

# NFPA® 55

## Compressed Gases and Cryogenic Fluids Code

### 2010 Edition



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## NFPA® 55

# Compressed Gases and Cryogenic Fluids Code

## 2010 Edition

This edition of NFPA 55, *Compressed Gases and Cryogenic Fluids Code*, was prepared by the Technical Committee on Industrial and Medical Gases. It was issued by the Standards Council on May 26, 2009, with an effective date of June 15, 2009, and supersedes all previous editions.

This edition of NFPA 55 was approved as an American National Standard on June 15, 2009.

### Origin and Development of NFPA 55

NFPA 55 was developed by the Industrial and Medical Gases Committee in recognition of the need to provide information on the use of cylinder gases in one standard. The Compressed Gas Association assisted the project by submitting a draft that was used as the framework for the standard.

NFPA 55 supersedes NFPA 43C, *Code for the Storage of Gaseous Oxidizing Materials*, which was developed by the Committee on Hazardous Chemicals and transferred to the Industrial and Medical Gases Committee. The committee believed that one standard covering storage of all gas cylinders was needed and, with the new NFPA 55, the need for NFPA 43C no longer existed.

Since this standard was introduced in 1993, it has been widely used and accepted by users of different types of gases as a single source covering requirements for installation and usage of gases in portable cylinders. The 1998 edition clarified many requirements and provided additional advisory information to assist the users of the standard. Editorial changes were also incorporated for clarity.

The 2003 edition of NFPA 55 was a complete revision of the document that significantly expanded the document scope and introduced requirements for areas not addressed in previous editions. For example, the 1998 edition covered only compressed and liquefied gases in portable cylinders and only at consumer (user) locations; the 2003 edition covered the use of compressed and liquefied gases in portable and stationary containers and at manufacturer sites and consumer sites. This expansion to manufacturer sites took a large portion of gas usage that was outside the scope of NFPA 55 and placed it under NFPA 55.

There were many new subjects and requirements in the 2003 edition, including the following:

- (1) Requirements for cryogenic fluids
- (2) Use of the concept of control areas for defining storage amounts and requirements
- (3) An expanded classification scheme to cover a greater range of gaseous materials
- (4) Specifications for a Hazardous Materials Management Plan
- (5) Requirements for treating waste gases
- (6) More detailed requirements in many of the areas than the 1998 edition of NFPA 55 covered

The 2003 edition was also restructured to comply with the *Manual of Style for NFPA Technical Committee Documents*.

The 2005 edition of NFPA 55 was a complete revision of the document. The following were some of the significant changes to the document:

- (1) Incorporation of the requirements of NFPA 50, *Standard for Bulk Oxygen Systems at Consumer Sites*, into Chapter 9
- (2) Incorporation of the requirements of NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites*, into Chapter 10
- (3) Incorporation of NFPA 50B, *Standard for Liquefied Hydrogen Systems at Consumer Sites*, into Chapter 11
- (4) Clarification of threshold storage requirements in Chapters 6 and 7
- (5) Clarification of the separation distance tables formerly in NFPA 50, NFPA 50A, and NFPA 50B, and now in Chapters 9–11
- (6) Schematic drawings added to annex material to illustrate system siting requirements in Chapters 9 and 11

The 2010 edition of NFPA 55 includes a change in the document's title, from a standard to a code. The following are some of the significant changes to the document in this edition:

- (1) Incorporation of the requirements of NFPA 560, *Standard for the Storage, Handling, and Use of Ethylene Oxide for Sterilization and Fumigation*, into Chapter 14
- (2) Updated separation distances to exposure from gaseous hydrogen systems based upon new research
- (3) Incorporation of the requirements on medical bulk oxygen systems from NFPA 99, *Standard for Health Care Facilities*, based on joint task group recommendations
- (4) Addition of a new chapter, Chapter 12, on gas generation systems
- (5) Addition of a new chapter, Chapter 13, on insulated liquid carbon dioxide systems

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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.

**Committee Scope:** This Committee shall have primary responsibility for documents on the storage, transfer, and use of industrial gases. Included are the storage and handling of such gases in their gaseous or liquid phases; the installation of associated storage, piping, and distribution equipment; and operating practices. The Committee also has a technical responsibility for contributions in the same areas for medical gases and clean rooms.

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## NFPA 55

Compressed Gases and Cryogenic Fluids  
Code

## 2010 Edition

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A reference in brackets [ ] following a section or paragraph indicates material that has been extracted from another NFPA document. As an aid to the user, the complete title and edition of the source documents for extracts in mandatory sections of the document are given in Chapter 2 and those for extracts in informational sections are given in Annex H. Extracted text may be edited for consistency and style and may include the revision of internal paragraph references and other references as appropriate. Requests for interpretations or revisions of extracted text shall be sent to the technical committee responsible for the source document.

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

## Chapter 1 Administration

## 1.1 Scope.

**1.1.1 Applicability.** This code shall apply to the installation, storage, use, and handling of compressed gases and cryogenic fluids in portable and stationary containers, cylinders, equipment, and tanks in all occupancies.

**1.1.2 Specific Applications.** This code shall not apply to the following:

- (1)\*Off-site transportation of materials covered by this code.
- (2) Storage, use, and handling of radioactive gases in accordance with NFPA 801, *Standard for Fire Protection for Facilities Handling Radioactive Materials*.
- (3)\*Use and handling of medical compressed gases at health care facilities in accordance with NFPA 99, *Standard for Health Care Facilities*.
- (4) Systems consisting of cylinders of oxygen and cylinders of fuel gas used for welding and cutting in accordance with NFPA 51, *Standard for the Design and Installation of Oxygen-Fuel Gas Systems for Welding, Cutting, and Allied Processes*.
- (5) Acetylene cylinders in acetylene cylinder charging plants in accordance with NFPA 51A, *Standard for Acetylene Cylinder Charging Plants*.
- (6)\*Flammable gases used as a vehicle fuel when stored on a vehicle.
- (7)\*Storage, use, and handling of liquefied and nonliquefied compressed gases in laboratory work areas in accordance with NFPA 45, *Standard on Fire Protection for Laboratories Using Chemicals*.
- (8) Storage, use, and handling of liquefied petroleum gases in accordance with NFPA 58, *Liquefied Petroleum Gas Code*.

- (9) Storage, use, and handling of gases within closed-cycle refrigeration systems complying with the mechanical code.
- (10) Liquefied natural gas (LNG) storage at utility plants under NFPA 59A, *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)*.
- (11) Compressed natural gas (CNG), liquefied natural gas (LNG), compressed hydrogen gas (GH<sub>2</sub>), or liquefied hydrogen gas (LH<sub>2</sub>) handled as a vehicle fuel in accordance with NFPA 52, *Vehicular Gaseous Fuel Systems Code*. Where a bulk hydrogen system is intended for vehicular fueling applications, the applicable provisions of NFPA 52 required for fuel dispensing operations shall be required in addition to the requirements of this code.
- (12) Nonflammable mixtures of ethylene oxide with other chemicals.
- (13) Ethylene oxide in chambers 10 ft<sup>3</sup> (0.283 m<sup>3</sup>) or less in volume or for containers holding 7.05 oz (200 g) of ethylene oxide or less.

**1.2\* Purpose.** The purpose of this code shall be to provide fundamental safeguards for the installation, storage, use, and handling of compressed gases and cryogenic fluids in portable and stationary containers, cylinders, and tanks.

**1.3 Application.** The requirements in this code shall apply to users, producers, distributors, and others who are involved with the storage, use, or handling of compressed gases or cryogenic fluids.

**1.4 Retroactivity.** The provisions of this code reflect a consensus of what is necessary to provide an acceptable degree of protection from the hazards addressed in this code at the time the code was issued.

**1.4.1** Unless otherwise specified, the provisions of this code shall not apply to facilities, equipment, structures, or installations that existed or were approved for construction or installation prior to the effective date of the code. Where specified, the provisions of this code shall be retroactive.

**1.4.2** In those cases where the authority having jurisdiction determines that the existing situation presents an unacceptable degree of risk, the authority having jurisdiction shall be permitted to apply retroactively any portions of this code deemed appropriate.

**1.4.3** The retroactive requirements of this code shall be permitted to be modified if their application clearly would be impractical in the judgment of the authority having jurisdiction and only where it is clearly evident that a reasonable degree of safety is provided.

**1.5 Equivalency.** Nothing in this standard is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this code.

**1.5.1** Technical documentation shall be submitted to the authority having jurisdiction to demonstrate equivalency.

**1.5.2** The system, method, or device shall be approved for the intended purpose by the authority having jurisdiction.

**1.6 Units and Formulas.**

**1.6.1** The units of measure in the code are presented first in U.S. customary units (inch-pound units), followed by International System (SI) units in parentheses.

**1.6.2** Either system of units shall be acceptable for satisfying the requirements in this code.



**1.6.3** Users of this code shall apply one system of units consistently and shall not alternate between units.

**1.6.4** The values presented for measurements in this code are expressed with a degree of precision appropriate for practical application and enforcement. It is not intended that the application or enforcement of these values be more precise than the precision expressed.

**1.6.5** Where extracted text contains values expressed in only one system of units, the values in the extracted text have been retained without conversion to preserve the values established by the responsible technical committee in the source document.

**1.7 Enforcement.** This code shall be administered and enforced by the authority having jurisdiction designated by the governing authority. (See Annex F for sample wording for enabling legislation.)

## Chapter 2 Referenced Publications

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

**2.2 NFPA Publications.** National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA 1, *Fire Code*, 2009 edition.

NFPA 13, *Standard for the Installation of Sprinkler Systems*, 2010 edition.

NFPA 16, *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems*, 2007 edition.

NFPA 30, *Flammable and Combustible Liquids Code*, 2008 edition.

NFPA 31, *Standard for the Installation of Oil-Burning Equipment*, 2006 edition.

NFPA 45, *Standard on Fire Protection for Laboratories Using Chemicals*, 2004 edition.

NFPA 51, *Standard for the Design and Installation of Oxygen-Fuel Gas Systems for Welding, Cutting, and Allied Processes*, 2007 edition.

NFPA 51A, *Standard for Acetylene Cylinder Charging Plants*, 2006 edition.

NFPA 52, *Vehicular Gaseous Fuel Systems Code*, 2010 edition.

NFPA 54, *National Fuel Gas Code*, 2009 edition.

NFPA 58, *Liquefied Petroleum Gas Code*, 2008 edition.

NFPA 59A, *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)*, 2009 edition.

NFPA 69, *Standard on Explosion Prevention Systems*, 2008 edition.

NFPA 70®, *National Electrical Code*®, 2008 edition.

NFPA 72®, *National Fire Alarm and Signaling Code*, 2010 edition.

NFPA 79, *Electrical Standard for Industrial Machinery*, 2007 edition.

NFPA 80, *Standard for Fire Doors and Other Opening Protectives*, 2010 edition.

NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*, 2009 edition.

NFPA 99, *Standard for Health Care Facilities*, 2005 edition.

NFPA 101®, *Life Safety Code*®, 2009 edition.

NFPA 110, *Standard for Emergency and Standby Power Systems*, 2010 edition.

NFPA 251, *Standard Methods of Tests of Fire Resistance of Building Construction and Materials*, 2006 edition.

NFPA 259, *Standard Test Method for Potential Heat of Building Materials*, 2008 edition.

NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*, 2008 edition.

NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*, 2008 edition.

NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*, 2007 edition.

NFPA 801, *Standard for Fire Protection for Facilities Handling Radioactive Materials*, 2008 edition.

NFPA 853, *Standard for the Installation of Stationary Fuel Cell Power Systems*, 2007 edition.

### 2.3 Other Publications.

**2.3.1 ASCE Publications.** American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA 20191-4400.

ASCE/SEI 7, *Minimum Design Loads for Buildings and Other Structures*, 2005.

**2.3.2 ASME Publications.** American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990.

ASME A13.1, *Scheme for the Identification of Piping Systems*, 1996.

ANSI/ASME B31.3, *Process Piping*, 2008 edition.

*Boiler and Pressure Vessel Code*, "Rules for the Construction of Unfired Pressure Vessels," Section VIII, 2007.

**2.3.3 ASTM Publications.** ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM E 136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750 degree C*, 2009.

ASTM E 681, *Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapors and Gases)*, 2004.

ASTM E 1529, *Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies*, 2006.

**2.3.4 CGA Publications.** Compressed Gas Association, 4221 Walney Road, 5th floor, Chantilly, VA 20151-2923.

CGA C-7, *Guide to Preparation of Precautionary Labeling and Marking of Compressed Gas Containers*, 2004.

CGA G-4.1, *Cleaning Equipment for Oxygen Service*, 2004.

CGA G-5.5, *Hydrogen Vent Systems*, 2004.

ANSI/CGA G-13, *Storage and Handling of Silane and Silane Mixtures*, 2006.

CGA M-1, *Guide for Medical Gas Installations at Consumer Sites*, 2007.

CGA P-1, *Safe Handling of Compressed Gases in Containers*, 2006.

ANSI/CGA P-18, *Standard for Bulk Inert Gas Systems at Consumer Sites*, 2006.

CGA P-20, *Standard for the Classification of Toxic Gas Mixtures*, 2003.

CGA P-23, *Standard for Categorizing Gas Mixtures Containing Flammable and Nonflammable Components*, 2003.

CGA S-1.1, *Pressure Relief Device Standards – Part 1 – Cylinders for Compressed Gases*, 2005.

CGA S-1.2, *Pressure Relief Device Standards – Part 2 – Cargo and Portable Tanks for Compressed Gases*, 2005.

CGA S-1.3, *Pressure Relief Device Standards – Part 3 – Stationary Storage Containers for Compressed Gases*, 2005.

CGA V-6, *Standard Cryogenic Liquid Transfer Connections*, 2008.

**2.3.5\* CTA Publications.** Canadian Transportation Agency, Queen's Printer, Ottawa, Ontario, Canada. (Available from the Canadian Communications Group Publication Centre, Ordering Department, Ottawa, Canada K1A 0S9.)

*Transportation of Dangerous Goods Regulations.*

**2.3.6 IAPMO Publications.** International Association of Plumbing and Mechanical Officials, 5001 E. Philadelphia Street, Ontario, CA 91761.

*Uniform Mechanical Code*, 2003 edition.

**2.3.7 ICC Publications.** International Code Council, 5203 Leesburg Pike, Suite 600, Falls Church, VA 22041.

*International Fuel Gas Code (IFGC)*, 2009.

**2.3.8 ISO Publications.** International Organization for Standardization Publications, 1 rue de Varembe, Case Postale 56, CH-1211 Geneve 20, Switzerland.

ISO 10156, *Gases and gas mixtures — Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets*, 1996.

ISO 10298, *Determination of toxicity of a gas or gas mixture*, 1995.

ISO/DIS 22734, *Hydrogen generators using water electrolysis process*, under development (Draft International Standard).

**2.3.9 U.S. Government Publications.** U.S. Government Printing Office, Washington, DC 20402.

Title 16, Code of Federal Regulations, Part 1500, "Hazardous Substances and Articles": 1500.41, Method of testing primary irritant substances, and 1500.42, Test for eye irritants.

Title 29, Code of Federal Regulations, Part 1910.1000, "Air Contaminants."

Title 29, Code of Federal Regulations, 1910.1200, "Hazard Communication."

Title 49, Code of Federal Regulations, Part 173, "Shippers — General Requirements for Shipments and Packages."

### 2.3.10 Other Publications.

*Merriam-Webster's Collegiate Dictionary*, 11th edition, Merriam-Webster Inc., Springfield, MA, 2003.

## 2.4 References for Extracts in Mandatory Sections.

NFPA 1, *Fire Code*, 2009 edition.

NFPA 30, *Flammable and Combustible Liquids Code*, 2008 edition.

NFPA 52, *Vehicular Gaseous Fuel Systems Code*, 2010 edition.

NFPA 58, *Liquefied Petroleum Gas Code*, 2008 edition.

NFPA 99, *Standard for Health Care Facilities*, 2005 edition.

NFPA 101®, *Life Safety Code*®, 2009 edition.

NFPA 318, *Standard for the Protection of Semiconductor Fabrication Facilities*, 2009 edition.

NFPA 5000®, *Building Construction and Safety Code*®, 2009 edition.

*Dictionary*, 11th edition, shall be the source for the ordinarily accepted meaning.

## 3.2 NFPA Official Definitions.

**3.2.1\* Approved.** Acceptable to the authority having jurisdiction.

**3.2.2\* Authority Having Jurisdiction (AHJ).** An organization, office, or individual responsible for enforcing the requirements of a code or standard, or 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 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.

**3.2.5\* 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.

**3.2.6 Shall.** Indicates a mandatory requirement.

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

## 3.3 General Definitions.

**3.3.1\* Absolute Pressure.** Pressure based on a zero reference point, the perfect vacuum.

**3.3.2 Aeration Room.** A room or area with controlled temperature or airflow where ethylene oxide sterilized products are held initially for outgassing.

### 3.3.3 Area.

**3.3.3.1 Control Area.** A designated area, either indoors or outdoors, within which limited quantities of hazardous materials are allowed to be stored, used, handled, or dispensed.

**3.3.3.2 Indoor Area.** An area that is within a building or structure having overhead cover, other than a structure qualifying as "weather protection" in accordance with 6.5.2.

**3.3.3.3 Outdoor Area.** An area that is not an indoor area.

**3.3.4 ASME.** American Society of Mechanical Engineers. [58, 2008]

**3.3.5\* Assembly Occupancy.** An occupancy (1) used for a gathering of 50 or more persons for deliberation, worship, entertainment, eating, drinking, amusement, awaiting transportation, or similar uses; or (2) used as a special amusement building, regardless of occupant load. [101, 2009]

**3.3.6 ASTM.** American Society for Testing and Materials, now known as "ASTM International."

**3.3.7 Atmospheric Vents.** All points where pipes, stacks, or ducts are open to the atmosphere, including discharge points

## Chapter 3 Definitions

**3.1 General.** The definitions contained in this chapter shall apply to the terms used in this code. Where terms are not defined in this chapter or within another chapter, they shall be defined using their ordinarily accepted meanings within the context in which they are used. *Merriam-Webster's Collegiate*





from emissions control devices, vent pipes from safety valves, vent pipes from filters or pumps, and other vents.

**3.3.8 Back-Vent System.** An exhaust vent system designed to transport residual vapors from a sterilization chamber to a designated point of termination outside of the building.

**3.3.9 Building.** Any structure used or intended for supporting or sheltering any use or occupancy. [101, 2008]

**3.3.10 Building Code.** The building or construction code adopted by the jurisdiction.

**3.3.11 Bulk Gas System.** A system in which compressed gas is delivered, stored, and discharged in the gaseous form to a piping system. The threshold quantity used to define a bulk gas system is determined based on material-specific requirements. The compressed gas system terminates at the point where compressed gas at service pressure first enters the distribution piping system.

**3.3.12\* Bulk Hydrogen Compressed Gas System.** An assembly of equipment that consists of, but is not limited to, storage containers, pressure regulators, pressure relief devices, compressors, manifolds, and piping, with a storage capacity of more than 400 ft<sup>3</sup> (scf) (11 m<sup>3</sup>) of compressed hydrogen gas, including unconnected reserves on hand at the site, and that terminates at the source valve.

**3.3.13\* Bulk Inert Gas System.** An assembly of equipment that consists of, but is not limited to, storage containers, pressure regulators, pressure relief devices, vaporizers, manifolds, and piping, with a storage capacity of more than 20,000 ft<sup>3</sup> (scf) (566 m<sup>3</sup>) of inert gas, including unconnected reserves on hand at the site, and that terminates at the source valve.

**3.3.14\* Bulk Liquefied Hydrogen Gas System.** An assembly of equipment that consists of, but is not limited to, storage containers, pressure regulators, pressure relief devices, vaporizers, liquid pumps, compressors, manifolds, and piping, with a storage capacity of more than 39.7 gal (150 L) of liquefied hydrogen, including unconnected reserves on hand at the site, and that terminates at the source valve.

**3.3.15\* Bulk Oxygen System.** An assembly of equipment, such as oxygen storage containers, pressure regulators, pressure relief devices, vaporizers, manifolds, and interconnecting piping, that has a storage capacity of more than 20,000 ft<sup>3</sup> (scf) (566 m<sup>3</sup>) of oxygen, including unconnected reserves on hand at the site, and that terminates at the source valve.

**3.3.16\* Cathodic Protection.** A technique to resist the corrosion of a metal surface by making the surface the cathode of an electrochemical cell.

**3.3.17 Cathodic Protection Tester.** A person who demonstrates an understanding of the principles and measurements of all common types of cathodic protection systems applicable to metal piping and container systems and who has education and experience in soil resistivity, stray current, structure-to-soil potential, and component electrical isolation measurements of metal piping and container systems.

**3.3.18 CFR.** The Code of Federal Regulations of the United States Government. [1, 2009]

**3.3.19 CGA.** Compressed Gas Association. [1, 2009]

**3.3.20\* Chime Ring.** The two raised rings circling the outer shell of UN 1A1 ethylene oxide drums.

**3.3.21 Combustible Liquid.** A liquid having a closed-cup flash point at or above 100°F (37.8°C), subdivided as follows: (a) Class II liquids include those having a flash point at or above 100°F (37.8°C) and below 140°F (60°C); (b) Class IIIA liquids include those having a flash point at or above 140°F (60°C) and below 200°F (93.4°C); (c) Class IIIB liquids include those having a flash point at or above 200°F (93.4°C).

**3.3.22 Container.** A vessel, such as a cylinder, portable tank, or stationary tank, that varies in shape, size, and material of construction.

**3.3.22.1 Compressed Gas Container.** A pressure vessel designed to hold compressed gas at an absolute pressure greater than 1 atmosphere at 68°F (20°C) that includes cylinders, containers, and tanks.

**3.3.23 Corrosion Expert.** A person who, by reason of knowledge of the physical sciences and the principles of engineering acquired through professional education and related practical experience, is qualified to engage in the practice of corrosion control of container systems.

**3.3.24 Corrosion Protection.** Protecting a container, piping, or system to resist degradation of the metal through oxidation or reactivity with the environment in which it is installed.

**3.3.25 Court.** An open, uncovered, unoccupied space, unobstructed to the sky, bounded on three or more sides by exterior building walls. [101, 2009]

**3.3.25.1 Enclosed Court.** A court bounded on all sides by the exterior walls of a building or by the exterior walls and lot lines on which walls are permitted. [5000, 2009]

**3.3.26 Cryogenic Fluid.** A fluid with a boiling point lower than -130°F (-90°C) at an absolute pressure of 14.7 psi (101.3 kPa).

**3.3.27 Cryogenic Fluid System.** An assembly of equipment designed to contain, distribute, or transport cryogenic fluids.

**3.3.28 Cylinder.** A pressure vessel designed for absolute pressures higher than 40 psi (276 kPa) and having a circular cross-section. It does not include a portable tank, multiunit tank car tank, cargo tank, or tank car.

**3.3.29\* Cylinder Pack.** An arrangement of cylinders into a cluster where the cylinders are confined into a grouping or arrangement with a strapping or frame system and connections are made to a common manifold. The frame system is allowed to be on skids or wheels to permit movement.

**3.3.30 Cylinder Containment Vessel.** A gastight recovery vessel designed so that a leaking compressed gas container can be placed within its confines, thereby encapsulating the leaking container.

**3.3.31 Detached Building.** A separate building that is separated from other structures or uses as required by the building code for a freestanding structure.

**3.3.32 Distributor.** A business engaged in the sale or resale, or both, of compressed gases or cryogenic fluids, or both.

**3.3.33 Ethylene Oxide Drum.** For the purposes of this code, containers built to UN specification 1A1.

**3.3.34 Exit Access.** That portion of a means of egress that leads to an exit. [101, 2009]

**3.3.35 DOT.** U.S. Department of Transportation. [52, 2006]

**3.3.36 Emergency Shutoff Valve.** A designated valve designed to shut off the flow of gases or liquids.

**3.3.36.1 Automatic Emergency Shutoff Valve.** A designated fail-safe automatic closing valve designed to shut off the flow of gases or liquids that is initiated by a control system where the control system is activated by either manual or automatic means.

**3.3.36.2 Manual Emergency Shutoff Valve.** A designated valve designed to shut off the flow of gases or liquids that is manually operated.

**3.3.37 Excess Flow Control.** A fail-safe system or approved means designed to shut off flow due to a rupture in pressurized piping systems.

**3.3.38\* Exhausted Enclosure.** An appliance or piece of equipment that consists of a top, a back, and two sides that provides a means of local exhaust for capturing gases, fumes, vapors, and mists.

**3.3.39\* Explosion Control.** A means of preventing an explosion through the use of explosion suppression, fuel reduction, or oxidant reduction systems or a means to prevent the structural collapse of a building in the event of an explosion through the use of deflagration venting, barricades, or related construction methods.

**3.3.40\* Flammable Liquid (Class I).** Any liquid having a closed-cup flash point not exceeding 100°F (37.8°C).

**3.3.41 Full Trycock Valve.** A manual valve used to indicate when the container is filled to maximum design capacity.

**3.3.42 Gallon.** A standard U.S. gallon.

### 3.3.43 Gas.

**3.3.43.1\* Compressed Gas.** A material, or mixture of materials, that (1) is a gas at 68°F (20°C) or less at an absolute pressure of 14.7 psi (101.3 kPa) and (2) has a boiling point of 68°F (20°C) or less at an absolute pressure of 14.7 psi (101.3 kPa) and that is liquefied, nonliquefied, or in solution, except those gases that have no other health or physical hazard properties are not considered to be compressed gases until the pressure in the packaging exceeds an absolute pressure of 40.6 psi (280 kPa) at 68°F (20°C).

**3.3.43.2 Corrosive Gas.** A gas that causes visible destruction of or irreversible alterations in living tissue by chemical action at the site of contact.

**3.3.43.3 Flammable Gas.** A material that is a gas at 68°F (20°C) or less at an absolute pressure of 14.7 psi (101.3 kPa), that is ignitable at an absolute pressure of 14.7 psi (101.3 kPa) when in a mixture of 13 percent or less by volume with air, or that has a flammable range at an absolute pressure of 14.7 psi (101.3 kPa) with air of at least 12 percent, regardless of the lower limit.

**3.3.43.4 Flammable Liquefied Gas.** A liquefied compressed gas that, when under a charged pressure, is partially liquid at a temperature of 68°F (20°C) and is flammable.

**3.3.43.5 Highly Toxic Gas.** A chemical that has a median lethal concentration (LC<sub>50</sub>) in air of 200 ppm by volume or less of gas or vapor, or 2 mg/L or less of mist, fume, or dust, when administered by continuous inhalation for 1 hour (or less if death occurs within 1 hour) to albino rats weighing between 0.44 lb and 0.66 lb (200 g and 300 g) each.

**3.3.43.6\* Inert Gas.** A nonreactive, nonflammable, noncorrosive gas such as argon, helium, krypton, neon, nitrogen, and xenon.

**3.3.43.7 Irritant Gas.** A chemical that is not corrosive, but that causes a reversible inflammatory effect on living tissue by chemical action at the site of contact. A chemical is a skin irritant if, when tested on the intact skin of albino rabbits by the methods of 16 CFR 1500.41, for an exposure of 4 or more hours or by other appropriate techniques, it results in an empirical score of 5 or more. A chemical is classified as an eye irritant if so determined under the procedure listed in 16 CFR 1500.42, or other appropriate techniques.

**3.3.43.8 Nonflammable Gas.** A gas that does not meet the definition of a flammable gas.

**3.3.43.9\* Other Gas.** A gas that is not a corrosive gas, flammable gas, highly toxic gas, oxidizing gas, pyrophoric gas, toxic gas, or unstable reactive gas with a hazard rating of Class 2, Class 3, or Class 4 gas.

**3.3.43.10 Oxidizing Cryogenic Fluid.** An oxidizing gas in the cryogenic state.

**3.3.43.11 Oxidizing Gas.** A gas that can support and accelerate combustion of other materials more than air does.

**3.3.43.12 Pyrophoric Gas.** A gas with an autoignition temperature in air at or below 130°F (54.4°C).

**3.3.43.13 Toxic Gas.** A gas with a median lethal concentration (LC<sub>50</sub>) in air of more than 200 ppm but not more than 2000 ppm by volume of gas or vapor, or more than 2 mg/L but not more than 20 mg/L of mist, fume, or dust, when administered by continuous inhalation for 1 hour (or less if death occurs within 1 hour) to albino rats weighing between 0.44 lb and 0.66 lb (200 g and 300 g) each.

**3.3.43.14\* Unstable Reactive Gas.** A gas that, in the pure state or as commercially produced, will vigorously polymerize, decompose, or condense; become self-reactive; or otherwise undergo a violent chemical change under conditions of shock, pressure, or temperature.

**3.3.43.14.1 Class 2 Unstable Reactive Gas.** Materials that readily undergo violent chemical change at elevated temperatures and pressures.

**3.3.43.14.2 Class 3 Unstable Reactive Gas.** Materials that in themselves are capable of detonation or explosive decomposition or explosive reaction, but that require a strong initiating source or that must be heated under confinement before initiation.

**3.3.43.14.3 Class 4 Unstable Reactive Gas.** Materials that in themselves are readily capable of detonation or explosive decomposition or explosive reaction at normal temperatures and pressures.

**3.3.44\* Gas Cabinet.** A fully enclosed, noncombustible enclosure used to provide an isolated environment for compressed gas cylinders in storage or use. [5000, 2009]

**3.3.45 Gas Generator System.** An assembly of equipment that may consist of, but not be limited to, storage containers, pressure regulators, pressure relief devices, membranes, absorption material, and piping. The gas generating system terminates at the point where the gas supply, at service pressure, first enters the supply line.



**3.3.46 Gas Manufacturer/Producer.** A business that produces compressed gases or cryogenic fluids, or both, or fills portable or stationary gas containers, cylinders, or tanks.

**3.3.47\* Gas Room.** A separately ventilated, fully enclosed room in which only compressed gases, cryogenic fluids, associated equipment, and supplies are stored or used.

**3.3.48\* Gaseous Hydrogen System.** A system in which hydrogen is delivered, stored, and discharged in the gaseous form to a piping system. The gaseous hydrogen system terminates at the point where hydrogen at service pressure first enters the distribution piping.

**3.3.48.1 Hydrogen Generation System.** A packaged, factory matched, or site constructed hydrogen gas generation appliance or system such as (a) an electrolyzer that uses electrochemical reactions to electrolyze water to produce hydrogen and oxygen gas; (b) a reformer that converts hydrocarbon fuel to a hydrogen-rich stream of composition and conditions suitable for the type of device using the hydrogen; or (c) a gasifier that converts coal to a hydrogen-rich stream of composition and conditions suitable for a type of device using the hydrogen. It does not include hydrogen generated as a by-product of a waste treatment process.

**3.3.49 Gasifier.** An assembly of equipment that converts carbonaceous materials, such as coal or petroleum, into carbon monoxide and hydrogen by reacting the raw material at high temperatures with a controlled amount of oxygen.

**3.3.50 Handling.** The deliberate movement of material in containers by any means to a point of storage or use.

**3.3.51\* Hazard Rating.** The numerical rating of the health, flammability, self-reactivity, and other hazards of the material, including its reaction with water.

**3.3.52\* Health Care Facilities.** Buildings or portions of buildings in which medical, dental, psychiatric, nursing, obstetrical, or surgical care is provided. [99, 2005]

**3.3.53\* Immediately Dangerous to Life and Health (IDLH).** A concentration of airborne contaminants, normally expressed in parts per million (ppm) or milligrams per cubic meter, that represents the maximum level from which one could escape within 30 minutes without any escape-impairing symptoms or irreversible health effects.

**3.3.54\* ISO Module.** An assembly of tanks or tubular cylinders permanently mounted in a frame conforming to International Organization for Standardization (ISO) requirements.

### 3.3.55 Limit.

**3.3.55.1\* Ceiling Limit.** The maximum concentration of an airborne contaminant to which a person might be exposed. [5000, 2009]

**3.3.55.2\* Permissible Exposure Limit (PEL).** The maximum permitted 8-hour, time-weighted average concentration of an airborne contaminant.

**3.3.55.3\* Short-Term Exposure Limit (STEL).** The concentration to which it is believed that workers can be exposed continuously for a short period of time without suffering from irritation, chronic or irreversible tissue damage, or narcosis of a degree sufficient to increase the likelihood of accidental injury, impairment of self-rescue, or the material reduction of work efficiency, without exceeding the daily permissible exposure limit (PEL).

**3.3.56\* Limited Combustible.** A building construction material not complying with the definition of noncombustible material that, in the form in which it is used, has a potential heat value not exceeding 3500 Btu/lb (8141 kJ/kg), where tested in accordance with NFPA 259, *Standard Test Method for Potential Heat of Building Materials*, and complies with one of the following: (1) materials having a structural base of noncombustible material, with a surfacing not exceeding a thickness of 1/8 in. (3.2 mm) that has a flame spread index not greater than 50; and (2) materials, in the form and thickness used, other than as described in (1), having neither a flame spread index greater than 25 nor evidence of continued progressive combustion and of such composition that surfaces that would be exposed by cutting through the material on any plane would have neither a flame spread index greater than 25 nor evidence of continued progressive combustion. (Materials subject to increase in combustibility or flame spread index beyond the limits herein established through the effects of age, moisture, or other atmospheric condition shall be considered combustible.)

**3.3.57\* Liquefied Hydrogen System.** A system into which liquefied hydrogen is delivered and stored and from which it is discharged in the liquid or gaseous form to a piping system. The system originates at the storage container fill connection and terminates at the point where hydrogen at service pressure first enters the supply line.

**3.3.58 Material Safety Data Sheet (MSDS).** Written or printed material concerning a hazardous material that is prepared in accordance with the provisions of 29 CFR 1910.1200.

**3.3.59 Maximum Allowable Quantity per Control Area (MAQ).** A threshold quantity of hazardous material in a specific hazard class that once exceeded requires the application of additional administrative procedures, construction features, or engineering controls.

**3.3.60 Mechanical Code.** The mechanical or mechanical construction code adopted by the jurisdiction.

**3.3.61 Metal Hydride.** A generic name for compounds composed of metallic element(s) and hydrogen.

**3.3.62 Metal Hydride Storage System.** A closed system consisting of a group of components assembled as a package to contain metal-hydrogen compounds for which there exists an equilibrium condition where the hydrogen-absorbing metal alloy(s), hydrogen gas, and the metal-hydrogen compound(s) coexist and where only hydrogen gas is released from the system in normal use.

**3.3.63\* Mobile Supply Unit.** Any supply source that is equipped with wheels so it is able to be moved around.

**3.3.64 Nesting.** A method of securing cylinders upright in a tight mass using a contiguous three-point contact system whereby all cylinders in a group have a minimum of three contact points with other cylinders or a solid support structure (e.g., a wall or railing).

**3.3.65 Noncombustible Material.** A material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat. Materials that are reported as passing ASTM E 136 are considered noncombustible materials.



**3.3.66\* Normal Temperature and Pressure (NTP).** A temperature of 70°F (21°C) at an absolute pressure of 14.7 psi (101.3 kPa).

**3.3.67 OSHA.** The Occupational Safety and Health Administration of the U.S. Department of Labor.

**3.3.68 Outgassing.** Release of adsorbed or absorbed ethylene oxide after sterilization.

**3.3.69\* Piping System.** Interconnected piping consisting of mechanical components suitable for joining or assembly into pressure-tight fluid-containing system. Components include pipe, tubing, fittings, flanges, bolting, valves, and devices such as expansion joints, flexible joints, pressure hoses, in-line portions of instruments, and wetted components other than individual pieces or stages of equipment.

**3.3.70 Pressure Relief Device.** A device designed to open to prevent a rise of internal pressure in excess of a specified value.

**3.3.71\* Protection Level.** A tier of building safety that exceeds the construction requirements for control areas to accommodate quantities of hazardous materials in excess of those permitted using the control area concept.

**3.3.72 Qualified Individual.** An individual knowledgeable in the hazards of compressed gases and cryogenic fluids through training and work experience.

**3.3.73 Reformer.** An assembly of equipment that can be used to produce hydrogen gas from hydrocarbons or other hydrogen-containing fuel, usually at high temperature and usually in the presence of a catalyst. The gaseous stream consists principally of a mixture of hydrogen and carbon monoxide.

**3.3.74 Remotely Located, Manually Activated Shutdown Control.** A control system that is designed to initiate shutdown of the flow of gas or liquid that is manually activated from a point located some distance from the delivery system.

**3.3.75 Separation of Hazards.** Physically separated by a specified distance, construction, or appliance.

**3.3.76 Small Insulated Liquid Carbon Dioxide System.** An assembly of equipment consisting of one or more insulated carbon dioxide containers, interconnecting piping, pressure regulators, and pressure relief devices. The capacity of individual containers is 1000 pounds of carbon dioxide or less.

**3.3.77\* Source Valve.** A shutoff valve on the piping system serving a bulk gas supply system where the gas supply, at service pressure, first enters the supply line.

**3.3.78 Standard Cubic Foot (scf) of Gas.** Cubic foot of gas at an absolute pressure of 14.7 psi (101 kPa) and a temperature of 70°F (21°C).

**3.3.79\* Sterilization Building.** A detached building that contains all ancillary systems and rooms supporting the sterilization process.

**3.3.80 Storage.** An inventory of compressed gases or cryogenic fluids in containers that are not in the process of being examined, serviced, refilled, loaded, or unloaded.

**3.3.81 System.**

**3.3.81.1\* Compressed Gas System.** An assembly of equipment designed to contain, distribute, or transport compressed gases. [318, 2009]

**3.3.81.2 Continuous Gas Detection System.** A gas detection system in which the instrument is maintained in continuous operation and the interval between sampling of any point does not exceed 30 minutes.

**3.3.81.3 Cryogenic Fluid System.** An assembly of equipment designed to contain, distribute, or transport cryogenic fluids.

**3.3.81.4 Cylinder Containment System.** A gastight recovery system comprising equipment or devices that can be placed over a leak in a compressed gas container, thereby stopping or controlling the escape of gas from the leaking container.

**3.3.81.5 Treatment System.** An assembly of equipment capable of processing a hazardous gas and reducing the gas concentration to a predetermined level at the point of discharge from the system to the atmosphere.

**3.3.82 Tank.**

**3.3.82.1\* Portable Tank.** Any packaging over 60 U.S. gal (227.1 L) capacity designed primarily to be loaded into or on, or temporarily attached to, a transport vehicle or ship and equipped with skids, mountings, or accessories to facilitate handling of the tank by mechanical means.

**3.3.82.2\* Stationary Tank.** A packaging designed primarily for stationary installations not intended for loading, unloading, or attachment to a transport vehicle as part of its normal operation in the process of use.

**3.3.83 TC.** Transport Canada.

**3.3.84\* Tube Trailer.** A truck or semitrailer on which a number of very long compressed gas tubular cylinders have been mounted and manifolded into a common piping system.

**3.3.85 Use.** To place a material into action, including solids, liquids, and gases.

**3.3.86 Valve Outlet Cap or Plug.** A removable device that forms a gastight seal on the outlet to the control valve that is provided on a source containing a compressed gas or cryogenic fluid.

**3.3.87 Valve Protection Cap.** A rigid, removable cover provided for container valve protection during handling, transportation, and storage.

**3.3.88 Valve Protection Device.** A device attached to the neck ring or body of a cylinder for the purpose of protecting the cylinder valve from being struck or from being damaged by the impact resulting from a fall or an object striking the cylinder. [1, 2009]

## Chapter 4 General Requirements

**4.1 Permits.** Permits shall be obtained in accordance with the requirements of the jurisdiction in which the facility operates.

**4.2 Emergency Plan.**

**4.2.1 Emergency Plan Requirements.**

**4.2.1.1** An emergency plan shall be prepared and updated wherever compressed gases or cryogenic fluids are produced, handled, stored, or used in amounts exceeding the maximum allowable quantity (MAQ) per control area or where required by the authority having jurisdiction (AHJ).



**4.2.1.2** The plan shall be available for inspection by the AHJ upon reasonable notice and shall include the following information:

- (1) The type of emergency equipment available and its location
- (2) A brief description of any testing or maintenance programs for the available emergency equipment
- (3) An indication that hazard identification labeling is provided for each storage area
- (4) The location of posted emergency procedures
- (5) A material safety data sheet (MSDS) or equivalent for each compressed gas or cryogenic fluid stored or used on the site
- (6) A list of personnel who are designated and trained to be liaison personnel for the fire department and who are responsible for the following:
  - (a) Aiding the emergency responders in pre-emergency planning
  - (b) Identifying the location of the compressed gases and cryogenic fluids stored or used
  - (c) Accessing MSDSs
  - (d) Knowing the site emergency procedures
- (7) A list of the types and quantities of compressed gases and cryogenic fluids found within the facility

### 4.3 Facility Closure.

**4.3.1 Temporarily Out-of-Service Facilities.** Facilities that are temporarily out of service shall continue to maintain a permit and be monitored and inspected. [1:60.1.5.3.2]

**4.3.2 Permanently Out-of-Service Facilities.** Facilities for which a permit is not kept current or that are not monitored and inspected on a regular basis shall be deemed to be permanently out of service and shall be closed in accordance with 4.3.3. [1:60.1.5.3.3]

#### 4.3.3 Closure Plan.

**4.3.3.1** The permit holder or applicant shall submit a plan to the fire department to terminate storage, dispensing, handling, or use of hazardous materials at least 30 days prior to facility closure. [1:60.1.5.3.3.1]

**4.3.3.2** The plan shall demonstrate that hazardous materials that were stored, dispensed, handled, or used in the facility have been transported, disposed of, or reused in a manner that eliminates the need for further maintenance and any threat to public health and safety. [1:60.1.5.3.3.2]

**4.3.3.3** The plan shall be submitted with a permit application for facility closure in accordance with Section 4.1.

**4.4\* Out-of-Service Stationary Bulk Gas Systems.** Installed bulk gas systems no longer in use that remain in place shall be removed from service by the supplier or shall be safeguarded in accordance with the following:

- (1) Required permits shall be maintained.
- (2) The source and fill valves shall be closed to prevent the intrusion of air or moisture.
- (3) Cylinders, containers, and tanks shall be maintained in serviceable condition.
- (4) Security shall be maintained in accordance with 7.1.8.

### 4.5 Management Plan and Hazardous Materials Documentation.

**4.5.1 Hazardous Materials Management Plan.** Where required by the AHJ, permit applications shall include a hazardous materials management plan (HMMP). [1:60.1.6.1]

**4.5.1.1 Contents.** The HMMP shall include an emergency response training plan and facility site plan designating the following:

- (1) Storage and use areas
- (2) Maximum amount of each material stored or used in each area
- (3) Range of container sizes
- (4) Product-conveying piping containing liquids or gases, other than utility-owned fuel gas lines and low-pressure fuel gas lines
- (5) Locations of emergency isolation and mitigation valves and devices
- (6) ON and OFF positions of valves for valves that are of the self-indicating type
- (7) Storage plan that is legible and drawn approximately to scale showing the intended storage arrangement, including the location and dimensions of aisles, with separate distribution systems permitted to be shown on separate pages

[1:60.1.6.1.1]

**4.5.1.2 Location.** The location of the HMMP shall be posted adjacent to permits when an HMMP is provided. [1:60.1.6.1.2]

**4.5.2 Hazardous Materials Inventory Statement.** Where required by the AHJ, permit applications shall include a hazardous materials inventory statement (HMIS). [1:60.1.6.2]

**4.5.3 Material Safety Data Sheets.** Material safety data sheets (MSDS) shall be readily available on the premises for hazardous materials regulated by this code. [1:60.1.7]

### 4.6 Release of Hazardous Materials.

**4.6.1 Prohibited Releases.** Hazardous materials shall not be released into a sewer, storm drain, ditch, drainage canal, lake, river, or tidal waterway; upon the ground, sidewalk, street, or highway; or into the atmosphere unless such release is permitted by the following:

- (1) Federal, state, or local governing regulations
- (2) Permits of the jurisdictional air quality management board
- (3) National Pollutant Discharge Elimination System Permit
- (4) Waste discharge requirements established by the jurisdictional water quality control board
- (5) Local sewer pretreatment requirements for publicly owned treatment works

[1:60.1.8.1]

**4.6.2 Control and Mitigation of Unauthorized Discharges.** Provisions shall be made for controlling and mitigating unauthorized discharges. [1:60.1.8.2]

**4.6.3 Records of Unauthorized Discharges.** Accurate records of the unauthorized discharge of hazardous materials shall be kept by the permittee. [1:60.1.8.3]

**4.6.4 Notification of Unauthorized Discharges.** The fire department shall be notified immediately or in accordance with approved emergency procedures when an unauthorized discharge becomes reportable under state, federal, or local regulations. [1:60.1.8.4]

**4.6.5 Container Failure.** When an unauthorized discharge due to primary container failure is discovered, the involved primary container shall be repaired or removed from service. [1:60.1.8.5]



#### 4.6.6 Responsibility for Cleanup of Unauthorized Discharges.

**4.6.6.1** The person, firm, or corporation responsible for an unauthorized discharge shall institute and complete all actions necessary to remedy the effects of such unauthorized discharge, whether sudden or gradual, at no cost to the AHJ. [1:60.1.8.6.1]

**4.6.6.2** When deemed necessary by the AHJ, cleanup of an unauthorized discharge shall be permitted to be initiated by the fire department or by an authorized individual or firm, and costs associated with such cleanup shall be borne by the owner, operator, or other person responsible for the unauthorized discharge. [1:60.1.8.6.2]

**4.7 Personnel Training.** Persons responsible for the operation of areas in which hazardous materials are stored, dispensed, handled, or used shall be familiar with the chemical nature of the materials and the appropriate mitigating actions necessary in the event of fire, leak, or spill. [1:60.1.9]

#### 4.8 Fire Department Liaison.

**4.8.1** Responsible persons shall be designated and trained to be liaison personnel for the fire department. [1:60.1.10.1]

**4.8.2** Liaison personnel shall aid the fire department in pre-planning emergency responses and identification of the locations where hazardous materials are located and shall have access to MSDSs and be knowledgeable in the site emergency response procedures. [1:60.1.10.2]

#### 4.9 Ignition Source Controls.

**4.9.1 Smoking.** Smoking shall be prohibited in the following locations:

- (1) Within 25 ft (7.6 m) of outdoor storage or dispensing areas
- (2) In rooms or areas where hazardous materials are stored or dispensed or used in open systems in amounts requiring a permit in accordance with Section 4.1

[1:60.1.11.1]

**4.9.2 Open Flames and High-Temperature Devices.** Open flames and high-temperature devices shall not be used in a manner that creates a hazardous condition. [1:60.1.11.2]

**4.9.3 Energy-Consuming Equipment.** Energy-consuming equipment shall be listed for use with the hazardous materials stored or used. [1:60.1.11.3]

#### 4.10 Signs.

##### 4.10.1 General.

**4.10.1.1 Design and Construction.** Signs shall be durable, and the size, color, and lettering of signs shall be in accordance with nationally recognized standards. [1:60.1.13.1.1]

**4.10.1.2 Language.** Signs shall be in English as the primary language or in symbols allowed by this code. [1:60.1.13.1.2]

**4.10.1.3 Maintenance.** Signs shall not be obscured or removed. [1:60.1.13.1.3]

##### 4.10.2 Hazard Identification Signs.

**4.10.2.1 General.** Visible hazard identification signs in accordance with NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*, shall be placed on the following, except where the AHJ has received an HMMP

and a hazardous materials inventory statement in accordance with 4.5.1 through 4.5.2 and has determined that omission of such signs is consistent with safety:

- (1) Stationary aboveground tanks
- (2) Stationary aboveground containers
- (3) At entrances to locations where hazardous materials are stored, dispensed, used, or handled in quantities requiring a permit
- (4) At other entrances and locations designated by the AHJ

[1:60.1.13.2.1]

##### 4.10.2.2 Identification of Containers, Cartons, and Packages.

Individual containers, cartons, or packages shall be conspicuously marked or labeled in accordance with nationally recognized standards. [1:60.1.13.1.2.2]

**4.10.2.3 Identification of Gas Rooms and Cabinets.** Rooms or cabinets containing compressed gases shall be conspicuously labeled as follows:

##### COMPRESSED GAS

[1:60.1.13.2.3]

**4.10.3 No Smoking Signs.** Signs prohibiting smoking shall be provided for an entire site or building, or in the following locations:

- (1) In rooms or areas where hazardous materials are stored or dispensed or used in open systems in amounts requiring a permit in accordance with Section 4.1
- (2) Within 25 ft (7.6 m) of outdoor storage, dispensing, or open-use areas
- (3) In areas containing flammable gases

[1:60.1.13.3]

##### 4.11 Protection from Vehicular Damage.

**4.11.1** Where required, guard posts or other approved means shall be provided to protect against physical damage in accordance with 4.11.1.1 and 4.11.1.2.

