard. The document was revised again for the 1977 NFPA Annual Meeting.

A complete review of NFPA 56E was accomplished for the 1981 Fall Meeting. That edition was designated NFPA 56E-1982.

In 1984, NFPA 56E was combined with 11 other health care documents to form NFPA 99, *Standard for Health Care Facilities*. NFPA 56E essentially became Chapter 11 of NFPA 99. In that revision, the major change made to the 1982 edition of NFPA 56E was a complete revision of requirements for Class D chambers to reflect their use for high-altitude training purposes. (Such chambers do not require as extensive safety precautions as research and clinical chambers.)

During the revision for the 1987 edition of NFPA 99, it was brought to the attention of the Subcommittee on Hyperbaric and Hypobaric Facilities that hypobaric chambers were no longer used for medical purposes. As such, the material on hypobaric facilities really did not belong in NFPA 99. Thus, the Subcommittee proposed that this material be separated from NFPA 99 and again published as a distinct NFPA document. It was designated NFPA 99B.

Minor revisions were made to editions adopted in 1987 and 1990.

For the 1993 edition of *Standard for Hypobaric Facilities,* the one significant change was the identification of the safety director as the person responsible for disseminating information on hazards associated with operating hypobaric facilities.

For the 1996 edition, the major changes included clarifying the application of the document (Chapters 1–4) and deleting a Class F–type chamber because the committee is unaware of hypobaric techniques involving artificial atmospheres.

The 1999 edition modified several paragraphs to conform to the NFPA *Manual of Style* for enforceable language. Other changes were editorial in nature.

The 2002 edition includes format revisions. The NFPA *Manual of Style* was applied in this document's restructure and format. Introductory material in Chapter 1 has been formatted for consistency between all NFPA documents. Referenced publications that apply to the document have been relocated to Chapter 2, therefore resulting in the renumbering of chapters. Informational references remain in the last annex. Appendices are now designated as annexes. Definitions in Chapter 3 have been reviewed for consistency with definitions in other NFPA documents, are systematically aligned, and are individually numbered. Paragraph structuring has been revised with the intent of one mandatory requirement per section, subsection, or paragraph. Information that often accompanied many of the requirements was moved to Annex A. Exceptions have been deleted or rephrased in mandatory text, unless the exception represents an allowance or required alternate procedure to a general rule when limited specified conditions exist. The format appearance and structure provide continuity among NFPA documents, clarity of mandatory text, and greater ease in locating specific mandatory text.

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Committee Scope: This Committee shall have primary responsibility for documents that contain criteria for safeguarding patients and health care personnel in the delivery of health care services within health care facilities, as follows:

(1) From fire, explosion, electrical, and related hazards resulting either from the use of anesthetic agents, medical gas equipment, electrical apparatus, and high frequency electricity, or from internal or external incidents that disrupt normal patient care
(2) From fire and explosion hazards associated with laboratory practices
(3) In connection with the use of hyperbaric and hypobaric facilities (NFPA 99B) for medical purposes
(4) Through performance, maintenance, and testing criteria for electrical systems, both normal and essential
(5) Through performance, maintenance and testing, and installation criteria, as follows:
  (a) For vacuum systems for medical or surgical purposes
  (b) For medical gas systems

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Committee Scope: This Committee shall have primary responsibility for documents or portions of documents covering the construction, installation, testing, performance, and maintenance of hyperbaric and hypobaric facilities for safeguarding staff and occupants of chambers.

These lists represent the membership at the time the Committees were balloted on the final text of this edition. Since that time, changes in the membership may have occurred. A key to classifications is found at the back of the document.

NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Annex A.

Information on referenced publications can be found in Chapter 2 and Annex E.

Chapter 1 Administration

1.1 Scope.

1.1.1* This standard shall apply to all hypobaric facilities in which humans will be occupants or are intended to be occupants of the hypobaric chamber.

1.1.2 This standard shall not apply to hypobaric facilities used for animal experimentation if the size of the hypobaric chamber does not allow for human occupancy.

1.2 Purpose.

1.2.1 The purpose of this standard shall be to set forth minimum safeguards for the protection of personnel involved in the use of hypobaric facilities where the hypobaric chamber contains an oxygen-enriched atmosphere *(see Section 3.3)*, when operated at pressures less than 760 mm Hg; 101.3 kPa [1 atmosphere absolute (ATA)].

1.2.2 The purpose shall also be to offer guidance for rescue personnel who might not ordinarily be involved in the operation of hypobaric facilities, but who would become so involved in an emergency.

1.2.3 The purpose shall also be to provide minimum standards for the design, maintenance, and operation of hypobaric facilities.

1.2.4* Hypobaric chambers shall be classified according to the following criteria:

(1) Class D – Human rated, air atmosphere not oxygen enriched
(2) Class E – Human rated, oxygen-enriched atmosphere (partial pressure of oxygen is above 0.235 ATA)

1.3 Application.

1.3.1 This standard shall apply only to the following:

(1) New construction
(2) New equipment added to existing facilities

1.3.2 This standard shall not require the alteration or replacement of existing construction or equipment.

1.3.2.1 Existing construction or equipment shall be permitted to be continued in use where its use does not constitute a distinct hazard to life as determined by the authority having jurisdiction.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this standard and shall be considered part of the requirements of this document.

2.2 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 10, *Standard for Portable Fire Extinguishers,* 1998 edition.
NFPA 13, *Standard for the Installation of Sprinkler Systems,* 1999 edition.
NFPA 70, *National Electrical Code®,* 2002 edition.
NFPA 99, *Standard for Health Care Facilities,* 2002 edition.
NFPA 701, *Standard Methods of Fire Tests for Flame Propagation of Textiles and Films,* 1999 edition.

2.3 Other Publications.

2.3.1 ASME Publications. American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016–5990.

ANSI/ASME PVHO-1, *Safety Standard for Pressure Vessels for Human Occupancy,* 1993.

ASME *Boiler and Pressure Vessel Code*, 1995.

2.3.2 ASTM Publication. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D 2863, *Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-like Combustion of Plastics (Oxygen Index),* 1991.

2.3.3 CGA Publication. Compressed Gas Association, 1725 Jefferson Davis Highway, Arlington, VA 22202-4100.

Pamphlet C-4, *Standard Method of Marking Portable Compressed Gas Containers to Identify the Material Contained* (ANSI Z48.1), 1990.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter shall apply to the terms used in this standard. Where terms are not included, common usage of the terms shall apply.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction (AHJ). The organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.

3.2.3* Code. A standard that is an extensive compilation of provisions covering broad subject matter or that is suitable for adoption into law independently of other codes and standards.

3.2.4 Guide. A document that is advisory or informative in nature and that contains only nonmandatory provisions. A guide may contain mandatory statements such as when a guide can be used, but the document as a whole is not suitable for adoption into law.

3.2.5 Labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

3.2.6* Listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

3.2.7 Shall. Indicates a mandatory requirement.

3.2.8 Should. Indicates a recommendation or that which is advised but not required.

3.2.9 Standard. A document, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and which is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions shall be located in an appendix or annex, footnote, or fine-print note and are not to be considered a part of the requirements of a standard.

3.3 General Definitions. For purposes of this standard, the following definitions apply as indicated. The abbreviation of "(HYP)" at the end of a definition indicates that term is the responsibility of the NFPA Technical Committee on Hyperbaric and Hypobaric Facilities.

3.3.1 Adiabatic Heating. The heating of a gas caused by its compression. (HYP)

3.3.2 Anoxia. A state of markedly inadequate oxygenation of the tissues and blood, of more marked degree than hypoxia. (HYP)

3.3.3* Atmosphere. In a general sense, the pressure exerted by, and gaseous composition of, an environment. This term is normally used to represent the earth's atmosphere, including its pressure (e.g., 1 ATA = 760.0 mm Hg or 101.325 kPa, or 14.7 psia, with the gas being air). (HYP)

3.3.3.1 Ambient Atmosphere. The pressure and composition of the surrounding atmosphere. (HYP)

3.3.3.2 Chamber Atmosphere. The pressure and gaseous composition of the environment inside a chamber. (HYP)

3.3.3.3 Atmosphere Absolute (ATA). The pressure of the earth's atmosphere, 760.0 mm Hg, 101.325 kPa, or 14.7 psia. Two ATA = two atmospheres. *(See also Atmosphere.)* (HYP)

3.3.4* Atmosphere of Increased Burning Rate. According to the Cook diagram *(see A.3.3.4)*, any combination of pressure and oxygen fraction that has a burning rate greater than that of 23.5 percent oxygen at 1 ATA. It would be any combination that falls above a horizontal line drawn through a level of 23.5 percent oxygen at 1 ATA. (HYP)

3.3.5 Bends. Decompression sickness, caisson worker's disease. (HYP)

3.3.6 Critical Equipment. That equipment essential to the safety of the occupants of the facility. (HYP)

3.3.7 Decompression Sickness. A syndrome due to evolved gas in the tissues resulting from a reduction in ambient pressure. (HYP)

3.3.8* Flame Resistant. Where flame resistance of a material is required by this standard, that material shall pass successfully the small-scale test described in NFPA 701, *Standard Methods of Fire Tests for Flame Propagation of Textiles and Films,* except that the test shall be conducted in the gaseous composition and maximum pressure at which the chamber will be operated. (HYP)

3.3.9 Flame Retardant. *(See definition of Flame Resistant.)* (HYP)

3.3.10 Hypobaric. An adjective referring to pressures below (lower than) atmospheric pressure. (HYP)

3.3.11 Hypoxia. A state of inadequate oxygenation of the blood and tissue. (HYP)

3.3.12 Intrinsically Safe. As applied to equipment and wiring, equipment and wiring that are incapable of releasing sufficient electrical energy under normal or abnormal conditions to cause ignition of a specific hazardous atmospheric mixture. (HYP)

3.3.13 Noncombustible (Hypobaric). An adjective describing a substance that will not burn in 95 percent, plus or minus 5 percent oxygen at pressures of 760 mm Hg (101.325 kPa). (HYP)

3.3.14 Nonflammable. An adjective describing a substance that will not burn under the conditions set forth in the definition of flame resistant. Same as noncombustible as it applies to each chamber environment. (HYP)

3.3.15 Oronasal Mask. A device that fits over the mouth and nose and seals against the face for administering a breathing gas different from the chamber atmosphere (HYP)

3.3.16 Oxidizing Gas. A gas that supports combustion. Oxygen and nitrous oxide are examples of oxidizing gases. There are many others, including halogens. (HYP)

3.3.17 Oxygen-Enriched Atmosphere. For the purposes of this standard, an atmosphere in which the concentration of oxygen exceeds 23.5 percent by volume. (HYP)

3.3.18 Oxygen Hood. A device encapsulating the subject's or patient's head with a seal at the neck, for administering a breathing gas different from the chamber atmosphere. *(See definition of Oronasal Mask.)* (HYP)

3.3.19 Oxygen Index. The minimum concentration of oxygen, expressed as percent by volume, in a mixture of oxygen and nitrogen that will just support combustion of a material under conditions of ASTM D 2863, *Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-like Combustion of Plastics (Oxygen Index).* (HYP)

3.3.20 Oxygen Toxicity (Hypobaric). Physical impairment resulting from breathing oxygen-enriched gas mixtures at normal or elevated pressures for extended periods of time. The extent and nature of the toxicities are direct functions of oxygen partial pressure and duration of exposure. (HYP)

3.3.21 Pressure.

3.3.21.1 Absolute Pressure. The total pressure in a system with reference to zero pressure. (HYP)

3.3.21.2 Ambient Pressure. Refers to total pressure of the environment referenced. (HYP)

3.3.21.3 Gauge Pressure. Refers to total pressure above (or below) atmospheric. (HYP)

3.3.21.4* Partial Pressure. The pressure exerted by a particular gas in a gas mixture; the pressure contributed by other gases in the mixture is ignored. Partial pressure is calculated as the product of the fraction of the gas times the total absolute pressure; it is specified in any units of pressure, but atmospheres are preferred. (HYP)

3.3.22 Psia. Pounds per square inch absolute, a unit of pressure measurement with zero pressure as the base or reference pressure. (HYP)

3.3.23* Psig. Pounds per square inch gauge, a unit of pressure measurement with atmospheric pressure as the base or reference pressure. (HYP)

3.3.24 Self-Extinguishing. A characteristic of a material such that, once the source of ignition is removed, the flame is quickly extinguished without the fuel or oxidizer being exhausted. (HYP)

Chapter 4 Construction and Equipment

4.1 Housing for Hypobaric Facilities.

4.1.1* Hypobaric chambers and all ancillary service equipment shall be housed in fire-resistant construction of not less than 1-hour classification that shall be a building either isolated from other buildings or separated from contiguous construction by 1-hour noncombustible (under standard atmospheric conditions) wall construction.

4.1.1.1* If there are connecting doors through such common walls of contiguity, they shall be at least B label, 1-hour fire doors.

4.1.1.2 All construction and finish materials shall be noncombustible under standard atmospheric conditions.

4.1.1.3 The room or rooms housing the hypobaric chambers and service equipment, such as those described in 4.1.1, shall have an automatic sprinkler system installed in accordance with NFPA 13, *Standard for the Installation of Sprinkler Systems*.

4.1.1.4 The sprinkler requirement in 4.1.1.3 shall not apply if the air intake for the emergency repressurization valve cannot be exposed to smoke or fumes.

4.1.2 The room housing the hypobaric chamber shall be vented to the outside or be equipped with blow-in paneling so that the execution of the emergency "dump" procedure *(see Annex C)* will not disrupt the integrity of the walls of the building.

4.1.2.1 As an alternative, the piping for the "dump" valve shall be permitted to be exteriorized *(see 4.2.5)* provided that the valve will function within the parameters set forth in 4.2.5 and provided that the source of repressurization air cannot be contaminated.

4.2 Fabrication of the Hypobaric Chamber.

4.2.1 Hypobaric chambers shall be designed and fabricated to comply with the ASME *Boiler and Pressure Vessel Code*, Section VIII, Unfired Pressure Vessels, Division 1 or Division 2, by personnel qualified to fabricate vessels under such codes.

4.2.2 Flooring of Class E chambers shall be noncombustible.

4.2.2.1 If the procedures to be carried out in a Class E hypobaric chamber require antistatic flooring, the flooring shall be installed in accordance with E.6.6.8 of Annex E in NFPA 99, *Standard for Health Care Facilities*.

4.2.2.2* In a hypobaric chamber, if a bilge pump is installed, the floor overlying it shall be removable for cleaning the bilge.

4.2.3 The interior of Class E chambers shall be unfinished or treated with a finish that is one of the following:

(1) Inorganic zinc based
(2) High quality epoxy or equivalent
(3) Flame resistant

4.2.3.1 If sound-deadening materials are employed within a hypobaric chamber, they shall be flame resistant.

4.2.4* Viewing ports and access ports for piping, monitoring, and related leads shall be installed during initial fabrication of the chamber.

4.2.4.1 Electrical circuits that will be wetted by water extinguishing agents from the external sprinkler fire extinguishing system shall be weather/drip protected.

4.2.4.2 Viewports shall be designed and fabricated according to ANSI/ASME PVHO-1, *Safety Standard for Pressure Vessels for Human Occupancy*.

4.2.5* Hypobaric chambers shall have redundant capability for emergency repressurization of locks and chamber.

4.3 Illumination.

4.3.1 All power sources for illumination in Class E chambers shall be mounted outside the chamber and chamber lock.

4.3.2 Class D chambers shall be permitted to have power sources for illumination mounted inside the chamber and lock.

4.3.3* Lighting fixtures used in conjunction with viewports shall be designed as specified in ANSI/ASME PVHO-1, *Safety Standard for Pressure Vessels for Human Occupancy*.

4.3.3.1 Lamps shall be capable of being changed without disturbing a viewport's inner gaskets or seals.

4.3.3.2 Wherever a tungsten filament lamp is employed for illumination of a hypobaric chamber or chamber lock, a heat shield shall be incorporated in the fixture to prevent excessive surface temperatures.

4.3.3.3 Gasket material for Class E chambers shall be flame resistant.

4.3.4 Permanent lighting fixtures installed within Class E chambers or locks shall comply with the requirements of NFPA 70, *National Electrical Code*®, Articles 500 and 501, Class I, Division 1, Group C atmospheres.

4.3.4.1 Permanent lighting fixtures installed within Class E chambers or locks shall be rated for the maximum vacuum and oxygen concentration attainable within the chamber.

4.3.4.2* Portable spot illumination, if used, shall comply with 4.7.2.4.

4.3.4.2.1 If portable spot illumination is used, the flexible cord shall be of the type designated for extra hard usage as defined in Section 501-11 of NFPA 70, *National Electrical Code*.

4.3.4.2.2 If portable spot illumination is used, the flexible cord shall contain a grounding conductor.

4.3.4.2.3 If portable spot illumination is used, the flexible cord shall be manufactured of flame retardant materials rated for use in the presence of 95 ± 5 percent oxygen.