**4.11.1.1** Guard posts or other approved means shall be provided to protect the following areas where subject to vehicular damage:

- (1) Storage tanks and connected piping, valves, and fittings
- (2) Dispensing areas
- (3) Use areas

[1:60.1.15.1]

**4.11.1.2** Where guard posts are installed, the posts shall meet the following criteria:

- (1) They shall be constructed of steel not less than 4 in. (102 mm) in diameter and concrete filled.
- (2) They shall be spaced not more than 4 ft (1.2 m) between posts on center.
- (3) They shall be set not less than 3 ft (0.9 m) deep in a concrete footing of not less than a 15 in. (380 mm) diameter.
- (4) They shall be set with the top of the posts not less than 3 ft (0.9 m) above ground.
- (5) They shall be located not less than 5 ft (1.5 m) from the tank.

[1:60.1.15.2]



## Chapter 5 Classification of Hazards

### 5.1 Hazardous Materials Classification.

**5.1.1 Pure Gases.** Hazardous materials shall be classified according to hazard categories as follows:

- (1) Physical hazards, which shall include the following:
  - (a) Flammable gas
  - (b) Flammable cryogenic fluid
  - (c) Inert gas
  - (d) Inert cryogenic fluid
  - (e) Oxidizing gas
  - (f) Oxidizing cryogenic fluid
  - (g) Pyrophoric gas
  - (h) Unstable reactive (detonable) gas, Class 3 or Class 4
  - (i) Unstable reactive (nondetonable) gas, Class 3
  - (j) Unstable reactive gas, Class 1 or Class 2
- (2) Health hazards, which shall include the following:
  - (a) Corrosive gas
  - (b) Cryogenic fluids
  - (c) Highly toxic gas
  - (d) Toxic gas

**5.1.2 Other Hazards.** Although it is possible that there are other known hazards, the classification of such gases is not within the scope of this code and they shall be handled, stored, or used as an *other gas*.

**5.1.3 Mixtures.** Mixtures shall be classified in accordance with the hazards of the mixture as a whole.

**5.1.4 Responsibility for Classification.** Classification shall be performed by an approved organization, individual, or testing laboratory.

**5.1.4.1 Toxicity.** The toxicity of gas mixtures shall be classified in accordance with CGAP-20, *Standard for the Classification of Toxic Gas Mixtures*, or by testing in accordance with the requirements of 29 CFR 1910.1000, DOT 49 CFR 173, or ISO 10298, *Determination of toxicity of a gas or gas mixture*.

**5.1.4.2 Flammability of Gas Mixtures.** For gas mixtures other than those containing ammonia and nonflammable gases, flammability of gas mixtures shall be classified in accordance with CGAP-23, *Standard for Categorizing Gas Mixtures Containing Flammable and Nonflammable Components*; or by physical testing in accordance with the requirements of ASTM E 681, *Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapors and Gases)*, or ISO 10156, *Gases and gas mixtures — Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets*.

## Chapter 6 Building-Related Controls

### 6.1 General.

#### 6.1.1 Occupancy.

**6.1.1.1 Occupancy Requirements.** Occupancies containing compressed gases and cryogenic fluids shall comply with this chapter in addition to other applicable requirements of this code.

**6.1.1.2 Occupancy Classification.** The occupancy of a building or structure, or portion of a building or structure, shall be classified in accordance with the building code.

### 6.2 Control Areas.

**6.2.1 Construction Requirements.** Control areas shall be separated from each other by not less than a 1-hour fire-resistive occupancy separation as required by the building code.

**6.2.2 Number.** The number of control areas in buildings or portions of buildings shall not exceed that allowed by the building code.

**6.2.3 Quantities Less Than or Equal to the MAQ.** Building-related controls in areas with compressed gases or cryogenic fluids stored or used within an indoor control area in quantities less than or equal to those shown in Table 6.3.1.1 shall be in accordance with 6.3.1.6 and 6.3.1.7 and Sections 6.6, 6.7, 6.11, 6.14, and 6.15.

### 6.3 Occupancy Protection Levels.

#### 6.3.1 Quantity Thresholds for Compressed Gases and Cryogenic Fluids Requiring Special Provisions.

**6.3.1.1 Threshold Exceedences.** Where the quantities of compressed gases or cryogenic fluids stored or used within an indoor control area exceed those shown in Table 6.3.1.1, the area shall meet the requirements for Protection Levels 1 through 5 in accordance with the building code, based on the requirements of 6.3.2.

**6.3.1.2 Quantities Greater Than the MAQ.** Building-related controls in areas with compressed gases or cryogenic fluids stored or used within an indoor area in quantities greater than those shown in Table 6.3.1.1 shall be in accordance with the requirements of Chapter 6.

**6.3.1.3 Aggregate Allowable Quantities.** The aggregate quantity in use and storage shall not exceed the quantity listed for storage.

**6.3.1.4 Incompatible Materials.** When the classification of materials in individual containers requires the area to be placed in more than one protection level, the separation of protection levels shall not be required providing the area is constructed to meet the requirements of the most restrictive protection level and that the incompatible materials are separated as required by 7.1.10.2.

**6.3.1.5 Multiple Hazards.** Where a compressed gas or cryogenic fluid has multiple hazards, all hazards shall be addressed and controlled in accordance with the provisions for the protection level for which the threshold quantity is exceeded.

#### 6.3.1.6 Flammable and Oxidizing Gases.

**6.3.1.6.1** Flammable and oxidizing gases shall not be stored or used in other than industrial and storage occupancies.

**6.3.1.6.2** Containers, cylinders, or tanks not exceeding 250 ft<sup>3</sup> (7.1 m<sup>3</sup>) content at normal temperature and pressure (NTP) and used for maintenance purposes, patient care, or operation of equipment shall be permitted.

**6.3.1.7 Toxic and Highly Toxic Compressed Gases.** Except for containers or cylinders not exceeding 20 ft<sup>3</sup> (0.6 m<sup>3</sup>) content at NTP stored or used within gas cabinets or exhausted enclosures of educational occupancies, toxic or highly toxic compressed gases shall not be stored or used in other than industrial and storage occupancies.

**6.3.2 Classification of Protection Levels.** The protection level required shall be based on the hazard class of the material involved as indicated in 6.3.2.1 through 6.3.2.5.

**Table 6.3.1.1 MAQ of Gases per Control Area (Quantity Thresholds for Gases Requiring Special Provisions)**

Material	Unsprinklered Areas		Sprinklered Areas	
	No Gas Cabinet, Gas Room, or Exhausted Enclosure	Gas Cabinet, Gas Room, or Exhausted Enclosure	No Gas Cabinet, Gas Room, or Exhausted Enclosure	Gas Cabinet, Gas Room, or Exhausted Enclosure
Corrosive gas				
Liquefied	150 lb (68 kg)	300 lb (136 kg)	300 lb (136 kg)	600 lb (272 kg)
Nonliquefied	810 ft <sup>3</sup> (23 m <sup>3</sup> )	1620 ft <sup>3</sup> (46 m <sup>3</sup> )	1620 ft <sup>3</sup> (46 m <sup>3</sup> )	3240 ft <sup>3</sup> (92 m <sup>3</sup> )
Cryogenic fluid				
Flammable	0 gal (0 L)	45 gal (170 L)	45 gal (170 L)	45 gal (170 L)*
Oxidizing	45 gal (170 L)	90 gal (340 L)	90 gal (340 L)	180 gal (681 L)
Inert	No limit	No limit	No limit	No limit
Flammable gas				
Liquefied	150 lb (68 kg)	300 lb (136 kg)	300 lb (136 kg)	600 lb (272 kg)
Nonliquefied	1000 ft <sup>3</sup> (28 m <sup>3</sup> )	2000 ft <sup>3</sup> (56 m <sup>3</sup> )	2000 ft <sup>3</sup> (56 m <sup>3</sup> )	4000 ft <sup>3</sup> (112 m <sup>3</sup> )
Highly toxic gas				
Liquefied	0 lb (0 kg)	4 lb (1.8 kg)	0 lb (0 kg)	8 lb (3.6 kg)
Nonliquefied	0 ft <sup>3</sup> (0 m <sup>3</sup> )	20 ft <sup>3</sup> (0.6 m <sup>3</sup> )	0 ft <sup>3</sup> (0 m <sup>3</sup> )	40 ft <sup>3</sup> (1.1 m <sup>3</sup> )
Inert gas				
Liquefied	No limit	No limit	No limit	No limit
Nonliquefied	No limit	No limit	No limit	No limit
Oxidizing gas				
Liquefied	150 lb (68 kg)	300 lb (136 kg)	300 lb (136 kg)	600 lb (272 kg)
Nonliquefied	1500 ft <sup>3</sup> (43 m <sup>3</sup> )	3000 ft <sup>3</sup> (85 m <sup>3</sup> )	3000 ft <sup>3</sup> (85 m <sup>3</sup> )	6000 ft <sup>3</sup> (170 m <sup>3</sup> )
Pyrophoric gas				
Liquefied	0 lb (0 kg)	0 lb (0 kg)	4 lb (1.8 kg)	8 lb (3.6 kg)
Nonliquefied	0 ft <sup>3</sup> (0 m <sup>3</sup> )	0 ft <sup>3</sup> (0 m <sup>3</sup> )	50 ft <sup>3</sup> (1.4 m <sup>3</sup> )	100 ft <sup>3</sup> (2.8 m <sup>3</sup> )
Toxic gas				
Liquefied	150 lb (68 kg)	300 lb (136 kg)	300 lb (136 kg)	600 lb (272 kg)
Nonliquefied	810 ft <sup>3</sup> (23 m <sup>3</sup> )	1620 ft <sup>3</sup> (46 m <sup>3</sup> )	1620 ft <sup>3</sup> (46 m <sup>3</sup> )	3240 ft <sup>3</sup> (92 m <sup>3</sup> )
Unstable reactive (detonable) gas, Class 3 or Class 4				
Liquefied	0 lb (0 kg)	0 lb (0 kg)	1 lb (0.5 kg)	2 lb (1 kg)
Nonliquefied	0 ft <sup>3</sup> (0 m <sup>3</sup> )	0 ft <sup>3</sup> (0 m <sup>3</sup> )	10 ft <sup>3</sup> (0.3 m <sup>3</sup> )	20 ft <sup>3</sup> (0.6 m <sup>3</sup> )
Unstable reactive (nondetonable) gas, Class 3				
Liquefied	2 lb (1 kg)	4 lb (2 kg)	4 lb (2 kg)	8 lb (4 kg)
Nonliquefied	50 ft <sup>3</sup> (1.4 m <sup>3</sup> )	100 ft <sup>3</sup> (3 m <sup>3</sup> )	100 ft <sup>3</sup> (3 m <sup>3</sup> )	200 ft <sup>3</sup> (6 m <sup>3</sup> )
Unstable reactive gas, Class 2				
Liquefied	150 lb (68 kg)	300 lb (136 kg)	300 lb (136 kg)	600 lb (272 kg)
Nonliquefied	750 ft <sup>3</sup> (21 m <sup>3</sup> )	1500 ft <sup>3</sup> (43 m <sup>3</sup> )	1500 ft <sup>3</sup> (43 m <sup>3</sup> )	3000 ft <sup>3</sup> (85 m <sup>3</sup> )
Unstable reactive gas, Class 1				
Liquefied	No limit	No limit	No limit	No limit
Nonliquefied	No limit	No limit	No limit	No limit

Note: The maximum quantity indicated is the aggregate quantity of materials in storage and use combined.

\*A gas cabinet or exhausted enclosure is required. Pressure relief devices for stationary or portable containers shall be vented directly outdoors or to an exhaust hood. (See 8.2.5.6.)

**6.3.2.1 Protection Level 1.** Occupancies used for the storage or use of unstable reactive Class 4 and unstable reactive Class 3 detonable compressed gases in quantities that exceed the quantity thresholds for gases requiring special provisions shall be classified Protection Level 1.

**6.3.2.2 Protection Level 2.** Occupancies used for the storage or use of flammable, pyrophoric, and nondetonable, un-

stable reactive Class 3 compressed gases or cryogenic fluids in quantities that exceed the quantity thresholds for gases requiring special provisions shall be classified as Protection Level 2.

**6.3.2.3 Protection Level 3.** Occupancies used for the storage or use of oxidizing and unstable reactive Class 2 compressed gases or cryogenic fluids in quantities that exceed the quantity



thresholds for gases requiring special provisions shall be classified as Protection Level 3.

**6.3.2.4 Protection Level 4.** Occupancies used for the storage or use of toxic, highly toxic, and corrosive compressed gases in quantities that exceed the quantity thresholds for gases requiring special provisions shall be classified as Protection Level 4.

**6.3.2.5 Protection Level 5.** Buildings and portions thereof used for fabrication of semiconductors or semiconductor research and development and containing quantities of hazardous materials exceeding the maximum allowable quantities of high hazard level 5 contents permitted in control areas shall be classified as Protection Level 5.

**6.4 Gas Rooms.** Gas rooms shall meet the requirements of 6.4.1 through 6.4.5.

**6.4.1 Pressure Control.** Gas rooms shall operate at a negative pressure in relationship to the surrounding area.

**6.4.2 Exhaust Ventilation.** Gas rooms shall be provided with an exhaust ventilation system.

**6.4.3 Construction.** Gas rooms shall be constructed in accordance with the building code.

**6.4.4 Separation.** Gas rooms shall be separated from other occupancies by a minimum of 1-hour fire resistance.

**6.4.5 Limitation on Contents.** The function of compressed gas rooms shall be limited to storage and use of compressed gases and associated equipment and supplies.

**6.5 Detached Buildings.** Occupancies used for the storage or use of compressed gases in quantities exceeding those specified in Table 6.5 shall be in detached buildings constructed in accordance with the provisions of the building code.

**Table 6.5 Detached Buildings Required Where Quantity of Material Exceeds Amount Shown**

Gas Hazard	Class	Quantity of Material	
		ft <sup>3</sup>	m <sup>3</sup>
Unstable reactive (detonable)	4 or 3	Quantity thresholds for gases requiring special provisions*	
Unstable reactive (nondetonable)	3	2,000	57
Unstable reactive (nondetonable)	2	10,000	283
Pyrophoric gas	NA	2,000	57

NA: Not applicable.

\*See Table 6.3.1.1.

**6.5.1** For such storage or use areas to be regulated as outdoor storage or use, compliance with 6.5.3 and 6.5.4 shall be required.

**6.5.2 Classification of Weather Protection as an Indoor Versus Outdoor Area.**

**6.5.2.1** For other than explosive materials and hazardous materials presenting a detonation hazard, a weather protection structure shall be permitted to be used for sheltering outdoor

storage or use areas, without requiring such areas to be classified as indoor storage.

**6.5.2.2** For such storage or use areas to be regulated as outdoor storage or use, compliance with conditions in 6.5.3 and 6.5.4 shall be required.

**6.5.2.3** Where storage or use areas are provided with weather protection that does not comply with these conditions, the storage or use area shall be regulated as an indoor storage or use area.

**6.5.3** Supports and walls shall not obstruct more than one side or more than 25 percent of the perimeter of the storage or use area.

**6.5.4 Structure Separation Distances.**

**6.5.4.1** The distance from the structure and the structural supports to buildings, lot lines, public ways or means of egress to a public way shall not be less than the distance required for an outside hazardous material storage or use area without weather protection.

**6.5.4.2** Where the weather protection structure is constructed of noncombustible materials, reductions in the separation distance shall be permitted based on the use of fire barrier walls where permitted for specific materials in accordance with the requirements of Chapters 7 through 11.

**6.6\* Electrical Equipment.** Electrical wiring and equipment shall be in accordance with Section 6.6 and *NFPA 70, National Electrical Code*.

**6.6.1 Standby Power.**

**6.6.1.1** Where the following systems are required by this code for the storage or use of compressed gases or cryogenic fluids that exceed the quantity thresholds for gases requiring special provisions, such systems shall be connected to a standby power system in accordance with *NFPA 70, National Electrical Code*:

- (1) Mechanical ventilation
- (2) Treatment systems
- (3) Temperature controls
- (4) Alarms
- (5) Detection systems
- (6) Other electrically operated systems

**6.6.1.2** The requirements of 6.6.1.1 shall not apply where emergency power is provided in accordance with *NFPA 70, National Electrical Code*.

**6.6.2 Emergency Power.** When emergency power is required, the system shall meet the requirements for a Protection Level 2 system in accordance with NFPA 110, *Standard for Emergency and Standby Power Systems*.

**6.7\* Employee Alarm System.** Where required by government regulations, an employee alarm system shall be provided to allow warning for necessary emergency action as called for in the emergency action plan required by 4.2.1.1, or for reaction time for safe egress of employees from the workplace or the immediate work area, or both.

**6.8\* Explosion Control.** Explosion control shall be provided as required by Table 6.8 in accordance with NFPA 69, *Standard on Explosion Prevention Systems*, where amounts of compressed gases in storage or use exceed the quantity thresholds requiring special provisions.



**Table 6.8 Explosion Control Requirements**

Material	Class	Explosion Control Methods	
		Barricade Construction	Explosion Venting or Prevention Systems
Flammable cryogenic fluid	—	Not required	Required
Flammable gas	Nonliquefied	Not required	Required
	Liquefied	Not required	Required
Pyrophoric gas	—	Not required	Required
Unstable reactive gas	4	Required	Not required
	3 (detonable)	Required	Not required
	3 (nondetonable)	Not required	Required

**6.9\* Fire Protection Systems.** Except as provided in 6.9.1, buildings or portions thereof required to comply with Protection Levels 1 through 5 shall be protected by an approved automatic fire sprinkler system complying with NFPA 13, *Standard for the Installation of Sprinkler Systems*.

**6.9.1** Rooms or areas that are of noncombustible construction with wholly noncombustible contents shall not be required to be protected by an automatic fire sprinkler system.

#### **6.9.2 Sprinkler System Design.**

**6.9.2.1** When sprinkler protection is provided, the area in which compressed gases or cryogenic fluids are stored or used shall be protected with a sprinkler system designed to be not less than that required by NFPA 13, *Standard for the Installation of Sprinkler Systems*, for Ordinary Hazard Group 2 with a minimum design area of 3000 ft<sup>2</sup> (278.7 m<sup>2</sup>).

**6.9.2.2** When sprinkler protection is provided, the area in which the flammable or pyrophoric compressed gases or cryogenic fluids are stored or used shall be protected with a sprinkler system designed to be not less than that required by NFPA 13, *Standard for the Installation of Sprinkler Systems*, for Extra Hazard Group 1 with a minimum design area of 2500 ft<sup>2</sup> (232.25 m<sup>2</sup>).

**6.10 Lighting.** Approved lighting by natural or artificial means shall be provided.

#### **6.11 Hazard Identification Signs.**

**6.11.1 Location.** Hazard identification signs shall be placed at all entrances to locations where compressed gases are produced, stored, used, or handled in accordance with NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*.

**6.11.1.1** Ratings shall be assigned in accordance with NFPA 704.

**6.11.1.2** The authority having jurisdiction shall be permitted to waive 6.11.1 where consistent with safety.

**6.11.2 Application.** Signage shall be provided as specified in 6.11.2.1 and 6.11.2.2.

**6.11.2.1 Signs.** Signs shall not be obscured or removed.

**6.11.2.2 No Smoking.** Signs prohibiting smoking or open flames within 25 ft (7.6 m) of area perimeters shall be provided in areas where toxic, highly toxic, corrosive, unstable reactive, flammable, oxidizing, or pyrophoric gases are produced, stored, or used.

**6.12 Spill Control, Drainage, and Secondary Containment.** Spill control, drainage, and secondary containment shall not be required for compressed gases.

#### **6.13 Shelving.**

**6.13.1** Shelves used for the storage of cylinders, containers, and tanks shall be of noncombustible construction and designed to support the weight of the materials stored.

**6.13.2** In seismically active areas, shelves and containers shall be secured from overturning.

**6.14 Vent Pipe Termination.** The termination point for piped vent systems serving cylinders, containers, tanks, and gas systems used for the purpose of operational or emergency venting shall be located to prevent impingement exposure on the system served and to minimize the effects of high temperature thermal radiation or the effects of contact with the gas from the escaping plume to the supply system, personnel, adjacent structures, and ignition sources.

**6.15 Ventilation.** Indoor storage and use areas and storage buildings for compressed gases and cryogenic fluids shall be provided with mechanical exhaust ventilation or natural ventilation, where natural ventilation can be shown to be acceptable for the material as stored.

**6.15.1 Mechanical Ventilation.** Where mechanical ventilation is provided, the system shall be operational during the time the building or space is occupied.

**6.15.2 Compressed Air.** The requirements of Section 6.15 and 6.15.1 shall not apply to cylinders, containers, and tanks containing compressed air.

**6.15.3 Mechanical Ventilation Rate.** Mechanical ventilation shall be at a rate of not less than 1 ft<sup>3</sup>/min/ft<sup>2</sup> (0.3048 m<sup>3</sup>/min/m<sup>2</sup>) of floor area over the area of storage or use.

**6.15.4 Continuous Operation.** Systems shall operate continuously unless an alternative design is approved by the AHJ.

**6.15.5 Shutoff Controls.** Where powered ventilation is provided, a manual shutoff switch shall be provided outside the room in a position adjacent to the principal access door to the room or in an approved location.

**6.15.6 Manual Shutoff Switch.** The switch shall be the break-glass or equivalent type and shall be labeled as follows:

WARNING:

VENTILATION SYSTEM EMERGENCY SHUTOFF



### 6.15.7 Inlets to the Exhaust System.

**6.15.7.1** The exhaust ventilation system design shall take into account the density of the potential gases released.

**6.15.7.2** For gases that are heavier than air, exhaust shall be taken from a point within 12 in. (304.8 mm) of the floor.

**6.15.7.3** For gases that are lighter than air, exhaust shall be taken from a point within 12 in. (304.8 mm) of the ceiling.

**6.15.8 Floor Level Exhaust.** The location of both the exhaust and inlet air openings shall be designed to provide air movement across all portions of the floor or room to prevent the accumulation of vapors.

**6.15.9 Recirculation of Exhaust.** Exhaust ventilation shall not be recirculated within the room or building if the cylinders, containers, or tanks stored are capable of releasing hazardous gases.

**6.15.10 Ventilation Discharge.** Ventilation systems shall discharge a minimum of 50 ft (15 m) from intakes of air-handling systems, air-conditioning equipment, and air compressors.

**6.15.11 Air Intakes.** Storage and use of compressed gases shall be located not less than 50 ft (15 m) from air intakes. For material-specific requirements, see Sections 7.4 through 7.10.

**6.16 Gas Cabinets.** Where a gas cabinet is required, is used to provide separation of gas hazards, or is used to increase the threshold quantity for a gas requiring special provisions, the gas cabinet shall be in accordance with the requirements of 6.16.1 through 6.16.5.

#### 6.16.1 Construction.

**6.16.1.1 Materials of Construction.** The gas cabinet shall be constructed of not less than 0.097 in. (2.46 mm) (12 gauge) steel.

**6.16.1.2 Access to Controls.** The gas cabinet shall be provided with self-closing limited access ports or noncombustible windows to give access to equipment controls.

**6.16.1.3 Self-Closing Doors.** The gas cabinet shall be provided with self-closing doors.

#### 6.16.2 Ventilation Requirements.

**6.16.2.1** The gas cabinet shall be provided with an exhaust ventilation system designed to operate at a negative pressure relative to the surrounding area.

**6.16.2.2** Where toxic, highly toxic, pyrophoric, unstable reactive Class 3 or Class 4, or corrosive gases are contained, the velocity at the face of access ports or windows, with the access port or window open, shall not be less than 200 ft/min (61 m/min) average, with not less than 150 ft/min (46 m/min) at any single point.

**6.16.3 Fire Protection.** Gas cabinets used to contain toxic, highly toxic, or pyrophoric gases shall be internally sprinklered.

**6.16.4 Quantity Limits.** Gas cabinets shall contain not more than three containers, cylinders, or tanks.

**6.16.5 Separation of Incompatibles.** Incompatible gases, as defined by Table 7.1.10.2, shall be stored or used within separate gas cabinets.

### 6.17 Exhausted Enclosures.

**6.17.1 Ventilation Requirements.** Where an exhausted enclosure is required or used to increase the threshold quantity for a gas requiring special provisions, the exhausted enclosure shall be provided with an exhaust ventilation system designed

to operate at a negative pressure in relationship to the surrounding area.

**6.17.1.1 Control Velocity at Access Openings.** Where toxic, highly toxic, pyrophoric, unstable reactive Class 3 or Class 4, or corrosive gases are contained, the velocity at the face openings providing access shall be not less than 200 ft/min (61 m/min) average, with not less than 150 ft/min (46 m/min) at any single point.

**6.17.1.2 Separation of Incompatible Gases Within Enclosures.** Cylinders, containers, and tanks within enclosures shall be separated in accordance with Table 7.1.10.2.

**6.17.1.3 Fire Protection.** Exhausted enclosures shall be internally sprinklered.

**6.17.2 Separation.** Incompatible gases, as defined by Table 7.1.10.2, shall be stored or used within separate exhausted enclosures.

**6.18\* Source Valve.** Bulk gas systems shall be provided with a source valve.

**6.18.1** The source valve shall be marked.

**6.18.2** The source valve shall be designated on the design drawings for the installation.

## Chapter 7 Compressed Gases

**7.1 General.** The storage, use, and handling of compressed gases in containers, cylinders, and tanks shall be in accordance with the provisions of Chapters 1 through 7.

### 7.1.1 Compressed Gas Systems.

**7.1.1.1 Design.** Compressed gas systems shall be designed for the intended use and shall be designed by persons competent in such design.

**7.1.1.2 Installation.** Installation of bulk compressed gas systems shall be supervised by personnel knowledgeable in the application of the standards for their construction and use.

**7.1.2 Small Insulated Liquid Carbon Dioxide Systems.** Small insulated liquid carbon dioxide systems shall be in accordance with Chapter 13.

### 7.1.3\* Listed and Approved Hydrogen Equipment.

**7.1.3.1** Listed and approved hydrogen generating and consuming equipment shall be in accordance with the listing requirements and manufacturers' instructions.

**7.1.3.2** Such equipment shall not be required to meet the requirements of Chapter 7.

### 7.1.4\* Metal Hydride Storage Systems.

#### 7.1.4.1 General Requirements.

**7.1.4.1.1 Metal Hydride Storage System Requirements.** The storage and use of metal hydride storage systems shall be in accordance with 7.1.4.

**7.1.4.1.2 Metal Hydride Systems Storing or Supplying Hydrogen.** Those portions of the system that are used as a means to store or supply hydrogen shall also comply with Chapter 7 and Chapter 10 as applicable.

**7.1.4.1.3 Classification.** The hazard classification of the metal hydride storage system, as required by 5.1.1 and 5.1.3, shall be based on the hydrogen stored without regard to the metal hydride content.

**7.1.4.1.4 Listed or Approved Systems.** Metal hydride storage systems shall be listed or approved for the application and designed in a manner that prevents the addition or removal of the metal hydride by other than the original equipment manufacturer.

**7.1.4.1.5 Containers, Design, and Construction.** Compressed gas containers, cylinders, and tanks shall be designed and constructed in accordance with 7.1.5.1.

**7.1.4.1.6 Service Life and Inspection of Containers.** Metal hydride storage system cylinders, containers, or tanks shall be inspected, tested, and requalified for service at not less than 5-year intervals.

**7.1.4.1.7 Marking and Labeling.** Marking and labeling of cylinders, containers, tanks, and systems shall be in accordance with 7.1.5 and the requirements in 7.1.4.1.7.1 through 7.1.4.1.7.4.

**7.1.4.1.7.1 System Marking.** Metal hydride storage systems shall be marked with the following:

- (1) Manufacturer's name
- (2) Service life indicating the last date the system can be used
- (3) A unique code or serial number specific to the unit
- (4) System name or product code that identifies the system by the type of chemistry used in the system
- (5) Emergency contact name, telephone number, or other contact information
- (6) Limitations on refilling of containers to include rated charging pressure and capacity

**7.1.4.1.7.2 Valve Marking.** Metal hydride storage system valves shall be marked with the following:

- (1) Manufacturer's name
- (2) Service life indicating the last date the valve can be used
- (3) Metal hydride service in which the valve can be used or a product code that is traceable to this information

**7.1.4.1.7.3 Pressure Relief Device Marking.** Metal hydride storage system pressure relief devices shall be marked with the following:

- (1) Manufacturer's name
- (2) Metal hydride service in which the device can be used or a product code that is traceable to this information
- (3) Activation parameters to include temperature, pressure, or both

**(A) Pressure Relief Devices Integral to Container Valves.** The required markings for pressure relief devices that are integral components of valves used on cylinders, containers, and tanks shall be allowed to be placed on the valve.

**7.1.4.1.7.4 Pressure Vessel Markings.** Cylinders, containers, and tanks used in metal hydride storage systems shall be marked with the following:

- (1) Manufacturer's name
- (2) Design specification to which the vessel was manufactured
- (3) Authorized body approving the design and initial inspection and test of the vessel
- (4) Manufacturer's original test date
- (5) Unique serial number for the vessel

- (6) Service life identifying the last date the vessel can be used
- (7) System name or product code that identifies the system by the type of chemistry used in the system

**7.1.4.1.8 Temperature Extremes.** Metal hydride storage systems, whether full or partially full, shall not be exposed to artificially created high temperatures exceeding 125°F (52°C) or subambient (low) temperatures unless designed for use under the exposed conditions.

**7.1.4.1.9 Falling Objects.** Metal hydride storage systems shall not be placed in areas where they are capable of being damaged by falling objects.

**7.1.4.1.10 Piping Systems.** Piping, including tubing, valves, fittings, and pressure regulators, serving metal hydride storage systems shall be maintained gastight to prevent leakage.

**7.1.4.1.10.1 Leaking Systems.** Leaking systems shall be removed from service.

**7.1.4.1.11 Refilling of Containers.** The refilling of listed or approved metal hydride storage systems shall be in accordance with the listing requirements and manufacturers' instructions.

**7.1.4.1.11.1 Industrial Trucks.** The refilling of metal hydride storage systems serving powered industrial trucks shall be in accordance with NFPA 52, *Vehicular Gaseous Fuel Systems Code*.

**7.1.4.1.11.2 Hydrogen Purity.** The purity of hydrogen used for the purpose of refilling containers shall be in accordance with the listing and the manufacturers' instructions.

**7.1.4.1.12 Electrical.** Electrical components for metal hydride storage systems shall be designed, constructed, and installed in accordance with NFPA 70, *National Electrical Code*.

#### **7.1.4.2 Portable Containers or Systems.**

**7.1.4.2.1 Securing Containers.** Containers, cylinders, and tanks shall be secured in accordance with 7.1.8.4.

**7.1.4.2.1.1 Use on Mobile Equipment.** Where a metal hydride storage system is used on mobile equipment, the equipment shall be designed to restrain containers, cylinders, or tanks from dislodgement, slipping, or rotating when the equipment is in motion.

**7.1.4.2.1.2 Motorized Equipment.** Metal hydride storage systems used on motorized equipment shall be installed in a manner that protects valves, pressure regulators, fittings, and controls against accidental impact.

**(A) Protection from Damage.** Metal hydride storage systems, including cylinders, containers, tanks, and fittings, shall not extend beyond the platform of the mobile equipment.

**7.1.4.2.2 Valves.** Valves on containers, cylinders, and tanks shall remain closed except when containers are connected to closed systems and ready for use.

#### **7.1.5 Containers, Cylinders, and Tanks.**

**7.1.5.1 Design and Construction.** Containers, cylinders, and tanks shall be designed, fabricated, tested, and marked (stamped) in accordance with regulations of DOT, Transport Canada (TC) *Transportation of Dangerous Goods Regulations*, or the ASME *Boiler and Pressure Vessel Code*, "Rules for the Construction of Unfired Pressure Vessels," Section VIII.



### 7.1.5.2 Defective Containers, Cylinders, and Tanks.

**7.1.5.2.1** Defective containers, cylinders, and tanks shall be returned to the supplier.

**7.1.5.2.2** Suppliers shall repair the containers, cylinders, and tanks, remove them from service, or dispose of them in an approved manner.

**7.1.5.3 Supports.** Stationary cylinders, containers, and tanks shall be provided with engineered supports of noncombustible material on noncombustible foundations.

**7.1.5.4 Containers, Cylinders, and Tanks Containing Residual Gas.** Compressed gas containers, cylinders, and tanks containing residual product shall be treated as full except when being examined, serviced, or refilled by a gas manufacturer or distributor.

### 7.1.5.5 Pressure Relief Devices.

**7.1.5.5.1** When required by 7.1.5.5.2, pressure relief devices shall be provided to protect containers and systems containing compressed gases from rupture in the event of overpressure from thermal exposure.

**7.1.5.5.2** Pressure relief devices to protect containers shall be designed and provided in accordance with CGA S-1.1, *Pressure Relief Device Standards – Part 1 – Cylinders for Compressed Gases*, for cylinders; CGA S-1.2, *Pressure Relief Device Standards – Part 2 – Cargo and Portable Tanks for Compressed Gases*, for portable tanks; and CGA S-1.3, *Pressure Relief Device Standards – Part 3 – Stationary Storage Containers for Compressed Gases*, for stationary tanks or in accordance with applicable equivalent requirements in the country of use.

**7.1.5.5.3** Pressure relief devices shall be sized in accordance with the specifications to which the container was fabricated.

**7.1.5.5.4** The pressure relief device shall have the capacity to prevent the maximum design pressure of the container or system from being exceeded.

**7.1.5.5.5** Pressure relief devices shall be arranged to discharge unobstructed to the open air in such a manner as to prevent any impingement of escaping gas upon the container, adjacent structures, or personnel. This requirement shall not apply to DOT specification containers having an internal volume of 2.0 ft<sup>3</sup> (0.057 m<sup>3</sup>) or less.

**7.1.5.5.6** Pressure relief devices or vent piping shall be designed or located so that moisture cannot collect and freeze in a manner that would interfere with operation of the device.

**7.1.6 Cathodic Protection.** Where required, cathodic protection shall be in accordance with 7.1.6.

**7.1.6.1 Operation.** Where installed, cathodic protection systems shall be operated and maintained to continuously provide corrosion protection.

**7.1.6.2 Inspection.** Container systems equipped with cathodic protection shall be inspected for the intended operation by a cathodic protection tester. The frequency of inspection shall be determined by the designer of the cathodic protection system.

**7.1.6.2.1** The cathodic protection tester shall be certified as being qualified by the National Association of Corrosion Engineers, International (NACE).

**7.1.6.3 Impressed Current Systems.** Systems equipped with impressed current cathodic protection systems shall be in-

spected in accordance with the requirements of the design and 7.1.4.1.12. The design limits shall be available to the AHJ upon request.

**7.1.6.3.1** The system owner shall maintain the following records to demonstrate that the cathodic protection is in conformance with the requirements of the design:

- (1) The results of inspections of the system
- (2) The results of testing that has been completed

**7.1.6.4** Repairs, maintenance, or replacement of a cathodic protection system shall be under the supervision of a corrosion expert certified by NACE.

**7.1.6.4.1** The corrosion expert shall be certified by NACE as a senior corrosion technologist, a cathodic protection specialist, or a corrosion specialist or shall be a registered engineer with registration in a field that includes education and experience in corrosion control.

### 7.1.7 Labeling Requirements.

**7.1.7.1 Containers.** Individual compressed gas containers, cylinders, and tanks shall be marked or labeled in accordance with DOT requirements or those of the applicable regulatory agency.

**7.1.7.2 Label Maintenance.** The labels applied by the gas manufacturer to identify the liquefied or nonliquefied compressed gas cylinder contents shall not be altered or removed by the user.

### 7.1.7.3 Stationary Compressed Gas Containers, Cylinders, and Tanks.

**7.1.7.3.1** Stationary compressed gas containers, cylinders, and tanks shall be marked in accordance with NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*.

**7.1.7.3.2** Markings shall be visible from any direction of approach.

### 7.1.7.4 Piping Systems.

**7.1.7.4.1** Except as provided in 7.1.7.4.2, piping systems shall be marked in accordance with ASME A13.1, *Scheme for the Identification of Piping Systems*, or other applicable approved standards as follows:

- (1) Marking shall include the name of the gas and a direction-of-flow arrow.
- (2) Piping that is used to convey more than one gas at various times shall be marked to provide clear identification and warning of the hazard.
- (3) Markings for piping systems shall be provided at the following locations:
  - (a) At each critical process control valve
  - (b) At wall, floor, or ceiling penetrations
  - (c) At each change of direction
  - (d) At a minimum of every 20 ft (6.1 m) or fraction thereof throughout the piping run

**7.1.7.4.2** Piping within gas manufacturing plants, gas processing plants, refineries, and similar occupancies shall be marked in an approved manner.

### 7.1.8 Security.

**7.1.8.1 General.** Compressed gas containers, cylinders, tanks, and systems shall be secured against accidental dislodgement and against access by unauthorized personnel.



**7.1.8.2 Security of Areas.** Storage, use, and handling areas shall be secured against unauthorized entry.

**7.1.8.3 Physical Protection.**

**7.1.8.3.1** Compressed gas containers, cylinders, tanks, and systems that could be exposed to physical damage shall be protected.

**7.1.8.3.2** Guard posts or other means shall be provided to protect compressed gas containers, cylinders, tanks, and systems indoors and outdoors from vehicular damage. (See Section 4.11.)

**7.1.8.3.3** Where guard posts are installed, the posts shall meet the following criteria:

- (1) They shall be constructed of steel not less than 4 in. (100 mm) in diameter and concrete-filled.
- (2) They shall be spaced not more than 4 ft (1.2 m) between posts on center.
- (3) They shall be set not less than 3 ft (0.9 m) deep in a concrete footing of not less than a 15 in. (380 mm) diameter.
- (4) They shall be set with the top of the posts not less than 3 ft (0.9 m) above ground.
- (5) They shall be located not less than 5 ft (1.5 m) from the tank. [1:60.1.15.2]

**7.1.8.4 Securing Compressed Gas Containers, Cylinders, and Tanks.** Compressed gas containers, cylinders, and tanks in use or in storage shall be secured to prevent them from falling or being knocked over by corralling them and securing them to a cart, framework, or fixed object by use of a restraint, unless otherwise permitted by 7.1.8.4.1 and 7.1.8.4.2.

**7.1.8.4.1** Compressed gas containers, cylinders, and tanks in the process of examination, servicing, and refilling shall not be required to be secured.

**7.1.8.4.2** At cylinder-filling plants and distributors' warehouses, the nesting of cylinders shall be permitted as a means to secure cylinders.

**7.1.9 Valve Protection.**

**7.1.9.1 General.** Compressed gas container, cylinder, and tank valves shall be protected from physical damage by means of protective caps, collars, or similar devices.

**7.1.9.2 Valve-Protective Caps.** Where compressed gas containers, cylinders, and tanks are designed to accept valve-protective caps, the user shall keep such caps on the compressed gas containers, cylinders, and tanks at all times, except when empty, being processed, or connected for use.

**7.1.9.3 Valve Outlet Caps or Plugs.**

**7.1.9.3.1** Gastight valve outlet caps or plugs shall be provided and in place for all full or partially full containers, cylinders, and tanks containing toxic, highly toxic, pyrophoric, or unstable reactive Class 3 or Class 4 gases that are in storage.

**7.1.9.3.2** Valve outlet caps and plugs shall be designed and rated for the container service pressure.

**7.1.10 Separation from Hazardous Conditions.**

**7.1.10.1 General.**

**7.1.10.1.1** Compressed gas containers, cylinders, tanks, and systems in storage or use shall be separated from materials and conditions that present exposure hazards to or from each other.

**7.1.10.1.2** Compressed gas containers, cylinders, tanks, and systems in storage or use shall be separated in accordance with 7.1.10.

**7.1.10.1.3** Subparagraph 7.1.10.1.2 shall not apply to gases contained within closed piping systems, compressed gas containers, cylinders, tanks, and systems in storage or use when separated in accordance with 7.1.10.

**7.1.10.2\* Incompatible Materials.** Gas containers, cylinders, and tanks shall be separated in accordance with Table 7.1.10.2.

**7.1.10.2.1** The distances shown in Table 7.1.10.2 shall be permitted to be reduced without limit where compressed gas cylinders, tanks, and containers are separated by a barrier of non-combustible construction that has a fire resistance rating of at least 0.5 hour and interrupts the line of sight between the containers.

**7.1.10.2.2** The 20 ft (6.1 m) distance shall be permitted to be reduced to 5 ft (1.5 m) where one of the gases is enclosed in a gas cabinet or without limit where both gases are enclosed in gas cabinets.

**7.1.10.2.3** Cylinders without pressure-relief devices shall not be stored without separation from flammable and pyrophoric gases with pressure relief devices.

**7.1.10.2.4** Spatial separation shall not be required between cylinders deemed to be incompatible that are connected to manifolds for the purposes of filling and manufacturing procedures, assuming the prescribed controls for the manufacture of gas mixtures are in place.

**7.1.10.3\* Clearance from Combustibles and Vegetation.** Combustible waste, vegetation, and similar materials shall be kept a minimum of 10 ft (3.1 m) from compressed gas containers, cylinders, tanks, and systems.

**7.1.10.3.1** A noncombustible partition without openings or penetrations and extending not less than 18 in. (457 mm) above and to the sides of the storage area shall be permitted in lieu of the minimum distance.

**7.1.10.3.2** The noncombustible partition shall be either an independent structure or the exterior wall of the building adjacent to the storage area.

**7.1.10.4 Ledges, Platforms, and Elevators.** Compressed gas containers, cylinders, and tanks shall not be placed near elevators, unprotected platform ledges, or other areas where compressed gas containers, cylinders, or tanks could fall distances exceeding one-half the height of the container, cylinder, or tank.

**7.1.10.5 Temperature Extremes.** Compressed gas containers, cylinders, and tanks, whether full or partially full, shall not be exposed to temperatures exceeding 125°F (52°C) or subambient (low) temperatures unless designed for use under such exposure.

**7.1.10.6 Falling Objects.** Compressed gas containers, cylinders, and tanks shall not be placed in areas where they are capable of being damaged by falling objects.

**7.1.10.7 Heating.** Compressed gas containers, cylinders, and tanks, whether full or partially full, shall not be heated by devices that could raise the surface temperature of the container, cylinder, or tank to above 125°F (52°C).



Table 7.1.10.2 Separation of Gas Containers, Cylinders, and Tanks by Hazard Class

Gas Category	Other Gas	Unstable Reactive Class 2, Class 3, or Class 4		Corrosive		Oxidizing		Flammable		Pyrophoric		Toxic or Highly Toxic	
		ft	m	ft	m	ft	m	ft	m	ft	m	ft	m
Toxic or highly toxic	NR	20	6.1	20	6.1	20	6.1	20	6.1	20	6.1	—	—
Pyrophoric	NR	20	6.1	20	6.1	20	6.1	20	6.1	—	—	20	6.1
Flammable	NR	20	6.1	20	6.1	20	6.1	—	—	20	6.1	20	6.1
Oxidizing	NR	20	6.1	20	6.1	—	—	20	6.1	20	6.1	20	6.1
Corrosive	NR	20	6.1	—	—	20	6.1	20	6.1	20	6.1	20	6.1
Unstable reactive Class 2, Class 3, or Class 4	NR	—	—	20	6.1	20	6.1	20	6.1	20	6.1	20	6.1
Other gas	—	NR		NR		NR		NR		NR		NR	

NR: No separation required.