4.4 Ventilation.

4.4.1 Whenever a hypobaric chamber is occupied, it shall be ventilated to avoid concentrating CO_2 and O_2 levels inside the chamber.

4.4.2 Individual breathing apparatus shall be supplied for each occupant of the chamber for immediate use in case air in the chamber is fouled by combustion or other means.

4.4.2.1 The source of the breathing mixture supplied to breathing apparatus shall be independent of chamber atmosphere.

4.4.2.2 The breathing gas supply shall be designed to allow for the simultaneous use of all breathing apparatus installed in the chamber.

4.4.2.3 All breathing apparatus shall function at any chamber pressure.

4.4.3 Sources of air for the chamber atmosphere and for individual breathing apparatus, if these do not have self-contained supplies, shall not allow the introduction of toxic or flammable gases.

4.4.3.1 Air intakes shall be located to prevent air contamination from the following sources:

(1) Vehicle exhaust
(2) Stationary engine exhaust
(3) Building exhaust outlets

4.4.3.2 Warming or cooling of the atmosphere within the chamber shall be permitted by circulating the ambient air within the chamber over or past coils through which a constant flow of warm or cool water is circulated.

4.4.3.3 Dehumidification shall be permitted through the use of cold coils.

4.4.3.4 Humidification shall be permitted by the use of gas powered water nebulizer.

4.4.3.5 When installed in Class E chambers, noncombustible packing and nonflammable lubricants shall be used on the fan shaft.

4.5 Fire Extinguishment Requirements for Class E Hypobaric Facilities.

4.5.1 Detection of fire shall be automatic, using either an ultraviolet or infrared detection system.

4.5.1.1 The detection system shall be capable of discriminating between chamber illumination and fire radiation.

4.5.1.2 Detectors shall be located to provide constant surveillance of all interior areas of the chamber.

4.5.2 A fixed automatic extinguishing system shall be installed within all Class E chambers.

4.5.2.1 The fixed automatic extinguishing system shall discharge automatically within one half second of sensible flame development.

4.5.2.2 The fixed automatic extinguishing system shall also be capable of manual operation.

4.5.2.3 Each final control element shall be furnished and installed in duplicate to provide control redundancy.

4.5.2.4 All chambers, manways, and air locks that communicate with each other shall be equipped with detectors, manual actuation means, and water spray systems.

4.5.2.5 If the communicating chambers are each to be protected by separate extinguishing systems, the water supply's hydraulic characteristics shall be capable of simultaneous operation of all systems.

4.5.3 A control panel shall be provided to control each fire extinguishing system.

4.5.3.1 Standby power shall be supplied by an uninterruptible power supply capacity to furnish necessary system operating energy for four continuous hours if the primary power source fails.

4.5.3.2 An alarm shall sound if the primary power fails.

4.5.3.3 Detector wiring shall be electrically supervised to determine continuity.

4.5.3.3.1 Integrity of all fire detection components shall be checked manually with a portable or fixed radiation source at each detection device at least semi-annually.

4.5.3.3.2 A disenabling "test" switch shall be provided in the panel to prevent discharge of water from nozzles during tests; the switch shall be of a type that cannot be left in the "test" position.

4.5.3.4 Circuitry to solenoid valves or other remote system actuators shall be equipped with necessary end-of-line resistors and/or relays to assure maintenance of continuity.

4.5.3.5 A visual and audible alarm shall sound if an actuator circuit fails.

4.5.3.6 The automatic control system shall provide for double complements of remote electrohydraulic or mechanical devices.

4.5.3.7 Connection of the automatic control system shall be redundant.

4.5.3.8 A timer shall be furnished and adjusted to allow actuation of the fire protection system for 20-second consecutive intervals, so long as the flame detectors report a fire condition.

4.5.3.9 The design of the control panel shall preclude use of all time delay relays and other time-consuming devices in the system actuation circuitry.

4.5.3.10 Supervisory lights and audible signals shall be provided to monitor the position of water supply main control valves.

4.5.3.11 Audible signals shall be initiated by the control panel upon either the actuation of any flame detector or initiation of water flow into the chamber.

4.5.3.12 Auxiliary contacts shall actuate relays or contactors in lighting and power circuits.

4.5.3.13 Supervisory switches shall be attached to all main water supply valves.

4.5.3.14 Supervisory switches shall be connected to the fire protection control panel.

4.5.3.14.1 Audible signals shall be located exterior to the chamber at the fire protection control panel and at other designated points in the facility to alert all concerned personnel of fire or water flow in the chamber.

4.5.3.14.2 Only water or water containing thickening or wetting agents shall be used in hypobaric chambers for fire fighting.

4.5.3.15* Total water demand shall be determined by multiplying the total chamber floor area by 202.9 $L/m^2/min$ (7.5 $gal/ft^2/min$).

4.5.3.15.1 The minimum operating water pressure at the nozzle shall be 206.8 kPa (30 psi).

4.5.3.15.2 The water supply shall be constantly and fully charged.

4.5.3.15.3 The water supply shall not be delayed by the starting of fire pumps.

4.5.3.15.4 The water supply for fire protection of chambers shall furnish water for at least a 1-minute duration (three consecutive 20-second applications).

4.5.3.16 Spray nozzles shall be placed to produce overlapping cones of water spray covering all chamber areas.

4.5.3.17 Spray nozzles shall be equipped with remotely controlled internal valve mechanisms that accommodate fully priming all piping with operating standby water pressure.

4.5.3.18 Connecting piping systems shall be proven by calculation to hydraulically produce uniform distribution of water.

4.5.3.19 The system design shall automatically deactivate the interior chamber power prior to activation of the water deluge system, whether operated in the automatic or manual mode.

4.5.3.20 The system shall automatically activate the emergency lighting and communication system prior to activation of the water deluge system, whether operated in the automatic or manual mode.

4.6 Fire Extinguishment Requirements for Class D Chambers.

4.6.1 Fire extinguishing capability inside Class D chambers shall be one of the following types:

(1) Manual
(2) Portable
(3) Fixed

4.6.2 When installed, spray nozzles shall produce overlapping cones of water spray directed to all chamber areas.

4.6.3 Only water or water containing thickening or wetting agents shall be used in hypobaric chambers for fire fighting.

4.6.4 A control switch shall be located on the operator control console to manually disconnect all power to the chamber.

4.6.5 Manual fire alarm switches shall be located at the operator console or at other designated points in the facility to alert all concerned personnel of fire in or around the chamber.

4.7* Electrical Systems.

4.7.1 Source of Power to Hypobaric Chambers.

4.7.1.1 All hypobaric chamber service equipment, switchboards, and panelboards shall be installed outside of the chamber enclosure and be arranged to allow manual supervisory control by operators in visual contact with the chamber interior.

4.7.1.2 All critical electrical equipment and circuits associated with the hypobaric chamber, whether within or outside of the chamber, shall have a minimum of two independent sources of electric power.

4.7.1.3 All critical electrical circuits contained within the chamber, all emergency lighting, whether within or outside of the chamber, and all circuits used for communication and alarm systems shall be connected to the emergency system, according to Chapter 4, "Electrical Systems," of NFPA 99, *Standard for Health Care Facilities.*

4.7.1.4 For Class E chambers, the circuits and equipment listed in 4.5.2.3, 4.5.3.14.1, and 4.7.1.3 shall be so installed and connected to an alternate source of power that they will be automatically restored to operation within 10 seconds after interruption of the source.

4.7.2 Electrical Wiring and Equipment.

4.7.2.1* All electrical equipment installed or used in a Class E hypobaric chamber or lock shall be approved for use in Class I, Division 1, Group C locations at the highest oxygen partial pressure and lowest total pressure and oxygen concentration attainable in the chamber or lock.

4.7.2.2 All approved intrinsically safe electrical equipment installed or used in a Class E hypobaric chamber or lock shall be constructed with noncombustible insulation.

4.7.2.3 All electrical circuits serving equipment located adjacent to, or in the vicinity of, hypobaric chambers, the housing for which is sprinkler-protected as per 4.1.1.3, shall be installed to prevent water from interfering with the operation of the equipment or be equipped with a power drop capability if the sprinkler system is activated.

4.7.2.4* All power and lighting electrical circuits contained within a Class E chamber shall be supplied from an ungrounded electrical system, fed from isolating transformers located outside of the chamber, and equipped with a line isolation monitor with signal lamps as specified in Chapter 4, "Electrical Systems," of NFPA 99, *Standard for Health Care Facilities.*

4.7.2.5 All electrical wiring installed in a Class E hypobaric chamber shall comply with the requirements of NFPA 70, *National Electrical Code,* Articles 500 and 501, Class I, Division 1.

4.7.2.6 Wiring installed Class E hypobaric chambers shall be approved for use in Class I, Group C atmospheres at the maximum proposed vacuum and oxygen concentration.

4.7.2.7 The wiring method used in Class E hypobaric chambers shall be threaded metal conduit or Type MI cable with terminal fittings approved for the location.

4.7.2.8 All boxes, fittings, and joints used in Class E hypobaric chambers shall be explosionproof.

4.7.2.9 Fixed electrical equipment within a Class E hypobaric chamber enclosure shall comply with the requirements of NFPA 70, *National Electrical Code,* Articles 500 and 501, Class I, Division 1.

4.7.2.10 Equipment installed within a Class E hypobaric chamber shall be approved for use in Class I, Group C atmospheres at the maximum vacuum and oxygen concentration attainable.

4.7.2.11 For Class E hypobaric chambers, overcurrent protective devices shall comply with the requirements in Article 240 of NFPA 70, *National Electrical Code.*

4.7.2.11.1 Overcurrent protective devices shall be installed outside of, and adjacent to, Class E hypobaric chambers.

4.7.2.11.2 Equipment used inside Class E hypobaric chambers is permitted to have its own individual overcurrent devices incorporated within the equipment, provided this device is approved for Class I, Division 1, Group C atmospheres at the maximum vacuum and oxygen concentration attainable.

4.7.2.11.3 For equipment used inside Class E hypobaric chambers, each circuit shall have its own individual overcurrent protection in accordance with Section 240-11 of NFPA 70, *National Electrical Code*.

4.7.2.12 Each ungrounded circuit within or partially within a Class E hypobaric chamber or lock shall be controlled by a switch outside the enclosure having a disconnecting pole, each of which is ganged, for each conductor.

4.7.2.13* Switches, receptacles, and attachment plugs designed for electrical systems used in ordinary locations shall be prohibited from use in Class E hypobaric chambers or locks because of the frequent sparks or arcs that result from their normal use.

4.7.2.14 All receptacles and attachment plugs used inside Class E hypobaric chambers shall conform to E.2.4 in Annex E of NFPA 99, *Standard for Health Care Facilities*.

4.8 Intercommunications and Monitoring Equipment.

4.8.1 Intercommunications equipment shall be used in the operation of hypobaric chambers, regardless of its classification.

4.8.1.1 All intercommunications equipment shall be approved as intrinsically safe.

4.8.1.2 Except as permitted in 4.8.1.4 and 4.8.1.5, microphones, loudspeakers, and handheld phones located in the chamber and personnel locks shall be intrinsically safe at the maximum proposed vacuum and oxygen concentration.

4.8.1.3 All other components of the intercommunications equipment, including audio output transformers, shall be located outside of the hypobaric chamber.

4.8.1.4 Oxygen mask microphones with external relays designed to operate on 28 V or less and not exceed a current of 0.25 A, shall be permitted provided they qualify as intrinsically safe for the condition of use.

4.8.1.5 If push-to-talk or toggle switches are used in Class E hypobaric chambers, they shall be of the hermetically sealed, pressure-tested type, with arc-suppressed circuits incorporated in the switch.

4.8.1.6 Voice sensors, where part of an oxygen mask, shall be approved as intrinsically safe for 95 ± 5 percent oxygen at atmospheric pressure.

4.8.1.7 Except as permitted in 4.8.1.8, all electrical conductors inside Class E chambers, or personnel locks adjacent thereto, shall be insulated with insulation that is flame resistant.

4.8.1.8 Grounds through the piping system of Class E hypobaric chambers shall not be required to be insulated.

4.8.1.9 The intercommunications system shall connect all chamber personnel areas and the chamber operator's control panel.

4.8.1.10 All hypobaric chambers shall be equipped with a communications system that has redundant capabilities.

4.8.2 Except as permitted in 4.8.2.1, all personnel monitoring equipment shall be located on the outside of the chamber and the monitoring leads conveyed through pass-throughs.

4.8.2.1 Monitors continuously purged with inert gas and designed so as not to exceed maximum operating temperatures and pressure changes shall be permitted inside the chamber.

4.8.2.2 The conductors or patient leads extending into the chamber shall be intrinsically safe at the maximum vacuum and oxygen concentration that will be encountered in the chamber or system.

4.8.3* Any other electrically operated equipment brought into a Class E hypobaric chamber, or installed in the chamber, including monitoring and intercommunications equipment, shall be approved for use in Class I, Division 1, Group C hazardous locations at the maximum altitude and oxygen concentration that will be encountered in the chamber or system.

4.8.4 Sensors shall be installed to detect levels of carbon dioxide above 0.2 percent and carbon monoxide above 15 ppm in Class E chambers.

Chapter 5 Administration and Maintenance

5.1 General.

5.1.1 Purpose. This chapter contains requirements for administration and maintenance that shall be followed as an adjunct to the physical precautions specified in Chapter 4.

5.1.2 Recognition of Hazards. The safety director shall review the potential hazards outlined in Annex B.

5.1.3* Responsibility.

5.1.3.1 A safety director shall be appointed who is responsible for the safety of the operations of the hypobaric facility.

5.1.3.2 Because the operation of hypobaric chambers is complex, a chamber flight supervisor shall be designated as the position of responsible authority.

5.1.3.2.1 The chamber flight supervisor shall ensure that a chamber preflight checklist has been completed before the chamber is operated.

5.1.3.2.2 The chamber flight supervisor shall ensure that the chamber is manned for the type of hypobaric chamber profile to be conducted.

5.1.3.3 The administration of the facility shall adopt and correlate regulations and standard operating procedures to ensure that the physical qualities and the operating methods pertaining to hypobaric facilities meet the requirements of this standard.

5.1.4 Rules and Regulations.

5.1.4.1 Administrative, technical, and professional staffs shall jointly establish rules and regulations for the use of hypobaric facilities.

5.1.4.2 Copies of the rules and regulations shall be prominently displayed in and around the hypobaric chamber.

5.1.4.3 All personnel who are to be exposed to hypobaric atmospheres shall be given physical examinations to ensure that they have no physical condition that would increase their physical risks from exposure to the hypobaric environment.

5.1.4.4* All chamber operating personnel shall be trained in the purpose, application, operation, and limitations of emergency equipment.

5.1.4.5* Emergency procedures tailored to the individual facility shall be established.

5.1.4.5.1 All hypobaric facility personnel shall know the emergency procedures and how to implement them.

5.1.4.5.2* Fire training drills shall be conducted at least annually.

5.1.5 General Requirements.

5.1.5.1 Smoking, open flames, hot objects, and ultraviolet sources that would cause premature operation of flame detectors shall be prohibited inside hypobaric chambers and from the vicinity of the chamber.

5.1.5.2 The use of flammable agents, such as burners employing natural or LP-Gas for laboratory purposes, cigarette lighters, and flammable anesthetic gases shall be prohibited inside a hypobaric chamber.

5.1.5.3 The use of flammable personal care items such as hair sprays, hair oils, and facial makeup by chamber occupants shall be prohibited in Class E chambers.

5.1.5.4 The use of potentially flammable agents, such as alcohol swabs, parenteral alcohol based pharmaceuticals, and topical creams shall be approved by the safety director.

5.1.6 Personnel.

5.1.6.1 All personnel entering Class E hypobaric chambers in which use of flammable gases is planned shall be in electrical contact with the conductive floor through the wearing of conductive footwear or an alternative method of providing a path of conductivity.

5.1.6.2 Except as permitted in 5.1.6.3, if a patient is brought into a chamber, electrical connection to the conductive floor shall be ensured by the provision of a conductive strap in contact with the patient's skin, with one end of the strap fastened to the metal frame of the table (or other equipment) in accordance with E.6.6 in Annex E of NFPA 99, *Standard for Health Care Facilities.*

5.1.6.3 A conductive strap shall not be required when a patient is in direct contact with a conductive mattress that is grounded.

5.1.6.4 Because of the possibility of percussion sparks, shoes having ferrous nails that make contact with the floor shall not be permitted to be worn in Class E chambers.

5.1.6.5 Equipment manufactured from the following metals shall not be used inside hypobaric chambers:

(1) Cerium
(2) Magnesium
(3) Magnesium alloys

5.1.6.6 The number of occupants of the chamber shall be kept to the minimum number necessary to carry out the procedure.

5.1.7 Textiles.

5.1.7.1 Cotton, silk, wool, or synthetic textile materials shall not be permitted in Class E chambers, unless the fabric meets the requirements of 5.1.7.4.