**7.1.10.7.1 Electrically Powered Heating Devices.** Electrical heating devices shall be in accordance with *NFPA 70, National Electrical Code*.

**7.1.10.7.2 Fail-Safe Design.** Devices designed to maintain individual compressed gas containers, cylinders, or tanks at constant temperature shall be designed to be fail-safe.

**7.1.10.8 Sources of Ignition.** Open flames and high-temperature devices shall not be used in a manner that creates a hazardous condition.

**7.1.10.9 Exposure to Chemicals.** Compressed gas containers, cylinders, and tanks shall not be exposed to corrosive chemicals or fumes that could damage containers, cylinders, tanks, or valve-protective caps.

**7.1.10.10 Exposure to Electrical Circuits.** Compressed gas containers, cylinders, and tanks shall not be placed where they could become a part of an electrical circuit.

**7.1.11 Service and Repair.** Service, repair, modification, or removal of valves, pressure relief devices, or other compressed gas container, cylinder, or tank appurtenances shall be performed by trained personnel and with the permission of the container owner.

**7.1.12 Unauthorized Use.** Compressed gas containers, cylinders, and tanks shall not be used for any purpose other than to serve as a vessel for containing the product for which it was designed.

**7.1.13 Containers, Cylinders, and Tanks Exposed to Fire.** Compressed gas containers, cylinders, and tanks exposed to fire shall not be used or shipped while full or partially full until they are requalified in accordance with the pressure vessel code under which they were manufactured.

**7.1.14 Leaks, Damage, or Corrosion.**

**7.1.14.1 Removal from Service.** Leaking, damaged, or corroded compressed gas containers, cylinders, and tanks shall be removed from service.

**7.1.14.2 Replacement and Repair.** Leaking, damaged, or corroded compressed gas systems shall be replaced or repaired.

**7.1.14.3\* Handling of Containers, Cylinders, and Tanks Removed from Service.** Compressed gas containers, cylinders, and tanks that have been removed from service shall be handled in an approved manner.

**7.1.14.4 Leaking Systems.** Compressed gas systems that are determined to be leaking, damaged, or corroded shall be repaired to a serviceable condition or shall be removed from service.

**7.1.15 Surfaces.**

**7.1.15.1** To prevent bottom corrosion, containers, cylinders, and tanks shall be protected from direct contact with soil or surfaces where water might accumulate.

**7.1.15.2** Surfaces shall be graded to prevent accumulation of water.

**7.1.16 Storage Area Temperature.**

**7.1.16.1 Compressed Gas Containers.** Storage area temperatures shall not exceed 125°F (52°C).

**7.1.17 Underground Piping.**

**7.1.17.1** Underground piping shall be of welded construction without valves, unwelded mechanical joints, or connections installed underground.

**7.1.17.1.1** Valves or connections located in boxes or enclosures shall be permitted to be installed underground where such boxes or enclosures are accessible from above ground and where the valves or connections contained are isolated from direct contact with earth or fill.

**7.1.17.1.1.1** Valve boxes or enclosures installed in areas subject to vehicular traffic shall be constructed to resist uniformly distributed and concentrated live loads in accordance with the building code for areas designated as vehicular driveways and yards, subject to trucking.

**7.1.17.1.2\*** Piping installed in trench systems located below grade where the trench is open to above shall not be considered to be underground.

**7.1.17.2** Gas piping in contact with earth or other material that could corrode the piping shall be protected against corrosion in an approved manner.

**7.1.17.2.1** When cathodic protection is provided, it shall be in accordance with 7.1.6.

**7.1.17.3** Underground piping shall be installed on at least 6 in. (150 mm) of well-compacted bedding material. [30:27.6.5.1]

**7.1.17.4** In areas subject to vehicle traffic, the pipe trench shall be deep enough to permit a cover of at least 18 in. (450 mm) of well-compacted backfill material and pavement. [30:27.6.5.2]

**7.1.17.5** In paved areas where a minimum 2 in. (50 mm) of asphalt is used, backfill between the pipe and the asphalt shall be permitted to be reduced to 8 in. (200 mm) minimum. [30:27.6.5.3]

**7.1.17.6** In paved areas where a minimum 4 in. (100 mm) of reinforced concrete is used, backfill between the pipe and the concrete shall be permitted to be reduced to 4 in. (100 mm) minimum. [30:27.6.5.4]

**7.1.17.7** In areas not subject to vehicle traffic, the pipe trench shall be deep enough to permit a cover of at least 12 in. (300 mm) of well-compacted backfill material.

**7.1.17.8** A greater burial depth shall be provided when required by the manufacturer's instructions or where frost conditions are present. [30:27.6.5.6]

**7.1.17.9** Piping within the same trench shall be separated horizontally by at least two pipe diameters. Separation shall not need to exceed 9 in. (230 mm). [30:27.6.5.7]

**7.1.17.10** Two or more levels of pipes within the same trench shall be separated vertically by a minimum 6 in. (150 mm) of well-compacted bedding material. [30:27.6.5.8]

## **7.2 Storage.**

### **7.2.1 General.**

**7.2.1.1 Applicability.** The storage of compressed gas containers, cylinders, and tanks shall be in accordance with Section 7.2.

**7.2.1.2 Upright Storage Flammable Gas in Solution and Liquefied Flammable Gas.** Cylinders, containers, and tanks containing liquefied flammable gases and flammable gases in solution shall be positioned in the upright position.

**7.2.1.2.1 Containers and Cylinders of 1.3 Gal (5 L) or Less.** Containers with a capacity of 1.3 gal (5 L) or less shall be permitted to be stored in a horizontal position.

**7.2.1.2.2 Containers, Cylinders, and Tanks Designed for Horizontal Use.** Containers, cylinders, and tanks designed for use in a horizontal position shall be permitted to be stored in a horizontal position.

**7.2.1.2.3 Palletized Containers, Cylinders, and Tanks.** Containers, cylinders, and tanks, with the exception of those containing flammable liquefied compressed gases, that are palletized for transportation purposes shall be permitted to be stored in a horizontal position.

**7.2.1.3 Classification of Weather Protection as an Indoor Versus an Outdoor Area.** For other than explosive materials and hazardous materials presenting a detonation hazard, a weather protection structure shall be permitted to be used for sheltering outdoor storage or use areas without requiring such areas to be classified as indoor storage.

### **7.2.2 Material-Specific Regulations.**

**7.2.2.1 Indoor Storage.** Indoor storage of compressed gases shall be in accordance with the material-specific provisions of Sections 7.4 through 7.10.

### **7.2.2.2 Exterior Storage.**

**7.2.2.2.1 General.** Exterior storage of compressed gases shall be in accordance with the material-specific provisions of Sections 7.4 through 7.10.

**7.2.2.2.2 Separation.** Distances from property lines, buildings, and exposures shall be in accordance with the material-specific provisions of Sections 7.4 through 7.10.

### **7.3 Use and Handling.**

#### **7.3.1 General.**

**7.3.1.1 Applicability.** The use and handling of compressed gas containers, cylinders, tanks, and systems shall be in accordance with 7.3.1.

#### **7.3.1.2 Controls.**

**7.3.1.2.1** Compressed gas system controls shall be designed to prevent materials from entering or leaving the process at an unintended time, rate, or path.

**7.3.1.2.2** Automatic controls shall be designed to be fail-safe.

**7.3.1.3 Piping Systems.** Piping, tubing, fittings, and related components shall be designed, fabricated, and tested in accordance with the requirements of ANSI/ASME B31.3, *Process Piping*, or other approved standards.

**7.3.1.3.1 Integrity.** Piping, tubing, pressure regulators, valves, and other apparatus shall be kept gastight to prevent leakage.

**7.3.1.3.2 Backflow Prevention.** Backflow prevention or check valves shall be provided where the backflow of hazardous materials could create a hazardous condition or cause the unauthorized discharge of hazardous materials.

#### **7.3.1.4 Valves.**

**7.3.1.4.1** Valves utilized on compressed gas systems shall be designed for the gas or gases and pressure intended and shall be accessible.

**7.3.1.4.2** Valve handles or operators for required shutoff valves shall not be removed or otherwise altered to prevent access.

#### **7.3.1.5 Vent Pipe Termination.**

**7.3.1.5.1** Venting of gases shall be directed to an approved location.

**7.3.1.5.2** The termination point for piped vent systems serving cylinders, containers, tanks, and gas systems used for the purpose of operational or emergency venting shall be in accordance with Section 6.14.

#### **7.3.1.6 Upright Use.**

**7.3.1.6.1** Compressed gas containers, cylinders, and tanks containing flammable liquefied gas, except those designed for use in a horizontal position and those compressed gas containers, cylinders, and tanks containing nonliquefied gases, shall be used in a "valve end up" upright position.

**7.3.1.6.2** An upright position shall include a position in which the container, cylinder, or tank axis is inclined as much as 45 degrees from the vertical and in which the relief device is always in direct communication with the gas phase.

**7.3.1.7 Inverted Use.** Cylinders, containers, and tanks containing nonflammable liquefied gases shall be permitted to be used in the inverted position when the liquid phase is used.



**7.3.1.7.1** Flammable liquefied gases at processing plants shall be permitted to use this inverted position method while transfilling.

**7.3.1.7.2** The container, cylinder, or tank shall be secured, and the dispensing apparatus shall be designed for use with liquefied gas.

**7.3.1.8 Containers and Cylinders of 1.3 Gal (5 L) or Less.** Containers or cylinders with a water volume of 1.3 gal (5 L) or less shall be permitted to be used in a horizontal position.

**7.3.1.9 Transfer.** Transfer of gases between containers, cylinders, and tanks shall be performed by qualified personnel using equipment and operating procedures in accordance with CGA P-1, *Safe Handling of Compressed Gases in Containers*.

**7.3.1.10 Use of Compressed Gases for Inflation.** Inflatable equipment, devices, or balloons shall only be pressurized or filled with compressed air or inert gases.

**7.3.1.11 Emergency Shutoff Valves.**

**7.3.1.11.1** Accessible manual valves or automatic remotely activated fail-safe emergency shutoff valves shall be provided and clearly marked.

**7.3.1.11.2** Emergency shutoffs shall be located at the point of use and at the tank, cylinder, or bulk source.

**7.3.1.12 Excess Flow Control.**

**7.3.1.12.1\*** Where compressed gases or liquids having a hazard ranking of the following in accordance with NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*, are carried in pressurized piping above a gauge pressure of 15 psi (103 kPa), an approved means of leak detection and emergency shutoff or excess flow control shall be provided:

- (1) Health hazard Class 3 or Class 4
- (2) Flammability Class 4
- (3) Reactivity Class 3 or Class 4

**7.3.1.12.1.1 Excess Flow Control Location with Hazardous Material Storage.** Where the piping originates from within a hazardous material storage room or area, the excess flow control shall be located within the storage room or area.

**7.3.1.12.1.2 Excess Flow Control Location with Bulk Storage.** Where the piping originates from a bulk source, the excess flow control shall be located at the bulk source.

**7.3.1.12.2** The controls required by 7.3.1.12 shall not be required for the following:

- (1) Piping for inlet connections designed to prevent backflow at the source
- (2) Piping for pressure relief devices
- (3) Where the source of the gas is not in excess of the quantity threshold indicated in Table 6.3.1.1

**7.3.1.12.3 Location.** The location of excess flow control shall be as specified in 7.3.1.12.1.1 and 7.3.1.12.1.2.

**7.3.1.12.3.1** Where piping originates from a source located in a room or area, the excess flow control shall be located within the room or area.

**7.3.1.12.3.2** Where piping originates from a bulk source, the excess flow control shall be as close to the bulk source as possible.

**7.3.1.12.4 Location Exemptions.** The requirements of 7.3.1.12 shall not apply to the following:

- (1) Piping for inlet connections designed to prevent backflow

- (2) Piping for pressure relief devices

- (3) Systems containing 450 scf (12.7 m<sup>3</sup>) or less of flammable gas

**7.3.2 Material-Specific Regulations.**

**7.3.2.1 Indoor Use.** Indoor use of compressed gases shall be in accordance with the requirements of Sections 7.4 through 7.10.

**7.3.2.2 Exterior Use.**

**7.3.2.2.1 General.** Exterior use of compressed gases shall be in accordance with the requirements of Sections 7.4 through 7.10.

**7.3.2.2.2 Separation.** Distances from property lines, buildings, and exposure hazards shall be in accordance with the material-specific provisions of Sections 7.4 through 7.10.

**7.3.3 Handling.**

**7.3.3.1 Applicability.** The handling of compressed gas containers, cylinders, and tanks shall be in accordance with 7.3.3.

**7.3.3.2 Carts and Trucks.**

**7.3.3.2.1** Containers, cylinders, and tanks shall be moved using an approved method.

**7.3.3.2.2** Where containers, cylinders, or tanks are moved by hand cart, hand truck, or other mobile device, such carts, trucks, or devices shall be designed for the secure movement of containers, cylinders, or tanks.

**7.3.3.3 Lifting Devices.** Ropes, chains, or slings shall not be used to suspend compressed gas containers, cylinders, and tanks unless provisions at time of manufacture have been made on the container, cylinder, or tank for appropriate lifting attachments, such as lugs.

**7.4 Medical Gas Systems.** Medical gas systems for health care shall be in accordance with NFPA 99, *Standard for Health Care Facilities*.

**7.5 Corrosive Gases.**

**7.5.1 General.** The storage or use of corrosive compressed gases exceeding the quantity thresholds for gases requiring special provisions as specified in Table 6.3.1.1 shall be in accordance with Chapters 1 through 6 and Sections 7.1 through 7.3 and 7.5.

**7.5.2 Distance to Exposures.** The outdoor storage or use of corrosive compressed gas shall not be within 20 ft (6.1 m) of buildings not associated with the manufacture or distribution of corrosive gases, lot lines, streets, alleys, public ways, or means of egress.

**7.5.2.1** A 2-hour fire barrier wall without openings or penetrations and that extends not less than 30 in. (762 mm) above and to the sides of the storage or use area shall be permitted in lieu of the 20 ft (6.1 m) distance.

**7.5.2.1.1\*** Where a fire barrier is used to protect compressed gas systems, the system shall terminate downstream of the source valve.

**7.5.2.1.2** The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage or use area.

**7.5.2.1.3** The 2-hour fire barrier shall be located at least 5 ft (1.5 m) from any exposure.

**7.5.2.1.4** The 2-hour fire barrier wall shall not have more than two sides at approximately 90 degree (1.57 rad) directions or not more than three sides with connecting angles of approximately 135 degrees (2.36 rad).

**7.5.3 Indoor Use.** The indoor use of corrosive gases shall be provided with a gas cabinet, exhausted enclosure, or gas room.



**7.5.3.1 Gas Cabinets.** Gas cabinets shall be in accordance with Section 6.16.

**7.5.3.2 Exhausted Enclosures.** Exhausted enclosures shall be in accordance with Section 6.17.

**7.5.3.3 Gas Rooms.** Gas rooms shall be in accordance with Section 6.4.

**7.5.3.4 Treatment Systems.** Treatment systems, except as provided for in 7.5.3.4.1, gas cabinets, exhausted enclosures, and gas rooms containing corrosive gases in use shall be provided with exhaust ventilation, with all exhaust directed to a treatment system designed to process the accidental release of gas.

**7.5.3.4.1** Treatment systems shall not be required for corrosive gases in use where provided with the following:

- (1) Gas detection in accordance with 7.9.3.2.1.1
- (2) Fail-safe automatic closing valves in accordance with 7.9.3.2.2

**7.5.3.4.2** Treatment systems shall be capable of diluting, adsorbing, absorbing, containing, neutralizing, burning, or otherwise processing the release of corrosive gas in accordance with 7.9.3.4.1.

**7.5.3.4.3** Treatment system sizing shall be in accordance with 7.9.3.4.

## 7.6 Flammable Gases.

### 7.6.1 Storage, Use, and Handling.

**7.6.1.1** The storage or use of flammable gases exceeding the quantity thresholds for gases requiring special provisions as specified in Table 6.3.1.1 shall be in accordance with Chapters 1 through 6 and Sections 7.1 through 7.3 and 7.6.

**7.6.1.2** Storage, use, and handling of gaseous hydrogen shall be in accordance with 7.6.1 and Chapter 10.

**7.6.2 Distance to Exposures.** The outdoor storage or use of flammable compressed gas shall be located from lot lines, public streets, public alleys, public ways, or buildings not associated with the manufacture or distribution of such gases in accordance with Table 7.6.2.

**7.6.2.1** Bulk hydrogen gas installations shall be in accordance with Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b).

**7.6.2.1.1\*** Where a protective structure is used to protect compressed gas systems, the system shall terminate downstream of the source valve.

**7.6.2.1.2** The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage or use area.

**7.6.2.2** Bulk gas systems for flammable gases other than hydrogen shall be in accordance with Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b) where the quantity of flammable compressed gas exceeds 5000 ft<sup>3</sup> (scf) (141.6 m<sup>3</sup>).

**7.6.2.3** The configuration of the protective structure shall be designed to allow natural ventilation to prevent the accumulation of hazardous gas concentrations.

**7.6.2.4** Storage and use of flammable compressed gases shall not be located within 50 ft (15.2 m) of air intakes.

**7.6.2.5** Storage and use of flammable gases outside of buildings shall also be separated from building openings by 25 ft (7.6 m). Fire barriers shall be permitted to be used as a means to separate storage areas from openings or a means of egress used to access the public way.

**7.6.2.5.1** Bulk hydrogen gas installations shall be separated from building openings in accordance with Table 10.3.2.2.1(a) or Table 10.3.2.2.1(b).

**7.6.3 Ignition Source Control.** Ignition sources in areas containing flammable gases shall be in accordance with 7.6.3.

**7.6.3.1 Static Producing Equipment.** Static producing equipment located in flammable gas areas shall be grounded.

**7.6.3.2 No Smoking or Open Flame.** Signs shall be posted in areas containing flammable gases stating that smoking or the use of open flame, or both, is prohibited within 25 ft (7.6 m) of the storage or use area perimeter.

**7.6.4 Electrical.** Areas in which the storage or use of compressed gases exceeds the quantity thresholds for gases requiring

**Table 7.6.2 Distance to Exposures for Nonbulk Flammable Gases**

Maximum Amount per Storage Area (ft <sup>3</sup> )	Minimum Distance Between Storage Areas (ft)	Minimum Distance to Lot Lines of Property That Can Be Built Upon (ft)	Minimum Distance to Public Streets, Public Alleys or Public Ways (ft)	Minimum Distance to Buildings on the Same Property		
				Less Than 2-Hour Construction	2-Hour Construction	4-Hour Construction
0-4225	5	5	5	5	0	0
4226-21,125	10	10	10	10	5	0
21,126-50,700	10	15	15	20	5	0
50,701-84,500	10	20	20	20	5	0
84,501-200,000	20	25	25	20	5	0

For SI units, 1 ft = 304.8 mm; 1 ft<sup>3</sup> = 0.02832 m<sup>3</sup>.

Note: The minimum required distances shall not apply when fire barriers without openings or penetrations having a minimum fire resistive rating of 2 hours interrupt the line of sight between the storage and the exposure. The configuration of the fire barriers shall be designed to allow natural ventilation to prevent the accumulation of hazardous gas concentrations.



special provisions shall be in accordance with *NFPA 70, National Electrical Code*.

#### 7.6.5 Maintenance of Piping Systems.

**7.6.5.1** Maintenance of flammable gas system piping and components shall be performed annually by a qualified representative of the equipment owner.

**7.6.5.2** This maintenance shall include inspection for physical damage, leak tightness, ground system integrity, vent system operation, equipment identification, warning signs, operator information and training records, scheduled maintenance and retest records, alarm operation, and other safety-related features.

**7.6.5.3** Scheduled maintenance and retest activities shall be formally documented, and records shall be maintained a minimum of 3 years.

#### 7.7 Oxidizing Gases.

**7.7.1 General.** The storage or use of oxidizing compressed gases exceeding the quantity thresholds for gases requiring special provisions as specified in Table 6.3.1.1 shall be in accordance with Chapters 1 through 6 and Sections 7.1 through 7.3 and 7.7.

**7.7.2 Distance to Exposures.** The outdoor storage or use of oxidizing compressed gas shall be in accordance with Table 7.7.2.

**7.7.2.1** The distances shall not apply where fire barriers having a minimum fire resistance of 2 hours interrupt the line of sight between the container and the exposure.

**7.7.2.1.1\*** Where a fire barrier is used to protect compressed gas systems, the system shall terminate downstream of the source valve.

**7.7.2.1.2** The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage or use area.

**7.7.2.2** The fire barrier shall be at least 5 ft (1.5 m) from the storage or use area perimeter.

**7.7.2.3** The configuration of the fire barrier shall allow natural ventilation to prevent the accumulation of hazardous gas concentrations.

#### 7.8 Pyrophoric Gases.

**7.8.1 General.** Pyrophoric compressed gases exceeding the quantity thresholds for gases requiring special provisions as specified in Table 6.3.1.1 shall be stored and used in accordance with Chapters 1 through 6 and Sections 7.1 through 7.3 and 7.8.

**7.8.2 Silane and Silane Mixtures.** Silane and silane mixtures shall be stored, used, and handled in accordance with the provisions of ANSI/CGA G-13, *Storage and Handling of Silane and Silane Mixtures*.

**7.8.3 Distance to Exposures.** The outdoor storage or use of pyrophoric compressed gas shall be in accordance with Table 7.8.3.

**7.8.3.1** The distances shall be allowed to be reduced to 5 ft (1.5 m) where fire barriers having a minimum fire resistance of 2 hours interrupt the line of sight between the container and the exposure.

**7.8.3.1.1\*** Where a fire barrier is used to protect compressed gas systems, the system shall terminate downstream of the source valve.

**7.8.3.1.2** The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage or use area.

**7.8.3.2** The fire barrier shall be at least 5 ft (1.5 m) from the storage or use area perimeter.

**7.8.3.3** The configuration of the fire barrier shall allow natural ventilation to prevent the accumulation of hazardous gas concentrations.

#### 7.9 Toxic and Highly Toxic Gases.

**7.9.1 General.** The storage or use of toxic and highly toxic gases exceeding the quantity thresholds for gases requiring special provisions as specified in Table 6.3.1.1 shall be in accordance with Chapters 1 through 6 and Sections 7.1 through 7.3 and 7.9.

#### 7.9.2 Ventilation and Arrangement.

**7.9.2.1 Indoors.** The indoor storage or use of highly toxic gases or toxic gases shall be provided with a gas cabinet, exhausted enclosure, or gas room.

**7.9.2.1.1** Gas cabinets shall be in accordance with Section 6.16.

**7.9.2.1.2** Exhausted enclosures shall be in accordance with Section 6.17.

**7.9.2.1.3** Gas rooms shall be in accordance with Section 6.4.

**7.9.2.2 Distance to Exposures.** The outdoor storage or use of toxic and highly toxic compressed gases shall not be within 75 ft (23 m) of lot lines, streets, alleys, public ways or means of egress, or buildings not associated with such storage or use.

**7.9.2.2.1** A 2-hour fire barrier wall without openings or penetrations that extends not less than 30 in. (762 mm) above and to the sides of the storage or use area and that interrupts the line of sight between the storage or use area and the exposure shall be permitted in lieu of the 75 ft (23 m) distance.

**7.9.2.2.1.1\*** Where a fire barrier is used to protect compressed gas systems, the system shall terminate downstream of the source valve.

**Table 7.7.2 Distance to Exposures for Oxidizing Gases**

Quantity of Gas Stored (at NTP)		Distance to a Building Not Associated with the Manufacture or Distribution of Oxidizing Gases or to a Public Way or Property Line		Minimum Distance Between Storage Areas	
ft <sup>3</sup>	m <sup>3</sup>	ft	m	ft	m
0-50,000	0-1416	5	1.5	5	1.5
50,001-100,000	1417- 2832	10	3.0	10	3.0
≥100,001	≥2833	15	4.6	15	4.6

Table 7.8.3 Distance to Exposures for Pyrophoric Gases

Maximum Amount per Storage Area		Minimum Distance Between Storage Areas		Minimum Distance to Property Lines		Minimum Distance to Public Ways		Minimum Distance to Buildings on the Same Property					
								Nonrated or Openings Within 25 ft (7.6 m)	2 Hour and No Openings Within 25 ft (7.6 m)	4 Hour and No Openings Within 25 ft (7.6 m)			
ft <sup>3</sup>	m <sup>3</sup>	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m
250	7.1	5	1.5	25	7.6	5	1.5	5	1.5	0	0	0	0
2500	71.0	10	3.0	50	15.2	10	3.0	10	3.0	5	1.5	0	0
7500	212.4	20	6.0	100	30.5	20	6.0	20	6.0	10	3.0	0	0

**7.9.2.2.1.2** The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage or use area.

**7.9.2.2.1.3** The 2-hour fire barrier wall shall be located at least 5 ft (1.5 m) from any exposure.

**7.9.2.2.1.4** The 2-hour fire barrier wall shall not have more than two sides at approximately 90 degree (1.5 rad) directions or more than three sides with connecting angles of approximately 135 degrees (2.36 rad).

**7.9.2.2.2** Where the storage or use area is located closer than 75 ft (23 m) to a building not associated with the manufacture or distribution of toxic or highly toxic compressed gases, openings in the building other than for piping shall not be permitted above the height of the top of the 2-hour fire barrier wall or within 50 ft (15 m) horizontally from the storage area, regardless of whether the openings are shielded by a fire barrier.

**7.9.2.3 Air Intakes.** Storage and use of toxic and highly toxic compressed gases shall not be located within 75 ft (23 m) of air intakes.

**7.9.3 Treatment Systems.** Except as provided in 7.9.3.1 and 7.9.3.2, gas cabinets, exhausted enclosures, and gas rooms containing toxic or highly toxic gases shall be provided with exhaust ventilation, with all exhaust directed to a treatment system designed to process accidental release of gas.

**7.9.3.1 Storage of Toxic or Highly Toxic Gases.** Treatment systems shall not be required for toxic or highly toxic gases in storage where containers, cylinders, and tanks are provided with the controls specified in 7.9.3.1.1 through 7.9.3.1.3.

**7.9.3.1.1 Valve Outlets Protected.** Valve outlets shall be equipped with outlet plugs or caps, or both, rated for the container service pressure.

**7.9.3.1.2 Handwheels Secured.** Where provided, handwheel-operated valves shall be secured to prevent movement.

**7.9.3.1.3 Containment Devices Provided.** Approved cylinder containment vessels or cylinder containment systems shall be provided at an approved location.

**7.9.3.2 Use of Toxic Gases.** Treatment systems shall not be required for toxic gases in use where containers, cylinders, and tanks are provided with the controls specified in 7.9.3.2.1 and 7.9.3.2.2.

#### 7.9.3.2.1 Gas Detection.

**7.9.3.2.1.1** A gas detection system with a sensing interval not exceeding 5 minutes shall be provided.

**7.9.3.2.1.2** The gas detection system shall monitor the exhaust system at the point of discharge from the gas cabinet, exhausted enclosure, or gas room.

**7.9.3.2.2 Fail-Safe Automatic Closing Valve.** An approved automatic-closing fail-safe valve shall be located immediately adjacent to and downstream of active container, cylinder, or tank valves.

**7.9.3.2.2.1** The fail-safe valve shall close when gas is detected at the permissible exposure limit, short-term exposure limit (STEL), or ceiling limit by the gas detection system.

**7.9.3.2.2.2** For attended operations, a manual closing valve shall be permitted when in accordance 7.9.3.4.3.

**7.9.3.2.2.3** For gases used at unattended operations for the protection of public health, such as chlorine at water or wastewater treatment sites, the automatic valve shall close if the concentration of gas detected by a gas detection system reaches one-half of the IDLH.

**7.9.3.2.2.4** The gas detection system shall also alert persons on-site and a responsible person off-site when the gas concentration in the storage/use area reaches the OSHA PEL, OSHA ceiling limit, or OSHA STEL for the gas employed.

**7.9.3.3 Treatment System Design and Performance.** Treatment systems shall be capable of diluting, adsorbing, absorbing, containing, neutralizing, burning, or otherwise processing stored or used toxic or highly toxic gas, or both.

**7.9.3.3.1** Where a total containment system is used, the system shall be designed to handle the maximum anticipated pressure of release to the system when it reaches equilibrium.

**7.9.3.3.2** Treatment systems shall be capable of reducing the allowable discharge concentrations to one-half the IDLH threshold at the point of discharge.

#### 7.9.3.4 Treatment System Sizing.

**7.9.3.4.1 Worst-Case Release of Gas.** Treatment systems shall be sized to process the maximum worst-case release of gas based on the maximum flow rate of release from the largest vessel utilized in accordance with 7.9.3.4.2.



**7.9.3.4.2 Largest Compressed Gas Vessel.** The entire contents of the single largest compressed gas vessel shall be considered.

**7.9.3.4.3 Attended Operations — Alternative Method of System Sizing.**

**7.9.3.4.3.1** Where source containers, cylinders, and tanks are used in attended process operations, with an operator present at the enclosure where the activity occurs, the volume of the release shall be limited to the estimated amount released from the process piping system within a period not to exceed 5 minutes.

**7.9.3.4.3.2** Such process piping systems shall comply with the requirements of 7.9.3.4.3.2(A) through 7.9.3.4.3.2(E).

**(A) Local Exhaust.** All gas transfer operations shall be conducted within a zone of local exhaust that is connected to a treatment system.

**(B) Gas Detection.** Gas detection shall be used to provide a warning to alert the operators to emission of gas into the zone of local exhaust, and the following requirements also shall apply:

- (1) The system shall be capable of detecting gas at the PEL or the ceiling limit for the gas being processed.
- (2) Activation of the gas detection system shall provide a local alarm.

**(C) Process Shutdown.** Operations involving the gas detected shall be shut down and leaks repaired.

**(D) Piping System Construction.** Piping systems used to convey gases shall be of all-welded construction throughout, with the exception of fittings used to connect containers, cylinders, or tanks, or any combination thereof, to the process system.

**(E) Piping System Accessibility.** Piping systems shall be designed to provide for readily accessible manual shutdown controls.

**7.9.3.5 Rate of Release.** The time release shall be in accordance with Table 7.9.3.5 for the type of container indicated.

**Table 7.9.3.5 Rate of Release**

Container Type	Time Release	
	Nonliquefied Gases	Liquefied Gases
Cylinders without restrictive flow orifices	5 minutes	30 minutes
Portable tanks without restrictive flow orifices	40 minutes	240 minutes
All others	Based on peak flow from maximum valve orifice	Based on peak flow from maximum valve orifice

**7.9.3.6\* Maximum Flow Rate of Release.**

**7.9.3.6.1** For portable containers, cylinders, and tanks, the maximum flow rate of release shall be calculated based on assuming the total release from the cylinder or tank within the time specified.

**7.9.3.6.2\*** When portable containers, cylinders, or tanks are equipped with reduced flow orifices, the worst-case rate of release shall be determined by the maximum achievable flow from the valve based on the following formula:

$$CFM = (767 \times A \times P) \frac{(28.96 / MW)^{1/2}}{60}$$

where:

*CFM* = standard cubic feet per minute of gas of concern under flow conditions

*A* = area of orifice in square inches (See Table A.7.9.3.6 for areas of typical restricted flow orifices.)

*P* = supply pressure of gas at NTP in pounds per square inch absolute

*MW* = molecular weight

**7.9.3.6.3** For mixtures, the average of the molecular weights shall be used.

**7.9.4 Leaking Containers, Cylinders, and Tanks.** When containers, cylinders, or tanks are used outdoors in excess of the quantities specified in Table 6.3.1.1 in the column for unsprinkled areas (unprotected by gas cabinets or exhausted enclosures), a gas cabinet, exhausted enclosure, or containment vessel or system shall be provided to control leaks from leaking containers, cylinders, and tanks in accordance with 7.9.4.1 through 7.9.4.2.3.

**7.9.4.1 Gas Cabinets or Exhausted Enclosures.** Where gas cabinets or exhausted enclosures are provided to handle leaks from containers, cylinders, or tanks, exhaust ventilation shall be provided that is directed to a treatment system in accordance with the provisions of 7.9.3.

**7.9.4.2 Containment Vessels or Systems.** Where containment vessels or containment systems are provided, they shall comply with the requirements of 7.9.4.2.1 through 7.9.4.2.3.

**7.9.4.2.1 Performance.** Containment vessels or containment systems shall be capable of fully containing or terminating a release.

**7.9.4.2.2 Personnel.** Trained personnel capable of operating the containment vessel or containment system shall be available at an approved location.

**7.9.4.2.3 Location.** Containment vessels or systems shall be capable of being transported to the leaking cylinder, container, or tank.

**7.9.5 Emergency Power.**

**7.9.5.1 General.** Emergency power shall comply with the requirements of 7.9.5 in accordance with *NFPA 70, National Electrical Code*.

**7.9.5.2 Alternative to Emergency Power.** Emergency power shall not be required where fail-safe engineering is provided for mechanical exhaust ventilation, treatment systems, and temperature control, and standby power is provided to alternative systems that utilize electrical energy.

**7.9.5.3 Where Required.** Emergency power shall be provided for the following systems:

- (1) Exhaust ventilation
- (2) Treatment system
- (3) Gas detection system
- (4) Temperature control system
- (5) Required alarm systems

**7.9.5.4 Level.** Emergency power systems shall comply with the requirements for a Level 2 system in accordance with *NFPA 110, Standard for Emergency and Standby Power Systems*.



**7.9.6 Gas Detection.** Except as provided in 7.9.6.1, a continuous gas detection system in accordance with the requirements of 7.9.6.2 through 7.9.6.6 shall be provided for the indoor storage or use of toxic or highly toxic compressed gases.

**7.9.6.1 Where Gas Detection Is Not Required.** A gas detection system shall not be required for toxic gases where the physiological warning properties for the gas are at a level below the accepted PEL or the ceiling limit for the gas.

**7.9.6.2 Local Alarm.** The gas detection system shall initiate a local alarm that is both audible and visible.

**7.9.6.3 Alarm Monitored.** The gas detection system shall transmit a signal to a constantly attended control station for quantities exceeding one toxic or highly toxic compressed gas cylinder.

**7.9.6.4 Automatic Shutdown.**

**7.9.6.4.1** Activation of the gas detection system shall automatically shut off the flow of gas related to the system being monitored.

**7.9.6.4.2** An automatic shutdown shall not be required for reactors utilized for the production of toxic or highly toxic gases when such reactors are operated at gauge pressures less than 15 psi (103.4 kPa), constantly attended, and provided with readily accessible emergency shutoff valves.

**7.9.6.5 Detection Points.** Detection shall be provided at the locations specified in 7.9.6.5.1 through 7.9.6.5.4.

**7.9.6.5.1 Treatment System Discharge.** Detection shall be provided at the discharge from the treatment system.

**7.9.6.5.2 Point of Use.** Detection shall be provided in the room or area in which the gas is used.

**7.9.6.5.3 Source.** Detection shall be provided at the source container, cylinder, or tank used for delivery of the gas to the point of use.

**7.9.6.5.4 Storage.** Detection shall be provided in the room or area in which the gas is stored.

**7.9.6.6 Level of Detection.** The gas detection system shall detect the presence of gas at or below the PEL or the ceiling limit of the gas for those points identified in 7.9.6.5.2 and 7.9.6.5.3 and at not less than one-half the IDLH level for points identified in 7.9.6.5.1.

**7.9.7 Automatic Smoke Detection System.** An automatic smoke detection system shall be provided for the indoor storage or use of highly toxic compressed gases in accordance with *NFPA 72, National Fire Alarm and Signaling Code*.

**7.10 Unstable Reactive Gases (Nondetonable).** The storage or use of unstable reactive (nondetonable) gases exceeding the quantity thresholds for gases requiring special provisions as specified in Table 6.3.1.1 shall be in accordance with Chapters 1 through 6 and Sections 7.1 through 7.3 and 7.10.

**7.10.1 Distances to Exposures for Class 2.**

**7.10.1.1** The outdoor storage or use of unstable reactive Class 2 compressed gas shall not be within 20 ft (6 m) of buildings, lot lines, streets, alleys, or public ways or means of egress.

**7.10.1.2** A 2-hour fire barrier wall without openings or penetrations shall be permitted in lieu of the 20 ft (6 m) distance required by 7.10.1.1.

**7.10.1.2.1\*** Where a fire barrier wall is used to protect compressed gas systems, the system shall terminate downstream of the source valve.

**7.10.1.2.2** The fire barrier wall shall be either an independent structure or the exterior wall of the building.

**7.10.1.2.3** The 2-hour fire barrier wall shall be located at least 5 ft (1.5 m) from any exposure.

**7.10.1.2.4** The 2-hour fire barrier wall shall not have more than two sides at approximately 90 degree (1.57 rad) directions or not more than three sides with connecting angles of approximately 135 degrees (2.36 rad).

**7.10.2 Distances to Exposures for Class 3.**

**7.10.2.1** The outdoor storage or use of unstable reactive Class 3 (nondetonable) compressed gas shall not be within 75 ft (23 m) of buildings, lot lines, streets, alleys, or public ways or means of egress.

**7.10.2.2** A 2-hour fire barrier wall without openings or penetrations, extending not less than 30 in. (762 mm) above and to the sides of the storage or use area, that interrupts the line of sight between the storage or use and the exposure shall be permitted in lieu of the 75 ft (23 m) distance specified in 7.10.2.1.

**7.10.2.2.1\*** Where a fire barrier wall is used to protect compressed gas systems, the system shall terminate downstream of the source valve.

**7.10.2.2.2** The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage or use area.

**7.10.2.2.3** The 2-hour fire barrier wall shall be located at least 5 ft (1.5 m) from any exposure.

**7.10.2.2.4** The 2-hour fire barrier wall shall not have more than two sides at approximately 90 degree (1.57 rad) directions or more than three sides with connecting angles of approximately 135 degrees (2.36 rad).

**7.10.3 Storage Configuration.**

**7.10.3.1** Unstable reactive Class 3 compressed gases stored in cylinders, containers, or tanks shall be arranged to limit individual groups of cylinders, containers, or tanks to areas not exceeding 100 ft<sup>2</sup> (9.3 m<sup>2</sup>).

**7.10.3.2** Multiple areas shall be separated by aisles.

**7.10.3.3** Aisle widths shall not be less than the height of the cylinders, containers, or tanks or 4 ft (1.2 m), whichever is greater.

**7.10.4 Basements.** Unstable reactive compressed gases shall not be stored in basements.

**7.10.5 Unstable Reactive Gases (Detonable).**

**7.10.5.1 Storage or Use.** The storage or use of unstable reactive (detonable) gases exceeding the quantity thresholds for gases requiring special provisions as specified in Table 6.3.1.1 shall be in accordance with Chapters 1 through 6, Sections 7.1 through 7.3, and 7.10.5.

**7.10.5.2 Location.** The location of storage areas shall be determined based on the requirements of the building code for explosive materials.



## Chapter 8 Cryogenic Fluids

**8.1 General.** This chapter shall apply to all cryogenic fluids, including those fluids regulated elsewhere in this code, except that where specific requirements are provided in other chapters, those specific requirements shall apply in accordance with the applicable chapter.

**8.1.1** Storage, use, and handling of cryogenic fluids shall be in accordance with Chapters 1 through 6 and Chapter 8 as applicable.

**8.1.2** Storage, use, and handling of inert cryogenic fluids shall be in accordance with CGA P-18, *Standard for Bulk Inert Gas Systems at Consumer Sites*.

**8.2\* Containers — Design, Construction, and Maintenance.** Containers employed for the storage or use of cryogenic fluids shall be designed, fabricated, tested, marked (stamped), and maintained in accordance with DOT regulations; Transport Canada (TC), *Transportation of Dangerous Goods Regulations*; the ASME *Boiler and Pressure Vessel Code*, “Rules for the Construction of Unfired Pressure Vessels”; or regulations of other administering agencies.

**8.2.1 Aboveground Tanks.** Aboveground tanks for the storage of cryogenic fluids shall be in accordance with 8.2.1.

**8.2.1.1 Construction of the Inner Vessel.** The inner vessel of storage tanks in cryogenic fluid service shall be designed and constructed in accordance with Section VIII, Division 1 of the ASME *Boiler and Pressure Vessel Code* and shall be vacuum jacketed in accordance with 8.2.1.2.

**8.2.1.2 Construction of the Vacuum Jacket (Outer Vessel).**

**8.2.1.2.1** The vacuum jacket used as an outer vessel for storage tanks in cryogenic fluid service shall be of welded steel construction designed to withstand the maximum internal and external pressure to which it will be subjected under operating conditions to include conditions of emergency pressure relief of the annular space between the inner vessel and the outer vessel.

**8.2.1.2.2** The jacket shall be designed to withstand a minimum collapsing pressure differential of 30 psi (207 kPa).

**8.2.1.2.3 Vacuum Level Monitoring.**

**8.2.1.2.3.1** A connection shall be provided on the exterior of the vacuum jacket to allow measurement of the pressure within the annular space between the inner vessel and the outer vessel.

**8.2.1.2.3.2** The connection shall be fitted with a bellows-sealed or diaphragm-type valve equipped with a vacuum gauge tube that is shielded to protect against damage from impact.

**8.2.2 Nonstandard Containers.**

**8.2.2.1** Containers, equipment, and devices that are not in compliance with recognized standards for design and construction shall be permitted if approved by the authority having jurisdiction upon presentation of evidence that they are designed and constructed for safe operation.

**8.2.2.2** The following data shall be submitted to the authority having jurisdiction with reference to the deviation from the standard with the application for approval:

- (1) Type and use of container, equipment, or device
- (2) Material to be stored, used, or transported

- (3) Description showing dimensions and materials used in construction
- (4) Design pressure, maximum operating pressure, and test pressure
- (5) Type, size, and setting of pressure relief devices

**8.2.3 Concrete Containers.**

**8.2.3.1** Concrete containers shall be built in accordance with the building code.

**8.2.3.2** Barrier materials and membranes used in connection with concrete, but not functioning structurally, shall be materials prescribed by nationally recognized standards.

**8.2.4 Foundations and Supports.** Stationary tanks shall be provided with concrete or masonry foundations or structural steel supports on firm concrete or masonry foundations, and the requirements of 8.2.4.1 through 8.2.4.5 also shall apply.

**8.2.4.1 Excessive Loads.** Stationary tanks shall be supported to prevent the concentration of excessive loads on the supporting portion of the shell.

**8.2.4.2 Expansion and Contraction.** Foundations for horizontal containers shall be constructed to accommodate expansion and contraction of the container.

**8.2.4.3\* Support of Ancillary Equipment.**

**8.2.4.3.1** Foundations shall be provided to support the weight of vaporizers or heat exchangers.

**8.2.4.3.2** Foundations shall be designed to withstand soil and frost conditions as well as the anticipated seismic, snow, wind, and hydrostatic loading under operating conditions.

**8.2.4.4 Temperature Effects.** Where drainage systems, terrain, or surfaces beneath stationary tanks are arranged in a manner that can subject stationary tank foundations or supports to temperatures below  $-130^{\circ}\text{F}$  ( $-90^{\circ}\text{C}$ ), the foundations or supports shall be constructed of materials that are capable of withstanding the low-temperature effects of cryogenic fluid spillage.

**8.2.4.5 Corrosion Protection.** Portions of stationary tanks in contact with foundations or saddles shall be painted to protect against corrosion.

**8.2.5 Pressure Relief Devices.**

**8.2.5.1 General.**

**8.2.5.1.1** Pressure relief devices shall be provided to protect containers and systems containing cryogenic fluids from rupture in the event of overpressure.

**8.2.5.1.2** Pressure relief devices shall be designed in accordance with CGA S-1.1, *Pressure Relief Device Standards — Part 1 — Cylinders for Compressed Gases*, and CGA S-1.2, *Pressure Relief Device Standards — Part 2 — Cargo and Portable Tanks for Compressed Gases*, for portable tanks; and CGA S-1.3, *Pressure Relief Device Standards — Part 3 — Stationary Storage Containers for Compressed Gases*, for stationary tanks.

**8.2.5.2 Containers Open to the Atmosphere.** Portable containers that are open to the atmosphere and are designed to contain cryogenic fluids at atmospheric pressure shall not be required to be equipped with pressure relief devices.

**8.2.5.3 Equipment Other Than Containers.** Heat exchangers, vaporizers, insulation casings surrounding containers, vessels, and coaxial piping systems in which liquefied cryogenic fluids could be trapped due to leakage from the primary container shall be provided with a pressure relief device.

#### 8.2.5.4 Sizing.

**8.2.5.4.1** Pressure relief devices shall be sized in accordance with the specifications to which the container was fabricated.

**8.2.5.4.2** The pressure relief device shall have the capacity to prevent the maximum design pressure of the container or system from being exceeded.

**8.2.5.5 Accessibility.** Pressure relief devices shall be located such that they are accessible for inspection and repair.

**8.2.5.5.1\*** ASME pressure relief valves shall be sealed to prevent adjustment of the set pressure by other than authorized personnel.

**8.2.5.5.2** Non-ASME pressure relief valves shall not be field adjusted.

#### 8.2.5.6 Arrangement.

**8.2.5.6.1 Pressure Relief Devices.** Pressure relief devices shall be arranged to discharge unobstructed to the open air in such a manner as to prevent impingement of escaping gas on personnel, containers, equipment, and adjacent structures or its entrance into enclosed spaces.

**8.2.5.6.2 Portable Containers with Volume Less Than 2.0 ft<sup>3</sup> (0.057 m<sup>3</sup>).**

**8.2.5.6.2.1** The arrangement of the discharge from pressure relief devices from DOT-specified containers with an internal water volume of 2.0 ft<sup>3</sup> (0.057 m<sup>3</sup>) or less shall be incorporated in the design of the container.

**8.2.5.6.2.2** Additional safeguards regarding placement or arrangement shall not be required.

#### 8.2.5.7 Shutoffs Between Pressure Relief Devices and Containers.

**8.2.5.7.1 General.** Shutoff valves installed between pressure relief devices and containers shall be in accordance with 8.2.5.7.

**8.2.5.7.2 Location.** Shutoff valves shall not be installed between pressure relief devices and containers unless the valves or their use meet the requirements of 8.2.5.7.2.1 or 8.2.5.7.2.2.

**8.2.5.7.2.1 Security.** Shutoff valves shall be of a locking type, and their use shall be limited to service-related work performed by the supplier under the requirements of the ASME *Boiler and Pressure Vessel Code*.

**8.2.5.7.2.2 Multiple Pressure Relief Devices.** Shutoff valves controlling multiple pressure relief devices on a container shall be installed so that either the type of valve installed or the arrangement provides the full required flow through the minimum number of required relief devices at all times.

**8.2.5.8 Temperature Limits.** Pressure relief devices shall not be subjected to cryogenic fluid temperatures except when operating.

### 8.3 Pressure Relief Vent Piping.

**8.3.1 General.** Pressure relief vent piping systems shall be constructed and arranged to direct the flow of gas to a safe location and in accordance with Section 8.3.

**8.3.2 Sizing.** Pressure relief device vent piping shall have a cross-sectional area not less than that of the pressure relief device vent opening and shall be arranged so as not to restrict the flow of escaping gas.

**8.3.3 Arrangement.** Pressure relief device vent piping and drains in vent lines shall be arranged so that escaping gas discharges unobstructed to the open air and does not impinge on personnel, containers, equipment, and adjacent structures or enter enclosed spaces.

**8.3.4 Installation.** Pressure relief device vent lines shall be installed in a manner that excludes or removes moisture and condensation to prevent malfunction of the pressure relief device due to freezing or ice accumulation.

**8.3.5 Overfilling.** Controls shall be provided to prevent overfilling of stationary containers.

### 8.4 Marking.

**8.4.1 General.** Cryogenic containers and systems shall be marked in accordance with nationally recognized standards and in accordance with Section 8.4.

#### 8.4.1.1 Portable Containers.

**8.4.1.1.1** Portable cryogenic containers shall be marked in accordance with CGA C-7, *Guide to the Preparation of Precautionary Labeling and Marking of Compressed Gas Containers*.

**8.4.1.1.2\*** All DOT-4L/TC-4LM liquid cylinders shall have product identification visible from all directions with minimum 2 in. (51 mm) high letters.

**8.4.1.2 Stationary Tanks.** Stationary tanks shall be marked in accordance with NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*.

**8.4.1.3 Identification Signs.** Visible hazard identification signs shall be provided in accordance with NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*, at entrances to buildings or areas in which cryogenic fluids are stored, handled, or used.

**8.4.2 Identification of Contents.** Stationary containers shall be placarded with the identity of their contents to indicate the name of the material contained.

**8.4.3 Container Specification.** Stationary containers shall be marked with the manufacturing specification and maximum allowable working pressure on a permanent nameplate.

**8.4.3.1** The nameplate shall be installed on the container in an accessible location.

**8.4.3.2** The nameplate shall be marked in accordance with nationally recognized standards.

#### 8.4.4 Identification of Container Connections.

**8.4.4.1** Container inlet and outlet connections, liquid-level limit controls, valves, and pressure gauges shall be identified using one of the methods prescribed by 8.4.4.1.1 through 8.4.4.1.2.

**8.4.4.1.1** They shall be marked with a permanent tag or label identifying their function.

**8.4.4.1.2** They shall be identified by a schematic drawing that indicates their function and designates whether they are connected to the vapor or liquid space of the container.

**8.4.4.1.2.1** When a schematic drawing is provided, it shall be attached to the container and maintained in a legible condition.





**8.4.5 Identification of Piping Systems.** Piping systems shall be identified in accordance with ASME A13.1, *Scheme for the Identification of Piping Systems*.

**8.4.6 Identification of Emergency Shutoff Valves.** Emergency shutoff valves on stationary containers shall be identified, visible, and indicated by means of a sign.

## 8.5 Medical Cryogenic Systems.

**8.5.1** Bulk cryogenic fluid systems in medical gas applications at health care facilities shall be in accordance with Chapter 8, 1.1.2(3), and the material-specific requirements of Chapter 9 as applicable.

**8.5.1.1** Bulk cryogenic fluid systems shall be in accordance with the following provisions as applicable:

- (1) Where located in a court, systems shall be in accordance with 8.13.2.7.2.
- (2) Where located indoors, systems shall be in accordance with 8.14.11.1.
- (3) Systems shall be installed by personnel qualified in accordance with CGA M-1, *Guide for Medical Gas Installations at Consumer Sites*.
- (4) Systems shall be installed in compliance with Food and Drug Administration Current Good Manufacturing Practices as found in 21 CFR 210 and 21 CFR 211.

**8.5.1.2** The following components of the bulk system shall be accessible and visible to delivery personnel during filling operations:

- (1) Fill connection
- (2) Top and bottom fill valves
- (3) Hose purge valve
- (4) Vent valve
- (5) Full trycock valve
- (6) Liquid level gauge
- (7) Tank pressure gauge

**8.5.1.3** Bulk cryogenic fluid systems shall be anchored with foundations in accordance with the provisions of CGA M-1, *Guide for Medical Gas Installations at Consumer Sites*.

**8.5.1.4** A delivery vehicle pad shall be provided in accordance with 9.3.2.3.

**8.5.1.5** Bulk cryogenic fluid systems shall consist of the following:

- (1) One or more main supply vessel(s), whose capacity shall be determined after consideration of the customer usage requirements, delivery schedules, proximity of the facility to alternative supplies, and the emergency plan
- (2) A contents gauge on each of the main vessel(s)
- (3) A reserve supply sized for greater than an average day's supply, with the size of vessel or number of cylinders being determined after consideration of delivery schedules, proximity of the facility to alternative supplies, and the facility's emergency plan
- (4) At least two main vessel relief valves and rupture discs installed downstream of a three-way (three-port) valve
- (5) A check valve located in the primary supply piping upstream of the intersection with a secondary supply or reserve supply

**8.5.1.6** Bulk cryogenic fluid reserve supply systems shall include the following:

- (1) A second cryogenic fluid vessel or a cylinder header having gas cylinder connections for an average day's supply, but not fewer than three

- (2) An actuating switch/sensor monitoring internal pressure of the reserve cryogenic fluid vessel (where provided)
- (3) A contents gauge monitoring liquid level in the reserve cryogenic fluid vessel (where provided)
- (4) A check valve to prevent backflow into the reserve system
- (5) A pressure switch monitoring the pressure in the cylinder header (where provided)

**8.5.1.7** Bulk cryogenic fluid systems shall include a fill mechanism consisting of the following components:

- (1) A nonremovable product-specific fill connection in compliance with CGA V-6, *Standard Cryogenic Liquid Transfer Connection*
- (2) A means to cap and secure the fill connection inlet
- (3) A strainer with a minimum 100 mesh screen with a body and screen both of Monel® or brass construction
- (4) A check valve to prevent product backflow from the fill inlet
- (5) A fill hose purge valve
- (6) Supports that hold the fill piping off the ground
- (7) A secure connection between the bulk tank and the fill piping
- (8) Supports as necessary to hold the fill line in position during all operations associated with the filling procedure

**8.5.1.8** Where vaporizers are required to convert cryogenic liquid to the gaseous state, the vaporizer units shall conform to the following:

- (1) Be permitted to operate by either ambient heat transfer or external thermal source (e.g., electric heater, hot water, steam)
- (2) Be designed to provide capacity for the customer's peak and average flow rates under local conditions, seasonal conditions for weather and humidity, and structures that obstruct air circulation flow and sunlight
- (3) If switching is required as part of the system design, have piping and manual/automatic valving configured in such a manner that operating vaporizer(s) or sections of the vaporizer can be switched to nonoperating vaporizer or section of the vaporizer to de-ice through a valving configuration that ensures continuous flow to the facility through either or both vaporizers and/or sections of the vaporizer if valving switchover fails

**8.5.1.9** Where a vaporizer requires an external thermal source, the flow from the source of supply shall be unaffected by the loss of the external thermal source through either of the following:

- (1) Reserve ambient heat transfer vaporizers capable of providing capacity for at least one day's average supply and piped so as to be unaffected by flow stoppage through the main vaporizer
- (2) A reserve noncryogenic source capable of providing at least one day's average supply

## 8.6 Security.

**8.6.1 General.** Cryogenic containers and systems shall be secured against accidental dislodgement and against access by unauthorized personnel in accordance with Section 8.6.

**8.6.2 Security of Areas.** Areas used for the storage of containers and systems shall be secured against unauthorized entry.

**8.6.3 Securing of Containers.** Stationary containers shall be secured to foundations in accordance with the building code.

**8.6.3.1** Portable containers subject to shifting or upset shall be secured.

**8.6.3.2** Nesting shall be permitted as a means of securing portable containers.

**8.6.4 Securing of Vaporizers.** Vaporizers, heat exchangers, and similar equipment shall be secured to foundations, and their connecting piping shall be designed and constructed to provide for the effects of expansion and contraction due to temperature changes.

**8.6.5 Physical Protection.** Containers, piping, valves, pressure relief devices, regulating equipment, and other appurtenances shall be protected against physical damage and tampering.

## 8.7 Separation from Hazardous Conditions.

**8.7.1 General.** Cryogenic containers and systems in storage or use shall be separated from materials and conditions that present exposure hazards to or from each other in accordance with Section 8.7.

**8.7.2\* Stationary Cryogenic Containers.** Stationary containers located outdoors shall be separated from exposure hazards in accordance with the minimum separation distances indicated in Table 8.7.2.

**Table 8.7.2 Minimum Separation Distance Between Stationary Cryogenic Containers and Exposures**

Exposure	Minimum Distance	
	ft	m
(1) Buildings, regardless of construction type	1	0.3
(2) Wall openings and other building exits	1	0.3
(3) Air intakes	10	3.1
(4) Property lines	5	1.5
(5) Places of public assembly (assembly occupancies)	50	15
(6) Nonambulatory patient areas	50	15
(7) Combustible materials, (e.g., paper, leaves, weeds, dry grass, debris)	15	4.5
(8) Incompatible hazardous materials	20	6.1
(9) Building exits	10	3.1

**8.7.2.1 Fire Barriers.** A 2-hour fire barrier wall shall be permitted in lieu of the distances specified in Table 8.7.2 for items 1, 4, 7, 8, and 9, where in accordance with the provisions of 8.7.2.1.1 through 8.7.2.1.4.

**8.7.2.1.1** The fire barrier wall shall be without openings or penetrations.

**8.7.2.1.1.1** Penetrations of the fire barrier wall by conduit or piping shall be permitted provided that the penetration is protected with a firestop system in accordance with the building code.

**8.7.2.1.2** The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage system.

**8.7.2.1.3** The fire barrier wall shall be located not less than 5 ft (1.5 m) from any exposure.

**8.7.2.1.4** The fire barrier wall shall not have more than two sides at 90 degree (1.57 rad) directions or not more than three sides with connecting angles of 135 degrees (2.36 rad).

**8.7.2.1.5** Where the requirement of 8.7.2.1.4 is met, the bulk system shall be a minimum distance of 1 ft (0.3 m) from the fire barrier wall.

**8.7.2.2 Point-of-Fill Connections.** Point-of-fill connections serving stationary containers filled by mobile transport equipment shall not be positioned closer to exposures than the minimum distances in Table 8.7.2.

**8.7.2.3 Surfaces Beneath Containers.** The surface of the area on which stationary containers are placed, including the surface of the area located below the point at which connections are made for the purpose of filling such containers, shall be compatible with the fluid in the container.

**8.7.3 Portable Cryogenic Containers.** Portable containers located outdoors shall be separated from exposure hazards in accordance with Table 8.7.3.

**Table 8.7.3 Minimum Separation Distance Between Portable Cryogenic Containers and Exposures**

Exposure	Minimum Distance	
	ft	m
Building exits	10	3.1
Wall openings	1	0.3
Air intakes	10	3.1
Property lines	5	1.5
Room or area exits	3	0.9
Combustible materials, (e.g., paper, leaves, weeds, dry grass, debris)	15	4.5
Incompatible hazardous materials	20	6.1

**8.7.3.1 Fire Barriers.** A 2-hour fire barrier wall shall be permitted in lieu of the distances specified by Table 8.7.3 when in accordance with the provisions of 8.7.3.1.1 through 8.7.3.1.4.

**8.7.3.1.1** The fire barrier wall shall be without openings or penetrations.

**8.7.3.1.1.1** Penetrations of the fire barrier wall by conduit or piping shall be permitted provided that the penetration is protected with a firestop system in accordance with the building code.

**8.7.3.1.2** The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage system.

**8.7.3.1.3** The fire barrier wall shall be located not less than 5 ft (1.5 m) from any exposure.



**8.7.3.1.4** The fire barrier wall shall not have more than two sides at approximately 90 degree (1.57 rad) directions or not more than three sides with connecting angles of approximately 135 degrees (2.36 rad).

## **8.8 Electrical Wiring and Equipment.**

**8.8.1 General.** Electrical wiring and equipment shall be in accordance with *NFPA 70, National Electrical Code*, and Section 8.8.

**8.8.2 Location.** Containers and systems shall not be located where they could become part of an electrical circuit.

**8.8.3 Electrical Grounding and Bonding.** Containers and systems shall not be used for electrical grounding.

**8.8.3.1** When electrical grounding and bonding are required, the system shall be in accordance with *NFPA 70, National Electrical Code*.

**8.8.3.2** The grounding system shall be protected against corrosion, including corrosion caused by stray electrical currents.

**8.9 Service and Repair.** Service, repair, modification, or removal of valves, pressure relief devices, or other container appurtenances shall be in accordance with nationally recognized standards.

**8.9.1 Containers.** Containers that have been removed from service shall be handled in an approved manner.

**8.9.1.1 Testing.** Containers out of service in excess of 1 year shall be inspected and tested as required in 8.9.1.2.

**8.9.1.2 Pressure Relief Device Testing.** The pressure relief devices shall be tested for operability and to determine if they are set at the relief pressure required by the tank design.

**8.9.2 Systems.** Service and repair of containers or systems shall be performed by trained personnel in accordance with nationally recognized standards and with the permission of the container owner.

**8.10 Unauthorized Use.** Containers shall not be used for any purpose other than to serve as a vessel for containing the product for which it is designated.

## **8.11 Leaks, Damage, and Corrosion.**

**8.11.1** Leaking, damaged, or corroded containers shall be removed from service.

**8.11.2** Leaking, damaged, or corroded systems shall be replaced, repaired, or removed from service.

**8.12 Lighting.** Where required by the authority having jurisdiction, lighting, including emergency lighting, shall be provided for fire appliances and operating facilities such as walkways, control valves, and gates ancillary to stationary containers.

## **8.13 Storage.**

### **8.13.1 Indoor Storage.**

**8.13.1.1 Installation.** Stationary containers indoors shall be installed in accordance with Chapters 9 and 11 or with ANSI/CGA P-18, *Standard for Bulk Inert Gas Systems at Consumer Sites*.

**8.13.1.2 Stationary Containers.** Stationary containers shall be in accordance with Section 8.2.

**8.13.1.3 Cryogenic Fluids.** Cryogenic fluids in stationary or portable containers stored indoors shall be stored in buildings, rooms, or areas constructed in accordance with the building code.

**8.13.1.4 Ventilation.** Ventilation shall be in accordance with Section 6.15.

### **8.13.2 Outdoor Storage.**

**8.13.2.1 General.** Cryogenic fluids in stationary or portable containers stored outdoors shall be in accordance with 8.13.2.

**8.13.2.2 Access.** Stationary containers shall be located to provide access by mobile supply equipment and authorized personnel.

**8.13.2.2.1** Where exit access is provided to serve areas in which equipment is installed, the minimum width shall be not less than 28 in. (710 mm).

**8.13.2.3 Physical Protection.** Cryogenic fluid containers, cylinders, tanks, and systems that could be exposed to physical damage shall be protected.

**8.13.2.3.1** Guard posts or other means shall be provided to protect cryogenic fluid containers, cylinders, tanks, and systems indoors and outdoors from vehicular damage. (*See Section 4.11.*)

**8.13.2.4 Diked Areas Containing Other Hazardous Materials.** Containers of cryogenic fluids shall not be located within diked areas with other hazardous materials.

**8.13.2.5\* Areas Subject to Flooding.** Stationary containers located in flood hazard areas shall be anchored to prevent flotation during conditions of the design flood as designated by the building code.

**8.13.2.5.1 Elevated Tanks.** Structures supporting elevated tanks and tanks that are supported at a level above that designated in the design flood shall be anchored to resist lateral shifting due to flood and other hydrostatic effects.

**8.13.2.5.2 Underground Tanks.** Underground tanks in flood hazard areas shall be anchored to prevent flotation, collapse, or lateral movement resulting from hydrostatic loads, including the effects of buoyancy, during conditions of the design flood.

### **8.13.2.6 Drainage.**

**8.13.2.6.1** The area surrounding stationary and portable containers shall be provided with a means to prevent accidental discharge of fluids from endangering personnel, containers, equipment, and adjacent structures and from entering enclosed spaces in accordance with *NFPA 1, Fire Code*.

**8.13.2.6.2** The stationary container shall not be placed where spilled or discharged fluids will be retained around the container.

**8.13.2.6.3** The provisions of 8.13.2.5.2 shall be permitted to be altered or waived where the authority having jurisdiction determines that the container does not constitute a hazard after consideration of special features such as the following:

- (1) Crushed rock utilized as a heat sink
- (2) Topographical conditions
- (3) Nature of occupancy
- (4) Proximity to structures on the same or adjacent property
- (5) Capacity and construction of containers and character of fluids to be stored

**8.13.2.6.4** The grade for a distance of not less than 50 ft (15.2 m) from where cryogenic fluid storage or delivery systems are installed shall be higher than the grade on which flammable or combustible liquids are stored or used.

#### 8.13.2.6.4.1\* Drainage Control.

(A) Where the grade differential between the storage or delivery system and the flammable or combustible liquids storage or use area is not in accordance with 8.13.2.6.4, diversion curbs or other means of drainage control shall be used to divert the flow of flammable or combustible liquids away from the cryogenic system.

(B) The means of drainage control shall prevent the flow of flammable or combustible liquid to a distance not less than 50 ft (15.2 m) from all parts of the delivery system.

#### 8.13.2.7 Outdoor Installations.

**8.13.2.7.1 Enclosed Courts.** Stationary containers shall not be installed within enclosed courts.

**8.13.2.7.2\* Courts.** Stationary containers shall be sited so that they are open to the surrounding environment except that encroachment by building walls of unlimited height shall be permitted when in accordance with the distances specified by Table 8.7.2 or the material-specific tables in Chapters 9 through 11.

**8.13.2.7.2.1\*** Where exterior building walls encroach on the system to form a court, the system shall be located at a distance not less than the height of the wall from at least two court walls.

**8.13.2.7.2.2** The required distance between the exterior walls of the building forming the court and the container shall be determined independently without regard to fire barrier walls used to allow encroachment by fire exposure hazards.

**8.13.2.7.3 Fire Department Access.** Fire department access roadways or other approved means shall be in accordance with NFPA 1, *Fire Code*.

#### 8.14 Use and Handling.

**8.14.1 General.** Use and handling of containers and systems shall be in accordance with Section 8.14.

**8.14.1.1 Operating Instructions.** Operating instructions shall be provided for installations that require the operation of equipment.

**8.14.1.2 Attended Delivery.** A qualified person shall be in attendance at all times cryogenic fluid is transferred from mobile supply units to a storage system.

##### 8.14.1.3 Inspection.

**8.14.1.3.1** Cryogenic fluid storage systems shall be inspected annually and maintained by a qualified representative of the equipment owner.

**8.14.1.3.2** A record of the inspection shall be prepared and provided to the user or the authority having jurisdiction upon request.

##### 8.14.1.4 Design.

**8.14.1.4.1 Nationally Recognized Good Practices.** Where nationally recognized good practices or standards have been established for the process employed, such practices and standards shall be followed.

**8.14.1.4.2 Piping Systems.** Piping, tubing, fittings, and related components shall be designed, fabricated, and tested in accordance with the requirements of ANSI/ASME B31.3, *Process Piping*, or other approved standards and shall be in accordance with 8.14.2.

#### 8.14.2 Piping and Appurtenances.

**8.14.2.1** Piping systems shall be designed for the use intended through the full range of pressure and temperature to which they will be subjected.

**8.14.2.2** Piping systems shall be designed and constructed to allow for expansion, contraction, vibration, settlement, and fire exposure.

**8.14.3 Joints.** Joints in piping and tubing shall be permitted to be made by welding or brazing or by use of flanged, threaded, socket, slip, or compression fittings.

**8.14.4 Valves and Accessory Equipment.** Valves and accessory equipment shall be acceptable for the intended use at the temperatures of the application and shall be designed and constructed to withstand the maximum pressure at the minimum temperature to which they will be subjected.

**8.14.5 Shutoff Valves on Containers.** Shutoff valves shall be provided on all container connections, except for pressure relief devices.

**8.14.5.1** Shutoff valves for containers with multiple pressure relief devices shall be permitted in accordance with 8.2.5.7.

**8.14.5.2** Shutoff valves shall be accessible and located as close as practical to the container.

##### 8.14.6 Shutoff Valves on Piping.

**8.14.6.1** Shutoff valves shall be installed in piping containing cryogenic fluids where needed to limit the volume of liquid discharged in the event of piping or equipment failure.

**8.14.6.2** Pressure relief valves shall be installed where liquid can be trapped between shutoff valves in the piping system. (See 8.2.5.)

##### 8.14.7 Physical Protection and Support.

**8.14.7.1** Aboveground piping systems shall be supported and protected from physical damage.

**8.14.7.2** Piping passing through walls shall be protected from mechanical damage.

##### 8.14.8 Corrosion Protection.

**8.14.8.1** Aboveground piping that is subject to corrosion shall be protected against corrosion.

**8.14.8.2** Belowground piping shall be protected against corrosion.

**8.14.9 Cathodic Protection.** Where required, cathodic protection shall be in accordance with 8.14.9.

**8.14.9.1 Operation.** Where installed, cathodic protection systems shall be operated and maintained to continuously provide corrosion protection.

##### 8.14.9.2 Inspection.

**8.14.9.2.1** Container systems equipped with cathodic protection shall be inspected for the intended operation by a cathodic protection tester.

**8.14.9.2.2** The cathodic protection tester shall be certified as being qualified by the National Association of Corrosion Engineers, International (NACE).

##### 8.14.9.3 Impressed Current Systems.

**8.14.9.3.1** Systems equipped with impressed current cathodic protection systems shall be inspected in accordance with the requirements of the design and 8.14.9.2.





**8.14.9.3.2** The design limits shall be available to the AHJ upon request.

**8.14.9.3.3** The system owner shall maintain the following records to demonstrate that the cathodic protection is in conformance with the requirements of the design:

- (1) The results of inspections of the system
- (2) The results of testing that has been completed

**8.14.9.4** Repairs, maintenance, or replacement of a cathodic protection system shall be under the supervision of a corrosion expert certified by NACE.

**8.14.9.4.1** The corrosion expert shall be certified by NACE as a senior corrosion technologist, a cathodic protection specialist, or a corrosion specialist or shall be a registered engineer with registration in a field that includes education and experience in corrosion control.

#### **8.14.10 Testing.**

**8.14.10.1** Piping systems shall be tested and proved free of leaks after installation as required by the standards to which they are designed and constructed.

**8.14.10.2** Test pressures shall not be less than 150 percent of the maximum allowable working pressure when hydraulic testing is conducted or 110 percent when testing is conducted pneumatically.

#### **8.14.11 Material-Specific Requirements.**

**8.14.11.1 Indoor Use.** Indoor use of cryogenic fluids shall be in accordance with the material-specific provisions of Chapters 9 and 11 or with ANSI/CGA P-18, *Standard for Bulk Inert Gas Systems at Consumer Sites*, and 8.14.2.

#### **8.14.11.2 Outdoor Use.**

**8.14.11.2.1 General.** Outdoor use of cryogenic fluids shall be in accordance with the material-specific provisions of Chapters 9 and 11 or with ANSI/CGA P-18, *Standard for Bulk Inert Gas Systems at Consumer Sites*, and 8.14.2.

**8.14.11.2.2 Separation.** Distances from property lines, buildings, and exposure hazards shall be in accordance with Table 8.7.2 and Table 8.7.3 and the material-specific provisions of Chapters 9 and 11 or with ANSI/CGA P-18, *Standard for Bulk Inert Gas Systems at Consumer Sites*.

#### **8.14.11.2.3 Shutoff Valves.**

**8.14.11.2.3.1** Shutoff valves shall be provided to shut off the cryogenic fluid supply in case of emergency.

**8.14.11.2.3.2** A shutoff valve shall be located at the source of supply and at the point where the system enters the building.

#### **8.14.11.3 Filling and Dispensing.**

**8.14.11.3.1 General.** Filling and dispensing of cryogenic fluids shall be in accordance with 8.14.1.2.

**8.14.11.3.2 Dispensing Areas.** Dispensing of cryogenic fluids associated with physical or health hazards shall be conducted in approved locations.

**8.14.11.3.2.1 Indoor Dispensing Areas.** Dispensing indoors shall be conducted in areas constructed in accordance with the building code.

**8.14.11.3.2.2 Ventilation.** Indoor areas in which cryogenic fluids are dispensed shall be ventilated in accordance with the requirements of Section 6.15 and the IAPMO *Uniform Mechanical Code*.

**8.14.11.3.2.3 Piping Systems.** Piping systems utilized for filling or dispensing of cryogenic fluids shall be designed and constructed in accordance with 8.14.2.

**8.14.11.3.3 Vehicle Loading and Unloading Areas.** Loading and unloading areas shall be constructed in accordance with the requirements of Chapter 9 for liquid oxygen, Chapter 11 for liquid hydrogen, or ANSI/CGA P-18, *Standard for Bulk Inert Gas Systems at Consumer Sites*, for inert cryogenic fluids, as applicable.

**8.14.11.3.4 Overfilling.** Controls shall be provided to prevent overfilling of stationary containers during filling operations.

#### **8.14.11.4 Handling.**

**8.14.11.4.1 Applicability.** Handling of cryogenic containers shall be in accordance with 8.14.11.4.

#### **8.14.11.4.2 Carts and Trucks.**

**8.14.11.4.2.1** Cryogenic containers shall be moved using an approved method.

**8.14.11.4.2.2** Where cryogenic containers are moved by hand cart, hand truck, or other mobile device, that device shall be designed for the secure movement of the container.

**8.14.11.4.3 Design.** Carts and trucks used to transport cryogenic containers shall be designed to provide a stable base for the commodities to be transported and shall have a means of restraining containers to prevent accidental dislodgement.

#### **8.14.11.4.4 Closed Containers.**

**8.14.11.4.4.1** Pressurized containers shall be closed while being transported.

**8.14.11.4.4.2** Containers designed for use at atmospheric conditions shall be transported with appropriate loose-fitting covers in place to prevent spillage.

## **Chapter 9 Bulk Oxygen Systems**

**9.1\* General.** The storage, use, and handling of oxygen in bulk oxygen systems shall be in accordance with the provisions of Chapters 1 through 9, as applicable.

### **9.1.1 Application.**

**9.1.1.1\*** This chapter shall not apply to oxygen storage systems having capacities less than those stated in 3.3.15, Bulk Oxygen System.

**9.1.1.2** Where a bulk oxygen system is intended for medical gas applications, the applicable provisions of NFPA 99, *Standard for Health Care Facilities*, shall be required in addition to the provisions stated herein.

### **9.2 Materials of Construction.**

**9.2.1\*** Oxygen system components, including, but not limited to, containers, valves, valve seats, lubricants, fittings, gaskets, and interconnecting equipment including hoses, shall be compatible with oxygen under the conditions of temperature and pressure to which the components are exposed in the containment and use of oxygen.

**9.2.2** The use of ignitable materials shall be prohibited unless they are parts of equipment or systems that are approved, listed, or proved suitable by tests or by past experience.



**9.3 Location of Bulk Oxygen Systems.** Bulk oxygen systems shall be located in accordance with one of the following:

- (1) Above ground and out of doors
- (2) In a detached building of fire-resistive or noncombustible/limited-combustible construction, ventilated to prevent the accumulation of oxygen vapors, and used exclusively for that purpose

**9.3.1 Rooftop Installation.** Bulk oxygen systems shall not be located on rooftops of buildings or other structures.

**9.3.2\* Separation from Exposure Hazards.** Oxygen systems located out of doors shall be separated from exposure hazards in accordance with the requirements of Table 9.3.2 as applicable.

**9.3.2.1\*** The distances shown in items 2, 4, 5, 8, and 10 through 14 of Table 9.3.2 shall not apply where a fire barrier wall having a minimum fire resistance of 2 hours interrupts the line of sight between uninsulated portions of the bulk storage system and the exposure.

**Table 9.3.2 Minimum Separation Distances Between Bulk Liquid Oxygen Systems and Exposure Hazards**

Type of Exposure	Distance (See 9.3.2.1.)	
	ft	m
(1) Buildings of Type I and II construction as defined by the building code	1	0.3
(2) Buildings of Type III, IV, or V construction as defined by the building code	50	15
(3) Wall openings as measured from high-pressure gas or liquefied gas regulators, pressure relief devices, vaporizers, manifolds, and interconnected piping	10	3
(4) Property lines	5	1.5
(5) Public sidewalks	10	3
(6) Public assembly	50	15
(7) Areas occupied by nonambulatory patients as measured from the primary pressure relief device discharge vent and from filling and vent connections	50	15
(8) Parked vehicles	10	3
(9) Exterior walls that encroach on the container to form a court with three or more sides	See 8.13.2.7.	
(10) All classes of flammable and combustible liquids above ground (See 9.3.2.2.)		
(a) 0 gal to 1000 gal (0 to 3785 L)	25	7.5
(b) Over 1000 gal (3785 L)	50	15
(11) All classes of flammable and combustible liquids in belowground tanks or vaults		
(a) Horizontal distance from oxygen storage container to tank or vault	15	4.6
(b) Horizontal distance from oxygen storage container to filling and vent connections or other openings to tank or vault	25	7.5
(12) Flammable gases aboveground		
(a) Liquefied hydrogen (any quantity)	75	22.5
(b) Other liquefied gas, 0 gal to 1000 gal (0 L to 3785 L)	25	7.5
(c) Other liquefied gas, over 1000 gal (3785 L)	50	15
(d) Nonliquefied or dissolved gases, 0 scf to 25,000 scf (0 m <sup>3</sup> to 708 m <sup>3</sup> )	25	7.5
(e) Nonliquefied or dissolved gases, over 25,000 scf (708 m <sup>3</sup> )	50	15
(13) Rapidly burning solids, including, but not limited to, excelsior, paper, or combustible waste	50	15
(14) Slowly burning solids, including, but not limited to, heavy timber or coal	25	7.5
(15) Inlets to underground sewer or drainage systems from liquid delivery connections, pressure relief device outlets, mobile supply equipment, and liquid withdrawal connections	8	2.5
(16) Areas below connections where liquid can fall during loading or unloading operations and system operation from combustible surfaces, including, but not limited to, asphalt or bitumastic paving and expansion joint fillers (See 9.3.2.3.)	3	1
(17) Encroachment by overhead utilities		
(a) Horizontal distance from the vertical plane below the nearest overhead wire of an electric trolley, train, or bus line	50	15
(b) Horizontal distance from the vertical plane below the nearest overhead electrical wire other than those noted in (a)	5	1.5
(c) Piping containing other hazardous materials	15	4.6

**9.3.2.1.1** Fire barrier walls shall comply with the requirements of 8.7.2.1.1 through 8.7.2.1.5.

**9.3.2.2** The distances shown shall be permitted to be reduced to 15 ft (4.6 m) for Class IIIB combustible liquids.

**9.3.2.3** The area of noncombustible surfacing provided under liquid mobile supply equipment shall have a width not less than the full width of the delivery vehicle and a length not less than 8 ft (2.5 m) in the direction of the vehicle axis.

#### **9.4 System Fabrication.**

##### **9.4.1 Piping, Tubing, and Fittings.**

**9.4.1.1 System Design.** Piping, tubing, valves, and fittings shall be designed, installed, and tested in accordance with the requirements of ANSI/ASME B31.3, *Process Piping*.

**9.4.1.2 Operating Conditions.** Piping systems shall be designed for the most severe condition of coincident internal or external pressures and temperatures expected during service.

**9.4.1.3\* Low-Temperature Service.** Piping or tubing operating at temperatures below  $-20^{\circ}\text{F}$  ( $-28.9^{\circ}\text{C}$ ) shall be fabricated from materials meeting the impact test requirements of Chapter III of ANSI/ASME B31.3, *Process Piping*, when tested at the minimum operating temperature to which the piping could be subjected when in service.

##### **9.4.1.4 Requirements for Piping Joints.**

**9.4.1.4.1** Joints in piping and tubing shall be permitted to be made by welding or brazing or by use of flanged, threaded, socket, slip, or compression fittings.

**9.4.1.4.2** Gaskets or thread sealants shall be designed for oxygen service. Brazing materials shall have a melting point above  $1000^{\circ}\text{F}$  ( $538^{\circ}\text{C}$ ).

**9.4.1.5 Accessory Equipment.** Valves, gauges, regulators, and other accessories shall be designed for oxygen service.

##### **9.4.1.6 Leak Testing.**

**9.4.1.6.1** After installation, all field-erected piping shall be tested and proved gastight in accordance with the requirements of ANSI/ASME B31.3, *Process Piping*.

**9.4.1.6.2** Any medium used for testing shall be oil-free and nonflammable.

**9.4.1.7 Underground Piping System for Gaseous Systems.** Underground piping systems for gaseous systems shall be in accordance with 7.1.17.

##### **9.4.1.8 Underground Piping Systems for Liquid Oxygen Systems. (Reserved)**

**9.4.2 Liquid Oxygen Vaporizers.** In addition to the requirements in Chapter 8, vaporizers used in liquid oxygen service shall be in accordance with the requirements of 9.4.2.1 and 9.4.2.1.1.

**9.4.2.1 Heating.** Heat used in an oxygen vaporizer shall be supplied indirectly through mediums such as steam, air, water, or materials that do not react with oxygen.

**9.4.2.1.1 Electric Heating.** If electric heaters are used to provide the primary source of heat to vaporizers, the vaporizing system shall be electrically grounded in accordance with the requirements of NFPA 70, *National Electrical Code*.

#### **9.4.3 Equipment Assembly and Installation.**

**9.4.3.1 Oxygen Cleaning.** Equipment used in a bulk oxygen system shall be cleaned in accordance with the requirements of CGA G-4.1, *Cleaning Equipment for Oxygen Service*, before placing the system in service in order to remove oil, grease, solvents, particulates, or other oxidizable materials.

**9.4.3.2 Venting of Enclosures.** Any enclosure containing oxygen control or operating equipment shall be vented to the atmosphere.

**9.4.4 Signage.** The bulk oxygen storage location shall be permanently placarded to read as follows:

OXYGEN

NO SMOKING — NO OPEN FLAMES

**9.4.5\* Electrical Wiring and Equipment.** Electrical wiring and equipment shall be installed in accordance with the applicable provisions of NFPA 70, *National Electrical Code*.

## **Chapter 10 Gaseous Hydrogen Systems**

**10.1 Applicability.** The storage, use, and handling of hydrogen in gaseous hydrogen systems shall be in accordance with the provisions of Chapters 1 through 10, as applicable.

**10.1.1** This chapter shall not apply to individual systems using containers having a total hydrogen content of less than 400 scf ( $11\text{ m}^3$ ) if each system is separated by a distance not less than 5 ft (1.5 m).

**10.1.2** Where individual systems, each having a total hydrogen content of less than 400 scf ( $11\text{ m}^3$ ), are located less than 5 ft (1.5 m) from each other, this code shall apply.

#### **10.2 Design of Gaseous Hydrogen Systems.**

**10.2.1\*** Piping, tubing, valves, and fittings shall be designed and installed in accordance with 7.3.1.3 and Sections 704.1.2.3, 704.1.2.4, and 704.1.2.5 of the ICC *International Fuel Gas Code (IFGC)*. Cast-iron pipe, valves, and fittings shall not be used.

**10.2.2 Pressure Relief Devices.** Hydrogen-venting systems discharging to the atmosphere shall be in accordance with CGA G-5.5, *Hydrogen Vent Systems*.

**10.2.2.1** Venting from the relief vents from the hydrogen supply piping serving listed fuel cell systems shall be permitted to be discharged into an enclosure integral to the fuel cell system where the concentration of hydrogen is diluted below 25 percent of the lower flammable limit (LFL) at the outlet of the enclosure.

**10.2.2.2** The hydrogen supply piping system shall be designed to isolate the source of hydrogen from the relief vent in the event of loss of dilution ventilation or power.

#### **10.2.3 Piping, Tubing, and Fittings.**

**10.2.3.1** In addition to the requirements of 7.3.1.3, brazing materials used for joints in piping and tubing systems shall have a melting point above  $1000^{\circ}\text{F}$  ( $538^{\circ}\text{C}$ ).

**10.2.3.2** Underground piping systems shall be in accordance with 7.1.17.

#### **10.2.4 Equipment Assembly.**

**10.2.4.1** Valves, gauges, regulators, and other accessories used for hydrogen systems shall be specified for hydrogen service by the manufacturer or the hydrogen supplier.

**10.2.4.1.1** Storage containers, piping, valves, regulating equipment, and other accessories shall be accessible and shall be protected against physical damage and tampering.

**10.2.4.2** Cabinets or enclosures containing hydrogen control or operating equipment shall be ventilated to minimize accumulation of hydrogen.

**10.2.4.3** Mobile hydrogen supply units used as part of a hydrogen system shall be secured to prevent movement.

**10.2.4.4** Mobile hydrogen supply units shall be electrically bonded to the storage system before hydrogen is discharged from the supply unit.

## 10.2.5 Marking.

**10.2.5.1** Hazard identification signs shall be provided in accordance with Section 6.11.

**10.2.5.2** In addition, the area in which a hydrogen system is located shall be permanently placarded as follows:

**WARNING: HYDROGEN — FLAMMABLE GAS**  
**NO SMOKING — NO OPEN FLAMES**

**10.2.6 Bonding and Grounding.** The gaseous hydrogen system shall be electrically bonded and grounded.

## 10.3 Location of Gaseous Hydrogen Systems.

### 10.3.1 General Requirements.

**10.3.1.1** Systems located above ground either at grade or above grade shall be in accordance with Section 10.3.

**10.3.1.2** Systems within 50 ft (15 m) of aboveground storage of all classes of flammable and combustible liquids shall be located on ground higher than such storage, except where dikes, diversion curbs, grading, or separating solid walls are used to prevent accumulation of these liquids under the system.

### 10.3.2 Specific Requirements.

**10.3.2.1** The location of hydrogen systems shall be in accordance with Table 10.3.2.1.

#### 10.3.2.2 Minimum Distance.

**10.3.2.2.1** The minimum distance from a bulk hydrogen compressed gas system located outdoors to specified exposures shall be in accordance with Table 10.3.2.2.1(a) or Table 10.3.2.2.1(b). (See also Annex G.)

**10.3.2.2.1.1 Maximum Internal Diameter of Interconnecting Piping.** The maximum internal diameter of the piping system used for interconnecting piping between the shutoff valve on

any single storage container to the point of connection to the system source valve shall not exceed the values shown in Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b) for the pressure range indicated except as allowed by 10.3.2.2.1.1(B) or 10.3.2.2.1.1(C).

**(A) Shutoff Valves on the Source of Supply.** When shutoff valves are not connected directly to the source of supply, all interconnecting piping between the source connection and points downstream shall be included in the determination of internal diameter for the piping system.

**(B)\* Alternative Internal Diameters.** The separation distance for piping systems with internal diameters greater than those specified in Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b) for the pressure range selected shall be permitted with tabular distances determined based on the use of the equations in Table 10.3.2.2.1.1(B).

**(C)** The separation distance for piping systems with internal diameters less than those specified in Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b) for the pressure range selected shall be allowed to be reduced with tabular distances determined based on the use of equations in Table 10.3.2.2.1.1(B).

**(D)** Separation distances determined based on the use of Table 10.3.2.2.1.1(B) shall be subject to review and approval by the AHJ.

**(E)\* Determination of Internal Diameter.** The internal diameter of the piping system shall be determined by the diameter of the piping serving a storage array with content greater than 400 scf (11.3 m<sup>3</sup>). The piping system size used in the application of Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b) shall be determined based on that portion of the system with the greatest maximum internal diameter.

**(F)\* Determination of System Pressure.** The system pressure shall be determined by the maximum operating pressure of the storage array with content greater than 400 scf (11.3 m<sup>3</sup>), irrespective of those portions of the system elevated to a higher pressure.

**10.3.2.2.2\*** Except for distances to lot lines, operable building openings, air intakes, and overhead utilities, the distances in Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b) shall not apply where fire barrier walls having a minimum fire resistance rating of 2 hours are located between the system and the exposure.

**10.3.2.2.3\*** The distances in (1), (2), (4), and (10) in Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b) shall be permitted to be reduced by one-half where fire barrier walls having a minimum fire resistance rating of 2 hours are located between the system and the exposure.

**Table 10.3.2.1 Location of Gaseous Hydrogen Systems**

Location	Quantity of Hydrogen			
	≤MAQ	>MAQ to <3500 scf (<99 m <sup>3</sup> )	≥3500 to <15,000 scf (≥99 m to <425 m <sup>3</sup> )	≥15,000 scf (≥425 m <sup>3</sup> )
Outdoors	A	A	A	A
In a detached building	A	A	A	A
In a gas room, in accordance with Section 6.4	A	A	A	Detached building required
Not in a gas room	A	NA	NA	NA

A: Allowed. NA: Not allowed.



**Table 10.3.2.2.1(a) Minimum Distance from Outdoor Gaseous Hydrogen Systems to Exposures (U.S. Units)**

Exposure	>15 to ≤250 psi 2.067 in. ID (ft)	>250 to ≤3000 psi 0.747 in. ID (ft)	>3000 to ≤7500 psi 0.312 in. ID (ft)	>7500 to ≤15,000 psi 0.282 in. ID (ft)
(1) Lot lines <sup>greater of a or b</sup>	40	45	30	35
(2) Exposed persons other than those involved in servicing of the system <sup>c</sup>	20	25	15	15
(3) Buildings and structures				
Combustible construction <sup>d</sup>	15	20	10	15
Noncombustible non-fire-rated construction <sup>c</sup>	15	20	10	15
Fire-rated construction with a fire resistance rating of not less than 2 hours <sup>f</sup>	5	5	5	5
(4) Openings in buildings of fire-rated or non-fire-rated construction (doors, windows, and penetrations)				
Openable <sup>a</sup>				
Fire-rated or non-fire-rated	40	45	30	35
Unopenable <sup>d</sup>				
Fire-rated or non-fire-rated	15	20	10	15
(5) Air intakes (HVAC, compressors, other) <sup>a</sup>	40	45	30	35
(6) Fire barrier walls or structures used to shield the bulk system from exposures <sup>f</sup>	5	5	5	5
(7) Unclassified electrical equipment <sup>g</sup>	15	15	15	15
(8) Utilities (overhead), including electric power, building services, hazardous materials piping <sup>d</sup>	15	20	10	15
(9) Ignition sources such as open flames and welding <sup>a</sup>	40	45	30	35
(10) Parked cars <sup>c</sup>	20	25	15	15
(11) Flammable gas storage systems, including other hydrogen systems above ground				
Nonbulk <sup>d</sup>	15	20	10	15
Bulk <sup>h</sup>	15	15	15	15

(continues)



Table 10.3.2.2.1(a) (continued)

Exposure	>15 to ≤250 psi 2.067 in. ID (ft)	>250 to ≤3000 psi 0.747 in. ID (ft)	>3000 to ≤7500 psi 0.312 in. ID (ft)	>7500 to ≤15,000 psi 0.282 in. ID (ft)
(12) Aboveground vents or exposed piping and components of flammable gas storage systems, including other hydrogen systems below ground <sup>d</sup> Gaseous or cryogenic	15	20	10	15
(13) Hazardous materials (other than flammable gases) storage below ground <sup>d</sup> Physical hazard materials or health hazard materials	15	20	10	15
(14) Hazardous materials storage (other than flammable gases) above ground <sup>d</sup> Physical hazard materials or health hazard materials	15	20	10	15
(15) Ordinary combustibles, including fast-burning solids such as ordinary lumber, excelsior, paper, and combustible waste and vegetation other than that found in maintained landscaped areas <sup>d</sup>	15	20	10	15
(16) Heavy timber, coal, or other slow-burning combustible solids <sup>d</sup>	15	20	10	15

Note: All pressures are gauge pressures.

<sup>a</sup>Unignited jet concentration decay distance to 4 percent mole fraction (volume fraction) hydrogen.

<sup>b</sup> $D_{\text{rad}}$  – radiation heat flux level of 500 Btu/hr · ft<sup>2</sup>.

<sup>c</sup> $D_{\text{rad}}$  for heat flux level of 1500 Btu/hr · ft<sup>2</sup> exposure to employees for a maximum of 3 minutes.

<sup>d</sup>The greater of  $D_{\text{rad}}$  for combustible heat flux level of 6340 Btu/hr · ft<sup>2</sup> or the visible flame length.