5.1.7.2 Any paper and plastic devices or otherwise restricted materials shall be permitted to be used in Class E chambers at the direction of the person in charge with the concurrence of the safety director.

5.1.7.3 Permission to use restricted materials in Class E chambers shall be by the written endorsement of the person in charge and the designated safety director.

5.1.7.4 Fabric used in Class E chambers shall meet the requirements set forth for the small-scale test in NFPA 701, *Standard Methods of Fire Tests for Flame Propagation of Textiles and Films*, except that the test atmosphere shall be 95 ± 5 percent oxygen at ambient pressure.

5.1.7.5 All chamber personnel shall wear tight-fitting garments with closures at the neck, wrists, and ankles when performing duties inside a Class E chamber.

5.1.7.6 All other fabrics used in Class E chambers such as sheets, drapes, and blankets shall be made of flame-resistant materials.

5.2 Equipment.

5.2.1 All equipment used in the hypobaric facility shall comply with Chapter 4 of this standard.

5.2.1.1* Permission to use equipment not covered in Chapter 4 of this standard in hypobaric chambers shall be by the written endorsement of the person in charge and the designated safety director.

5.2.1.2 Unmodified portable X-ray devices, electrocautery equipment, and other high-energy devices shall not be operated in the hypobaric chamber.

5.2.1.3 Photographic equipment employing photoflash, flood lamps, or light source equipment shall not remain in the hypobaric chamber when the chamber is depressurized.

5.2.1.4 Equipment known to be or suspected to be defective shall not be introduced into any hypobaric chamber or used in conjunction with the operation of a hypobaric chamber until repaired, tested, and accepted by qualified personnel and approved by the safety director *(see 5.1.3.1)*.

5.2.1.5* Combustible paper items such as cups, towels, or tissues shall not be brought into a Class E hypobaric chamber.

5.2.2 Oxygen piping systems, containers, valves, fittings, and interconnecting equipment shall be all metal except as permitted in 5.2.3.

5.2.3 Valve seats, gaskets, hoses, and lubricants shall be selected for oxygen compatibility under service conditions.

5.2.4 Equipment in support of Class E chambers requiring lubrication shall be lubricated with oxygen-compatible, flame-resistant materials.

5.3 Handling of Gases.

5.3.1 Flammable gases shall not be piped into, used, or stored within or in the immediate vicinity of Class D or E hypobaric chambers.

5.3.2 Nonflammable medical gases and breathing air shall be permitted to be piped into the hypobaric chambers, provided the container and contents are approved.

5.3.3* The institution's administrative personnel shall establish rules and regulations for handling of gases in the hypobaric facility *(see 5.1.3.1)*.

5.3.4 Oxygen and other gases shall not be introduced into the chamber in the liquid state.

5.4 Maintenance.

5.4.1 The hypobaric safety director shall be responsible for ensuring that all equipment such as valves, regulators, and meters used in the hypobaric chamber are compensated for use under hypobaric conditions and tested at least annually.

5.4.1.1 Life support systems, valves, controls, gauges, and pressure relief valves shall be tested and calibrated at least annually.

5.4.1.2 Except as permitted in 5.4.1.3, the hypobaric safety director shall be responsible for ensuring that all gas outlets for piped systems in the chambers are labeled or stenciled in accordance with CGA Pamphlet C-4, *Standard Method of Marking Portable Compressed Gas Containers to Identify the Material Contained*; Chapter 5, "Gas and Vacuum Systems," of NFPA 99, *Standard for Health Care Facilities*; or a comparable U.S. Department of Defense (DOD) standard.

5.4.1.3 Class D chambers that are equipped with only oxygen gas sources shall not be required to comply with the requirement of 5.4.1.2.

5.4.1.4 Before piping systems are initially put into use, the gas delivered at the outlet shall be verified in accordance with Chapter 5 of NFPA 99, *Standard for Health Care Facilities*, or a comparable DOD standard.

5.4.1.5 Before piping systems are initially put into use, connecting fittings shall be verified against their labels in accordance with Chapter 5, "Gas and Vacuum Systems," of NFPA 99, *Standard for Health Care Facilities*, or a comparable DOD standard.

5.4.1.6 Piping system inlets and outlets shall be protected against animals, birds, insects, and other foreign matter.

5.4.1.7 Piping system inlets and outlets shall be located to protect them from damage.

5.4.1.8 The guidelines set forth in Chapter 5, "Gas and Vacuum Systems," in NFPA 99, *Standard for Health Care Facilities*, or a comparable DOD standard concerning the storage, location, and special precautions required for compressed gases shall be followed.

5.4.2 Roentgen radiation equipment shall not be employed inside hypobaric chambers.

5.4.3 Before placing the hypobaric chamber back into service, installations, repairs, and modifications of equipment related to the chamber shall meet the following criteria:

(1) Evaluated by engineering or maintenance personnel
(2) Tested under operating pressure
(3) Approved by the safety director

5.4.3.1 Equipment maintenance, evaluation, and testing records shall be maintained by maintenance personnel.

5.4.3.2 After maintenance has been performed on the hypobaric chamber, maintenance personnel shall certify in writing that a preflight checklist has been completed prior to chamber operation.

5.4.3.3 Cleaning routines shall be established.

5.4.3.4 Operating equipment logs shall not be taken inside the chamber.

5.5 Electrical Safeguards.

5.5.1 Electrical equipment shall be installed and operated in accordance with Section 4.7.

5.5.1.1 All electrical circuits shall be operationally tested before chamber depressurization. *(See 4.7.2.4.)*

5.5.1.2 In the event of fire, all nonessential electrical equipment within the chamber shall be deenergized before extinguishing the fire.

5.5.1.3 Smoldering, burning electrical equipment shall be deenergized before a localized fire involving only the equipment is extinguished.

5.6 Electrostatic Safeguards.

5.6.1* Precautions against the hazard of electrostatic discharge shall be taken.

5.6.2 Textiles used or worn in the hypobaric chamber shall conform to 5.1.7.

5.6.3* In Class E chambers equipped with conductive floors, leg tips, tires, casters, or other conductive devices on furniture and equipment shall be inspected quarterly to ensure that they are maintained free of wax, polish, lint, or other extraneous material that insulates them and defeats the purpose for which they are used.

5.6.4* Metals capable of impact sparking shall not be allowed for casters or furniture leg tips.

5.6.5 Casters shall be lubricated only with oxygen compatible and flame resistant lubricants.

5.6.6* Conductive testing, if required, shall be in accordance with the requirements of E.6.6 in Annex E of NFPA 99, *Standard for Health Care Facilities.*

5.7 Fire Protection Equipment.

5.7.1 Electrical switches, valves, and electrical monitoring equipment associated with fire detection and extinguishing shall be visually inspected before each chamber depressurization.

5.7.2 Fire detection equipment shall be tested each week or prior to use.

5.7.3 Testing of the fire detection and suppression system, including activation of trouble circuits, signals, and discharge of extinguishing media, shall be conducted at least annually.

5.7.4 Where portable pressurized water fire extinguishers are provided inside Class D chambers, they shall be inspected prior to each depressurization.

5.7.5* Testing of portable pressurized fire extinguishers when used inside Class D chambers shall be in accordance with NFPA 10, *Standard for Portable Fire Extinguishers.*

5.8 Housekeeping.

5.8.1* A regular housekeeping program shall be implemented regardless of whether the hypobaric facility is in regular use.

5.8.2* Persons responsible for the hypobaric facility housekeeping program shall be trained on the hazards to occupants of hypobaric chambers.

5.8.3 Intakes and exhausts of piping within the facility or passing through exterior walls of the facility shall be inspected quarterly to ensure that animal, bird, and insect guards are in place, cleaned, and protected.

Annex A Explanatory Material

Annex A is not a part of the requirements of this NFPA document but is included for informational purposes only. This annex contains explanatory material, numbered to correspond with the applicable text paragraphs.

A.1.1.1 There is currently a widespread interest in high-altitude flight and space exploration. For this purpose, high-altitude chambers and space simulators have been developed and put to use. Equipment, experimental animals, and humans have been exposed to various artificial atmospheres under varying pressures ranging from 760 mm Hg (101.3 kPa) atmospheric pressure to close to 0 mm Hg (0 kPa).

In some chambers, the atmosphere might be enriched with oxygen or contain 100 percent oxygen. The increased combustibility of materials in those oxygen-enriched atmospheres has resulted in several fires in such chambers, with loss of life. See NFPA 53, *Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres,* for descriptions of some of these accidents.

There is continual need for human diligence and expertise in the establishment, operation, and maintenance of hypobaric facilities.

The partial pressure of oxygen present in the atmosphere of a hypobaric facility is one of the determining factors of the amount of available oxygen. This pressure will rise if the percentage of oxygen increases proportionately more than the fall in total pressure. Even more important than partial pressure of oxygen from the standpoint of fire hazards compared with normal air, however, is the decrease in percentage of nitrogen available. The absence of the inerting effect of this nitrogen will generally lower the ignition energy and markedly elevate the burning rate of combustible and flammable substances. *(See B.1.2.2.1 and B.1.2.2.2.)*

It is the responsibility of the chief administrator or commanding officer of the facility possessing a hypobaric chamber to adopt and enforce appropriate regulations for hypobaric facilities. In formulating and administering the program, full use should be made of technical personnel highly qualified in hypobaric facility operations and safety.

It is essential that hypobaric chamber personnel having responsibility for the hypobaric facility establish and enforce appropriate programs to fulfill the provisions of this standard.

Potential hazards can be controlled only when continually recognized and understood by all pertinent personnel. The Technical Committee on Hyperbaric and Hypobaric Facilities realizes that such facilities are not normally used to treat patients. Nevertheless, human beings are being exposed; hence the need for preparation of this standard.

This standard was prepared with the intent of offering standards for the design, maintenance, and operation of such facilities.

This standard covers the recognition of, and protection against, hazards of an electrical, explosion, and implosion nature, as well as fire hazards.

Medical complications of hypobaric procedures are discussed primarily to acquaint rescue personnel with these problems.

A.1.2.4 Chapter 20, "Hyperbaric Facilities," in NFPA 99, *Standard for Health Care Facilities*, classifies hyperbaric chambers as A, B, or C. To avoid confusion, hypobaric facilities are classified as D and E.

Chambers designed for animal experimentation equipped for access of personnel to care for the animals are classified as Class D and E for the purpose of this chapter depending upon atmosphere. Animal chambers of a size that cannot be entered by humans are not included in this standard.

Chambers used for high-altitude training are classified as Class D for the purpose of this standard.

A.3.2.1 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluate testing laboratories. In determining the acceptability of installations, procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A.3.2.2 Authority Having Jurisdiction (AHJ). The phrase "authority having jurisdiction," or its acronym AHJ, is used in NFPA documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A.3.2.3 Code. The decision to designate a standard as a "code" is based on such factors as the size and scope of the document, its intended use and form of adoption, and whether it contains substantial enforcement and administrative provisions.

A.3.2.6 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A.3.3.3 Atmosphere. As employed in this standard, atmosphere can refer to the environment within or outside of the hypobaric facility. When used as a measure of pressure, atmosphere is expressed as a fraction of standard air pressure [101.4 kPa (14.7 psi)]. *(See Annex D, Pressure Table, Column 1.)* (HYP)

A.3.3.4 Atmosphere of Increased Burning Rate. The degree of fire hazard of an oxygen-enriched atmosphere varies with the concentration of oxygen and diluent gas and the total pressure. The definition contained in the current edition of NFPA 53, *Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres,* and in editions of NFPA 56D, *Standard for Hyperbaric Facilities*, prior to 1982, did not necessarily reflect the increased fire hazard of hyperbaric and hypobaric atmospheres. (NFPA 56D, which is no longer published, was incorporated as a chapter within the 1984 edition of NFPA 99, *Standard for Health Care Facilities*.)

The definition for atmosphere of increased burning rate in Chapter 19, "Hyperbaric Facilities," in NFPA 99, *Standard for Health Care Facilities*, and for this standard defines an oxygen-enriched atmosphere with an increased fire hazard, as it relates to the increased burning rate of material in the atmosphere. It is based upon a 1.2 cm/s burning rate (at 23.5 percent oxygen at 1 ATA) as shown in Figure A.3.3.4.

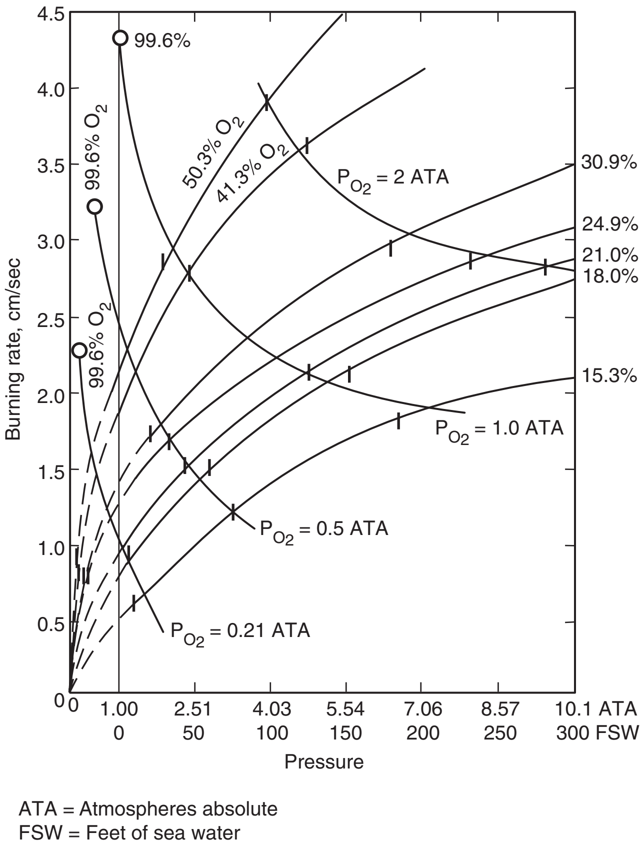

FIGURE A.3.3.4 Burning Rates of Filter Paper Strips at an Angle of 45 Degrees in N_2-O_2 Mixtures. (Adapted from Figure 4 of "Technical Memorandum UCRI-721, Chamber Fire Safety.")

A.3.3.8 Flame Resistant. A source of ignition alternate to the gas burner specified in NFPA 701, *Standard Methods of Fire Tests for Flame Propagation of Textiles and Films,* may be required for this test if it is to be performed in 100 percent oxygen at several atmospheres pressure.

A.3.3.21.4 Partial Pressure. An example follows: the fraction of oxygen in normal air is 0.209; thus the partial pressure of oxygen in air at a pressure of one atmosphere is 0.209 ATA (e.g., 0.209 × 1 ATA). At 3 ATA, the partial pressure of oxygen in air is 0.209 × 3 ATA = 0.62 ATA.

A.3.3.23 Psig. Under standard conditions, 0 psig is equivalent to 101.3 kPa (14.7 psia).

A.4.1.1 This standard does not restrict the number of chambers that can be placed in the same room or building.

A.4.1.1.1 Characteristics of building construction housing hypobaric chambers and ancillary facilities are no less important to safety from fire hazards than are the characteristics of the hypobaric chambers themselves. It is conceivable that a fire emergency occurring immediately outside a chamber, given sufficient fuel, could seriously endanger the life or lives of those inside the chamber. Service facilities will in all probability be within the same building. These will also need protection while in themselves supplying life-maintaining service to those inside.

A.4.2.2.2 Where feasible, it is recommended that hypobaric chambers be constructed without a bilge or other enclosures that will collect dirt, dust, or liquids. It might not be feasible or practical to construct certain chambers without a bilge.

A.4.2.4 A minimum of 150 percent excess pass-through capacity should be provided.

A.4.2.5 Repressurization schedules should be compatible with requirements for subject safety and with emergency rescue modes.

A.4.3.3 Gasket material should be of a type that allows for thermal expansion and rated for the temperature and vacuum involved.

A.4.3.4.2 Flexible cord can be hazardous in the limited confines of the chamber, and its use should be avoided.

A.4.5.3.15 The quantities and pressure of water for fire extinguishing indicated in 4.5.3.15 are based on limited testing and should be considered subject to change as additional data become available.

A.4.7 It is the intention of Chapter 4 that no electrical equipment be installed or used within the chamber that is not intrinsically safe or designed and tested for use under hypobaric conditions. Control devices, wherever possible, should be installed outside of the chamber.

A.4.7.2.1 See Article 500 of NFPA 70, *National Electrical Code*®. Electrical equipment that has been tested and found suitable for explosive atmospheres at ambient pressure and normal oxygen concentration might not be suitable when used in the presence of explosive atmospheres below ambient pressure and/or above normal oxygen concentrations.

A.4.7.2.4 Line isolation monitors for Class E chambers installed per 4.7.2.4 shall sense single or balanced capacitive resistive faults and leakage of current to ground.

A.4.7.2.13 Because of the corona problem, if switches are to be used, it is recommended that they be hermetically sealed.