<sup>e</sup>The greater of  $D_{\text{rad}}$  for noncombustible equipment heat flux level of 8000 Btu/hr · ft<sup>2</sup> or the visible flame length.

<sup>f</sup>The minimum clearance between the structure and the system required for access for service-related activities.

<sup>g</sup>Equipment classified as meeting Class I, Division 2, Group B requirements of NFPA 70, *National Electrical Code*, when the area is in accordance with NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*.

<sup>h</sup>Bulk hydrogen storage systems are allowed to integrate (co-locate) other nonliquefied flammable gas systems where the output of the system is designed to deliver a product in which the gases are mixed or blended for delivery into the user's system. The separation distance indicated requires a minimum separation between gaseous and liquid systems integrated into a single system where the liquid source is vaporized, compressed, and stored in the gaseous state.

**Table 10.3.2.2.1(b) Minimum Distance from Outdoor Gaseous Hydrogen Systems to Exposures (SI Units)**

Exposure	>103.4 to ≤1724 kPa 52.50 mm ID (m)	>1724 to ≤ 20,684 kPa 18.97 mm ID (m)	>20,684 to ≤51,711 kPa 7.92 mm ID (m)	>51,711 to ≤103,421 kPa 7.16 mm ID (m)
(1) Lot lines <sup>greater of a or b</sup>	12.14	14.00	8.75	10.38
(2) Exposed persons other than those involved in servicing of the system <sup>c</sup>	5.94	7.02	4.13	5.05
(3) Buildings and structures				
Combustible construction <sup>d</sup>	5.04	5.82	3.64	5.6
Noncombustible non-fire-rated construction <sup>e</sup>	5.04	5.82	3.64	3.64
Fire-rated construction with a fire resistance rating of not less than 2 hours <sup>f</sup>	1.5	1.5	1.5	1.5
(4) Openings in buildings of fire-rated or non-fire-rated construction (doors, windows, and penetrations)				
Openable <sup>a</sup>				
Fire-rated or non-fire-rated	12.14	14.00	8.75	10.38
Unopenable <sup>d</sup>				
Fire-rated or non-fire-rated	5.04	5.82	3.64	4.31
(5) Air intakes (HVAC, compressors, other) <sup>a</sup>	12.14	14.00	8.75	10.38
(6) Fire barrier walls or structures used to shield the bulk system from exposures <sup>f</sup>	1.5	1.5	1.5	1.5
(7) Unclassified electrical equipment <sup>g</sup>	4.7	4.7	4.7	4.7
(8) Utilities (overhead), including electric power, building services, or hazardous materials piping <sup>d</sup>	5.04	5.82	3.64	4.31
(9) Ignition sources such as open flames and welding <sup>a</sup>	12.14	14.00	8.75	10.38
(10) Parked cars <sup>c</sup>	5.94	7.02	4.13	5.05

(continues)

Table 10.3.2.2.1(b) (continued)

Exposure	>103.4 to ≤1724 kPa 52.50 mm ID (m)	>1724 to ≤ 20,684 kPa 18.97 mm ID (m)	>20,684 to ≤51,711 kPa 7.92 mm ID (m)	>51,711 to ≤103,421 kPa 7.16 mm ID (m)
(11) Flammable gas storage systems, including other hydrogen systems above ground Nonbulk <sup>d</sup> Bulk <sup>h</sup>	5.04 4.7	5.82 4.7	3.64 4.7	4.31 4.7
(12) Aboveground vents or exposed piping and components of flammable gas storage systems, including other hydrogen systems below ground <sup>d</sup> Gaseous or cryogenic	5.04	5.82	3.64	4.31
(13) Hazardous materials (other than flammable gases) storage below ground <sup>d</sup> Physical hazard materials or health hazard materials	5.04	5.82	3.64	4.31
(14) Hazardous materials storage (other than flammable gases) above ground <sup>d</sup> Physical hazard materials or health hazard materials	5.04	5.82	3.64	4.31
(15) Ordinary combustibles, including fast-burning solids such as ordinary lumber, excelsior, paper, or combustible waste and vegetation other than that found in maintained landscaped areas <sup>d</sup>	5.04	5.82	3.64	4.31
(16) Heavy timber, coal or other slow-burning combustible solids <sup>d</sup>	5.04	5.82	3.64	4.31

Note: All pressures are gauge pressures.

<sup>a</sup>Unignited jet concentration decay distance to 4 percent mole fraction (volume fraction) hydrogen.

<sup>b</sup> $D_{rad}$  – radiation heat flux level of 1577 W/m<sup>2</sup>.

<sup>c</sup> $D_{rad}$  for heat flux level of 4732 W/m<sup>2</sup> exposure to employees for a maximum of 3 minutes.

<sup>d</sup>The greater of  $D_{rad}$  for combustible heat flux level of 20,000 W/m<sup>2</sup> or the visible flame length.

<sup>e</sup>The greater of  $D_{rad}$  for noncombustible equipment heat flux level of 25,237 W/m<sup>2</sup> or the visible flame length.

<sup>f</sup>The minimum clearance between the structure and the system required for access for service-related activities.

<sup>g</sup>Equipment classified as meeting Class I, Division 2, Group B requirements of NFPA 70, *National Electrical Code*, when the area is in accordance with NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*.

<sup>h</sup>Bulk hydrogen storage systems are allowed to integrate (co-locate) other nonliquefied flammable gas systems where the output of the system is designed to deliver a product in which the gases are mixed or blended for delivery into the user's system. The separation distance indicated requires a minimum separation between gaseous and liquid systems integrated into a single system where the liquid source is vaporized, compressed, and stored in the gaseous state.



**Table 10.3.2.2.1(B) Separation Distance Based on Alternative Pipe or Tube Internal Diameters**

Notes*	>15 to ≤250 psi (>103.4 to ≤1724 kPa)	>250 to ≤3000 psi (>1724 to ≤20,684 kPa)	>3000 to ≤7500 psi (>20,684 to ≤51,711 kPa)	>7500 to ≤15,000 psi (>51,711 to ≤103,421 kPa)
(a)	$D_a = 0.23179d^{0.99931}$	$D_a = 0.73903d^{0.99962}$	$D_a = 1.1062d^{0.99959}$	$D_a = 1.4507d^{0.9995}$
(b)	$D_b = 0.091137d^{1.1303} + e^{-0.084081d}(0.087694d^{0.72681} - 0.091137d^{1.1303})$	$D_b = 0.36599d^{1.1152} + e^{-0.10771d}(0.1885d^{1.2531} - 0.36599d^{1.1152})$	$D_b = 0.60173d^{1.1063} + e^{-0.36516d}(-0.00002521d^{5.6078} - 0.60173d^{1.1063})$	$D_b = 0.84053d^{1.1023} + e^{-0.40365d}(-0.000043007d^{5.7146} - 0.84053d^{1.1023})$
(c)	$D_c = 0.075952d^{1.1022} + e^{-0.087589d}(0.076814d^{0.83088} - 0.075952d^{1.1022})$	$D_c = 0.2889d^{1.092} + e^{-0.10592d}(0.18705d^{1.1795} - 0.2889d^{1.092})$	$D_c = 0.45889d^{1.0887} + e^{-0.46723d}(-0.000027772d^{5.8841} - 0.45889d^{1.0887})$	$D_c = 0.6324d^{1.0859} + e^{-0.52477d}(-0.000086234d^{5.8213} - 0.6324d^{1.0859})$
(d)	$D_d = 0.096359d^{0.99928}$	$D_d = 0.3072d^{0.99962}$	$D_d = 0.45967d^{0.99971}$	$D_d = 0.60297d^{0.99956}$
(e)	$D_e = 0.096359d^{0.99928}$	$D_e = 0.3072d^{0.99962}$	$D_e = 0.45967d^{0.99971}$	$D_e = 0.60297d^{0.99956}$

Notes:

(1) Use of this table assumes a leak diameter of 3 percent of the pipe flow area or internal diameter where  $d$  = inside diameter (ID) of pipe or tube expressed in millimeters (mm), and  $D_{a,b,c,d, \text{ or } e}$  = separation distance in meters (m).

(2) All pressures are gauge pressures.

\*Notes are from Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b) as follows:

- (a) Unignited jet concentration decay distance to 4 percent mole fraction (volume fraction) hydrogen
- (b)  $D_{\text{rad}}$  = radiation heat flux level of 500 Btu/hr-ft<sup>2</sup> (1577 W/m<sup>2</sup>)
- (c)  $D_{\text{rad}}$  for heat flux level of 1500 Btu/hr-ft<sup>2</sup> (4732 W/m<sup>2</sup>) exposure to employees for a maximum of 3 minutes
- (d) The greater of  $D_{\text{rad}}$  for combustible heat flux level of 6340 Btu/hr-ft<sup>2</sup> (20,000 W/m<sup>2</sup>) or the visible flame length
- (e) The greater of  $D_{\text{rad}}$  for noncombustible equipment heat flux level of 8000 Btu/hr-ft<sup>2</sup> (25,237 W/m<sup>2</sup>) or the visible flame length

**10.3.2.2.4** Where fire barrier walls of three sides are used, the walls shall be in accordance with 11.3.2.2.4.

**10.3.2.3** Unloading connections on delivery equipment shall not be positioned closer to any of the exposures cited in Table 10.3.2.2.1(a) or Table 10.3.2.2.1(b) than the distances given for the storage system.

#### 10.4 Design Requirements at Specific Locations.

##### 10.4.1 Outdoor Locations.

**10.4.1.1** Where overhead cover is provided, it shall be in accordance with the provisions of 6.5.2.

**10.4.1.2** Electrical wiring and equipment shall be in accordance with Table 10.4.1.2.

**Table 10.4.1.2 Electrical Area Classification**

Location	Classification	Extent of Classified Area
Storage equipment excluding the piping system downstream of the source valve	Class I, Division 2	Between 0 ft (0 m) and 15 ft (4.6 m)

**10.4.1.3** Vehicular protection shall be provided in accordance with 7.1.8.3.

**10.4.2 Underground Systems.** Gaseous hydrogen systems installed underground where compressed gas containers are to be buried in contact with earth or fill shall be in accordance with 10.4.2.

**10.4.2.1 Design.** Pressure compressed gas containers installed underground using burial methods shall be of seamless con-

struction in accordance with Part UF or Appendix 22 of the ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1.

**10.4.2.1.1\*** Compressed gas containers shall be designed to include cyclic pressure life calculations using fracture mechanics methods.

##### 10.4.2.1.2 Compressed Gas Container Examination.

**10.4.2.1.2.1** Compressed gas containers shall be examined for internal and external surface flaws and inclusions before burial or at the time of manufacture.

**10.4.2.1.2.2** Compressed gas containers with flaws or inclusions exceeding the lesser of 5 percent of the wall thickness or 0.12 in. (3 mm) shall not be used.

##### 10.4.2.1.3 Composite Containers. (Reserved)

**10.4.2.2 Corrosion Protection.** Compressed gas containers and underground piping shall be protected from corrosion in accordance with 7.1.10.9 or 7.1.17 as applicable.

##### 10.4.2.3\* Outlet Connections.

**10.4.2.3.1** Threaded compressed gas container outlet connections shall be designed with primary and secondary seals that shall be tested for functionality.

**10.4.2.3.2** The seal design shall include a method of detecting a leak in the primary seal.

##### 10.4.2.4 Piping Systems.

**10.4.2.4.1** Joints in the piping system shall be butt welded and 100 percent inspected using nondestructive testing (NDT) methods in accordance with the requirements of ANSI/ASME B31.3, *Process Piping*, or other approved standards.

**10.4.2.4.2** Valves, controls, safety devices, and instrumentation shall be above ground and accessible to authorized personnel.

**10.4.2.5 Location.** Compressed gas containers shall be located in accordance with 10.4.2.5.1 through 10.4.2.5.5.

**10.4.2.5.1** Underground compressed gas containers shall not be located beneath buildings.



**10.4.2.5.2** Compressed gas containers and associated equipment shall be located with respect to foundations and supports of other structures such that the loads carried by such structures cannot be transmitted to the tank.

**10.4.2.5.3 Compressed Gas Container Separation Distances.**

**10.4.2.5.3.1** The distance from any part of the compressed gas container to the nearest wall of a basement, pit, cellar, or lot line shall not be less than 10 ft (3.1 m).

**10.4.2.5.3.2** A structure or foundation of a structure on the same property shall not be erected or constructed within 10 ft (3.1 m) of any point on the container surface, unless the footings extend to the bottom of the container or the container's foundation.

**10.4.2.5.4** A minimum distance of 1 ft (0.3 m), shell to shell, shall be maintained between adjacent underground containers.

**10.4.2.5.5\*** A minimum distance of 3 ft (0.9 m) shall be maintained between compressed gas containers and buried utilities.

**10.4.2.6 Foundations.** Underground compressed gas containers shall be set on foundations constructed in accordance with the building code, and surrounded with not less than 6 in. (152 mm) of noncorrosive inert material.

**10.4.2.7 Depth, Cover, and Fill.**

**10.4.2.7.1** Containers shall be buried such that the top of the container is covered with a minimum of 1 ft (0.3 m) of earth and with concrete a minimum of 4 in. (101 mm) thick placed over the earthen cover.

**10.4.2.7.2** The concrete shall extend a minimum of 1 ft (0.3 m) horizontally beyond the footprint of the tank in all directions.

**10.4.2.8\* Anchorage and Security.** Compressed gas containers installed underground in flood hazard areas shall be anchored to prevent flotation, collapse, or lateral movement resulting from hydrostatic loads, including the effects of buoyancy, during conditions of the design flood.

**10.4.2.9 Venting of Underground Compressed Gas Containers.** Vent pipes for underground compressed gas containers shall be in accordance with 10.2.1.

**10.4.2.10 Overfill Protection and Prevention Systems.** An approved means or method shall be provided to prevent the overfilling of the storage containers.

**10.4.2.11 Physical Protection.** Piping and control equipment ancillary to underground containers that is located above ground shall be protected from physical damage in accordance with 7.1.8.3.

**10.4.3 Installation in Vaults Above and Below Ground. (Reserved)**

**10.4.4 Detached Buildings.**

**10.4.4.1** Detached buildings shall be constructed of noncombustible or limited-combustible materials in accordance with the requirements of Section 6.5.

**10.4.4.2** Ventilation shall be provided in accordance with the requirements of Section 6.15.

**10.4.4.2.1** Outlet openings shall be located at the high point of the room in exterior walls or the roof.

**10.4.4.2.2** Inlet and outlet openings shall each have a minimum total area of  $1 \text{ ft}^2/1000 \text{ ft}^3$  ( $1 \text{ m}^2/305 \text{ m}^3$ ) of room volume.

**10.4.4.2.3** Discharge from outlet openings shall be directed or conducted to the atmosphere.

**10.4.4.3\*** Explosion control shall be provided in accordance with the requirements of Section 6.8.

**10.4.4.4** Electrical equipment shall be in accordance with Article 501 of *NFPA 70, National Electrical Code*, for Class I, Division 2 locations.

**10.4.4.5** Heating, if provided, shall be by steam, hot water, or other indirect means except that electrical heating shall be permitted to be used if in compliance with 10.4.4.4.

**10.4.5 Hydrogen Gas Rooms.**

**10.4.5.1** Floors, walls, and ceilings shall be constructed of noncombustible or limited-combustible materials in accordance with the requirements of the building code.

**10.4.5.1.1** Interior walls or partitions shall have a fire resistance rating of not less than 2 hours, shall be continuous from floor to ceiling, and shall be anchored to resist movement.

**10.4.5.1.2** Not less than 25 percent of the perimeter wall shall be an exterior wall.

**10.4.5.1.3** Openings to other parts of the building shall not be permitted.

**10.4.5.1.4** Windows and doors shall be in exterior walls only.

**10.4.5.2** Ventilation shall be as provided in Section 6.15.

**10.4.5.3** Explosion control shall be provided in accordance with the requirements of Section 6.8.

**10.4.5.4** There shall be no sources of ignition from open flames, electrical equipment, or heating equipment.

**10.4.5.5** Electrical equipment shall be in accordance with Article 501 of *NFPA 70, National Electrical Code*, for Class I, Division 2 locations.

**10.4.5.6** Heating, if provided, shall be by steam, hot water, or indirect means except that electrical heating shall be permitted to be used if in compliance with 10.4.5.5.

**10.4.6 Indoor Hydrogen System Location.**

**10.4.6.1** Hydrogen systems of less than 3500 scf (99 m<sup>3</sup>) and greater than the MAQ, where located inside buildings, shall be located in the building so that the system will be as follows:

- (1) In a ventilated area in accordance with the provisions of Section 6.15
- (2) Separated from incompatible materials in accordance with the provisions of 7.1.10.2
- (3) A distance of 25 ft (7.6 m) from open flames and other sources of ignition
- (4) A distance of 50 ft (15 m) from intakes of ventilation, air-conditioning equipment, and air compressors
  - (a) The distance shall be permitted to be reduced to 10 ft (3.1 m) where the room or area is protected by a listed detection system per Article 500.7(K) of *NFPA 70, National Electrical Code*, and the detection system shuts down the fuel supply in the event of a leak that results in a concentration that exceeds 25 percent of the LFL.
  - (b) Isolation valves used to isolate the fuel supply shall be of a fail-safe design.
- (5) A distance of 50 ft (15 m) from other flammable gas storage
- (6) Protected against damage in accordance with the provisions of 7.1.8.3



**10.4.6.2 Systems Installed in One Room.**

**10.4.6.2.1** More than one system of 3500 scf (99 m<sup>3</sup>) or less shall be permitted to be installed in the same room or area, provided the systems are separated by at least 50 ft (15 m) or a full-height fire-resistive partition having a minimum fire resistance rating of 2 hours is located between the systems.

**10.4.6.2.2** The separation distance between multiple systems of 3500 scf (99 m<sup>3</sup>) or less shall be permitted to be reduced to 25 ft (7.6 m) in buildings where the space between storage areas is free of combustible materials and protected with a sprinkler system designed for Extra Hazard, Group 1 in accordance with the requirements of Section 6.9.

**10.5 Operation and Maintenance.**

**10.5.1** Prior to acceptance and initial operation, all piping installations shall be inspected and pressure tested in accordance with the ICC *International Fuel Gas Code (IFGC)*, Section 705.

**10.5.2 Operating Instructions.**

**10.5.2.1** For installations that require any operation of equipment by the user, the user shall be instructed in the operation of the equipment and emergency shutdown procedures.

**10.5.2.2** Instructions shall be maintained at the operating site at a location acceptable to the authority having jurisdiction.

**10.5.3 Maintenance.** Maintenance shall be performed annually by a qualified representative of the equipment owner. The maintenance shall include inspection for physical damage, leak tightness, ground system integrity, vent system operation, equipment identification, warning signs, operator information and training records, scheduled maintenance and retest records, alarm operation, and other safety-related features. Scheduled maintenance and retest activities shall be formally documented, and records shall be maintained a minimum of 3 years.

**10.5.4 Clearance to Combustibles.** Clearance to combustibles shall be in accordance with the requirements of 7.1.10.3.

**10.6\* Fire Protection.** Fire protection shall be in accordance with the requirements of Section 6.9.

**10.7 Cargo Transport Unloading.**

**10.7.1** Unloading connections on delivery equipment shall not be positioned closer to any of the exposures cited in Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b) than the distances given for the storage system.

**10.7.2** During transfer of hydrogen from cargo vehicles, the hand or emergency brake of the vehicle shall be set, and chock blocks shall be used to prevent rolling of the vehicle.

**10.7.3** Cargo vehicles equipped with air-brake interlock in front of the unloading connection to protect against drive-aways shall be engaged such that the interlock is activated.

**10.7.4** Mobile hydrogen supply units shall be electrically bonded to the storage system before hydrogen is discharged from the supply unit.

**10.7.5 Transfer System Depressurization.**

**10.7.5.1** The transfer systems shall be capable of depressurizing to facilitate disconnection.

**10.7.5.2** Bleed connections shall be connected to a hydrogen venting system in accordance with 10.2.2.

**10.7.6** Where required, check valves on delivery systems shall be in accordance with 7.3.1.3.2.

**10.7.7** Prohibitions on smoking or the use of open flame shall be in accordance with 7.6.3.2.

**10.7.8** An emergency shutoff valve shall be provided in accordance with 7.3.1.11.

**10.8 Compression and Processing Equipment.** Compression and gas processing equipment integral to bulk gas storage systems shall be designed for use with GH2 and for maximum pressures and temperatures to which it can be subjected under normal operating conditions.

**10.8.1** Compression and gas processing equipment shall have pressure relief devices that limit each stage pressure to the maximum allowable working pressure for the compression cylinder and piping associated with that stage of compression.

**10.8.2** Where GH2 compression equipment is operated unattended, it shall be equipped with a high discharge and a low suction pressure automatic shutdown control.

**10.8.3** Control circuits that automatically shut down shall remain down until manually activated or reset after a safe shutdown is performed.

**10.8.4 Stationary Compressors.****10.8.4.1 Valves.**

**10.8.4.1.1** Valves shall be installed such that each compressor can be isolated for maintenance.

**10.8.4.1.2** The discharge line shall be equipped with a check valve to prevent the backflow of gas from high-pressure sources located downstream of the compressor.

**10.8.4.2 Foundations.**

**10.8.4.2.1** Foundations used for supporting equipment shall be designed and constructed to prevent frost heaving.

**10.8.4.2.2** The structural aspects of such foundations shall be designed and constructed in accordance with the provisions of the building code.

**10.8.4.3 Emergency Shutdown.** When an emergency shutdown system is required, activation of the emergency shutdown system shall shut down operation of all compressors serving a single bulk gas installation.

**10.8.4.4 Relief Valves.**

**10.8.4.4.1** Each compressor shall be provided with a vent or relief device that will prevent overpressurizing of the pump under normal or upset conditions.

**10.8.4.4.2** Pressure relief devices used to serve pumps or compression equipment shall be connected to a vent pipe system in accordance with 10.2.2.

**10.8.4.5 Pressure Monitoring.** The pressure on the compressor discharge shall be monitored by a control system.

**10.8.4.6 Protection.** Transfer piping and compressors shall be protected from vehicular damage.

## Chapter 11 Liquefied Hydrogen Systems

### 11.1\* General.

**11.1.1** The storage, use, and handling of liquefied hydrogen in liquefied hydrogen storage systems shall be in accordance with the provisions of Chapters 1 through 11, as applicable.

**11.1.2** Portable containers having a total liquefied hydrogen content of less than 39.7 gal (150 L) in compliance with the requirements of Chapter 8 shall not be required to comply with Chapter 11.

### 11.2 Design of Liquefied Hydrogen Systems.

#### 11.2.1 Fire Protection of Structural Supports.

**11.2.1.1** Steel supports in excess of 18 in. (457 mm) in height shall have a minimum 2-hour fire resistance rating in accordance with ASTM E 1529, *Determining the Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies*.

**11.2.1.2** Containers shall be marked in accordance with the provisions of Section 8.4 and as follows:

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**11.2.2 Pressure Relief Devices.** Stationary and portable containers and tanks shall be provided with pressure relief devices in accordance with the requirements of 8.2.5 and 11.2.2.1 through 11.2.2.3.

**11.2.2.1** Pressure relief devices serving stationary containers shall be in accordance with the provisions of 8.2.5.6.1 and arranged to discharge unobstructed to the outdoors.

**11.2.2.2** Hydrogen venting systems discharging to the atmosphere shall be in accordance with CGA G-5.5, *Hydrogen Vent Systems*.

**11.2.2.3** Stationary containers shall be provided with a sign, placed in proximity to the primary tank pressure relief valve vent stack, that warns against spraying water on or into the vent opening.

#### 11.2.3\* Piping, Tubing, and Fittings.

**11.2.3.1** Piping and tubing shall be in accordance with the requirements of ANSI/ASME B31.3, *Process Piping*.

**11.2.3.2** Piping or tubing used at operating temperatures below -20°F (-29°C) shall be fabricated from materials meeting the impact test requirements of Chapter III of ANSI/ASME B31.3, *Process Piping*, when tested at the minimum operating temperature to which the piping will be exposed when in service.

**11.2.3.3** Joints in piping and tubing shall be in accordance with the requirements of ANSI/ASME B31.3, *Process Piping*.

**11.2.3.4** Brazing materials, where used, shall have a melting point above 1000°F (538°C).

**11.2.3.5** Aluminum piping systems and components external to the storage vessel shall not be used with liquefied hydrogen, except for ambient air vaporizers.

**11.2.3.6** Means shall be provided to minimize exposure of personnel to piping operating at low temperatures and to prevent air condensate from contacting piping, structural members, and surfaces not designed for cryogenic temperatures.

**11.2.3.6.1** Insulation on piping systems used to convey cryogenic fluids shall be of noncombustible material and shall be designed to have a vaportight seal in the outer covering to

prevent the condensation of air and subsequent oxygen enrichment within the insulation.

**11.2.3.6.2** The insulation material and outside shield shall be designed to prevent deterioration of the insulation due to normal operating conditions.

**11.2.3.7** Uninsulated piping and equipment that operates at liquefied hydrogen temperatures shall not be installed above asphalt or other combustible materials or surfaces in order to prevent the contact of liquid air with such materials.

**11.2.3.8** Drip pans shall be allowed to be installed under uninsulated piping and equipment to retain and vaporize condensed liquid air.

#### 11.2.4 Equipment Assembly.

**11.2.4.1** Installation of liquefied hydrogen systems shall be supervised by personnel knowledgeable about the applicable standards and the construction and use of the system to be installed.

**11.2.4.2** Storage containers, piping, valves, regulating equipment, and other accessories shall be accessible and shall be protected against physical damage and tampering.

**11.2.4.2.1** An emergency shutoff valve shall be located in liquid supply lines as close to the container as practical.

**11.2.4.2.2** Containers exceeding 2000 gal (7570 L) capacity shall be provided with an automatic emergency shutoff valve.

**11.2.4.2.2.1** The automatic shutoff valve shall be operated by a remotely located, manually activated shutdown control.

**11.2.4.2.2.2** The shutoff valve shall be connected to the primary container by means of welded connections without the use of flanges or other appurtenances except that a manual shutoff valve equipped with welded connections is allowed to be installed immediately upstream of the automatic shutoff valve to allow for maintenance of the automatic valve.

**11.2.4.2.2.3** Connections downstream of the shutoff valve shall be in accordance with ANSI/ASME B31.3, *Process Piping*.

**11.2.4.3** Cabinets or enclosures containing hydrogen control equipment shall be ventilated to prevent any accumulation of hydrogen gas.

#### 11.2.5 Liquefied Hydrogen Vaporizers.

**11.2.5.1\*** Heat supplied to a liquefied hydrogen vaporizer shall be by indirect means utilizing a transfer medium.

**11.2.5.2\*** A low-temperature shutoff switch or valve shall be provided in the vaporizer discharge piping to prevent flow of liquefied hydrogen downstream of the vaporizer in the event that liquid is discharged from the vaporizer.

**11.2.6 Electrical Systems.** Electrical wiring and equipment shall be in accordance with Table 11.2.6 and NFPA 70, *National Electrical Code*.

**11.2.6.1** Where equipment approved for Class I, Group B atmospheres is not commercially available, the equipment used shall meet at least one of the following:

- (1) Purged or ventilated in accordance with NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*
- (2) Intrinsically safe

**11.2.6.2** Electrical equipment installed on mobile supply trucks or tank cars from which the storage container is filled shall not be subject to 11.2.6.1.



**Table 11.2.6 Electrical Area Classification**

Location	Division	Extent of Classified Area
Points where connections to the hydrogen system are regularly made and disconnected	1	Within 3 ft (1 m) of connection
Storage equipment, excluding the piping system downstream of the source valve	2	Between 3 ft (1 m) and 25 ft (7.6 m)

**11.2.7 Bonding and Grounding.** The liquefied hydrogen system shall be electrically bonded and grounded.

#### **11.2.8 Stationary Pumps and Compressors.**

##### **11.2.8.1 Valve Isolation.**

**11.2.8.1.1** Valves shall be installed such that each pump or compressor can be isolated for maintenance.

**11.2.8.1.2** Where pumps or compressors are installed for operation in parallel, each discharge line shall be equipped with a check valve to prevent the backflow of liquid from one system to the other.

##### **11.2.8.2 Foundation Design and Construction.**

**11.2.8.2.1** Foundations used for supporting pumps and equipment shall be designed and constructed to prevent frost heaving.

**11.2.8.2.2** The structural aspects of such foundations shall be designed and constructed in accordance with the provisions of the building code.

**11.2.8.3 Emergency Shutdown System Operation.** When an emergency shutdown (ESD) is required, activation of the ESD system shall shut down operation of all pumps and compressors.

##### **11.2.8.4 Pump or Compressor Venting.**

**11.2.8.4.1** Each pump or compressor shall be provided with a vent or relief device that will prevent overpressurizing of the pump under normal or upset conditions.

**11.2.8.4.2** Pressure relief devices used to serve pumps or compression equipment shall be connected to a vent pipe system in accordance with 11.2.2.2.

**11.2.8.5 Pressure Monitoring.** Pressure on each pump and compressor discharge shall be monitored by the control system.

**11.2.8.6 Protection of Transfer Piping, Pumps, and Compressors.** Transfer piping, pumps, and compressors shall be protected from vehicular damage.

**11.2.9 Emergency Shutdown System.** An ESD system shall be provided at the bulk source to stop the flow of liquid when actuated.

**11.2.9.1** The ESD system shall be operated by a remotely located, manually activated shutdown control located not less than 15 ft (4.5 m) from the source of supply.

**11.2.9.2** Reactivation of the ESD system after ESD shall require that the ESD system be manually reset.

**11.2.9.3** The ESD system shall be identified by means of a sign.

#### **11.3 Location of Liquefied Hydrogen Systems.**

##### **11.3.1 General.**

**11.3.1.1** Stationary storage containers shall be located so that they are accessible from mobile supply equipment.

**11.3.1.2\*** Diking shall not be used to contain a liquid hydrogen spill.

**11.3.1.3** Storage sites shall be placarded as follows:

##### **WARNING:**

LIQUEFIED HYDROGEN

FLAMMABLE GAS

NO SMOKING — NO OPEN FLAMES

##### **11.3.2 Specific Requirements.**

**11.3.2.1** The location of liquefied hydrogen storage, as determined by the MAQ of liquefied hydrogen, shall be in accordance with Table 11.3.2.1.

**11.3.2.2\*** The minimum distance from liquefied hydrogen systems of indicated capacity shall be in accordance with Table 11.3.2.2.

**Table 11.3.2.1 Location of Liquefied Hydrogen Systems**

Location	Quantity of Hydrogen			
	MAQ	>MAQ to 300 gal (>170.32 to 1135.5 L)	>300 to 600 gal (>1135.5 to 2271 L)	>600 gal (>2271 L)
Outdoors	A	A	A	A
In a detached building	A	A	A	NA
In a gas room	A	A	NA	NA
Inside a building (not in a gas room or detached building) and exposed to other occupancies	A	NA	NA	NA

MAQ: Maximum allowable quantity. A: Allowed. NA: Not allowed.



**Table 11.3.2.2 Minimum Distance from Liquefied Hydrogen Systems to Exposures**

Type of Exposure	Total Liquefied Hydrogen Storage					
	39.7 gal to 3500 gal	150 L to 13,250 L	3501 gal to 15,000 gal	13,251 L to 56,781 L	15,001 gal to 75,000 gal	56,782 L to 283,906 L
	ft	m	ft	m	ft	m
1. Building or structure						
(a) Wall(s) adjacent to system constructed of noncombustible or limited-combustible materials						
(1) Sprinklered building or structure or unsprinklered building or structure having noncombustible contents	5 <sup>a</sup>	1.5	5 <sup>a</sup>	1.5	5 <sup>a</sup>	1.5
(2) Unsprinklered building or structure with combustible contents						
(i) Adjacent wall(s) with fire resistance rating less than 3 hours	25	7.6	50	15	75	23
(ii) Adjacent wall(s) with fire resistance rating of 3 hours or greater <sup>b</sup>	5	1.5	5	1.5	5	1.5
(b) Wall(s) adjacent to system constructed of combustible materials						
(1) Sprinklered building or structure	50	15	50	15	50	15
(2) Unsprinklered building or structure	50	15	75	23	100	30.5
2. Wall openings						
(a) Operable	75	23	75	23	75	23
(b) Inoperable	25	7.6	50	15	50	15
3. Air compressor intakes or inlets for air-conditioning or ventilating equipment	75	23	75	23	75	23
4. All classes of flammable and combustible liquids (above ground and vent or fill openings if below ground) <sup>c</sup>	50	15	75	23	100	30.5
5. Between stationary liquefied hydrogen containers	5	1.5	5	1.5	5	1.5
6. Flammable gas storage other than hydrogen	50	15	75	23	75	23
7. Liquid oxygen storage and other oxidizers	75	23	75	23	75	23
8. Combustible solids	50	15	75	23	100	30.5
9. Open flames and welding	50	15	50	15	50	15
10. Places of public assembly	75	23	75	23	75	23
11. Public ways, railroads, and property lines	25	7.6	50	15	75	23
12. Inlet to underground sewers	5	1.5	5	1.5	5	1.5
13. Encroachment by overhead power lines						
(a) Horizontal distance from the vertical plane below the nearest overhead wire of an electric trolley, train, or bus line	50	15	50	15	50	15
(b) Horizontal distance from the vertical plane below the nearest overhead electrical wire	25	7.5	25	7.5	25	7.5
(c) Piping containing other hazardous materials	15	4.6	15	4.6	15	4.6

<sup>a</sup> Portions of wall less than 10 ft (3.1 m) (measured horizontally) from any part of a system shall have a fire resistance rating of not less than 1 hour.

<sup>b</sup> Exclusive of windows and doors.

<sup>c</sup> The separation distances for Class IIIB combustible liquids shall be permitted to be reduced to 15 ft (4.6 m).



**11.3.2.2.1** The distances in 1, 4, 6, 7, 8, and 11 in Table 11.3.2.2 shall be permitted to be reduced by two-thirds, but not to less than 5 ft (1.5 m), for insulated portions of the system.

**11.3.2.2.2\*** For uninsulated portions of the system, the distances shall be permitted to be reduced by the use of fire barrier walls having a fire resistance rating of not less than 2 hours when constructed in accordance with 8.7.2.1 and 11.3.2.2.3.

**11.3.2.2.3** The fire barrier or the insulated liquefied hydrogen tank shall interrupt the line of sight between uninsulated portions of the liquefied hydrogen storage system and the exposure.

**11.3.2.2.4** The fire barrier wall shall not have more than two sides at 90 degree (1.57 rad) directions or not more than three sides with connecting angles of not less than 135 degrees (2.36 rad).

**11.3.2.2.4.1\*** When fire barrier walls of three sides are used, piping and control systems serving stationary tanks shall be located at the open side of the enclosure created by the barrier walls to provide access for filling and ventilation.

(A) Vertical tanks shall be located at a distance not less than one tank diameter from the enclosing walls.

(B) Where horizontal tanks are used, the distance to any enclosing wall shall be not less than one-half the length of the tank.

**11.3.2.3** Unloading connections on delivery equipment shall not be positioned closer to any of the exposures cited in Table 11.3.2.2 than the distances given for the storage system.

**11.3.2.4** The minimum distance of container fill connections from parked vehicles shall be 25 ft (7.6 m).

**11.3.2.5** Fire department access to outdoor storage areas where bulk systems are installed shall be provided and maintained in accordance with NFPA 1, *Fire Code*.

**11.3.3 Installation of Liquefied Hydrogen Inside Buildings Other Than Detached Buildings and Gas Rooms.** Portable liquefied hydrogen containers of 50 gal (189 L) or less capacity located as allowed in Table 11.3.2.1 and in compliance with 11.3.1 where housed inside buildings, not located in a gas room, and exposed to other occupancies shall comply with the following minimum requirements:

- (1) Containers shall be located 20 ft (6.1 m) from all classes of flammable or combustible liquids and combustible materials such as excelsior or paper.
- (2) Containers shall be located 25 ft (7.6 m) from ordinary electrical equipment and other sources of ignition, including process or analytical equipment. (See Section 8.7.)
- (3) Containers shall be located 50 ft (15 m) from intakes for ventilation, air-conditioning equipment, or compressors.
- (4) Containers shall be located 50 ft (15 m) from storage or use of other flammable gases or storage or use of incompatible gases.
- (5) Containers shall be protected against physical damage in accordance with the requirements of 8.6.5.
- (6) Containers shall be secured in accordance with the requirements of 8.6.3.
- (7) Welding or cutting operations and smoking shall be prohibited while hydrogen is in the room, and signs shall be provided as required by 6.11.2.2.
- (8) Ventilation shall be provided in accordance with the requirements of Section 6.15.

- (9) Pressure relief devices on stationary or portable containers shall be vented directly outdoors or to an exhaust hood. (See 8.2.5.6.)

#### **11.4 Design Considerations at Specific Locations.**

##### **11.4.1 Outdoor Locations.**

**11.4.1.1** Roadways and yard surfaces located below liquefied hydrogen piping as well as areas located under the fill connections and delivery vehicles' uninsulated hydrogen piping from which liquid air is able to drip shall be constructed of noncombustible materials.

**11.4.1.1.1** Asphalt and bitumastic paving shall be assumed to be combustible.

**11.4.1.1.2** Expansion joints and fillers used in the construction of concrete slabs shall be of noncombustible materials.

**11.4.1.2** Weather protection shall be constructed in accordance with the requirements of 6.5.2 and the building code.

**11.4.1.3** Lighting shall be provided for nighttime transfer operation, and supplemental lighting shall be provided where required by Section 8.12.

**11.4.1.4** User storage sites shall be fenced and posted to prevent entry by unauthorized personnel.

**11.4.1.4.1** At least two means of egress shall be provided from any fenced area.

##### **11.4.2 Aboveground Tanks.**

**11.4.2.1 Construction.** Stationary storage tanks for liquid hydrogen shall be designed and constructed in accordance with ASME *Boiler and Pressure Vessel Code* (Section VIII, Division 1) and shall be vacuum jacketed in accordance with 11.4.2.2.

##### **11.4.2.2 Construction of the Vacuum Jacket (Outer Vessel).**

**11.4.2.2.1** The vacuum jacket used as an outer vessel for storage tanks in liquid hydrogen service shall be of welded steel construction designed to withstand the maximum internal and external pressures to which it will be subjected under operating conditions to include conditions of emergency pressure relief of the annular space between the inner and outer vessel.

**11.4.2.2.2** The jacket shall be designed to withstand a minimum collapsing pressure differential of 30 psi (207 kPa).

##### **11.4.2.3 Vacuum Level Monitoring.**

**11.4.2.3.1** A connection shall be provided on the exterior of the vacuum jacket to allow measurement of the pressure within the annular space between the inner and outer vessels.

**11.4.2.3.2** The connection shall be fitted with a bellows-sealed or diaphragm-type valve equipped with a vacuum gauge tube that is shielded to protect against damage from impact.

**11.4.3 Underground Tanks.** Underground tanks for the storage of liquid hydrogen shall be in accordance with this subsection.

**11.4.3.1 Construction.** Storage tanks for liquid hydrogen shall be designed and constructed in accordance with Section VIII of ASME *Boiler and Pressure Vessel Code* and shall be vacuum jacketed in accordance with 11.4.3.1.1.

##### **11.4.3.1.1 Vacuum Jacket Construction.**

**11.4.3.1.1.1** The vacuum jacket shall be designed and constructed in accordance with Section VIII of ASME *Boiler and Pressure Vessel Code* and shall be designed to withstand the anticipated loading, including loading from vehicular traffic, where applicable.

**11.4.3.1.1.2** Portions of the vacuum jacket installed below grade shall be designed to withstand anticipated soil, hydrostatic, and seismic loading.

**(A) Material.** The vacuum jacket shall be constructed of stainless steel or other approved corrosion-resistant material.

**(B) Corrosion Protection.** The vacuum jacket shall be protected by an engineered cathodic protection system. A cathodic protection system maintenance schedule shall be provided and reconciled by the owner/operator. Exposed components shall be inspected at least twice a year.

**11.4.3.2 Location.** Tanks shall be located in accordance with 11.4.3.2.1 through 11.4.3.2.4.

**11.4.3.2.1** Underground storage tanks shall not be located beneath buildings.

**11.4.3.2.2** Tanks and associated equipment shall be located with respect to foundations and supports of other structures such that the loads carried by such structures cannot be transmitted to the tank.

**11.4.3.2.3** The distance from any part of the tank to the nearest wall of a basement, pit, cellar, or lot line shall not be less than 10 ft (3.1 m).

**11.4.3.2.4** A minimum distance of 1 ft (0.3 m), shell to shell, shall be maintained between adjacent underground tanks.

#### **11.4.3.3 Depth, Cover, and Fill.**

**11.4.3.3.1** The tank shall be buried such that the top of the vacuum jacket is covered with a minimum of 1 ft (0.3 m) of earth and with concrete a minimum of 4 in. (101 mm) thick placed over the earthen cover.

**11.4.3.3.2** The concrete shall extend a minimum of 1 ft (0.3 m) horizontally beyond the footprint of the tank in all directions.

**11.4.3.3.3** Underground tanks shall be set on foundations constructed in accordance with the building code and surrounded with not less than 6 in. (152 mm) of noncorrosive inert material.

**11.4.3.3.4** The vertical extension of the vacuum jacket required for service connections shall be allowed to extend above grade.

**11.4.3.4 Anchorage and Security.** Tanks and systems shall be secured against accidental dislodgment due to seismic events or flooding.

**11.4.3.5 Venting of Underground Tanks.** Vent pipes for underground storage tanks shall be in accordance with 11.2.2.2.

#### **11.4.3.6 Underground Liquid Hydrogen Piping.**

**11.4.3.6.1** Underground liquid hydrogen piping shall be vacuum jacketed.

**11.4.3.6.2** Unjacketed piping shall not be buried and shall exit the tank annular space above grade.

**11.4.3.7 Overfill Protection and Prevention Systems.** An approved means or method shall be provided to prevent the overfilling of storage tanks.

**11.4.3.8 Vacuum Level Monitoring.** An approved monitoring method shall be provided to indicate vacuum degradation within the vacuum jacket(s).

**11.4.3.9 Physical Protection.** Piping and control equipment ancillary to the underground tank located above ground shall be protected from physical damage in accordance with 8.6.5.

**11.4.3.10 Tanks Not in Service.** Tanks not in service shall be maintained in accordance with 11.4.3.10.1.

**11.4.3.10.1** Corrosion protection shall be maintained in operation.

#### **11.4.4 Detached Buildings.**

##### **11.4.4.1 Explosion Control.**

**11.4.4.1.1** Detached buildings containing more than 300 gal (1136 L) of liquefied hydrogen shall be constructed of non-combustible or limited-combustible materials in accordance with the requirements of the building code.

**11.4.4.1.2** Explosion control shall be provided in accordance with the requirements of Section 6.8.

**11.4.4.2 Ventilation.** Ventilation shall be provided in accordance with the requirements of Section 6.15 and 11.4.4.2.1 through 11.4.4.2.4.

**11.4.4.2.1** Inlet openings shall be located within 18 in. (0.46 m) of the floor in exterior walls only.

**11.4.4.2.2** Outlet openings shall be located at the high point of the room in exterior walls or the roof.

**11.4.4.2.3** Both the inlet and outlet vent openings shall have a minimum total area of 1 ft<sup>2</sup>/1000 ft<sup>3</sup> (1 m<sup>2</sup>/300 m<sup>3</sup>) of room volume.

**11.4.4.2.4** Discharge from outlet openings shall be directed or conducted to a location that allows for dissipation of the exhaust air in the ambient surroundings away from air intakes and occupied spaces.

**11.4.4.3\* Ignition Sources.** There shall be no sources of ignition within the room or area where the hydrogen system is installed.

##### **11.4.4.4 Heating.**

**11.4.4.4.1** Heating, if provided, shall be by indirect means such as steam or hot water.

**11.4.4.4.2** Electrical heating in accordance with Section 8.8 shall be allowed.

#### **11.4.5 Gas Rooms.**

**11.4.5.1** Heating, if provided, shall be by steam, hot water, or other indirect means.

**11.4.5.2** Electrical heating in accordance with Section 8.8 shall be allowed.

#### **11.5 Cargo Transport Unloading.**

**11.5.1** Unloading connections on delivery equipment shall not be positioned closer to any of the exposures cited in Table 11.3.2.2 than the distances given for the storage system.

**11.5.2** During transfer of hydrogen from cargo vehicles, the hand or emergency brake of the vehicle shall be set, and chock blocks shall be used to prevent rolling of the vehicle.

**11.5.3** Cargo vehicles equipped with air-brake interlock in front of the unloading connection to protect against drive-aways shall be engaged such that the interlock is activated.

**11.5.4** Mobile hydrogen supply units shall be electrically bonded to the storage system before hydrogen is discharged from the supply unit.



**11.5.5** The transfer systems shall be capable of depressurizing to facilitate disconnection. Bleed connections shall be connected to a hydrogen venting system in accordance with 11.2.2.2.

**11.5.6** Prohibitions on smoking or the use of open flame shall be in accordance with 11.3.1.3.

**11.5.7** An emergency shutoff valve shall be provided in accordance with 8.14.11.2.3.1.

## Chapter 12 Gas Generation Systems

**12.1 General.** Systems used to generate gases shall be in accordance with Chapters 1 through 6 and Chapter 12.

**12.1.1** Sufficient space shall be provided around generators for safe maintenance and egress.

**12.1.2** Waste gases shall be vented outdoors away from structures and personnel.

**12.1.3** Piping shall be installed in accordance with ANSI/ASME B31.3, *Process Piping*.

**12.2 Corrosive Gases. (Reserved)**

**12.3 Flammable Gases — Gaseous.**

**12.3.1\* Hydrogen.**

**12.3.1.1** Listed and approved hydrogen-generating and -consuming equipment shall be in accordance with the listing requirements and manufacturers' instructions.