A.4.8.3 Because of the corona problem, if switches are to be used, it is recommended that they be hermetically sealed.

A.5.1.3 Responsibility for the maintenance of safe conditions and practices both in and around hypobaric facilities falls mutually upon the governing body of the institution, all personnel using or operating the hypobaric facility, and the administration of the institution.

A.5.1.4.4 A suggested outline for emergency action in the case of fire is contained in Annex C.

A.5.1.4.5 A calm reaction to an emergency situation can be expected only if the said guidance is familiar to, and rehearsed by, all concerned.

A.5.1.4.5.2 A calm reaction to an emergency situation can be expected only if the said guidance is familiar to, and rehearsed by, all concerned.

A.5.2.1.1 Users should be aware that many items, if ignited in oxygen-enriched atmospheres, are not self-extinguishing. Iron alloys, aluminum, and stainless steel are, to various degrees, in that category, as well as human skin, muscle, and fat, and plastic tubing such as polyvinyl chloride. Testing for oxygen compatibility is very complicated. Very little data exist, and many standards still have to be determined. Suppliers do not normally have facilities for testing their products in controlled atmospheres. Both static conditions as well as impact conditions are applicable. Self-ignition temperatures normally are unknown in special atmospheres.

A.5.2.1.5 The use of paper inside hypobaric chambers should be kept to a minimum.

A.5.3.3 Quantities of oxygen stored in the chamber should be kept to a minimum.

A.5.6.1 Parts of this chapter deal with the elements required to be incorporated into the structure of the chamber to reduce the possibility of electrostatic spark discharges, which are a possible cause of ignition in hypobaric atmospheres. The elimination of static charges is dependent on the vigilance of administrative activities in materials purchase, maintenance supervision, cleaning procedures, and periodic inspection and testing. It cannot be emphasized too strongly that an incomplete chain of precautions generally will increase the electrostatic hazard. For example, in research chambers where use of flammable gases is planned, conductive flooring *(see 4.2.2)* might contribute to the hazard unless all personnel wear conductive shoes, unless all objects in the room are electrically continuous with the floor, and unless the room's humidity is maintained.

A.5.6.3 See E.6.6 in Annex E of NFPA 99, *Standard for Health Care Facilities.*

A.5.6.4 Ferrous metals can cause such sparking. Magnesium or magnesium alloys can also cause sparking if contact is made with rusted steel.

A.5.6.6 Material such as rubber that might deteriorate in oxygen-enriched atmospheres should be inspected regularly, especially at points of high stress.

A.5.7.5 Discharge of extinguishant can be limited to 10 percent of the system capacity provided simultaneous discharge of all systems is demonstrated.

A.5.8.1 All areas of, and components associated with, the hypobaric chamber should be kept meticulously free of grease, lint, dirt, and dust. The area around any hypobaric chamber should be kept clean and tidy.

Vacuum cleaning of walls, floors, underflooring, shelves, cabinets, and so forth, of the chamber and its contents is recommended.

Equipment to be used in the chamber should be cleaned, not only on the exterior, but on the interior of its cabinet where fine flammable dust can collect.

A.5.8.2 In Class E chambers, cleaning materials that leave a flammable film should not be used in the chamber or on any material entering the chamber. In Class E chambers, cloths and brushes that might leave flammable strands should be used with extreme caution.

Annex B Nature of Hazards

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

B.1 Nature of Hazards.

B.1.1 General.

B.1.1.1 There are several hazards involved in the design, construction, operation, and maintenance of hypobaric facilities. Some equipment could prove to be extremely hazardous in oxygen-enriched atmospheres compared with similar use in air. Under small-scale test conditions, some materials that are self-extinguishing in air, for example, have horizontal burning rates of more than 50 cm/s (20 in./s) in oxygen at atmospheric pressure.

B.1.1.2 All items brought into a hypobaric chamber should comply with acceptance criteria. Waivers should be granted in accordance with clearly defined criteria that include both ignitibility and propagation rates and, furthermore, are subject to periodic review. It should also be an accepted fact that, despite great care, some materials in a hypobaric chamber will be flammable, and a fire, once started, can quickly become catastrophic.

B.1.1.3 Ventilation in a hypobaric chamber is significantly different from that in normal atmospheres. For example, if a hypobaric chamber atmosphere is cycled through a purifier to remove only excess carbon dioxide or water vapor, flammable gas levels could build up to excessive levels as in any closed breathing circuit.

B.1.1.4 The quantity of oxygen in the atmosphere of a hypobaric chamber can be related to the number of pounds of fuel that would burn, the number of Btu's released in such a reaction, and the pressure rise. Typically, for 4 lb of oxygen, 1 lb of a hydrocarbon fuel is consumed, liberating approximately 20,000 Btu/lb.

B.1.2 Fire and Explosion.

B.1.2.1 The occurrence of a fire requires the presence of a combustible material, an oxidizer, and a source of energy to provide ignition.

B.1.2.2 Under hypobaric conditions, the oxygen content of the atmosphere can be increased from 21 percent to as much as 100 percent. Both the increased partial pressure of oxygen and the reduction in diluent inert or nonoxidizing gas contribute to an increased fire hazard. *(See Figure B.1.2.2.)*

B.1.2.2.1 Material self-extinguishing in air at atmospheric pressure can burn vigorously in an oxygen-enriched atmosphere. The specific rates, or ability to continue burning once an igniter is removed, depend on the composition of the material and the geometry of the system. Examples include wool, leather, polyvinyl chloride, silicone rubber, neoprene, epoxy adhesives, and many fire-retardant compounds. The resulting higher flame temperature from materials burning in oxygen also plays a significant role, as it enables materials that are harder to burn to enter into combustion, such as metals that have high heats of combustion. There is also a slight reduction in ignition energy. Thus, the following effects are produced in an oxygen-enriched hypobaric atmosphere:

(1) Reduced inert gas
(2) Increased partial pressure of oxygen giving increased available oxygen

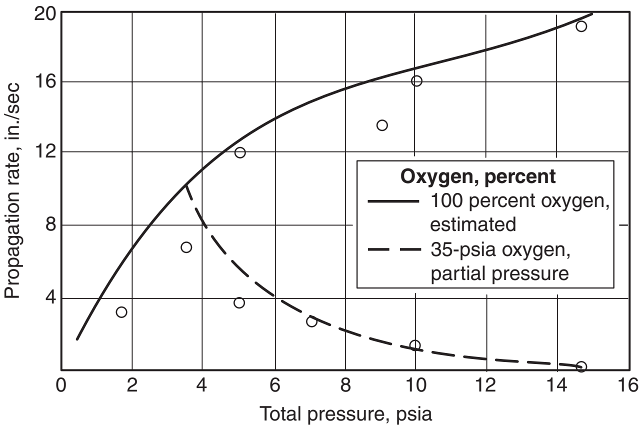

FIGURE B.1.2.2 Horizontal Flame Propagation Rate on Open Polyurethane Foam.

(3) Slightly reduced ignition energy
(4) Increased burning rates
(5) Higher flame temperature and lower flash point than at 14.7 psia; 101.3 kPa (1 ATA)

B.1.2.2.2 There is a change in "flash point" and "fire point" as pressure is reduced. Published data obtained in air at 14.7 psia; 101.3 kPa (1 ATA) are therefore not reliable for hypobaric atmospheres, nor is there a clear-cut way to estimate the change.

B.1.2.2.3 The flammability of petroleum products and other compounds containing carbon and hydrogen is well known. Hazards of liquids and gases that are flammable in air are apparent in hypobaric chambers. Some guidelines to their use in oxygen are documented in Chapter 5, "Gas and Vacuum Systems," and E.6.6 in Annex E of NFPA 99, *Standard for Health Care Facilities.* [See also NFPA 53*, Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres, and* NFPA 325*, Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids.* (Although NFPA 325 has been officially withdrawn from the *National Fire Codes*®, the information is still available in NFPA's *Fire Protection Guide to Hazardous Materials.*)] Lubricants, cleaning agents, and sterilization agents, such as ethylene oxide, are also in this category. They should be avoided unless data are available to verify their safety in the chamber.

B.1.2.3 Garments used by occupants of a hypobaric chamber produce a special hazard. All conventional fabrics used as clothing are highly combustible under oxygen-enriched conditions, except while saturated with water. Dependence should not be placed on fire-retardant treatments for service in oxygen-enriched atmospheres. Bedding, including mattresses, sheets, pillows, and blankets, is combustible. All conventional waterproof fabrics are combustible, including gloves. All bandages and dressings, including wooden splints, canvas, and most conventional medical equipment, are combustible. Other combustible products include name tags, checklists, notebooks, towels, sponges, and dry food products.

B.1.2.3.1 Choice of construction materials is based on many factors including availability, ease of cleaning, toxic properties, and cost, to name a few. Approved materials for use elsewhere in an institution normally are the basis for selection in hypobaric facilities. For Class D chambers, this is normally adequate. However, Class E chambers raise the difficult question of oxygen compatibility. As this document is a standard, not a handbook, complete guidelines or design tips are not appropriate. Flammable liquids and gases are covered in the preceding section. The criteria in selecting solids, both metals and nonmetals, are not so easily dealt with. *(See 4.1.1 and Sections 4.2 and 4.3.)*

B.1.2.3.2 Metal screens, woven wire shields on cables, and braided wire coverings on electrical or pneumatic tubing can present unusual fire hazards. Whether aluminum, stainless steel, or other alloys containing iron, titanium, nickel, chromium, or silver, and so forth, are involved, a fire started by an electric arc can produce considerable heat and is difficult to extinguish.

B.1.2.4 Sources of Ignition.

B.1.2.4.1 Sources of ignition that can be encountered in a hypobaric chamber include, but are not necessarily limited to, the following: defective electrical equipment (including failure of high-voltage equipment), heated surfaces in broken vacuum tubes or broken lamps used for general illumination, open or arcing switches (including motor switches), overheated motors, electrical thermostats, and communications equipment.

B.1.2.4.2 Sources of ignition that should not be encountered in a hypobaric facility, but that might be introduced by inept practice, include the following:

(1) Lighted matches or tobacco
(2) Static sparks from improper use of personal attire
(3) Electrical wiring not complying with Section 4.7 including convenience outlets and brushes on motor rotors
(4) Photographic equipment
(5) Cigarette lighters
(6) Animal or vegetable oil contaminated materials

B.1.2.4.3 In oxygen-enriched atmospheres as defined in Section 3.3, the minimum energy necessary to ignite flammable or combustible materials is generally reduced below the energy required in atmospheres of ambient air in most instances.

Note that items previously sterilized and packaged within biological barriers can be charged with significant levels of static energy. Upon opening such packages, the neutralization of the static charge can release sufficient energy to cause ignition. The situation is worse if the inside atmosphere is dried by the use of a package of desiccant, and, if packaged in a sterilized atmosphere containing ethylene oxide, an explosion could result as the static electricity is released as a spark. The force of the explosion will probably be at a low level, but the resulting flame could ignite adjacent material including the arm of the person opening the package.

B.1.3 Mechanical Hazards.

B.1.3.1 A vacuum vessel is subject to implosion and/or sudden inlet of surrounding atmosphere. As a result, inlets into the chamber must be protected from harming exterior personnel and chamber occupants by the vacuum action, and structures surrounding the chamber must be vented to allow pressure equalization. Inlet valves should be protected.

B.1.3.2 A particular hazard can be created if individuals attempt to drill, cut, or weld the vessel in a manner contrary to ASME PVHO-1, *Safety Standard for Pressure Vessels for Human Occupancy*.

B.1.3.3 The restriction on escape and the impedance to rescue and fire-fighting efforts posed by the chamber create a significant hazard to life in the case of a fire or other emergency.

B.1.3.3.1 A particular hazard to chamber personnel exists in the event of a fire within the structure housing the chamber. Inability to escape from the chamber and loss of services of the chamber operator would pose serious threats to life of all occupants of the chamber.

B.1.3.3.2 All occupants of hypobaric chambers should be aware that accidental fires are extremely dangerous but can be avoided by exercising due care in restricting burnables, reducing oxygen concentration, and eliminating ignition sources.

B.1.3.4 Viewing ports, if of small size, limit the vision of chamber operators and other observers, reducing their effectiveness as safety monitors.

B.1.3.5 Containers, including aerosol cans, and enclosures are subjected to rupture or collapse in consequence of the changing pressures in the hypobaric chamber. Items containing entrained gas include, but are not necessarily limited to, the following:

(1) Ampuls
(2) Partially filled syringes
(3) Stopped or capped bottles
(4) Cuffed endotracheal catheters
(5) Pneumatic cushions employed for breathing masks or as aids in positioning patients

The rupture of such containers having combustible or flammable liquids would also constitute a severe fire or explosion hazard, and they should be excluded from the chamber.

B.1.3.5.1 Containers sealed in a hypobaric environment can implode and containers sealed at atmospheric pressure can explode when pressure is elevated or reduced, respectively. The fracture of a container of flammable liquid would constitute a severe fire or explosion hazard from the spill and vaporization of the liquid. *(See 5.1.5.2, 5.1.5.4, 5.1.7.2, and B.1.2.2.3.)*

B.1.3.5.2 The pressure rise due to fire can cause the chamber interior to reach high pressures.

B.1.3.5.3 The hot gases vented in an emergency should be ducted to atmosphere. Care must be exercised in the location of such a vent, in that flame propagation will be enhanced by the flow of gases.

B.1.3.6 Other mechanical hazards relate to the malfunction, disruption, or inoperativity of many standard items when placed in service under evacuated atmospheres. Hazards that could be encountered in this regard include the following:

(1) Explosion of containers that are normally hermetically sealed at atmospheric pressure, such as condensers, batteries, tin cans and the like
(2) Overheating of devices that require convection to remove heat, such as motors, lamps, transistors, and the like

Corona effects (ionization flashover) are more likely to occur in vacuum than at pressure, resulting in arcs, destruction of electrical apparatus, and possible fire in an oxygen-enriched atmosphere.

B.1.3.6.1 Sealed electrical equipment or convectively cooled apparatus can be a source of ignition.

B.1.4 Physiological and Medical Hazards.

B.1.4.1 Medical hazards that can be encountered routinely include compression problems and the direct effects of sudden pressure changes, such as dysbarism, anoxia, hypoxia, and so forth.

B.1.4.1.1 Inability to equalize pressure differentials between nasopharynx (nose) and nasal sinuses or middle ear can result in excruciating pain and can cause rupture of the ear drum or hemorrhage into the ear cavity or nasal sinus.

B.1.4.1.2 Direct effects of reduction in pressure include inability to equalize pressures between the nose and sinuses or middle ear, expansion of gas pockets in the gastrointestinal tract, and expansion of trapped gas in the lungs.

B.1.4.1.3 The presence of personnel within the cramped confines of the hypobaric chamber in close proximity to grounded metallic structures on all sides creates a definite shock hazard if contact is made with a live electrical conductor or a defective piece of electrical equipment. Such contact also could be a source of ignition of flammable or combustible materials. *(See B.1.2.4.)*

B.1.4.2 Medical hazards that are not ordinarily encountered during use of hypobaric facilities but that could arise during malfunction, fire, or other emergency conditions include electric shock and fouling of the atmosphere of the chamber with carbon dioxide, carbon monoxide pyrolysis products from overheated materials, or the toxic products of combustion from any fire.

B.1.4.2.1 Increased concentrations of carbon dioxide within the chamber, as might result from malfunction of the systems responsible for monitoring or removal thereof, can be toxic under decreased pressures.

B.1.4.2.2 The development of combustion products or gases evolved from heated substances, particularly organic materials, within the closed space of the hypobaric chamber can be extremely toxic because of the confining nature of the chamber and the increased hazards of breathing such products under reduced pressure.

Note that extreme pressure rises have accompanied catastrophic fires in confined atmospheres. These pressures have driven hot, toxic gases into the lungs of victims as well as exceeded the structural limits of the vessel.

B.1.4.3 Physiological hazards include exposure to high noise levels and decompression sickness. Rapid release of pressurized gases can produce shock waves and loss of visibility.

B.1.4.3.1 During rapid changes in pressure, the noise level within the chamber becomes quite high. Such a level can be hazardous because it is distracting, interferes with communication, and, if prolonged, can be injurious, produce headaches, or cause other problems to susceptible individuals.

B.1.4.3.2 Decompression sickness or bends results from the formation of bubbles in the blood stream or extravascular tissues from the dissolved inert gas, mainly nitrogen. The bubbles can form when the chamber pressure is reduced below atmospheric.

B.1.4.3.3 Decompression sickness can result if any personnel are exposed to a hypobaric atmosphere without prior denitrogenation. *(See 5.1.2.)*

Note that there is a potential for nitrogen in leakage in any closed oxygen system.

B.1.4.3.4 The sudden release of gas, whether by rupture of a container, a medical gas or breathing air piping system, or operation of a device such as used in fire fighting, will produce noise, possibly shock waves, reduced or obscured visibility, and temperature changes.