**12.3.1.2** Such equipment shall not be required to meet the requirements of Chapter 7.

**12.3.2 Hydrogen Generation Systems.**

**12.3.2.1** The installation and interconnection of hydrogen generation equipment shall be in accordance with 12.3.2.

**12.3.2.2** Permanently installed hydrogen generation systems with rated capacity to generate greater than 0.08 lb/hr (36 g/hr) but less than 55 lb/hr (25 kg/hr) shall be installed in accordance with the requirements of 12.3.2.

**12.3.2.2.1** Systems that generate hydrogen in excess of the quantity indicated in 12.3.2.2 shall be constructed, installed, and operated in accordance with nationally recognized standards.

**12.3.2.3** Fuel processing equipment integral to listed fuel cell appliances installed in accordance with NFPA 853, *Standard for the Installation of Stationary Fuel Cell Power Systems*, shall not be required to meet 12.3.2.

**12.3.2.4 General Siting Requirements.** Hydrogen generation system(s) shall be installed in accordance with Chapters 1 through 7 and Chapter 10 of this code, and the system(s) shall be installed as follows:

- (1) The system shall be placed on a firm foundation that is capable of supporting the equipment or components as in accordance with ASCE/SEI 7, *Minimum Design Loads for Buildings and Other Structures*.
- (2) The system shall be anchored, located, and protected so that the system and equipment will not be adversely affected by rain, snow, ice, freezing temperatures, wind, seismic events, and lightning.

- (3)\*The system shall be protected against access by unauthorized persons commensurate with the location and installation environment. Fire department access shall be provided.
- (4) The system shall be located outside potentially hazardous areas defined by NFPA 70, *National Electrical Code*, Article 500 unless listed and approved for such areas.
- (5) Vent terminations from hydrogen generation systems shall be in accordance with Section 6.14.
- (6) Setbacks of hydrogen generation system equipment from exposures shall be in accordance with Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b).
- (7) A hydrogen generation system and associated hydrogen storage not exceeding a total of 400 scf (11.33 m<sup>3</sup>) shall not be required to have fire-rated separation.
- (8) All safety-related controls shall comply with NFPA 79, *Electrical Standard for Industrial Machinery*.

**12.3.2.5 Outdoor and Rooftop Installations.**

**12.3.2.5.1** For outdoor or rooftop installations, a hydrogen generation system and related components shall be designed and constructed for outdoor installation.

**12.3.2.5.1.1** Hydrogen reformers or gasifiers shall not be installed on rooftops or in penthouse areas of occupied structures.

**12.3.2.5.1.2** The installation of listed or approved reformers or gasifiers shall be allowed provided the listing or approval is specific to rooftop installations.

**12.3.2.5.2** The area classification around hydrogen generation system outlets that exhaust flammable gas in concentrations greater than 25 percent LFL shall be in accordance with Article 500 or 505 of NFPA 70, *National Electrical Code*.

**12.3.2.5.3** For units installed on rooftops, the roofing material under and within 12 in. (305 mm) horizontally of a fuel cell power system or component shall be noncombustible or shall have a Class A rating in accordance with the building code.

**12.3.2.6 Indoor Installations.** A hydrogen generation system installed indoors shall be in accordance with 12.3.2.8.3.

**12.3.2.7 Electrolyzers.**

**12.3.2.7.1** Electrolyzers shall be tested and approved in accordance with ISO/DIS 22734, *Hydrogen generators using water electrolysis process*.

**12.3.2.7.2** With the exception of gaseous hydrogen, electrolyzers that contain or utilize hazardous materials as defined by the building code shall be designed and installed to contain such materials in accordance with the building code.

**12.3.2.8 Catalytic Reforming-Based Hydrogen Generation Systems.**

**12.3.2.8.1 Siting and Interconnecting.** Siting and interconnection of catalytic reformer-type hydrogen generation system shall be in accordance with 10.7.1 as modified or appended by 12.3.2.8.

**12.3.2.8.2 Outdoor and Rooftop Installations.**

**12.3.2.8.2.1** The area containing the catalytic reformer system and associated conditioning equipment shall be located such that HVAC air intakes, windows, doors, and other openings into buildings cannot be exposed to the following:

- (1) Hazardous atmospheres
- (2) Toxic gases in excess of applicable OSHA exposure limits



**12.3.2.8.2.2 Exhaust Outlets.**

(A) The exhaust outlet(s) from process areas or areas that contain fuel-bearing components of a catalytic reforming system shall be located at least 50 ft (15 m) from HVAC air intakes, windows, doors, and other openings into buildings.

(B) The exhaust outlet(s) shall not be directed onto walkways or other paths of travel for pedestrians.

**12.3.2.8.2.3** Process air intakes to a hydrogen generation system shall be located so the plant is not adversely affected by other exhausts, gases, or contaminants.

**12.3.2.8.2.4** Security barriers, fences, landscaping, and other enclosures shall not affect the required process air flow into the hydrogen generation system and its components.

**12.3.2.8.3 Indoor Installations.**

**12.3.2.8.3.1** A catalytic reformer-type hydrogen generation system and its associated components that are not located in areas designed for industrial uses shall be located in a room that meets the conditions of 10.4.6.1(1) through 10.4.6.1(6).

**12.3.2.8.3.2** The area containing the gasifier and associated conditioning equipment shall be located such that HVAC air intakes, windows, doors, and other openings into buildings cannot be exposed to the following:

- (1) Hazardous atmospheres
- (2) Toxic gases in excess of applicable OSHA exposure limits

**12.3.2.8.3.3** The room shall be separated from the remainder of the building by floor, wall, and ceiling construction that has at least a 1-hour fire resistance rating in accordance with NFPA 251, *Standard Methods of Tests of Fire Resistance of Building Construction and Materials*.

**12.3.2.8.3.4** Electrical and piping penetrations and joints associated with the room shall be sealed with approved materials that have a 1-hour fire resistance rating.

**12.3.2.8.3.5** Openings between the room and other occupied spaces shall be protected by fire doors and dampers.

**12.3.2.8.3.6** Fire doors shall be installed in accordance with NFPA 80, *Standard for Fire Doors and Other Opening Protectives*, and shall have a minimum fire resistance rating equivalent to that of the barrier.

**12.3.2.8.3.7** Fire dampers shall be installed in accordance with NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*.

**12.3.2.8.3.8** Each room shall be provided with egress in accordance with NFPA 101, *Life Safety Code*.

**12.3.2.8.4 Fuel Piping and Hydrogen Storage for Catalytic Reforming-Based Hydrogen Generation Systems.**

**12.3.2.8.4.1** Piping for natural gas, compressed natural gas, LP-Gas, or other liquid fuels shall be in accordance with NFPA 54, *National Fuel Gas Code*; NFPA 58, *Liquefied Petroleum Gas Code*; or NFPA 30, *Flammable and Combustible Liquids Code*, as applicable.

**12.3.2.8.4.2** Hydrogen piping, valves, and fittings from the catalytic reforming-based hydrogen generation equipment to hydrogen storage system shall conform to ASME/ANSI B31.3, *Process Piping*.

**12.3.2.8.4.3** An accessible shutoff valve shall be located in the fuel piping to the catalytic reforming-based hydrogen generation system's power system within 6 ft (1.8 m) of the storage container.

**12.3.2.8.4.4** The fuel piping to the catalytic reforming-based hydrogen generation system's power system shall be provided with a second accessible shutoff valve that is located within 6 ft (1.8 m) of the power system, unless the power system is enclosed by a room with a 1-hour fire resistance rating.

**12.3.2.8.4.5** If the power system is enclosed by a room with a 1-hour fire resistance rating, the shutoff valve shall be located outside the room.

**12.3.2.8.4.6 Indoor Installation of Reforming Systems.**

(A) For indoor installation of a reforming system, where the fuel supply is stored outdoors, an automatic shutoff valve interlocked with gas detection shall be located outside the building that houses the power system.

(B) The valve and the detector shall be installed such that the valve will close upon detection of a concentration of greater than 25 percent LFL.

**12.3.2.8.4.7** Piping, valves, regulators, or other equipment shall be located so that it is not subject to physical damage or shall otherwise be protected against physical damage.

**12.3.2.8.4.8** Backflow prevention shall be provided to preclude inducing external atmospheres into the catalytic reforming systems.

**12.3.2.8.4.9** The output of catalytic reformer systems, which typically contains significant quantities of carbon monoxide and other toxic substances, shall be controlled.

(A) The output from the final element of conditioning equipment shall be handled as hydrogen gas unless residual toxic content remains that would exceed applicable OSHA exposure limits in the event of a leak, in which case the requirements of 12.3.2.8.4.9 shall apply.

(B) Materials for outlet interface piping shall be selected based on both the temperature and the chemical composition of the gas.

**12.3.2.8.5 Ventilation and Exhaust for Catalytic Reforming-Based Hydrogen Generation Systems.**

**12.3.2.8.5.1** Pressurized portions of process exhaust system piping shall be in accordance with ANSI/ASME B31.3, *Process Piping*.

**12.3.2.8.5.2** With the exception of units located outdoors, catalytic reforming-based hydrogen generation systems shall be provided with a source of ventilation, exhaust, and makeup air in accordance with this chapter.

**12.3.2.8.5.3** The ventilation and exhaust system shall be designed to provide a negative or neutral pressure in the room, with respect to the building.

**12.3.2.8.5.4** If mechanical ventilation is required, a control interlock shall be provided to shut down the unit upon loss of ventilation.

**12.3.2.8.5.5 Ventilation Air.**

(A) A separate mechanical ventilation system shall be provided for the area where a catalytic reforming-based hydrogen generation system's power system is located.

(B) If it can be verified, natural ventilation shall be permitted to provide all required ventilation and makeup air.

(C) The inlet air vent shall be designed to prevent foreign matter from entering.



**12.3.2.8.5.6 Exhaust Systems.** As required by the manufacturer's instructions and the product listing, a process exhaust system shall be installed to carry combustion and reforming process by-products such that all emissions are exhausted to an approved location.

**12.3.2.8.5.7\* Process Purging and Venting.** Process purging and vents shall conform to the following:

- (1) Pressure equipment and piping intended to be purged, pressure regulators, relief valves, and other potential sources of combustible gas shall be vented to the outside of the building.
- (2) The vent shall be designed to prevent entry of water or foreign objects.
- (3) The vent gas shall be directed so as to not create additional hazards to the building openings, such as windows, doors, or HVAC intakes.

**12.3.2.8.6 Fire Protection for Catalytic Reforming-Based Hydrogen Generation Systems.** The fire protection requirements of NFPA 853, *Standard for the Installation of Stationary Fuel Cell Power Systems*, shall apply, in addition to the following:

- (1) A carbon monoxide detector shall be installed in the catalytic reformer system enclosure, the cabinet exhaust system, or the room that encloses the installation.
- (2) Where installed in a room containing a catalytic reformer system, the location of the detector shall be approved.

**12.3.2.8.7 Small Catalytic Reforming-Based Hydrogen Generation Systems.**

**12.3.2.8.7.1 Scope.** Small catalytic reforming-based hydrogen systems shall comply with 12.3.2.8.7.

**12.3.2.8.7.2 Outdoor Installations.**

(A) The exhaust outlets of the system shall be located at least 50 ft (15 m) from HVAC air intakes, windows, doors, and other openings into buildings.

(B) The exhaust outlet(s) shall not be directed onto walkways or other paths of travel for pedestrians.

**12.3.2.8.7.3 Indoor Installations.**

(A) Clearances from combustible construction and other combustible materials shall be in accordance with manufacturers' instructions; NFPA 31, *Standard for the Installation of Oil-Burning Equipment*; NFPA 54, *National Fuel Gas Code*; or NFPA 58, *Liquefied Petroleum Gas Code*.

(B) Indoor use of catalytic reforming systems that operate without ventilation air from the outside shall be provided with limit controls that will not permit room ambient oxygen levels to drop below 18 percent unless it can be demonstrated by other means that the oxygen level will not drop below 18 percent.

(C) The exhaust system materials shall be compatible with the exhaust gas and any resulting condensate.

(D) Catalytic reforming systems using a flammable liquid as a fuel shall be located outside unless they meet the requirements for indoor installations in Chapters 1 through 8 or meet all the requirements in 10.4.6.1(1) through 10.4.6.1(6) and the following:

- (1) The catalytic reforming system enclosure plus the connected indoor liquid fuel piping shall contain less than 5 gal (0.019 m<sup>3</sup>) of liquid fuel during all modes of operation, standby, and shutdown.

- (2) The bulk fuel storage shall be located outside.

- (3) The indoor fuel piping shall be of solid pipe or tube or all-welded, soldered, or brazed construction up through the catalytic reforming enclosure.

- (4) The catalytic reforming system shall be equipped with leakage detection and automatic isolation of the indoor fuel piping from the outdoor bulk fuel supply upon detection of fuel leakage using pump stoppage, valve closure, or other appropriate means as determined by the manufacturer.

- (5) Outdoor bulk fuel storage located at an elevation above the fuel cell power system shall be equipped with an automatic isolation valve at the tank.

(E) Catalytic reforming systems that store hydrogen shall be installed in accordance with the manufacturers' instructions and Chapter 10.

(F) **Fire Protection.** The requirements of Section 10.6 shall not apply to 8.8 lb/hr (4 kg/hr) or smaller systems except as modified herein.

**12.3.2.8.8 Combustible Gas Detection.**

**12.3.2.8.8.1** Combustible gas detection shall be installed in accordance with 8.1.5.4 through 8.1.5.8 of NFPA 853, *Standard for the Installation of Stationary Fuel Cell Power Systems*, except where the fuel gas system is listed for indoor use and the fuel is odorized.

**12.3.2.8.8.2** Listed catalytic reformer systems that fall within the scope of 12.3.2.8.7 shall not require a written fire prevention and emergency plan.

**12.3.2.9 Requirements for Installation of Gasifiers.**

**12.3.2.9.1** Gasifier systems shall comply with the requirements of Chapters 1 through Chapter 7 and Chapter 10 and the modifications identified in Chapter 12.

**12.3.2.9.2\* Siting and Interconnection of Gasifiers.**

**12.3.2.9.2.1\*** Gasification systems contain conditioning equipment to cool and scrub the gas prior to delivery as a fuel; the conditioning equipment shall comply with 12.3.2.9.2.1(A) and 12.3.2.9.2.1(B).

(A) Materials for conditioning equipment shall be selected based on both the temperature and the chemical composition of the gas.

(B) The output from the final element of conditioning equipment shall be handled as hydrogen gas unless residual toxic content remains that would exceed applicable OSHA exposure limits in the event of a leak, in which case the requirements of this section shall be applied.

**12.3.2.9.2.2** The area classification around the gasification equipment shall be in accordance with Article 500 or 505 of NFPA 70, *National Electrical Code*.

**12.3.2.9.2.3** Gasifier systems shall be isolated from public access areas based on a risk assessment of potential exposure to the following:

- (1) Atmospheres containing flammable gas in excess of 25 percent of the LFL should a leak event occur
- (2) Thermal radiation from flare stacks
- (3) Toxic constituents in the fuel should a leak event occur

**12.3.2.9.2.4** In no case shall this distance (hereinafter referred to as the "gasifier hazard area") be less than the distance specified in 7.9.2.2.

**12.3.2.9.2.5** Air intakes to the gasifier systems shall be located so the equipment is not adversely affected by other exhausts, gases, or contaminants.

**12.3.2.9.2.6** Security barriers, fences, landscaping, or other obstacles shall be provided to define the gasifier hazard area and prevent access by unauthorized persons.

**12.3.2.9.2.7 Warning Signals.**

(A) Warning signals (strobes or rotating lights) shall be provided at all gasifier hazard area access points.

(B) These signals shall be tied to the detection systems outlined in 12.3.2.8.4.6(B) to warn of hazardous conditions.

**12.3.2.9.2.8** The controller for the gasifier process control system shall be located in a safe area, isolated from the gasifier hazard area.

**12.3.2.9.3 Outdoor Installations.** The area containing the gasifier and associated conditioning equipment shall be located such that HVAC air intakes, windows, doors, and other openings into buildings cannot be exposed to the following:

- (1) Hazardous atmospheres
- (2) Toxic gases in excess of applicable OSHA exposure limits

**12.3.2.9.4 Indoor Installations.**

**12.3.2.9.4.1\*** Buildings for gasifier equipment shall be highly ventilated and include pressure relief panels to prevent overpressure from deflagrations.

**12.3.2.9.4.2** Security barriers, fences, landscaping, or other obstacles shall be provided in the vicinity of the relief panels to prevent access to the potentially hazardous outlet areas.

**12.3.2.9.4.3** For gasifiers in separate buildings, the building shall be isolated from other structures such that HVAC air intakes, windows, doors, and other openings into buildings cannot be exposed to the following:

- (1) Hazardous atmospheres.
- (2) Toxic gases in excess of applicable OSHA exposure limits

**12.3.2.9.4.4** Gasifiers that occupy a portion of a building shall be separated from other occupancies in accordance with Section 7.9.

**12.3.2.9.5 Process Systems for Gasifiers.**

**12.3.2.9.5.1** Piping, valves, and fittings from the gasifier chamber to the end use or storage system shall conform to ANSI/ASME B31.3, *Process Piping*.

**12.3.2.9.5.2** Backflow prevention shall be provided to preclude inducing external atmospheres into the gasifier systems.

**12.3.2.9.5.3 Manual Shutoff Valve.**

(A) A manual flow shutoff valve shall be provided at a point outside the gasifier hazard area/building and prior to the end user/storage area.

(B) This valve shall be monitored by the gasifier process control system and shall trigger an emergency shutdown of the gasifier process when moved from the full open position.

**12.3.2.9.5.4** Emergency stop capability shall be available both at the process control system controller location and at access points to the gasifier hazard area and building.

**12.3.2.9.5.5** Activation of the emergency stop system shall do the following:

- (1) Isolate the gasifier from all downstream users and storage facilities
- (2) Immediately halt the flow of feedstock
- (3) Depressurize the gasifier chamber and associated gas conditioning equipment

**12.3.2.9.5.6** Vented gas from the gasifier process shall be routed to a flare stack sited in a location where the radiant flux does not pose a risk to personnel or a risk of ignition of combustible materials, in accordance with Chapter 10.

**12.3.2.9.5.7** The emergency stop capability shall be provided by an independent controller from the main process controller.

**12.3.2.9.6 Hazard Detection and Fire Protection for Gasifiers.**

**12.3.2.9.6.1** Flammable gas detection shall be provided in the vicinity of major gasifier components.

(A) For indoor installations, detection shall also be provided in areas where hydrogen could collect in the event of a leak.

(B) To minimize the potential of deflagration at an indoor installation, the process shall be shut down if the gas level exceeds 25 percent of the LFL.

**12.3.2.9.6.2\* Toxic Gas Detection.**

(A) Toxic gas detection shall be provided in the gasifier hazard area or building for all gas constituents that, when released, could reach the OSHA PEL, OSHA ceiling limit, or STEL.

(B) This detection capability shall include detection of carbon monoxide as a minimum.

**12.3.2.9.6.3\* Thermal Detection.**

(A) Thermal detectors shall be provided throughout the gasifier area to detect fires and activate the fire suppression system and initiate a gasifier shutdown.

(B) The detection system shall comply with *NFPA 72, National Fire Alarm and Signaling Code*.

(C) Ultraviolet/infrared (UV/IR) flame detection shall be provided in the vicinity of the gasifier vessel and all downstream equipment in which the gas temperature exceeds 80 percent of the lowest autoignition temperature of a contained constituent that exceeds 3 percent of the gas mix by volume.

**12.3.2.9.6.4 Detection Devices and Visual Warning System.**

(A) Detection devices shall be connected to visual warning devices.

(B) Activation of emergency stop for detected hazards other than fire shall be as recommended by the manufacturer or as required by local regulatory requirements.

**12.3.2.9.6.5\*** Fire suppression systems for gasifiers shall be selected to avoid imposing excessive thermal distress on the high-temperature components, which could cause distress to the equipment and contribute to a larger or extended fire situation.

**12.4 Flammable Gases — Cryogenic. (Reserved)**

**12.5 Oxidizing Gases. (Reserved)**

**12.6 Other Gases. (Reserved)**

**12.7 Pyrophoric Gases. (Reserved)**

**12.8 Toxic and Highly Toxic Gases. (Reserved)**

**12.9 Unstable Reactive Gases. (Reserved)**





## Chapter 13 Insulated Liquid Carbon Dioxide Systems

**13.1 General.** The storage, use, and handling of liquid carbon dioxide in insulated systems shall be in accordance with the provisions of Chapter 13 and Chapters 1 through 7 as applicable.

**13.1.1\* Pressure Relief Devices.** Containers used for liquid carbon dioxide shall be equipped with pressure relief devices piped from the uppermost part of the containers and communicating with the vapor space.

### 13.1.1.1 Physical Protection.

**13.1.1.1.1** Pressure relief devices shall be located to minimize tampering, damage, and obstruction to flow.

**13.1.1.1.2** The inlet and outlet of the relief devices shall not be blocked by a valve or plug during normal operation.

**13.1.1.2 Vent Pipe Systems.** Pressure relief devices shall be piped to the outdoors where the discharge will not impinge on the structure, personnel, or means of egress and will not create a hazardous concentration of carbon dioxide.

**13.1.1.2.1** Pressure relief devices from portable DOT 4L containers that are not a component of a stationary system shall not be required to meet the requirements of 13.1.1.2.

**13.1.1.2.2\*** Vent piping systems serving pressure relief devices shall be protected from water intrusion to prevent moisture or solid carbon dioxide from collecting and freezing and interfering with the operation of the pressure relief device.

**13.1.1.2.3** Vent piping systems serving pressure relief devices shall be designed to prevent backflow restrictions exceeding 10 percent backpressure on the pressure relief device under full flow conditions.

### 13.1.2 Pressure and Level Indicators.

**13.1.2.1** Containers, cylinders, and tanks shall be provided with a pressure gauge and a level gauge or device for indicating the quantity of liquid carbon dioxide.

**13.1.2.2** These devices shall be designed for the temperatures and pressures associated with liquid carbon dioxide service.

**13.1.2.3** Where containers, cylinders, and tanks are in locations remote from the filling connection, a means to determine when the containers have been filled to their design capacity shall be provided and shall be verifiable from the filling connection.

### 13.1.3 Piping Systems.

**13.1.3.1** Carbon dioxide piping shall be located and supported to protect against damage from strain on piping and fittings; the effects of expansion, contraction, and vibration; mechanical damage; and heat sources.

**13.1.3.2** Piping, tubing, and hoses and fittings shall be designed to a bursting pressure of at least four times the system design pressure.

**13.1.4\* Materials of Construction.** Materials of construction shall be employed for potential exposure to a temperature of  $-109.3^{\circ}\text{F}$  ( $-78.5^{\circ}\text{C}$ ).

**13.1.5 Operating Instructions.** Operating instructions shall account for potential exposure of personnel to extremely low temperatures in accordance with 13.2.3.

## 13.2 Small Insulated Liquid Carbon Dioxide Indoor Systems.

**13.2.1\*** Container foundations or floors in multistoried buildings shall be designed to support the weight of the system at its full capacity in accordance with the building code.

**13.2.2\*** Rooms or areas where container systems are filled and used indoors or in enclosed outdoor locations shall be provided with a gas detection and alarm system that is capable of detecting and notifying the building occupants of a gas release that creates carbon dioxide vapors in excess of its PEL.

**13.2.2.1\*** Activation of the gas detection system shall initiate an audible alarm within the room or area in which the system is installed.

**13.2.2.2** Subsection 13.2.2 shall not apply to manufacturer locations where containers are filled indoors and distributed for use.

**13.2.2.3** Activation of the gas detection system shall sound a local alarm to notify persons responsible for system operation of a hazard condition in the area in which the system is installed.

**13.2.3** A warning sign shall be posted at the entrance to the building, room, enclosure, or confined area where the container is located.

**13.2.3.1** The warning sign shall be at least 8 in. (200 mm) wide and 6 in. (150 mm) high and state the following:

CAUTION — CARBON DIOXIDE GAS.

Ventilate the area before entering.

A high carbon dioxide ( $\text{CO}_2$ ) gas concentration in this area can cause suffocation.

## 13.3 Small Insulated Liquid Carbon Dioxide Outdoor Systems.

**13.3.1** Container systems located in enclosed spaces shall be in accordance with Section 13.2 for indoor systems.

**13.3.1.1\*** Aboveground outdoor locations shall not be required to be provided with a gas detection and alarm system in accordance with 13.2.2 where the system is unenclosed.

**13.3.1.1.1** To be considered unenclosed, enclosures constructed to limit access or otherwise provide a visual or architectural barrier for the installation shall be constructed in accordance with the requirements in 6.5.2 for weather protection or with the following:

- (1) The enclosure shall be constructed without a roof or overhead cover.
- (2) Supports and walls shall not obstruct more than three sides nor more than 75 percent of the perimeter of the storage or use area with 25 percent of the perimeter being open to the atmosphere.

**13.3.1.1.2** Enclosures that do not meet the requirements of 13.3.1.1 shall be permitted when constructed in accordance with the following:

- (1) The enclosure shall be constructed without a roof or overhead cover.
- (2) Continuous mechanical exhaust ventilation shall be provided.



**13.3.1.1.2.1** Where mechanical exhaust ventilation is provided, it shall be in accordance with the following:

- (1) The exhaust system shall be installed in accordance with the requirements of the mechanical code.
- (2) The exhaust system shall be designed to consider the density of the potential vapors released with exhaust taken from a point within 12 in. (305 mm) of the floor.
- (3) The location of both the exhaust and the inlet air openings shall be designed to provide air movement across all portions of the enclosure to prevent the accumulation of vapors.
- (4) The rate of exhaust ventilation shall be not less than 1 ft<sup>3</sup>/min per square foot (0.028 m<sup>3</sup>/min per square meter) of floor area within the enclosure.

**13.4 Large Indoor Insulated Liquid Carbon Dioxide Systems. (Reserved)**

**13.5 Large Outdoor Insulated Liquid Carbon Dioxide Systems. (Reserved)**

## **Chapter 14 Storage, Handling, and Use of Ethylene Oxide for Sterilization and Fumigation**

**14.1 General.** The storage, handling, and use of ethylene oxide for sterilization and fumigation shall be in accordance with the provisions of Chapters 1 through 7, as applicable.

**14.2 Receiving and Unloading Ethylene Oxide Containers.**

**14.2.1 Scope.** This subsection shall apply to the handling of both full and empty ethylene oxide containers at a facility, including the following:

- (1) Handling of the containers between the truck and the dock
- (2) Inspecting containers at the dock
- (3) Handling of the containers within the facility

**14.2.2 Procedures.**

**14.2.2.1** Drums shall not be lifted by placing the forks under the chime rings on the drums.

**14.2.2.2** Prior to the unloading of ethylene oxide containers, the vehicle engine shall be turned off, the brakes set, and the wheels chocked.

**14.2.2.3** Smoking or open flames shall not be permitted within 25 ft (7.62 m) of any area where ethylene oxide containers are handled.

**14.2.2.4** Ethylene oxide cylinders shall be secured to hand trucks or lift trucks during movement.

**14.2.2.5** Ethylene oxide containers shall be kept upright at all times.

**14.2.2.5.1** Containers shall not be stacked or rolled.

**14.2.2.6** Immediately after offloading, ethylene oxide containers shall be inspected and the following checks performed:

- (1) An examination for evidence of damage to the container or valves
- (2) A confirmation that the valves are equipped with valve outlet plugs or caps
- (3) An inspection of the container labeling to confirm that each container is labeled as containing ethylene oxide
- (4)\*A leak test of the container, including valves and fuse plugs

**14.2.2.6.1** Ethylene oxide containers shall not be moved to storage until the inspection is complete.

**14.2.2.7** In the event that any container fails incoming inspection, the ethylene oxide supplier shall be notified.

**14.2.2.7.1** If a leaking container is found, the facility procedures for handling ethylene oxide leaks and spills shall be followed.

**14.3 Storage of Ethylene Oxide.**

**14.3.1 General.**

**14.3.1.1** Ethylene oxide containers shall be kept upright at all times.

**14.3.1.2** Ethylene oxide containers shall not be stacked.

**14.3.2 Indoor Storage.**

**14.3.2.1 Storage Within Sterilization Buildings.**

**14.3.2.1.1\*** The maximum quantity of ethylene oxide stored in a special sterilization building or special room shall be 10,000 lb (4536 kg).

**14.3.2.1.2** The construction of all such special sterilization buildings shall comply with Section 14.11.

**14.3.2.1.3** Special sterilization buildings or rooms shall be classified for purposes of ignition source control in accordance with 14.7.1.1.

**14.3.2.1.4** Heated indoor storage areas shall be arranged so that stored cylinders or other containers cannot be spot heated or heated above 125°F (51.7°C).

**14.3.3 Storage Outside of Buildings.**

**14.3.3.1 Location of Storage Outside of Buildings.** Storage outside of buildings shall be located in accordance with 7.10.2 and 7.10.3.

**14.3.3.2 Outdoor Storage Areas.**

**14.3.3.2.1** Outdoor storage areas shall have a minimum of 25 percent of the perimeter open to the atmosphere.

**14.3.3.2.2** This open space shall be permitted to incorporate chain link fence, lattice construction, open block, or similar materials for the full height and width of the opening.

**14.3.3.2.3** Storage areas shall be kept clear of dry vegetation and combustible materials for a minimum distance of 15 ft (4.6 m).

**14.3.3.2.4** Cylinders stored outside shall not be placed on the ground (earth) or on surfaces where water can accumulate.

**14.3.3.2.5** Storage areas shall be provided with physical protection from vehicle damage.

**14.3.3.2.6\*** Storage areas shall be permitted to be covered with canopies of noncombustible construction.

**14.4 Piping Systems.**

**14.4.1 Scope.**

**14.4.1.1** This section shall apply to ethylene oxide piping systems, including pipe, tubing, flanges, gaskets, valves, fittings, flexible connectors, and to the pressure-containing parts of other components, such as expansion joints and strainers, and devices used to mix, separate, distribute, meter, and control the flow of ethylene oxide.



**14.4.1.2** This section shall not apply to scrubber and vent systems.

#### **14.4.2 Materials for Piping, Valves, and Fittings.**

##### **14.4.2.1 Materials.**

**14.4.2.1.1** All metallic materials used shall be as specified in ANSI/ASME B31.3, *Process Piping*.

**14.4.2.1.2** The requirements of the hazardous materials section shall apply.

**14.4.2.1.3** The following restrictions shall also apply:

- (1) All metallic materials used shall have a minimum melting point greater than 1500°F (815.6°C).
- (2) No furnace butt-welded steel product shall be used.

##### **14.4.2.2\* Joining Methods.**

**14.4.2.2.1** Joints shall be made gastight and shall be welded, flanged, brazed, or threaded.

**14.4.2.2.2** Joints shall be welded where located in concealed spaces within buildings.

**14.4.2.2.3** The requirements in 14.4.2.2.3.1 through 14.4.2.2.3.4 shall apply.

##### **14.4.2.2.3.1 Welding.**

(A) All welding processes and procedures shall be in conformance with ANSI/ASME B31.3, *Process Piping*.

(B) The Oxy-Fuel Gas Welding (OFW) procedure shall not be used on any component or system fabricated to this code.

##### **14.4.2.2.3.2 Brazing.**

(A) All brazing processes and procedures shall be in strict conformance with ANSI/ASME B31.3, *Process Piping*.

(B) All braze alloys shall have a minimum melting point of 1000°F (537.8°C).

(C) The failure of the braze joint in the event of a fire exposure shall not in any way result in the release of additional fuel that can accelerate or spread the existing fire.

##### **14.4.2.2.3.3 Soldering.**

(A) Soldering shall not be used for pressure containment or structural purposes.

(B) Soldering for hermetic or environmental sealing purposes as part of a mechanical sealing system shall be permitted.

(C) The failure of any soldering application in the event of a fire shall not allow a release of fuel that can accelerate or spread the existing fire.

**14.4.2.2.3.4 Threading.** Threaded joints shall be made with a thread sealant or lubricant compatible with ethylene oxide.

##### **14.4.3\* Preparation for Dismantling of Piping.**

**14.4.3.1** Any piping and valves that have been used to transport ethylene oxide to or from a sterilizer to the emission control or release point shall be drained and purged prior to dismantling.

**14.4.3.2** The piping shall be purged free of flammable concentrations of ethylene oxide prior to cutting or welding on the lines.

**14.4.3.3** The piping shall be inspected for evidence of polymers prior to cutting or welding.

**14.4.3.4** If found, all polymers shall be removed prior to cutting or welding.

##### **14.4.4 Valves.**

**14.4.4.1** Valves shall be designed for a minimum operating pressure of 150 psi (1030 kPa).

**14.4.4.2** All materials used, including valve seat discs, packing, seals, and diaphragms, shall be in accordance with 14.4.2.

**14.4.5 Testing.** Pressure piping systems shall be tested in accordance with ANSI/ASME B31.3, *Process Piping*, prior to use.

**14.4.6\* Identification.** Ethylene oxide lines shall be identified.

#### **14.5 Gas Dispensing Areas.**

**14.5.1 General.** In addition to the requirements in Section 14.3, the requirements in 14.5.1.1 through 14.5.1.3 shall apply to areas where ethylene oxide is dispensed from containers.

**14.5.1.1** Ethylene oxide storage shall be permitted in dispensing areas.

**14.5.1.2\*** Indoor dispensing areas shall be equipped with a continuous gas detection system that provides an alarm when ethylene oxide levels exceed 25 percent of the LFL (7500 ppm).

**14.5.1.3\*** Exhaust ventilation shall be installed in all indoor dispensing areas used for ethylene oxide.

**14.5.1.4** Exhaust ventilation shall comply with the following:

- (1) Mechanical ventilation shall be operated continuously at a rate of not less than 1 ft<sup>3</sup>/min·ft<sup>2</sup> (0.3 m<sup>3</sup>/min·m<sup>2</sup>) of floor area of dispensing area.
- (2) Exhaust ventilation shall not be recirculated within a room or building unless under the following conditions:
  - (a) Where the air is treated to reduce the ethylene oxide concentration to below that which represents a hazard, recirculation shall be permitted.
  - (b) Controls shall be provided to ensure the performance of the treatment and recirculation system.
- (3) The ventilation system shall be designed to prevent accumulation of ethylene oxide anywhere in the dispensing area.

##### **14.5.2 Ethylene Oxide Containers.**

**14.5.2.1** No more than two ethylene oxide containers shall be connected to each sterilizer.

**14.5.2.2** Before connections are made, containers shall be grounded.

**14.5.2.3** The ethylene oxide supply line shall have a reverse flow prevention device to prevent contamination of the supply container where automatic switchover of containers is used.

**14.5.2.4** Each ethylene oxide piping system from the containers to the process chamber shall have two remotely operated shutoff valves in the flow stream.

**14.5.2.4.1** The valve required in 14.5.2.4 closest to the container shall be located 5 ft (1.5 m) or less from the container.

**14.5.2.4.2** The valves shall be operable from the sterilizer control room or other location outside the dispensing area.

**14.5.2.5** Any supply piping containing liquid ethylene oxide that can be isolated shall be equipped with a pressure relief device.

### 14.5.3 Nitrogen System.

**14.5.3.1** Nitrogen used for head space pressurization shall be no less than 99.0 percent nitrogen and shall contain no impurities that are chemically incompatible with ethylene oxide.

**14.5.3.2** A reverse flow prevention device shall be provided to prevent ethylene oxide from entering the nitrogen supply system.

**14.5.3.3** A particulate filter shall be provided to prevent rust from being introduced into an ethylene oxide container.

**14.5.3.4** Refillable containers shall be pressurized with nitrogen to 50 psi (345 kPa) prior to disconnection and shipment to the supplier.

### 14.5.4 Vaporizer.

#### 14.5.4.1 Liquid Flow Control Valve.

**14.5.4.1.1** A valve shall be provided to control liquid flow to the vaporizer.

**14.5.4.1.2** This valve shall be permitted to be one of the valves required in 14.5.2.4.

#### 14.5.4.2\* Temperature Recording Device.

**14.5.4.2.1** An indicating or recording device shall be provided at the control panel to demonstrate that the ethylene oxide temperature is within the range of 60°F (16°C) to 200°F (93.3°C).

**14.5.4.2.2** An alarm shall be provided for out-of-range conditions.

**14.5.5 Liquid Ethylene Oxide Piping.** Ethylene oxide shall not be piped outside the confines of the process area.

## 14.6 Operations.

### 14.6.1 Operating Procedures Manual.

**14.6.1.1** Each facility shall prepare and maintain an operating procedures manual covering facility start-up, operation, and shutdown.

**14.6.1.2** Operating procedures manuals shall include procedures for the safe operation of the facility under normal and nonroutine operation conditions.

**14.6.1.3** Operating procedures manuals shall be accessible to facility operators at all times.

**14.6.1.4** Operating procedures manuals shall include operator actions to be taken if toxic or flammable concentrations of ethylene oxide are detected in the facility.

**14.6.1.5** Operating procedures manuals shall include procedures for purging and inerting equipment and piping.

**14.6.1.6** Operating procedures manuals shall include procedures for addressing leakage and spills of ethylene oxide.

### 14.6.2\* Sterilizer Operation.

**14.6.2.1\* Purging.** The vessel shall be purged to reduce the ethylene oxide concentration to less than 25 percent of the LFL prior to opening the chamber door.

**14.6.2.2\* Postcycle Ventilation.** A nonrecirculating ventilation system or equivalent means shall be provided to prevent ethylene oxide accumulation due to product outgassing prior to and during unloading of the sterilizer.

### 14.6.2.3 Cycle Abort.

**14.6.2.3.1** Ethylene oxide sterilizers shall be equipped with a manually initiated cycle abort feature accessible to the operator.

**14.6.2.3.2** This cycle abort feature also shall be operable from outside the sterilizer area.

**14.6.2.3.3** A key-locked device shall not be permitted.

**14.6.2.3.4** The cycle abort operation shall allow for the controlled removal of flammable concentrations of ethylene oxide from the sterilizer.

**14.6.3 Area Monitoring for Ethylene Oxide.** Ethylene oxide sterilizer areas shall be monitored continuously for ethylene oxide concentrations.

**14.6.3.1** The gas detection system shall provide an audible and visual warning signal to indicate when concentrations of ethylene oxide reach a level of 25 percent of the LFL of ethylene oxide.

**14.6.3.2\*** The gas detection system shall automatically shut off the supply at the ethylene oxide containers when the concentration of ethylene oxide exceeds 25 percent of the lower limit of flammability.

### 14.6.4 Emergency Stop.

**14.6.4.1** An emergency stop device shall be provided to halt all operating equipment, including valves, rotating equipment, and heating apparatus on the sterilizer and gas dispensing equipment.

**14.6.4.2** The emergency stop shall be activated by a manually initiated feature accessible in the control room or at the control panel.

## 14.7 Electrical Installation.

### 14.7.1 Area Electrical Classification.

**14.7.1.1** The sterilizer room, gas dispensing room, ethylene oxide container storage area, aeration rooms, and emission control area shall be classified as a Class I, Division 2, Group B area in accordance with *NFPA 70, National Electrical Code*, unless under the conditions of 14.7.1.1.1.

**14.7.1.1.1** Aeration rooms shall be permitted to be unclassified electrically where it is demonstrated that flammable concentrations of ethylene oxide cannot occur during all normal and nonroutine operating conditions, including power failure.

**14.7.1.2** The interior of the sterilization vessel shall be classified Class I, Division 1, Group B.

**14.7.2\* Static Electricity Control.** All piping shall be bonded to an earth ground.

**14.7.3 Grounding Requirements.** All equipment shall be grounded in accordance with *NFPA 70, National Electrical Code*, Article 250.

## 14.8 Sterilizer Construction.

**14.8.1\* Vessel.** Sterilizers operating at gauge pressure of 15 psi (100 kPa) or higher shall be designed, built, and stamped in accordance with the *ASME Boiler and Pressure Vessel Code*, Section VIII.

**14.8.2 Rotating Equipment.** Rotating equipment exposed to flammable concentrations of ethylene oxide shall be designed to prevent sparking and localized overheating of surfaces during normal and nonroutine operation.



**14.8.3 Pressure Relief Device.** A pressure relief device, set to open at the sterilizer's design pressure, shall be installed on each sterilizer.

**14.8.3.1** Pressure relief devices shall be inspected annually for corrosion or accumulation of material (such as polymer buildup) that could prevent operation.

**14.8.3.2** The point of discharge of the pressure relief device shall not be located in an area where potential ignition sources exist or where ethylene oxide vapors could re-enter the building.

**14.8.3.3** Shutoff valves shall not be installed in relief device discharge piping.

#### **14.9 Disposal and Emissions.**

**14.9.1\* Scope.** This section shall apply to the disposal and emission of ethylene oxide from sterilization buildings.

**14.9.2 Wet Scrubbers.** Where a wet scrubber is used, the following requirements shall apply:

- (1) Wet scrubbing systems shall be designed so that scrubber solution cannot enter ethylene oxide vent or process lines.
- (2) Sources of pure ethylene oxide liquid shall be prevented from being fed directly to scrubber systems designed only for ethylene oxide gas treatment.

**14.9.3 Flare Stacks.** Where a flare stack is used, the following requirements shall apply:

- (1) Flame arresters shall be installed to prevent flame flash-back into the sterilizer.
- (2) Flare stack failure shall initiate a shutdown of the flare stack feed and an audible alarm.

**14.9.4 Catalytic Converter.** Where a catalytic converter is used, it shall be designed to shut down or be bypassed if the temperature exceeds the maximum temperature determined by the catalyst supplier.

#### **14.9.5\* Oxidizing Emission Control Devices.**

##### **14.9.5.1 General.**

**14.9.5.1.1** All interlocks and safeguards shall be in place before sterilization begins.

**14.9.5.1.2** Sterilization products that sit idle in the sterilization or aeration room shall be periodically washed or vented.

**14.9.5.1.3** Confined spaces shall be vented to the outside after power loss.

**14.9.5.1.4** Regular preventive maintenance shall be performed.

##### **14.9.5.2 Sterilizers Equipped with Back-Vent Systems Connected to Emission Control Devices.**

**14.9.5.2.1** Sterilizers equipped with a back-vent system connected to an oxidizing emission control device shall be in accordance with 14.9.5.2.1.

**14.9.5.2.1\* Engineering controls** shall be provided to ensure that residual ethylene oxide concentration at the entrance to the oxidizing emission control device does not exceed 25 percent of the LFL (0.75 percent by volume).

**(A)** The sterilization chamber shall be equipped with gas detection to monitor the concentration of ethylene oxide within the sterilization chamber.

**(B)** A safety interlock shall be provided to prevent the back-vent system from opening if the concentration of ethylene oxide in the sterilization chamber exceeds the predetermined limits required by the operating procedures specified in 14.6.1.1.

**(C)\* Exhaust duct systems** used to convey ethylene oxide vapors shall be in accordance with the mechanical code.

**14.9.5.3** Piping used to convey ethylene oxide to the sterilization process shall not be purged to an oxidizing emission control device.

#### **14.10 Maintenance.**

**14.10.1 General Requirements.** A written program shall be developed for the following maintenance activities:

- (1) Confined space entry
- (2) Purging of equipment and piping
- (3) Welding (hot work) permit system
- (4) Lockout/tagout
- (5) Preventive maintenance for key equipment

**14.10.2 Maintenance Manuals.** Manuals shall be accessible to facility operators and maintenance personnel at all times.

#### **14.11 Construction.**

##### **14.11.1 Scope.**

**14.11.1.1** This section covers the construction, ventilation, and heating of structures that house ethylene oxide storage, dispensing, and use.

**14.11.1.2** These structures shall be used exclusively for ethylene oxide storage, dispensing, and use and for the housing of other materials having similar hazards, or they shall be permitted to be rooms attached to or located within buildings used for other purposes.

##### **14.11.2 Separate Structures or Buildings.**

**14.11.2.1 Construction of Structures or Buildings.** Separate structures or buildings shall be one story in height and shall have walls, floors, ceilings, and roofs constructed of noncombustible or limited-combustible materials.

**14.11.2.1.1** Exterior walls, ceilings, and roofs shall be constructed in one of the following ways:

- (1) Of lightweight material designed for explosion venting
- (2)\*Of heavy construction, such as solid brick masonry, concrete block, or reinforced concrete construction, provided there are explosion venting windows or panels in the walls or roofs

**14.11.2.1.2** The floor of such structures or buildings shall not be located below ground level.

**14.11.2.1.3** Any space beneath the floor shall be of solid fill, or the perimeter of the space shall be entirely unenclosed.

**14.11.2.2\* Structure or Building Ventilation.** The structure or building shall be provided with general ventilation through the use of air supply inlets and exhaust outlets.

**14.11.2.2.1** These inlets and outlets shall be arranged to provide movement of well-mixed air throughout the space.

**14.11.2.2.2** Air circulation shall be at least 1 cfm/ft<sup>2</sup> (0.3 m<sup>3</sup>/m<sup>2</sup>) of floor area and shall be permitted to be provided by natural or mechanical means.



**14.11.2.3 Structure or Building Heating.** Heating shall be by electrical appliances listed for Class I, Group B, Division 2 locations in accordance with *NFPA 70, National Electrical Code*, or shall be by means of steam or hot water radiation or other heating transfer medium with the heat source located in one of the following locations:

- (1) Outside the building
- (2) In a separate room with a 2-hour fire resistance rating pressurized relative to the remainder of the building

**14.11.2.4 Sterilization Rooms.** The sterilization room shall be provided with Protection Level 2 and Protection Level 4 controls as specified by the building code.

**14.11.2.4.1** Sterilizing rooms with quantities of hazardous materials, including ethylene oxide, in quantities less than the MAQ per control area as established by the building code shall not be required to have Protection Level 2 and Protection Level 4 controls.

**14.11.2.5\* Explosion Control.** Explosion control shall be provided in accordance with Section 6.8.

**14.11.2.5.1** When explosion venting is provided, interior walls and other walls of the sterilization room not designed as explosion venting shall be designed to withstand an overpressure of at least 100 lb/ft<sup>2</sup> (4.8 kPa).

## 14.12 Fire Protection.

**14.12.1 Sprinklers.** Facilities using ethylene oxide shall be protected by an automatic sprinkler system in accordance with Section 6.9.

**14.12.1.1 Ethylene Oxide Storage Areas.** Ethylene oxide storage areas shall be equipped with a deluge system in accordance with NFPA 16, *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems*.

## 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.1.1.2(1)** For regulations on the transportation of gases, see 49 CFR 100–185 (Transportation) and *Transportation of Dangerous Goods Regulations*.

**A.1.1.2(3)** Bulk compressed gas and cryogenic fluid system installations are intended to be covered by the requirements of this code. Instrumentation and alarms that are attendant to the system and designed to interface with the application in a health care facility are to be retained within the purview of NFPA 99, *Standard for Health Care Facilities*.

**A.1.1.2(6)** For information, see NFPA 52, *Vehicular Gaseous Fuel Systems Code*, or NFPA 58, *Liquefied Petroleum Gas Code*.

**A.1.1.2(7)** The storage of gases outside laboratory work areas is covered by this code.

**A.1.2** Reference is made to other material-specific standards published by NFPA where appropriate. The material-specific standards are limited in number, and controls are focused on select materials through the use of those standards. NFPA 55 is intended to be generic and applicable to all materials in the gaseous or cryogenic state.

**A.2.3.5** Applicable equivalent regulations apply in the country of use.

**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.3.2.5 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.3.3.1 Absolute Pressure.** Measured from this reference point, the standard atmospheric pressure at sea level is an absolute pressure of 14.7 psi (101.3 kPa).

**A.3.3.5 Assembly Occupancy.** Assembly occupancies might include the following:

- (1) Armories
- (2) Assembly halls
- (3) Auditoriums
- (4) Bowling lanes
- (5) Club rooms
- (6) College and university classrooms, 50 persons and over
- (7) Conference rooms
- (8) Courtrooms
- (9) Dance halls
- (10) Drinking establishments
- (11) Exhibition halls
- (12) Gymnasiums
- (13) Libraries
- (14) Mortuary chapels



- (15) Motion picture theaters
- (16) Museums
- (17) Passenger stations and terminal of air, surface, underground, and marine public transportation facilities
- (18) Places of religious worship
- (19) Pool rooms
- (20) Recreation piers
- (21) Restaurants
- (22) Skating rinks
- (23) Special amusement buildings, regardless of occupant load
- (24) Theaters

Assembly occupancies are characterized by the presence or potential presence of crowds with attendant panic hazard in case of fire or other emergency. These are generally open or occasionally open to the public, and the occupants, who are present voluntarily, are not ordinarily subject to discipline or control. Such buildings are ordinarily occupied by able-bodied persons and are not used for sleeping purposes. Special conference rooms, snack areas, and other areas incidental to, and under the control of, the management of other occupancies, such as offices, fall under the 50-person limitation. Restaurants and drinking establishments with an occupant load of fewer than 50 persons should be classified as mercantile occupancies. For special amusement buildings, see 16.4.7 of *NFPA 5000*.

**A.3.3.12 Bulk Hydrogen Compressed Gas System.** The bulk system terminates at the source valve, which is the point where the gas supply, at service pressure, first enters the supply line, or at a piece of equipment that utilizes the hydrogen gas, such as a hydrogen dispenser. The containers are either stationary or movable, and the source gas for the system is stored as a compressed gas.

Bulk hydrogen compressed gas systems can include a bulk storage source, transfer piping and manifold system, compression system, and other components. The gaseous source can include a tube trailer, tube bank, or other high pressure storage vessels used to serve the piping system that transports hydrogen to the end user. Compressors can be installed downstream of the storage supply to boost the pressure of the source gas, and intermediate high pressure storage might be present. This is done where the end use requires hydrogen at a pressure higher than that of the bulk supply. In these instances, there may be intermediate storage vessels used to store the gas at elevated pressures. It is not uncommon for the bulk supply as delivered to be furnished at nominal gauge pressure of 3000 psi (20,684 kPa), and the intermediate high pressure storage to be stored at gauge pressures up to 15,000 psi (103,421 kPa). See Figure A.3.3.12(a) through (f).

**A.3.3.13 Bulk Inert Gas System.** The bulk system terminates at the point where the gas supply, at service pressure, first enters the supply line. The containers are either stationary or movable, and the source gas is stored as a compressed gas or cryogenic fluid.

**A.3.3.14 Bulk Liquefied Hydrogen Gas System.** The bulk system terminates at the source valve, which is commonly the point where the gas supply, at service pressure, first enters the supply line or a piece of equipment that utilizes the gas or the liquid, such as a hydrogen dispenser. The containers are either stationary or movable, and the source gas for the system is stored as a cryogenic fluid.

A bulk liquefied hydrogen gas system can include a liquid source where the liquid is vaporized and subsequently com-

pressed and transferred to storage in the compressed gaseous form. It is common for liquid hydrogen systems to be equipped with vaporizers that are used to gasify the cryogen for ultimate use in the compressed state; however, there are also systems that can be used to transfer liquid in the cryogenic state. Bulk liquefied hydrogen gas systems can be either in an all-liquid state or in a hybrid system that can consist of storage containers for gas in the liquid state and other containers for gas in the compressed state. For the purposes of the application of the code, a hybrid system is viewed as a bulk liquefied hydrogen gas system.

**A.3.3.15 Bulk Oxygen System.** The bulk oxygen system terminates at the point where oxygen at service pressure first enters the supply line. The oxygen containers are either stationary or movable, and the oxygen is stored as a compressed gas or cryogenic fluid.

**A.3.3.16 Cathodic Protection.** This protection renders a metallic container or piping system or component negatively charged with respect to its surrounding environment.

**A.3.3.20 Chime Ring.** These rings protect the drum but are not intended for lifting purposes.

**A.3.3.29 Cylinder Pack.** *Six-packs* and *twelve-packs* are terms used to further define cylinder packs with a specific number of cylinders. The characteristic internal water volume of individual cylinders in a cylinder pack ranges from 1.52 ft<sup>3</sup> to 1.76 ft<sup>3</sup> (43 L to 50 L) or a water capacity of 95 lb to 110 lb (43 kg to 50 kg).

**A.3.3.38 Exhausted Enclosure.** Such enclosures include laboratory hoods, exhaust fume hoods, and similar appliances and equipment used to retain and exhaust locally the gases, fumes, vapors, and mists that could be released. Rooms or areas provided with general ventilation, in and of themselves, are not exhausted enclosures.

**A.3.3.39 Explosion Control.** NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, provides guidance on the use of deflagration venting systems in buildings and other enclosures. The primary purpose of a venting system is to relieve the overpressure produced in an explosion to limit the potential damage to the building where the explosion occurs. Although some structural damage can be anticipated, the use of relief venting is expected to prevent massive building failure and collapse. In cases where detonation is probable, venting is often used in conjunction with barricade construction where the pressure-resistant portions of the building have been constructed to resist the pressures anticipated should an explosive event occur. Design of barricade systems is highly specialized and the subject of military standards applicable to the subject. NFPA 69, *Standard on Explosion Prevention Systems*, provides guidance on the use of suppression, ventilation systems, and the limiting of oxidants as a means to prevent the occurrence of an explosion. When relief vents are to be used as a means to provide explosion relief, the fundamental requirements of the building code for structural elements, including snow, wind, and seismic events, should be considered. In some instances, the requirements for wind resistance can impose more rigorous requirements on the relief vents than required by the engineering analysis used to determine the relief pressure. In such cases, users must demonstrate that the relief vents will not become airborne or release in such a manner as to create secondary hazards within or external to the building in which they are installed. Specific designs might require approval by the AHJ.

**A.3.3.40 Flammable Liquid (Class I).** Materials that boil at a temperature of less than 68°F (20°C) are compressed gases. Users are cautioned that the use of the definitions found in

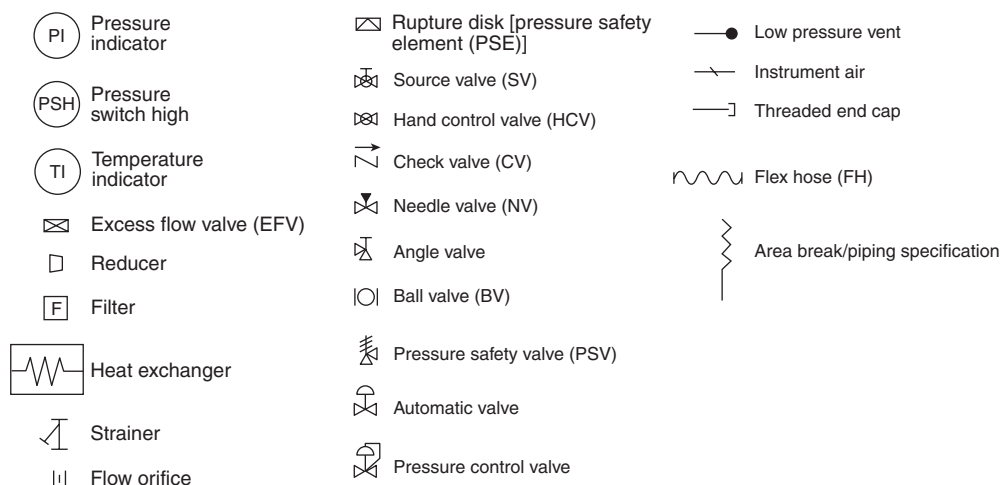


FIGURE A.3.3.12(a) Symbol Legend for Figure A.3.3.12(b) through Figure A.3.3.12(f).

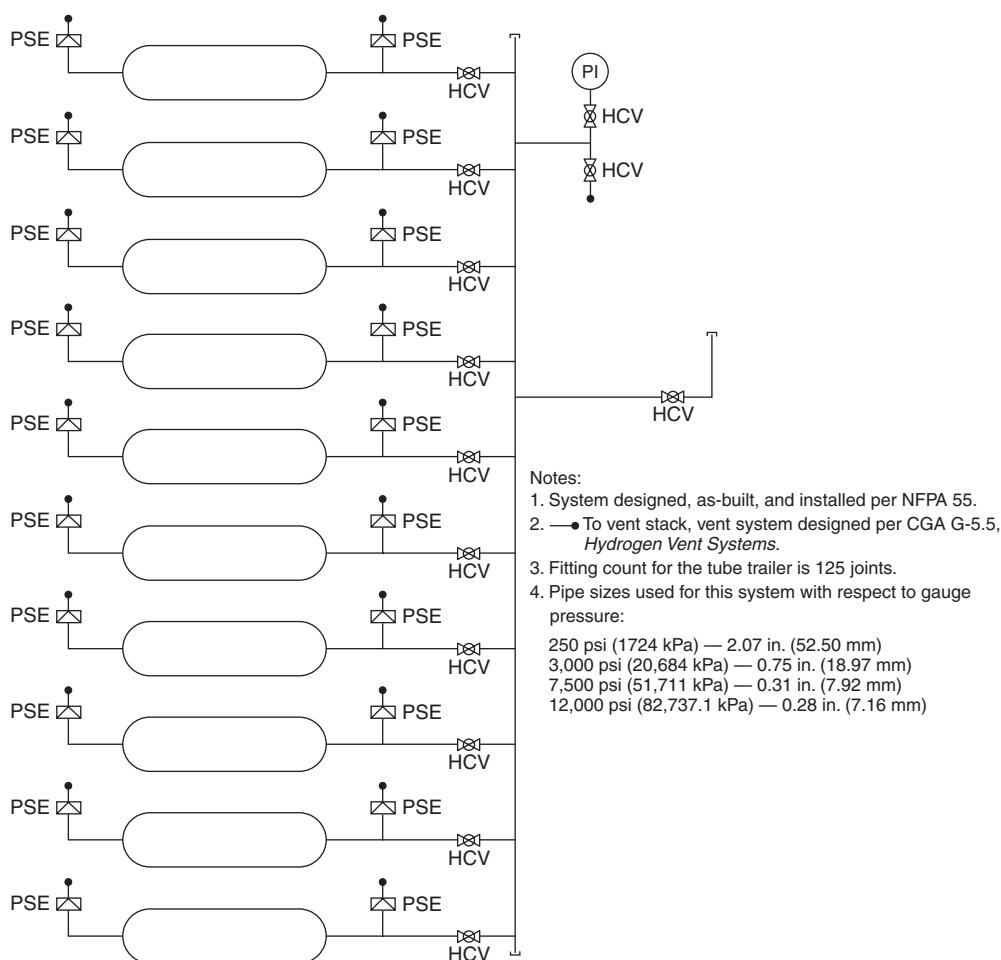
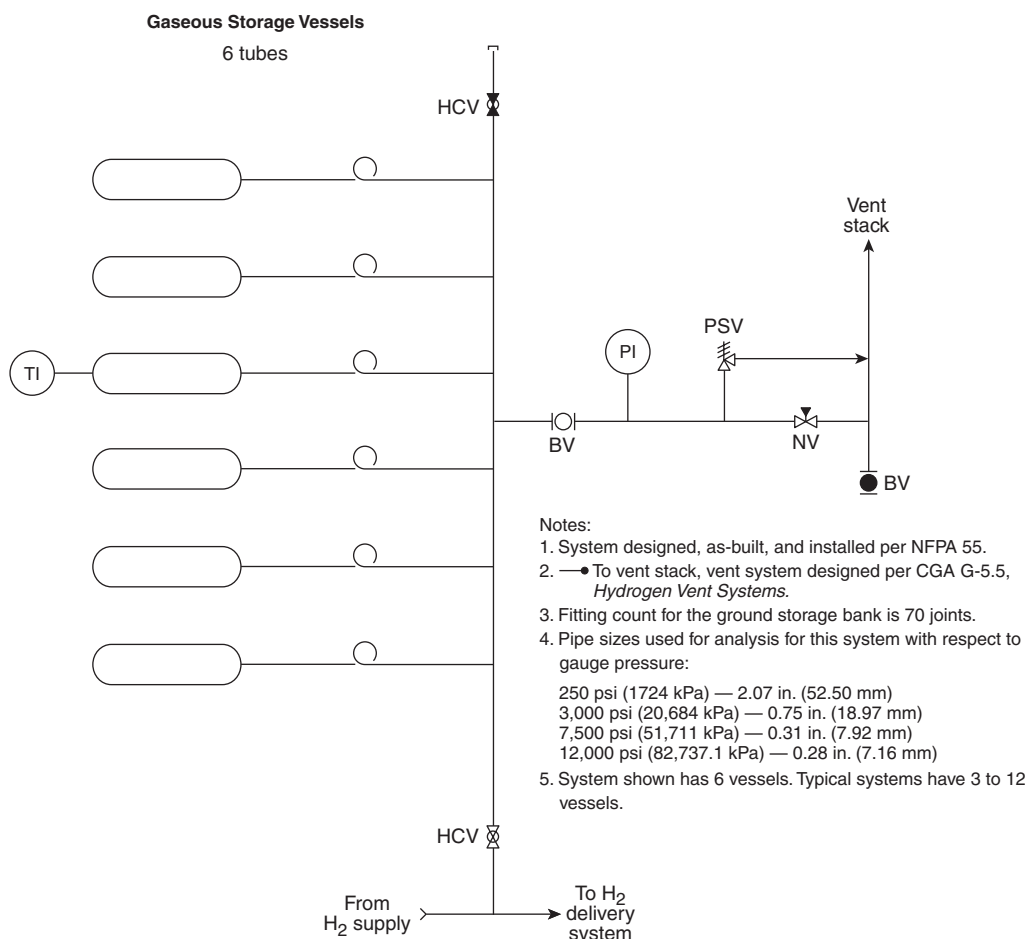


FIGURE A.3.3.12(b) Typical Tube Trailer.



**FIGURE A.3.3.12(c) Typical Bulk Compressed Gaseous Storage System.**

NFPA 30, *Flammable and Combustible Liquids Code*, can result in the misclassification of certain liquefied compressed gases as flammable liquids (Class IA). Liquefied hydrogen is classed as a flammable compressed gas by the U.S. Department of Transportation. It is regulated as a cryogenic fluid within this code.

**A.3.3.43.1 Compressed Gas.** The states of a compressed gas are categorized as follows:

- (1) Nonliquefied compressed gases are gases, other than those in solution, that are in a packaging under the charged pressure and are entirely gaseous at a temperature of 68°F (20°C).
- (2) Liquefied compressed gases are gases that, in a packaging under the charged pressure, are partially liquid at a temperature of 68°F (20°C). Cryogenic fluids represent a transient state of a gas that is created through the use of refrigeration. Cryogenic fluids cannot exist in the liquid form or partial liquid form at temperatures of 68°F (20°C); hence, they are not “compressed gases” as defined.
- (3) Compressed gases in solution are nonliquefied gases that are dissolved in a solvent.
- (4) Compressed gas mixtures consist of a mixture of two or more compressed gases contained in a packaging, the hazard properties of which are represented by the properties of the mixture as a whole.

**A.3.3.43.6 Inert Gas.** Inert gases do not react readily with other materials under normal temperatures and pressures. For example, nitrogen combines with some of the more active metals such as lithium and magnesium to form nitrides, and at high temperatures it will also combine with hydrogen, oxygen, and other elements. The gases neon, krypton, and xenon are considered rare due to their scarcity. Although these gases are commonly referred to as inert gases, the formation of compounds is possible. For example, xenon combines with fluorine to form various fluorides and with oxygen to form oxides; the compounds formed are crystalline solids.

**A.3.3.43.9 Other Gas.** A gas classified as an “other gas” might be a nonflammable gas or an inert gas.

**A.3.3.43.14 Unstable Reactive Gas.** Unstable reactive materials are subdivided into five classifications. Class 4 materials are materials that in themselves are readily capable of detonation or explosive decomposition or explosive reaction at normal temperatures and pressures. They include the following:

- (1) Materials that are sensitive to localized thermal or mechanical shock at normal temperatures and pressures
- (2) Materials that have an instantaneous power density (product of heat of reaction and reaction rate) at 482°F (250°C) of 1000 W/mL or greater



## Notes:

1. System designed, as-built, and installed per NFPA 55.
2. —●— To vent stack, vent system designed per CGA G-5.5, *Hydrogen Vent Systems*.
3. Fitting count for the pressure control manifold is 111 joints.
4. Fitting count for the stanchion is 29 joints.
5. Pipe sizes used for analysis for this system with respect to gauge pressure:
  - 250 psi (1724 kPa) — 2.07 in. (52.50 mm)
  - 3,000 psi (20,684 kPa) — 0.75 in. (18.97 mm)
  - 7,500 psi (51,711 kPa) — 0.31 in. (7.92 mm)
  - 12,000 psi (82,737.1 kPa) — 0.28 in. (7.16 mm)

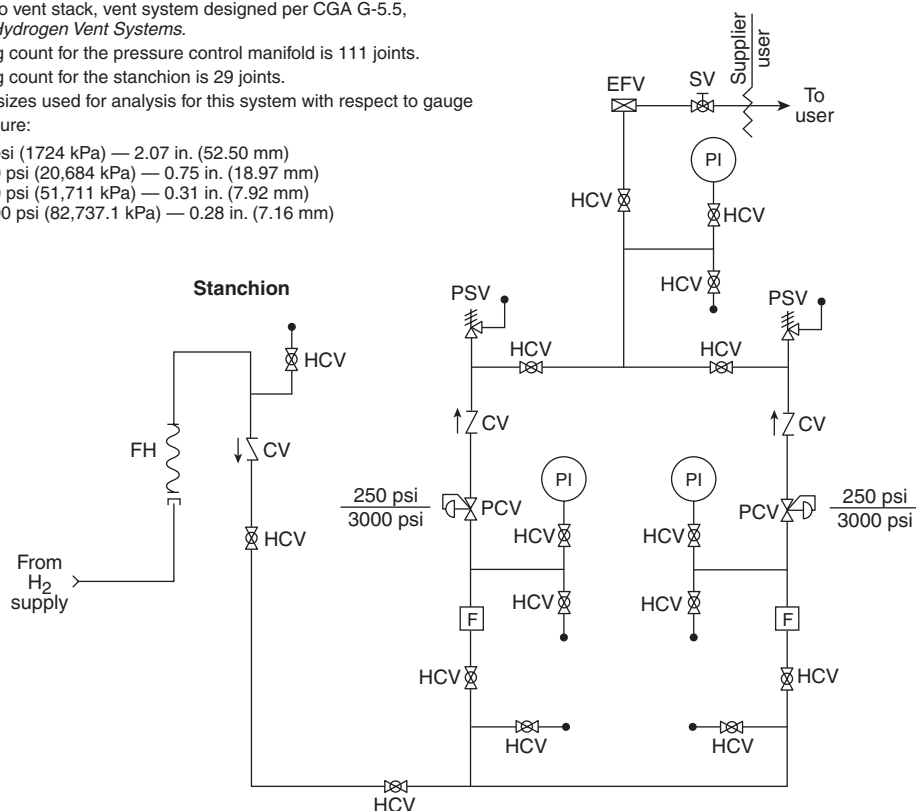


FIGURE A.3.3.12(d) Typical Tube Trailer Discharge Stanchion and Pressure Control Manifold.

Class 3 materials are materials that in themselves are capable of detonation or explosive decomposition or explosive reaction but require a strong initiating source or heat under confinement before initiation. Class 3 materials include the following:

- (1) Materials that have an instantaneous power density (product of heat of reaction and reaction rate) at 482°F (250°C) at or above 100 W/mL and below 1000 W/mL
- (2) Materials that are sensitive to thermal or mechanical shock at elevated temperatures and pressures
- (3) Materials that react explosively with water without requiring heat or confinement

Class 2 materials are materials that readily undergo violent chemical change at elevated temperatures and pressures, including the following:

- (1) Materials that have an instantaneous power density (product of heat of reaction and reaction rate) at 482°F (250°C) at or above 10 W/mL and below 100 W/mL
- (2) Materials that react violently with water or form potentially explosive mixtures with water

Class 1 materials are materials that in themselves are normally stable but that can become unstable at elevated temperatures and pressures, including the following:

- (1) Materials that have an instantaneous power density (product of heat of reaction and reaction rate) at 482°F (250°C) at or above 0.01 W/mL and below 10 W/mL

- (2) Materials that react vigorously with water, but not violently
- (3) Materials that change or decompose on exposure to air, light, or moisture

Class 0 materials are materials that in themselves are normally stable, even under fire conditions, including the following:

- (1) Materials that have an instantaneous power density (product of heat of reaction and reaction rate) at 482°F (250°C) below 0.01 W/mL
- (2) Materials that do not react with water
- (3) Materials that do not exhibit an exotherm at temperatures less than or equal to 932°F (500°C) when tested by differential scanning calorimetry

**A.3.3.44 Gas Cabinet.** Doors and access ports for exchanging cylinders and accessing pressure-regulating controls are permitted to be included as part of a gas cabinet.

**A.3.3.47 Gas Room.** Gas rooms must be constructed and utilized in accordance with Section 6.4.

**A.3.3.48 Gaseous Hydrogen System.** The system includes stationary or portable containers, pressure regulators, pressure-relief devices, manifolds, interconnecting piping, and controls as required.

**A.3.3.51 Hazard Rating.** The criteria for hazard rating are as defined in NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*.



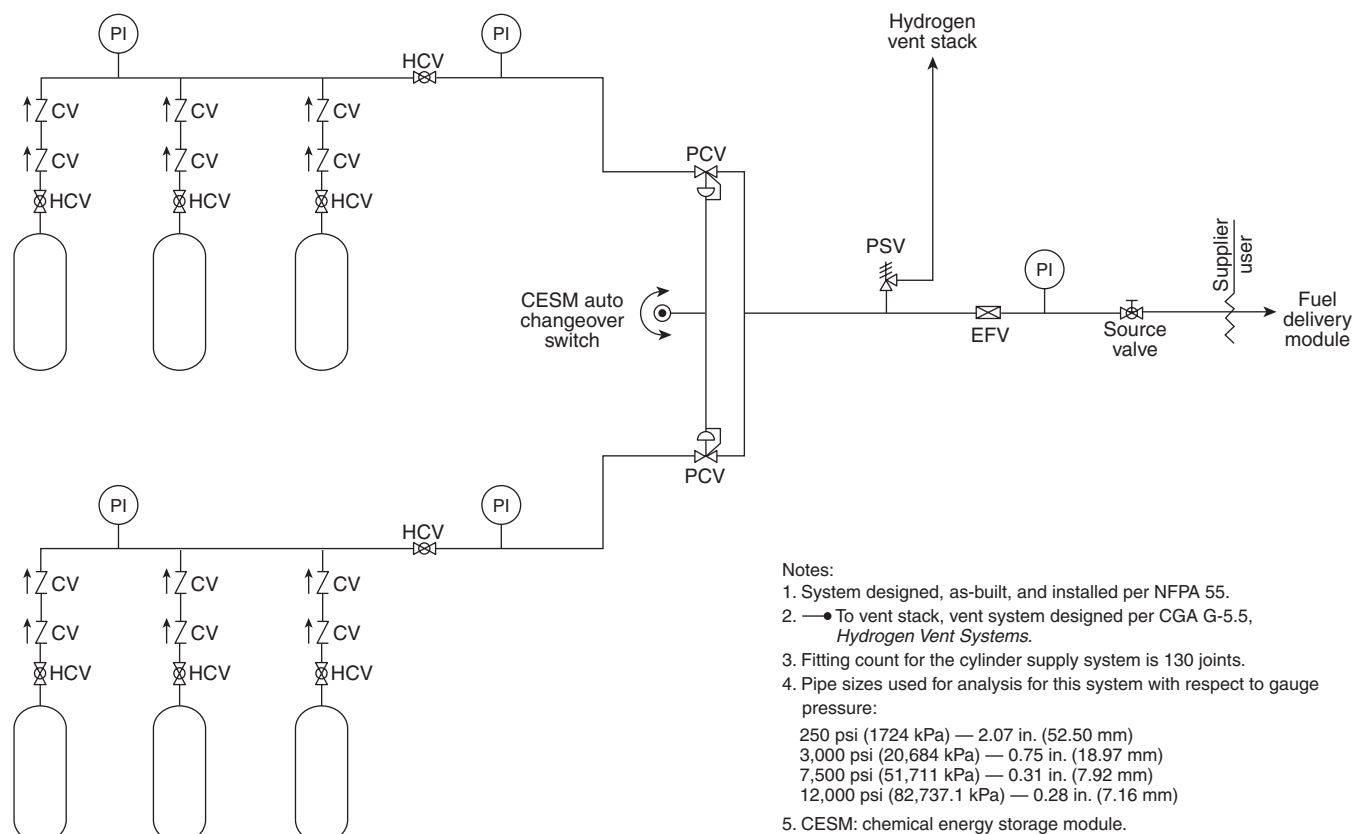


FIGURE A.3.3.12(e) Typical Chemical Energy Storage Module (CESM).

**A.3.3.52 Health Care Facilities.** Health care facilities include, but are not limited to, hospitals, nursing homes, limited care facilities, clinics, medical and dental offices, and ambulatory health care centers, whether permanent or movable. [99, 2010]

**A.3.3.53 Immediately Dangerous to Life and Health (IDLH).** This level is established by the National Institute for Occupational Safety and Health (NIOSH). If adequate data do not exist for precise establishment of IDLH, an independent certified industrial hygienist, industrial toxicologist, or appropriate regulatory agency should make such determination.

**A.3.3.54 ISO Module.** The characteristic internal water volume of individual tubular cylinders is 43 ft<sup>3</sup> (1218 L) or a water capacity of 2686 lb (1218 kg). The frame of an ISO container module and its corner castings are specially designed and dimensioned to be used in multimodal transportation service on container ships, special highway chassis, and container-on-flatcar railroad equipment.

**A.3.3.55.1 Ceiling Limit.** The ceiling limits utilized are those published in 29 CFR 1910.1000.

**A.3.3.55.2 Permissible Exposure Limit (PEL).** The maximum permitted time-weighted average exposures to be utilized are those published in 29 CFR 1910.1000.

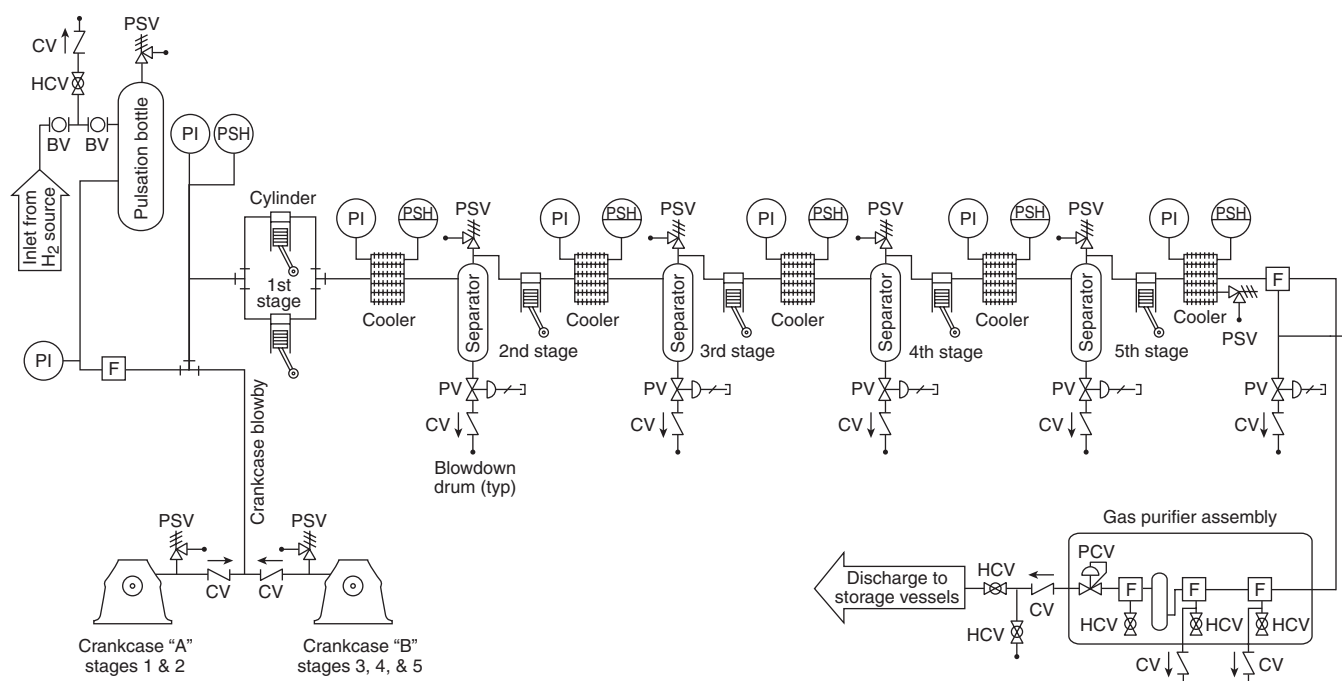
**A.3.3.55.3 Short-Term Exposure Limit (STEL).** STEL limits are published in 29 CFR 1910.1000.

**A.3.3.56 Limited Combustible.** On November 28, 1942, a total of 490 people died in a fire in the Cocoanut Grove nightclub in Boston. On June 5, 1946, more than 60 people died in

the La Salle Street Hotel fire in Chicago. On December 7, 1946, a fire in the Winecoff Hotel in Atlanta claimed the lives of 119 people. These fires had one thing in common: rapid flame spread along the surfaces of interior finish was judged to be a major factor in fire growth. Two of the structures had burlap wall coverings, and the other had an early type of plywood that had seriously delaminated.

Within the context of the building code the term *limited-combustible* also includes materials that are noncombustible. Combustible materials meet neither the definition of materials that are either noncombustible or limited-noncombustible. The building code intends to allow limited-combustible materials to be used in various applications in buildings viewed as “noncombustible” within the construction Types designated as Type I and Type II. Materials are evaluated for their acceptability as a building component based on the rate at which they generate heat as well as other parameters, since it is recognized that buildings of noncombustible construction might contain insulation, floor and wall coverings, blocking, and other components that do not meet the definition of *noncombustible*.

Heat value, flame spread, and the ability of a material to sustain progressive burning are characteristics that are included within the definition of *limited-combustible* based on specific tests prescribed by various NFPA standards. The flame spread index represents a comparison between the burning of the material under consideration versus that of select grade red oak flooring under a set of controlled conditions. The burning of red oak flooring under the prescribed test conditions measuring time, temperature, and distance establishes a



## Notes:

1. System designed, as-built, and installed per NFPA 55.
2. —●— To vent stack, vent system designed per CGA G-5.5, *Hydrogen Vent Systems*.
3. Fitting count for the compression system is 225 joints.
4. Pipe sizes used for analysis for this system with respect to gauge pressure:
 

250 psi (1724 kPa)	— 2.07 in. (52.50 mm)
3,000 psi (20,684 kPa)	— 0.75 in. (18.97 mm)
7,500 psi (51,711 kPa)	— 0.31 in. (7.92 mm)
12,000 psi (82,737.1 kPa)	— 0.28 in. (7.16 mm)

FIGURE A.3.3.12(f) Typical Compressor Module.

baseline of 100 for the test. The lower end of the scale is represented by reinforced cement board. Materials are compared to red oak and then assigned a flame spread index falling between 0 and 100.

**A.3.3.57 Liquefied Hydrogen System.** The system includes stationary or portable containers, including unconnected reserves, pressure regulators, pressure relief devices, manifolds, interconnecting piping, and controls as required.

**A.3.3.63 Mobile Supply Unit.** Examples include ISO modules, tube trailers, and cylinder packs.

**A.3.3.66 Normal Temperature and Pressure (NTP).** There are different definitions of normal conditions. The normal conditions defined here are the ones most commonly used in the compressed gas and cryogenic fluid industry.

**A.3.3.69 Piping System.** Equipment such as a compressor or an intermediate storage vessel should be considered individual pieces of equipment. The equipment is not piping within the context of the definition of a piping system.

**A.3.3.71 Protection Level.** NFPA uses the concept of protection levels in a manner that is analogous to Group H occupancies in other model codes. Although NFPA 1, *Fire Code*, and NFPA 5000, *Building Construction and Safety Code*, do not have unique occupancy classifications for occupancies containing hazardous materials, Protection Levels 1 to 5 in NFPA codes

and standards reflect increased building safety requirements that are applicable to occupancies containing hazardous materials, which generally correlate to the Group H, Division 1 to 5 occupancy classifications in other codes.

**A.3.3.77 Source Valve.** The source valve is located at a point downstream of a bulk gas supply system and used as the defined point of termination of the bulk supply. It is a point that differentiates between the “supplier” side of the system and what is commonly referred to as the “user” or “customer” side of the system.

**A.3.3.79 Sterilization Building.** This building can include the mechanical room, electrical room, nitrogen tank and vaporizers area, chiller area, preconditioning room or preconditioning cells, conveyance rooms, preheat room, sterilizer room, aeration room or cells, emissions control area, ethylene oxide drum storage room, gas transfer room, shipping and receiving office(s), unprocessed and processed product storage areas, control room, maintenance areas, offices for the process support personnel, and any other rooms or systems as applicable in supporting the sterilization process.

**A.3.3.81.1 Compressed Gas System.** A compressed gas system can consist of a compressed gas container or containers, reactors, and appurtenances, including pumps, compressors, and connecting piping and tubing.



**A.3.3.82.1 Portable Tank.** A portable tank does not include any cylinder having less than 1000 lb (453.5 kg) water capacity, cargo tank, tank car tank, or trailers carrying cylinders of over 1000 lb (453.5 kg) water capacity.

**A.3.3.82.2 Stationary Tank.** A stationary tank does not include a cylinder having less than 1000 lb (453.5 kg) water capacity.

**A.3.3.84 Tube Trailer.** The characteristic internal water volume of individual tubular cylinders ranges from 43 ft<sup>3</sup> to 93 ft<sup>3</sup> (1218 L to 2632 L) or a water capacity of 2686 lb to 5803 lb (1218 kg to 2632 kg).

**A.4.4** Out-of-service systems should not be abandoned in place. Systems that remain out of service should be maintained in a usable condition to ensure that the appropriate safeguards are in place. Permits should be maintained in a current state so that the AHJ remains aware of the installation until such time that the system is removed.

**A.6.6** Electrical and electronic equipment and wiring for use in hazardous locations as defined in Article 500 of *NFPA 70, National Electrical Code*, should meet the requirements of Articles 500 and 501 of *NFPA 70*. Note that Article 505 also details requirements for this equipment and wiring in hazardous locations and uses a zone classification method rather than the division method of Article 500.

**A.6.7** Under the requirements of 29 CFR 1910.38 established by OSHA regulations, employers must establish an employee alarm system that complies with 29 CFR 1910.165. The requirements of 29 CFR 1910.165 for the employee alarm system include, but are not limited to, systems that are capable of being perceived above ambient noise or light levels by all employees in the affected portions of the workplace. Tactile devices may be used to alert those employees who would not otherwise be able to recognize the audible or visual alarm. The alarm system can be electrically powered or powered by pneumatic or other means. State, local, or other governmental regulations might also establish requirements for employee alarm systems.

**A.6.8** NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, provides more information on this subject.

**A.6.9** The intent of this section is to require a water-based fire extinguishing system to keep vessels containing compressed gases cool in the event of an exposure fire, thereby minimizing the likelihood of a release and associated consequences. Accordingly, alternative fire extinguishing systems, such as dry-chemical or gaseous agent systems, should not be substituted.

**A.6.18** Figure A.6.18 shows three possible locations of the source valve.

**A.7.1.3** The compressed gas system equipment referenced is intended to include fuel cell applications, generation of hydrogen from portable or transportable hydrogen generation equipment, batteries, and similar devices and equipment that utilize hydrogen for the purpose of power generation. It does not include hydrogen production facilities intended to produce hydrogen used for distribution or repackaging operations operated by gas producers, distributors, and repackagers.

**A.7.1.4** Numerous metal hydrides are currently being tested for gaseous hydrogen storage applications. While certain Class D extinguishing agents have been effective on some metal hy-

dride materials, they have not been tested on the wide range of hydrides. It is crucial to understand any adverse chemical reactions between the hydride and the agent prior to using the fire suppressant. Additionally, it is important to understand that the application should be limited to small incipient stage fires. Larger fires would require the use of personal protective equipment in the application of the extinguishing agent.

**A.7.1.10.2** Figure A.7.1.10.2 is a schematic showing the separation distances required by 7.1.10.2.

**A.7.1.10.3** Clearance is required from combustible materials to minimize the effects of exposure fires to the materials stored or used. The requirement to separate the materials from vegetation should not be interpreted to mean that the area is maintained free of all vegetation. In some settings, gas systems are located on grounds that are maintained with formal landscaping. Some judgment must be exercised to determine whether the vegetation poses what might be viewed as an exposure hazard to the materials stored. Cut lawns, formal landscaping, and similar vegetation do not ordinarily present a hazard and should be allowed. On the other hand, tall, dry grass or weeds and vegetation that fringes on the border of an urban-wildland interface might be viewed as a hazard.

**A.7.1.14.3** The gas supplier should be consulted for advice under these circumstances.

**A.7.1.17.1.2** Underground piping systems are those systems that are buried and in contact with earth fill or similar materials. Piping located in open-top or grated-top trenches is not considered to be underground although it may be below grade.

**A.7.3.1.12.1** An approved means of leak detection and emergency shutoff is one way of meeting the requirements for excess flow control.

**A.7.5.2.1.1** Portions of the system upstream of the source valve include the containers or bulk supply as well as control equipment designed to control the flow of gas into a piping system. The piping system downstream of the source valve is protected by excess flow control should failure occur in the piping system and is not required to be protected by the fire barrier. The fire barrier serves to protect those portions of the system that are the most vulnerable along with the necessary controls used to operate the system.

**A.7.6.2.1.1** See A.7.5.2.1.1.

**A.7.7.2.1.1** See A.7.5.2.1.1.

**A.7.8.3.1.1** See A.7.5.2.1.1.

**A.7.9.2.2.1.1** See A.7.5.2.1.1.

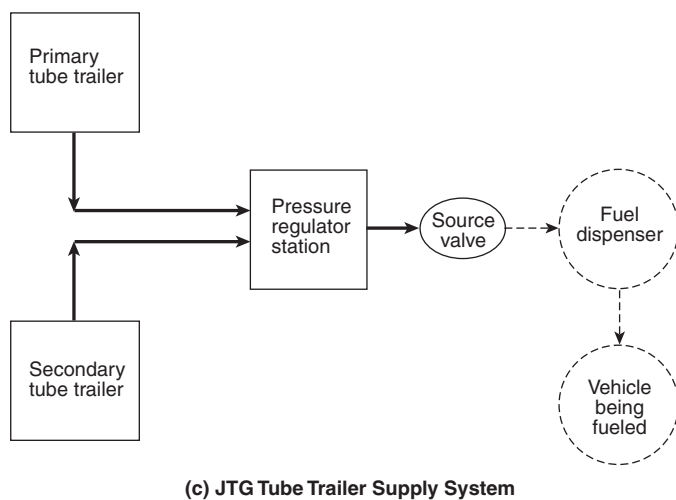
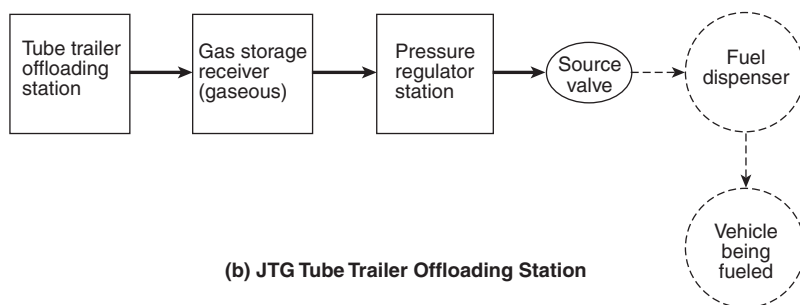
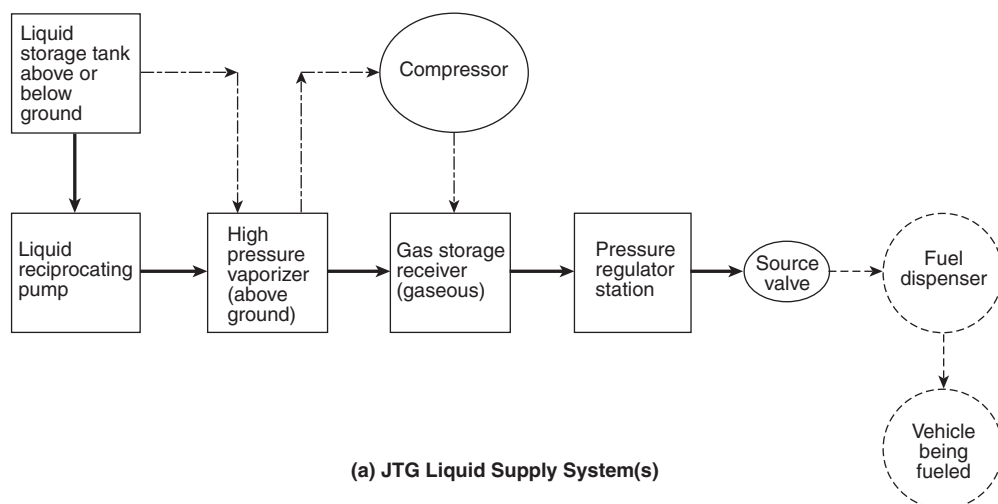
**A.7.9.3.6** The areas for typical restricted flow orifices are shown in Table A.7.9.3.6.

**A.7.9.3.6.2** The formula has been taken from industry publications, including the Scott Specialty Gases *Design and Safety Handbook*. It is based on estimated flow rates for air at 70°F (21°C) discharging to normal atmospheric pressure through an average shape and quality orifice. It can be assumed to be ±15 percent accurate. Correction factors have been built into the formula as presented in 7.9.3.6.2 to accommodate the use of gases other than air (e.g., use of specific gravity data).

**A.7.10.1.2.1** See A.7.5.2.1.1.

**A.7.10.2.2.1** See A.7.5.2.1.1.





- > Piping within the scope of NFPA 55
- > Piping within the scope of NFPA 52
- - - - -> Optional piping within the scope of NFPA 55

**FIGURE A.6.18 Three Examples of Source Valve Locations.**

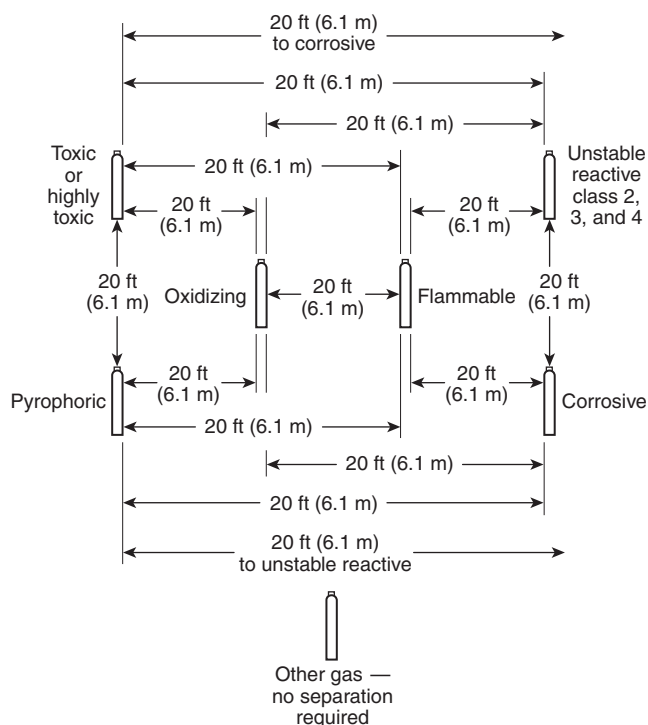


FIGURE A.7.1.10.2 Separation of Gas Cylinders by Hazard.

Table A.7.9.3.6 Typical Orifice Areas

Orifice Diameter		Area	
in.	cm	in. <sup>2</sup>	cm <sup>2</sup>
0.006	0.015	$2.83 \times 10^{-5}$	$1.83 \times 10^{-4}$
0.010	0.025	$7.85 \times 10^{-5}$	$5.06 \times 10^{-4}$
0.014	0.036	$1.54 \times 10^{-4}$	$9.93 \times 10^{-4}$

**A.8.2** Pressure vessels of any type can be subject to additional regulations imposed by various states or other legal jurisdictions. Users should be aware that compliance with DOT or ASME requirements might not satisfy all the required regulations for the location in which the vessel is to be installed or used.

**A.8.2.4.3** Vaporizers or heat exchangers used to vaporize cryogenic fluids can accumulate a large load of ice during operation. Additional requirements to be considered in the design include snow load for the area where the installation is located as well as the requirements for seismic conditions. The operating conditions of systems vary, and the designer has a responsibility to consider all the loads that might be imposed. Foundations that could be used to support delivery vehicles as well might require special consideration relevant to live loads as well as for the dead loads imposed by the equipment itself.

**A.8.2.5.5.1** Pressure relief valves typically are spring-loaded valves where the relief pressure is set by adjustment of a spring. Valves should be sealed to prevent adjustment by other than authorized personnel typically found at a retest facility. An ASME pressure relief valve is designed to comply with the re-

quirements of the ASME *Boiler and Pressure Vessel Code* and typically is equipped with a wire seal to prevent tampering

**A.8.4.1.1.2** An example of this identification is 360 degree wraparound tape.

**A.8.7.2** It is not uncommon to have inert cryogenic fluids used to provide stage effects for theatrical performances that are conducted within assembly occupancies. The fluids are sometimes placed within these occupancies with special controls, including ventilation systems, fire detection systems, monitors for oxygen deficiency, warning signs, and remote fill indicating devices that indicate tank volume when a remote filling point is provided and stationary tanks are involved. Such installations are normally permitted on a case-by-case basis under the requirements of Section 1.5.

Clearance is required from combustible materials to minimize the effects of exposure fires to the materials stored or used. The requirement to separate the materials from vegetation should not be interpreted to mean that the area is maintained free of all vegetation. In some settings, gas systems are located on grounds that are maintained with formal landscaping. Some judgment must be exercised to determine whether the vegetation poses what might be viewed as an exposure hazard to the materials stored. Cut lawns, formal landscaping, and similar vegetation do not ordinarily present a hazard, and should be allowed. On the other hand, tall, dry grass or weeds and vegetation that fringes on the border of an urban-wildland interface might be viewed as a hazard.

**A.8.13.2.5** Flood hazard areas typically are identified on either (1) the special flood hazard area shown on the flood insurance rate map or (2) the area subject to flooding during the design flood and shown on a jurisdiction's flood hazard map or otherwise legally designated.

**A.8.13.2.6.4.1** The intent of these provisions is to make certain that the cryogenic installation is not exposed to the potential of a pool fire from the release of flammable or combustible liquids. Cryogenic fluids are not diked in order that they are allowed to dissipate should leakage occur. Studies conducted by NASA (NSS 1740.16, *Safety Standard for Hydrogen and Hydrogen Systems*) show that the use of dikes around liquid hydrogen storage facilities serves to prolong ground-level flammable cloud travel and that the dispersion mechanism is enhanced by vaporization-induced turbulence. The travel of spilled or leaked cryogenic fluid to distances greater than a few feet (meters) from the source given the nature of the typical leak is considered to be implausible due to the character of cryogenic fluids and their ability to quickly absorb heat from the surrounding environment.

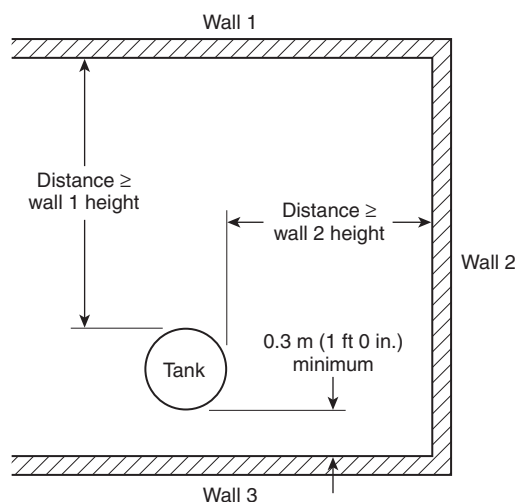
**A.8.13.2.7.2** The placement of stationary containers is limited with respect to exposure hazards. Table 8.7.2 establishes the minimum separation distance between a building and any stationary tank at 1 ft (0.3 m). Additional limitations are placed on wall openings, air intakes, and other exposures. The material-specific tables for liquid hydrogen and liquid oxygen specify increased distances according to the type of construction adjacent to the tank. A problem arises when courtyards are configured so as to interrupt the free movement of air around a tank where an asphyxiation hazard, a flammable hazard, or an oxygen-enriched environment can be created.

Placement of stationary containers proximate to the wall of the building served is allowable providing the minimum separation distances for exposure hazards are met. When additional walls encroach on the installation to form a court, the

focus of concern shifts away from the exposure hazards associated with the building itself to the hazards associated with personnel due to hazardous atmospheres that can be created due to the lack of free air movement and ventilation.

By specifying the minimum distance between the tank and the encroaching walls that form the court, the circulation of adequate air is ensured. Placing the tank at not less than the height of two of the three encroaching walls results in creating an opening such that the angular dimension between the top of two of the three encroaching walls and the point over which the tank is placed is not greater than 45 degrees, thereby allowing the circulation of air through the space in which the tank is installed.

**A.8.13.2.7.2.1** The separation distances shown in Figure A.8.13.2.7.2.1 are required to provide for ventilation in the space in order to avoid creating a confined space. Chapter 8 is a generic chapter used to establish minimum requirements for all cryogenics. Material-specific requirements for oxygen, hydrogen, or other gases might require greater separation distances based on the type of construction or the related exposure. For example, wall number 3 shown in Figure A.8.13.2.7.2.1 could be an exterior building wall, and the gas could be hydrogen. Refer to Table 8.7.2, Table 9.3.2 and Table 11.3.2.2 for specific details regarding building walls, wall openings, air intakes, and similar conditions.



**FIGURE A.8.13.2.7.2.1 Bulk Cryogenic System Located in a Courtyard.**

**A.9.1** Oxygen gas is colorless, odorless, tasteless, and non-toxic. It comprises about 21 percent of atmospheric air and is about 10 percent heavier than air. At atmospheric pressure and temperatures below  $-297^{\circ}\text{F}$  ( $-182.5^{\circ}\text{C}$ ), oxygen is a liquid. Oxygen is stable in both gas and liquid phases. In the absence of moisture, oxygen in the gaseous or liquid form is noncorrosive.

Oxygen is nonflammable. Ignition of combustible materials occurs more readily in an oxygen-rich atmosphere than in air, and combustion proceeds at a more rapid rate, although no more total heat is released. This code provides for the pro-

tection of the bulk oxygen system from involvement by fire from sources apart from the system itself. It is important to locate bulk oxygen systems in well-ventilated locations, since oxygen-rich atmospheres are able to collect temporarily in confined areas in the event of functioning of a pressure relief device or leakage from the system.

**A.9.1.1.1** For information on oxygen systems having capacities less than those stated in 3.3.15, see NFPA 51, *Standard for the Design and Installation of Oxygen-Fuel Gas Systems for Welding, Cutting, and Allied Processes*, and NFPA 99, *Standard for Health Care Facilities* (Chapters 4 and 8).

**A.9.2.1** Compatibility involves both combustibility and ease of ignition. Materials that burn in air will burn violently in pure oxygen at atmospheric pressure and will burn explosively in pressurized oxygen. Also, a number of materials that do not burn in air will do so in pure oxygen or oxygen-enriched atmospheres, particularly under pressure. Metals for containers and piping must be selected carefully, depending on service conditions. Various steels can be used for a number of applications, but some service conditions can call for other materials (typically copper or its alloys) because of their greater resistance to ignition and lower rate of combustion. Data regarding the combustibility and ease of ignition of materials are available in NFPA 53, *Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres*.

Materials that can be ignited in air have lower ignition energies in oxygen. A number of such materials can be ignited by friction at a valve seat or stem packing or by adiabatic compression produced when oxygen at high pressure is rapidly introduced into a system initially at low pressure. Other recognized ignition mechanisms include particle impact, mass impact, static electric discharge, electrical arc, fresh metal exposure, resonance, and piloted ignition.

**A.9.3.2** Figure A.9.3.2 serves to illustrate the separation distances between bulk oxygen systems and exposures.

These distances do not apply where fire barriers having a minimum fire resistance rating of 2 hours interrupt the line of sight between uninsulated portions of the bulk oxygen storage installation and the exposure. The fire barriers protect uninsulated oxygen storage containers or supports, control equipment, and system piping (or parts thereof) from external fire exposure. Liquid oxygen storage containers are insulated. Such containers can provide line-of-sight protection for uninsulated system components. Interruption of the line of sight means that an “eye” on any part of the uninsulated portion of the bulk oxygen storage installation cannot “see” any part of the exposure.

**A.9.3.2.1** The distances required by Table 9.3.2 can be reduced when a fire barrier wall is constructed to shield the oxygen installation from the exposure as well as to limit the exposure of sensitive receptors to the effects of an incident involving the oxygen source. In most circumstances, a fire barrier wall will be needed to allow encroachment on property lines where the adjacent property is suitable for building. The separation distances given in Table 9.3.2 assume that any structure on the adjoining property does not dictate a greater distance.

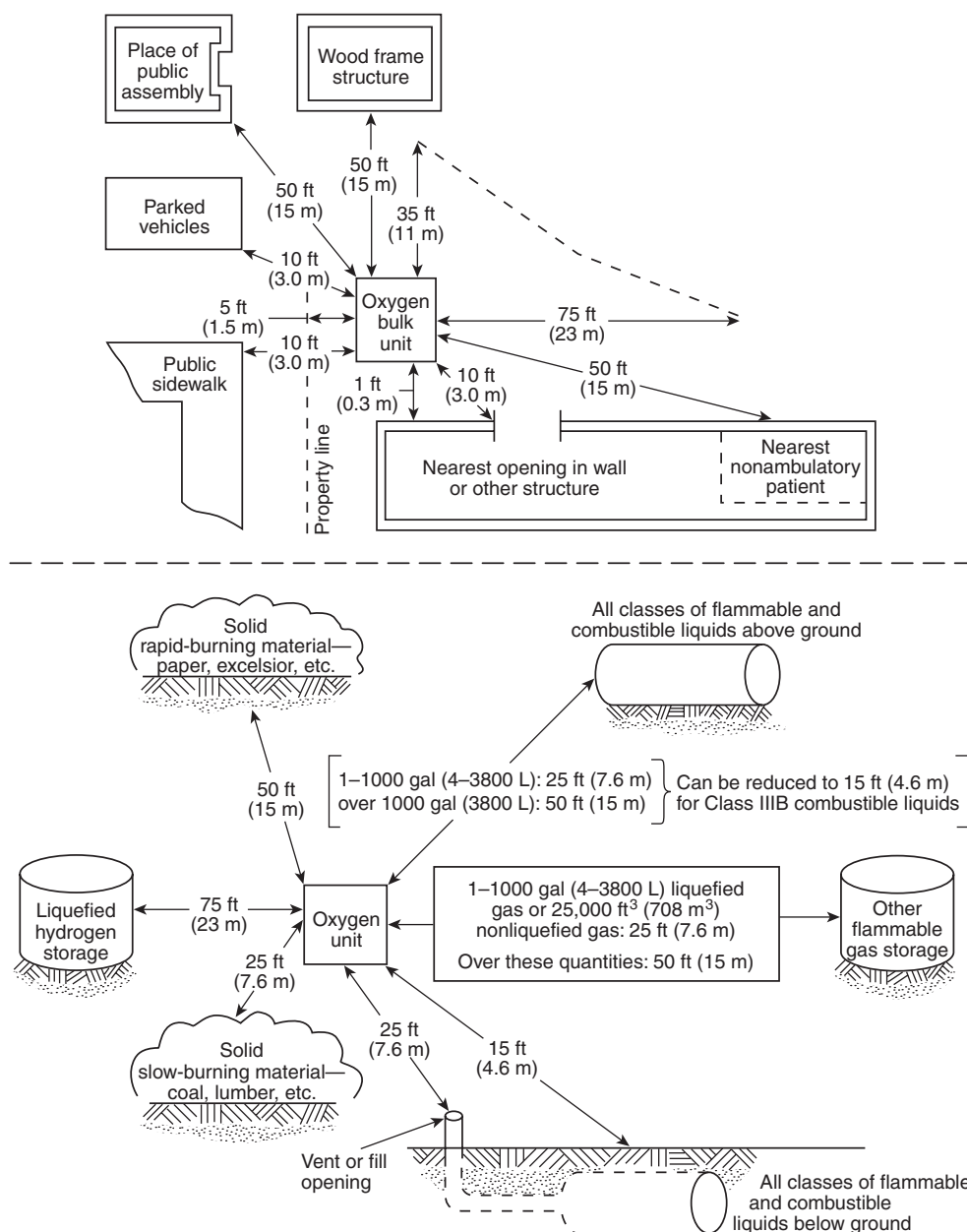


FIGURE A.9.3.2 Distances Between Bulk Oxygen Systems and Exposures.

**A.9.4.1.3** Some materials commonly used for low-temperature piping are austenitic chromium–nickel alloy steels, copper, copper–silicon alloys, aluminum, and some brasses and bronzes.

**A.9.4.5** Bulk oxygen installations are not hazardous (classified) locations as defined by *NFPA 70, National Electrical Code*. The use of general-purpose electrical wiring and equipment should be allowed unless otherwise indicated.

**A.10.2.1** Any reference to listed or approved equipment in the noted sections of the IFGC is within the context of the ANSI/ASME B31.3, *Pressure Piping*, standard and describes a material or

component that conforms to the specifications integral to ANSI/ASME B31.3.

**A.10.3.2.2.1.1(B)** The following is a sample calculation for separation distances using ¼ in. ID tubing at gauge pressure of 250–3000 psi:

- (1) Determine internal diameter (ID) where  $ID = OD - (2 \times \text{wall thickness})$ ; wall thickness = 0.049 in. (known); outside diameter (OD) = 0.250 in.:

$$ID = d = 0.250 - (2 \times 0.049) = 0.152 \text{ in.} = 3.86 \text{ mm}$$

To use the equations in Table 10.3.2.2.1.1(B) the ID values (the value of  $d$  in the equation) to be used must be expressed in millimeters.



- (2) Next, determine separation distance(s). The separation distances  $D_a$ ,  $D_b$ , etc., are calculated in meters to two significant places after the decimal. To convert meters to feet, multiply meters by 3.281 and round off to the nearest 5 ft.

For example, assuming the 250–3000 psi pressure range (second column), calculations for separation distance for the Table 10.3.2.2.1.1(B) footnotes (a) through (e) are as follows.

Where:

$D_a, b, c, d, e$  = calculated separation distance for  $D_a, D_b$ , etc.

$e = 2.71828 \dots$ , the base of natural logarithms

Then:

- (a)  $D_a = 0.74d^{0.99962}$   
 $D_a = 0.74(3.86^{0.99962})$   
 $D_a = 0.74(3.858) = 2.85 \text{ m} = 9.4 \text{ ft} \rightarrow 10 \text{ ft}$
- (b)  $D_b = 0.37d^{1.1152} + e^{-0.10771d} (0.19d^{1.2531} - 0.37d^{1.1152})$   
 $D_b = 0.37(3.86^{1.1152}) +$   
 $e^{-(0.10771)(3.86)} [(0.19)(3.86^{1.2531}) -$   
 $(0.37)(3.86^{1.1152})]$   
 $D_b = 0.37(4.51) + e^{-0.4158} [(0.19)(5.43) -$   
 $(0.37)(4.51)]$   
 $D_b = 1.67 + 0.66(1.03 - 1.67)$   
 $D_b = 1.67 - 0.42$   
 $D_b = 1.25 \text{ m} = 4.1 \text{ ft} \rightarrow 5 \text{ ft}$
- (c)  $D_c = 0.29d^{1.092} + e^{-0.10392d} (0.19d^{1.1795} - 0.29d^{1.092})$   
 $D_c = 0.29(3.86^{1.092}) +$   
 $e^{-(0.10392)(3.86)} [(0.19)(3.86^{1.1795}) -$   
 $(0.29)(3.86^{1.092})]$   
 $D_c = 0.29(4.37) + e^{-0.4011} [(0.19)(4.92) -$   
 $(0.29)(4.37)]$   
 $D_c = 1.27 + 0.67(0.94 - 1.27)$   
 $D_c = 1.27 - 0.22$   
 $D_c = 1.05 \text{ m} = 3.45 \text{ ft} \rightarrow 5 \text{ ft}$
- (d)  $D_d = 0.31d^{0.99962}$   
 $D_d = 0.31(3.86^{0.99962})$   
 $D_d = 0.31(3.84) = 1.19 \text{ m} = 3.9 \text{ ft} \rightarrow 5 \text{ ft}$
- (e)  $D_e = 0.31d^{0.99962}$   
 $D_e = 0.31(3.86^{0.99962})$   
 $D_e = 0.31(3.84) = 1.19 \text{ m} = 3.9 \text{ ft} \rightarrow 5 \text{ ft}$

The subscripts to  $D$ ,  $a$ ,  $b$ ,  $c$ ,  $d$ , and  $e$ , relate to notes (a) through (e), respectively, in Table 10.3.2.2.1.1(B). To convert the distance in meters to feet, multiply by 3.2808. The resultant distance in feet is then rounded off to the nearest 5 foot dimension. For example, a distance of 5.2 ft would be rounded down to 5 ft. A distance of 7.6 ft would be rounded up to 10 ft.

**A.10.3.2.2.1.1(E)** Systems that employ compressors downstream of a bulk supply typically operate at higher pressures than that of the bulk supply. As a result, the diameter of the piping system can vary with the pressure. The use of a higher pressure rating or variation of internal diameters is not warranted unless there is a storage component with a hydrogen content that exceeds 400 scf (11.3 m<sup>3</sup>) located downstream of the primary storage source and upstream of the source valve. The volume of gas contained within the piping system is not included in determining the quantity in storage.

For example, a 3000 psi (20,684 kPa) storage system that supplies a 6000 psi (41,369 kPa) compressor that directly feeds a process with less than 400 scf (11.3 m<sup>3</sup>) of intervening storage at a pressure of 6000 psi (41,369 kPa) or less is considered a 3000 psi (20,684 kPa) system. Conversely, a system with the primary storage of 3000 psi (20,684 kPa) might supply a compressor that in turn delivers hydrogen to intermediate storage with a quantity of greater than 400 scf (11.3 m<sup>3</sup>). (Note: Pres-

ures given are gauge pressures.) The piping serving the intermediate storage system from a point of discharge on the compressor can have an internal diameter of less than that serving the primary storage system upstream of the compressor. Accordingly, each portion of the system must be analyzed with respect to the tabular distances. See the typical P&IDs shown in Figure A.3.3.12(a) through Figure A.3.3.12(f) for additional information in this regard.

The use of Table 10.3.2.2.1.1(B) is based on the maximum internal diameter of the piping system over the range of pressures specified. In practice, it is common to maintain a consistent size of piping throughout the system; however, there might be cases where the ID of the piping system varies. In such cases, the piping with the largest internal diameter in the system is used to establish the system pipe size for the purposes of using the table, regardless of the length of the piping. It is not uncommon for portions of the system equipped with pressure gauges, pressure transducers, or other instrumentation to be served by small-diameter piping systems. However, the maximum internal diameter of the piping system will control the establishment of distance for the exposures indicated.

Pipe sizes are typically expressed in nominal terms as illustrated in Table A.10.3.2.2.1.1(E) below. This is compared with tubing in which the outside diameter (OD) is expressed in exact terms. Designers commonly use pipe schedule to specify the wall thickness for a given material based on the design conditions. Typical pipe sizes found in commerce include those shown in Table A.10.3.2.2.1.1(E).

**Table A.10.3.2.2.1.1(E) Typical Pipe Sizes**

Nominal Pipe Size (in.)	O.D. (in.)	Pipe Schedules — Wall Thickness (in.)			
		40	80	XH	XXH
¼	0.540	0.088	0.119	0.119	—
⅜	0.675	0.091	0.126	0.126	—
½	0.840	0.109	0.147	0.147	0.294
¾	1.050	0.113	0.154	0.154	0.308
1	1.315	0.133	0.179	0.179	0.358
1¼	1.660	0.140	0.191	0.191	0.382
1½	1.900	0.145	0.200	0.200	0.400
2	2.375	0.154	0.218	0.218	0.436
2½	2.875	0.203	0.276	0.276	0.552
3	3.500	0.216	0.300	0.300	0.600
3½	4.000	0.226	0.318	0.318	0.636
4	4.500	0.237	0.337	0.337	0.674

XH = extra heavy; XXH = extra extra heavy.

Note: Standard pipe schedule or pipe size as listed by ANSI/ASME B36.10M, *Welded and Seamless Wrought Steel Pipe*, and API Spec 5L, *Specification for Line Pipe*.

To determine internal diameter (ID) of a selected pipe size, multiply by 2 the wall thickness for the selected schedule and subtract the result from the outside diameter (OD):

$$\text{ID} = \text{OD} - (2 \times \text{wall thickness})$$

For example, for 2 in. Schedule 40 pipe:

Wall thickness = 0.154 in.; OD = 2.375 in.

Then:

$$\text{ID} = 2.375 - (2 \times 0.154) = 2.067 \text{ in.}$$

When tubing is used in lieu of pipe, the OD of the tubing is designated in inches (e.g., ¼, ⅜, ½, 1, 1¼, 1½, 2), and the

tubing is manufactured to those specific dimensions. Tube wall thickness is determined based on the working pressure and materials of construction. The calculation of internal diameter is the same as that used for conventional pipe:

$$\text{ID} = \text{OD} - (2 \times \text{wall thickness})$$

For example, for ¼ in. OD tubing, if the wall thickness is 0.049 in. and the OD is 0.250 in.,

then:

$$\text{ID} = 0.250 - (2 \times 0.049) = 0.152 \text{ in.}$$

**A.10.3.2.2.1.1(F)** Portions of a system might operate at higher pressures than the bulk supply; however, those portions of the system do not require the use of a pressure rating higher than that of the bulk supply unless there is a storage component exceeding 400 scf (11.3 m<sup>3</sup>) downstream of the primary storage source and upstream of the source valve. The volume of gas contained within the piping system is not included when the quantity in storage is determined. For example, a 3000 psi (20,684 kPa) storage system that supplies a 6000 psi (41,369 kPa) compressor that directly feeds a process with less than 400 scf (11.3 m<sup>3</sup>) of intervening storage at a pressure of 6000 psi (41,369 kPa) or less is considered a 3000 psi (20,684 kPa) system.

**A.10.3.2.2.2** Distances to assumed lot lines established for the purpose of determining exterior wall and opening protection should not be confused with lot lines that are property lines in the true sense of the definition, and distances to assumed lot lines can be disregarded in the application of Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b). The lot lines specified in 10.3.2.2.2 are property lines used to separate one lot from another or to separate a property from a street or other public space.

A permit holder cannot exercise any right of control over the property of others, whether the ownership is public or private. In cases where the permit holder owns an adjacent lot or parcel, the separation from property lines assumes that the permit holder could transfer ownership of the adjacent property at some point, and therefore the requirements for property line separation should be observed.

**A.10.3.2.2.3** The code has historically recognized that, in certain instances, fire barrier walls can serve as a means to reduce the limits of unacceptable consequences due to the release of hydrogen from high-pressure equipment. Testing other than that related to establish fire resistance of the fire barrier walls has not been documented. Researchers at Sandia National Laboratories have been investigating the use of fire barrier walls as a means of mitigation in the establishment of distances related to the installation of bulk gaseous hydrogen systems, and a technical paper has been presented detailing the early findings.

As stated by Houf, Schefer, and Evans in "Analysis of Barriers for Mitigation of Unintended Releases of Hydrogen," the purpose of the Sandia study was to extend the available database on barrier walls as a hazard mitigation strategy and to provide technical data for risk-informed decisions in hydrogen codes and standards regarding barrier wall design and implementation. The focus of the research included testing to assess the effectiveness of various barrier designs in terms of the following:

- (1) Deflecting jet flames
- (2) Reducing the extent of the flammable cloud resulting from an unignited release
- (3) Reducing the magnitude of the radiative heat flux produced by a jet flame from an ignited release
- (4) Minimizing the amount of ignition overpressure produced from the barrier confinement

When the work is concluded, it is expected that the results will likely provide the basis for criteria for the proper configuration, design, and construction of such barriers in order that the walls do not create other hazards. The work to date has been limited; however, the results have been promising. Houf, Schefer, and Evans have determined that for the conditions investigated, 2000 psi (13.79 MPa) source pressure and a ⅛ in. (3.175 mm) diameter round leak, the barrier configurations studied were found to (1) reduce horizontal jet flame impingement hazard by deflecting the jet flame, (2) reduce radiation hazard distances for horizontal jet flames, and (3) reduce horizontal unignited jet flammability hazard distances. For the one-wall vertical barrier and the three-wall barrier configurations examined in the tests, the simulations of the peak overpressure hazard from ignition were found to be approximately 5.8 psi (40 kPa) on the release side of the barrier and approximately 0.73 psi to 0.44 psi (5 kPa to 3 kPa) on the downstream side of the barrier.

Investigation is continuing into the parameters for the construction of fire barrier walls. In the interim, a risk-informed approach to the establishment of distance has been introduced into Chapter 10 of this code. The Industrial and Medical Gases Technical Committee recognizes that previous editions of the code have allowed the use of fire barrier walls as a mitigation method. Until such time as the investigation by Sandia National Laboratories or others has been completed, 10.3.2.2.3 provides for the use, in limited cases, of fire barrier walls to mitigate effects on the downstream side of the wall by allowing a reduction of one-half of the separation distance otherwise required through the use of the risk-informed tables.

The resultant distances should be measured from a point on the unexposed (or downstream side) of the fire-barrier wall to the exposure. For example, the 45 ft (14.0 m) distance to lot lines shown for a 3,000 psi gauge (20,684 kPa gauge) system using piping with a maximum internal diameter (ID) of 0.747 in. (18.97 mm) can be reduced to 22.5 ft (7.0 m) between the property line and the fire barrier wall.

The concept of limiting the use of barrier walls is an interim determination that augments the requirements now found in the risk-informed approach to the establishment of separation distances. The outcome of the scientific research underway will measure the effect of the mitigation provided by the walls and will bring a firmness to the fire barrier requirements. The importance of completing the research is that all the factors integral to the construction of fire barrier walls will have been established through the scientific process. The use of the scientific process is a fundamental precept established in the acceptance of the risk-informed approach.

**A.10.4.2.1.1** Fracture mechanic methods given in recognized standards such as API RP 579, *Recommended Practice for Fitness-for-Service*, or BS 7910, *Guide to Methods for Assessing the Acceptability of Flaws in Metallic Structures*, can be used. Additional information is provided in BS 7910, *Guide to Methods for Assessing the Acceptability of Flaws in Metallic Structures*.

**A.10.4.2.3** Straight threads alone are not considered to be a seal.

**A.10.4.2.5.5** Buried utilities include electrical, sewer, water, gas, storm drains, and similar services. A greater distance may be required by the service provided. For example, public utility easements might dictate greater distances.

**A.10.4.2.8** Flood hazard areas are typically identified on either (1) the special flood hazard area shown on the flood insurance rate map or (2) the area subject to flooding during the design flood and shown on a jurisdiction's flood hazard map, or are otherwise legally designated.

**A.10.4.4.3** For guidance in these construction techniques, see NFPA 68, *Standard on Explosion Protection by Deflagration Venting*.

**A.10.6** Hydrogen fires should not be extinguished until the supply of hydrogen has been shut off because of the danger of re-ignition or explosion. In the event of fire, large quantities of water should be sprayed on adjacent equipment to cool the equipment and prevent involvement in the fire. Combination fog and solid stream nozzles are preferred, to permit widest adaptability in fire control. Small hydrogen fires can be extinguished with dry chemical extinguishers or with carbon dioxide, nitrogen, and steam. Re-ignition can occur if a heated surface adjacent to the flame is not cooled with water or other means.

**A.11.1** For information on gaseous hydrogen systems, see Chapter 10.

**A.11.2.3** Some materials acceptable for liquefied hydrogen temperature include austenitic chromium–nickel alloys, certain copper alloys, and aluminum, which retain ductility and do not become brittle at the temperature of liquefied hydrogen.

**A.11.2.5.1** To be indirect, heat must be transferred by a transfer medium such as air, steam, water, oil, or comparable heat sources. The use of direct-heat transfer media, including electrical sources or flame, presents a potential hazard should the system overheat, resulting in damage to the wall of the tubing used to construct the vaporizer.

**A.11.2.5.2** The loss of heat or the withdrawal of hydrogen at a rate exceeding the design capacity of the vaporizer presents a circumstance where cryogenic fluid is transported into portions of the piping system that have been designed to contain gaseous — not liquid — hydrogen. Such an event can result in brittle failure of the piping system downstream of the vaporizer. The potential to trap liquid in parts of the system that have not been designed to accommodate liquid can result in a loss of hydrogen and the generation of hazardous conditions.

**A.11.3.1.2** When locating liquefied hydrogen storage containers in proximity to all classes of aboveground flammable and combustible liquid storage or liquid oxygen storage, the liquefied hydrogen container should be on ground higher than all classes of flammable and combustible liquid storage or liquid oxygen storage, because spilled material will quickly vaporize, thereby mitigating the potential exposure hazard to the other fluids.

**A.11.3.2.2** The Occupational Safety and Health Administration (OSHA) established requirements for hydrogen systems in 29 CFR 1910.103. The tabular distances in Annex G reflect those values published in the July 1, 2006 edition of the CFR. The criteria established in Table G.2(a) and Table G.2(b) are based on the 1969 edition of NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites*, which superseded the 1963 edition. Subsequent editions were adopted in 1973, 1978, 1984, 1989, 1994, and 1999. In 2003, the document was integrated into NFPA 55 because the committee believed that one standard covering storage and use of all compressed gases and cryogenic fluids was needed. NFPA 55 was revised in 2005 as the requirements for compressed gases and cryogenic fluids were broadened.

Throughout those eight revision cycles, the distances were subject to revision as the technology in the use of hydrogen advanced. However, the distances listed in the OSHA tables remain based on the 1969 data. It is important to recognize that the OSHA tables represent the current statutory requirements. While the tables might be accurate, it should be recognized that the OSHA tables in some cases lack clarity, and in other cases hazards recognized by the ongoing evolution of the separation tables have not been acknowledged.

For an example of clarity, consider row 1, “Building or structure,” of Table 11.3.2.2. The OSHA table refers to buildings by construction types, including wood frame, heavy timber, ordinary, and fire resistive. The current construction types are now designated as Types I through V with variations to address the elements of construction, including the supporting structure as well as the construction of the roof and exterior walls. Although one can guess as to the original intent, there is no clear correlation between the construction types designated in the OSHA tables and the types in either NFPA 220, *Standard on Types of Building Construction*, or the building code.

Other examples where hazards are not addressed include the fact that there are no prescribed distances for separation from property lines, public sidewalks, and parked vehicles. A close comparison between the OSHA table and the distance tables in the 2005 edition of NFPA 55 reveals a number of discrepancies. As the 2010 edition of NFPA 55 was being developed, a collective effort was undertaken by a joint task group established between the NFPA Industrial and Medical Gases Committee and the NFPA Hydrogen Technology Committee. The scope of the Hydrogen Technology Committee's work was to review and verify the separation distances for exposures integral to the distance tables found in NFPA 55. Research on separation distances funded by the U.S. Department of Energy (DOE) and undertaken by Sandia National Laboratories in 2007 focused on the effects of fire and potential explosion due to an inadvertent release of hydrogen. The initial work had as its focus the use of hydrogen as an alternative vehicle fuel; however, the data produced present the case for separation based on radiant heat flux from hydrogen jet flames and flammability envelopes from unintended releases of hydrogen. The work was based on modeling that was then validated against Sandia National Laboratories and SRI International experiments.

As the work continued, it became apparent to the group that a risk-informed approach to separation distance could be developed. At that juncture, the committee developed consequence-based tables for separation as well as a set of risk-informed tables. The consequence-based tables present the hazard without regard to probability or frequency. However, there are variables that have not previously been considered in the evolution of the tabular distances.

On the other hand, the risk-informed tables consider the cumulative frequency of accidents and the distance required to prevent an undesired consequence across a spectrum of varying pressures.

Additionally, the fundamental requirements of NFPA 55 prescribe a minimum set of engineering controls and construction features. As the work evolved, it became clear that with mitigation methodology, an unintended release could be minimized or eliminated. The developmental work was focused on using a scientific method to obtain separation distances to verify or revise the tabular distances accordingly.

The OSHA tables are provided to inform the code user of the minimum requirements as they currently exist under 29 CFR and the federal OSHA program. It is incumbent on



installers and property owners to recognize the limitations of OSHA based on the precedent requirements established with the use of the 1969 edition of NFPA 50A. The use of alternative approaches to distance as now embodied within the body of the code is subject to approval on a location-by-location basis. The typical AHJ has traditionally been the fire official who might not be the only official that exercises regulatory control for installations of this nature.

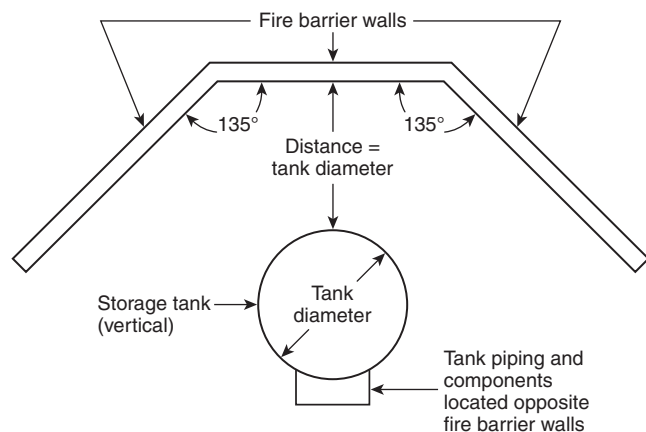
**A.11.3.2.2.2** See NFPA 259, *Standard Test Method for Potential Heat of Building Materials*. Separation distances to exposures in Table 11.3.2.2 should be measured in a direct line of sight or horizontally in the shortest path along the outside of buildings. The 5 ft (1.5 m) distance in Table 11.3.2.2 facilitates maintenance and enhances ventilation.

**A.11.3.2.2.4.1** Figure A.11.3.2.2.4.1(a) and Figure A.11.3.2.2.4.1(b) illustrates wall enclosures for a hydrogen storage system. The geometry of the three-sided enclosure should not contain any hydrogen release that would be enough to create a significant hazard.

**A.11.4.4.3** Hydrogen fires should not be extinguished until the supply of hydrogen has been shut off because of the danger of re-ignition or explosion. In the event of fire, large quantities of water will normally be sprayed on adjacent equipment to cool the equipment and prevent involvement in the fire. Combination fog and solid stream nozzles are preferred, to permit the widest adaptability in fire control. Small hydrogen fires have been extinguished with dry chemical extinguishers or with carbon dioxide, nitrogen, and steam. Re-ignition can occur if a metal surface adjacent to the flame is not cooled with water or other means.

**A.12.3.1** The equipment referenced is intended to include fuel cell applications, generation of hydrogen from portable or transportable hydrogen generation equipment, batteries, and similar devices and equipment that utilize hydrogen for the purpose of power generation. It does not include hydrogen production facilities intended to produce hydrogen used for distribution or repackaging operations operated by gas producers, distributors, and repackagers.

**A.12.3.2.4(3)** Protection can be integral to the hydrogen generator (locked enclosures, guards, etc.), or the hydrogen generator can be installed in a controlled-access area.



**FIGURE A.11.3.2.2.4.1(a)** Schematic of Three-Sided Fire Barrier Wall Enclosure for a Vertical Hydrogen Storage System.

**A.12.3.2.8.5.7** Process gases within catalytic reformer systems, in addition to their flammability hazard, can contain significant quantities of carbon monoxide and other toxic substances.

**A.12.3.2.9.2** There are two considerations unique to gasification:

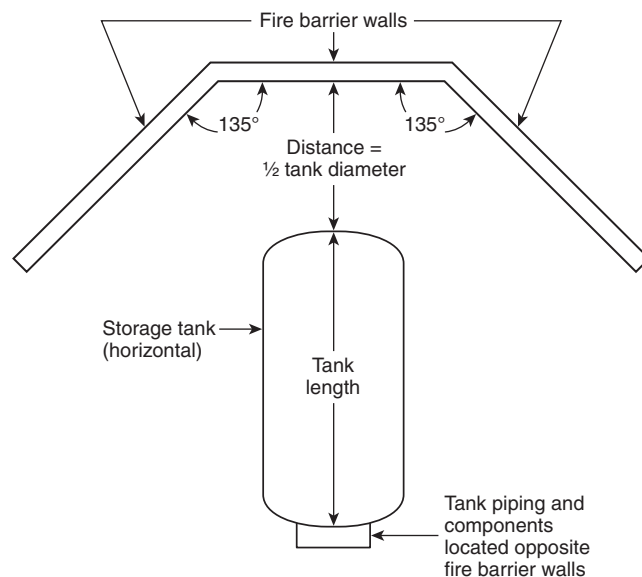
- (1) Gasifiers typically operate in excess of 2600°F (1425°C). Gas delivery temperature is a strict function of the amount of cooling provided by the system.
- (2) The output of the gasifier typically contains significant quantities of carbon monoxide, hydrogen sulfide, and other toxic substances.

**A.12.3.2.9.2.1** This equipment consists of piping, valves, vessels, and instrumentation for monitoring of the process.

**A.12.3.2.9.4.1** Pressure relief panels should be designed as outlined in NFPA 68, *Standard on Explosion Protection by Deflagration Venting*.

**A.12.3.2.9.6.2** The inclusion of detection for other potential constituents in the gas flow such as hydrogen sulfide, carbon monoxide, and so on should be based on the volumetric content of such constituents and an assessment of the potential health hazards in the event of a leak. This risk assessment must consider indoor versus outdoor locations, ventilation capabilities, personal protective equipment (PPE) requirements to be imposed for area access, and so on. For carbon monoxide, it is recommended that gas detection be provided for any systems or portions of systems that contain greater than 1 percent concentration by volume in the gas flow. Reference to applicable threshold limit value or PEL information should be made for other toxic constituents.

**A.12.3.2.9.6.3** Due to the high temperatures associated with the gasification process, ignition of leaks is likely, especially in the vicinity of the gasifier vessel proper. Hydrogen burns with



**FIGURE A.11.3.2.2.4.1(b)** Schematic of Three-Sided Fire Barrier Wall Enclosure for a Horizontal Hydrogen Storage System



a nearly invisible flame, so detection and warning systems are necessary to advise personnel when a fire exists. It is recommended that corn straw brooms or cotton rags on poles be readily available for use by personnel entering the area to clear the path of travel for fires.

**A.12.3.2.9.6.5** The application of water deluge fire protection against the gasifier vessel and other very hot components must be done carefully to avoid rapid cooling and the associated material stresses that result. The first consideration in controlling a fire near this equipment is to halt the flow of combustible materials (shutting down the feedstock supply and venting the internal pressure to the flare stack). Once the fuel supply is halted, the task of extinguishing the fire is simplified. If water deluge is selected as the fire suppression method, controlling the direction of the spray pattern from the nozzles and the application of spray shields will minimize the thermal distress to susceptible components. Consideration should be given to the application of alternative fire suppression methods, such as water mist, that impose less thermal distress on the equipment. NFPA 850, *Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations*, contains additional recommendations applicable to fire protection of gasifiers.

**A.13.1.1** The response to carbon dioxide inhalation depends on the degree and duration of exposure, and it varies greatly even in healthy, normal individuals. The medical term for the physiological effects of excess carbon dioxide in the blood is *hypercapnia*. Carbon dioxide can be dangerous even when normal oxygen levels are present. Low concentrations of inspired carbon dioxide can be tolerated for a considerable period of time without noticeable effect or cause merely an unnatural feeling of shortness of breath. Sustained exposure to 5 percent carbon dioxide produces stressful rapid breathing. When the level of inspired carbon dioxide exceeds 7 percent, the rapid breathing becomes labored (dyspnea), and restlessness, faintness, severe headache, and dulling of consciousness occur. At 15 percent, unconsciousness accompanied by rigidity and tremors occur in less than 1 minute, and in the 20 percent to 30 percent range, it produces unconsciousness and convulsions in less than 30 seconds. The reason these effects occur quickly is that the carbon dioxide diffuses in the tissue fluids at a rate approximately 20 times more rapidly than oxygen. High concentrations of carbon dioxide can asphyxiate quickly without warning and with no possibility of self-rescue regardless of the oxygen concentration.

**A.13.1.1.2.2** Vent pipes must be protected to prevent the intrusion of water that can freeze and interfere with the operation of the pressure relief device. Covers can be employed to protect the vent pipe against the elements. Carbon dioxide when released through vent pipes can be transformed to the solid state through the production of what is dry ice in the form of "snow." It is possible for dry ice to form a plug in the vent line system. For this reason, designers might choose to locate the pressure relief device at the end of a vent line rather than on the unit itself. There are alternative designs that accomplish this intent. It is important that the system designer provide a system that is not susceptible to the formation of ice plugs due to moisture or solid carbon dioxide so that vent lines function as intended.

**A.13.1.4** Materials used in the system can become brittle and fail if subjected to low temperatures. Maintain the system at or above the minimum design temperature by appropriate design materials or operating instructions to prevent system failure.

In North America, the majority of the containers in refrigerated carbon dioxide service are fabricated using low-alloy carbon steels such as SA-212, SA-515, SA-516, and SA-612. Containers manufactured before 1990 typically had a minimum design metal temperature (MDMT), the lowest temperature at which a container is designed to operate at a given pressure at  $-20^{\circ}\text{F}$  ( $-28.9^{\circ}\text{C}$ ). When the container wall is at an operating temperature colder than the MDMT, it is out of its intended operating condition.

**A.13.2.1** The building code establishes requirements for the structure based on loads imposed by the elements of construction as well as for the loads that could be imposed by machinery or equipment. Building owners are responsible for understanding the limitations of loads on the building in which these installations are to be located. A professional engineer representing the building owner might have to make a determination as to the adequacy of the structure regarding the loads that are to be imposed for systems of this nature.

**A.13.2.2** Enclosed areas can include indoor as well as outdoor locations such as one with four solid walls and no roof or ceiling. The PEL is established by OSHA in 29 CFR 1910.1000, Table Z-1.

**A.13.2.2.1** The American Conference of Governmental Industrial Hygienists (ACGIH), in *TLVs<sup>®</sup> and BEIs<sup>®</sup>, Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, has established threshold limit values (TLVs<sup>®</sup>). The threshold limit value-time weighted average basis (TLV-TWA<sup>®</sup>) for CO<sub>2</sub> has been established at 5000 ppm with a short-term exposure limit (STEL-TLV<sup>®</sup>) value of 30,000 ppm.

As stated by ACGIH, the TLV-TWA represents a time-weighted average concentration for a conventional 8-hour workday and a 40-hour workweek to which it is believed that nearly all workers can be repeatedly exposed, day after day, without adverse effect. The STEL-TLV is the concentration to which it is believed that workers can be exposed continuously for a short period of time without suffering from irritation, chronic or irreversible tissue damage, or narcosis of sufficient degree to increase the likelihood of accidental injury, to impair self-rescue, or to materially reduce work efficiency, provided that the daily TLV-TWA is not exceeded. The STEL-TLV is not a separate, independent exposure guideline; rather, it supplements the TLV-TWA where there are recognized acute effects from a substance whose toxic effects are primarily of a chronic nature. TLV-STELs are recommended only where toxic effects have been reported from high short-term exposures in either humans or animals.

**A.13.3.1.1** Aboveground locations include locations that are above grade. Although some installations may be above ground, the actual grade of the terrain on which the installation is located could result in entrapment of vapors. Designers should avoid locating enclosures in areas where natural terrain features or other impediments serve to act as impediments to the dissipation of vapors should a release occur.

**A.14.2.2.6(4)** Ethylene oxide containers should be tested for leakage prior to moving them inside a facility. Leak detection solutions can be used to test for leaks around valves and fuse plugs. This is often referred to as a soap test. Inexpensive hand-held leak detection instruments also are available.

**A.14.3.2.1.1** Storage of over 5000 lb (2268 kg) of ethylene oxide is also covered by 29 CFR 1910.119, "Process Safety Management of Highly Hazardous Chemicals" (OSHA). Hazard analyses



are required by OSHA for facilities storing more than 5000 lb (2268 kg) of ethylene oxide in one location. Hazard analyses are recommended for all facilities that store, use, and handle ethylene oxide. Refer to 29 CFR 1910.119 for guidance on conducting such an analysis. The analysis should address the hazards of the operation, identification of any previous incidents, engineering and administrative controls to protect against hazards, consequences of the failure of engineering and administrative controls, facility site, human factors, and qualitative evaluation of the range of possible effects on employee safety and health due to the failure of controls.

**A.14.3.3.2.6** The rate of formation of ethylene oxide polymers increases as the temperature increases. Therefore, to minimize polymer formation, ethylene oxide containers should be sheltered from intense sunlight. Ethylene oxide containers should not be stored under plastic sheets. This can produce a greenhouse effect that results in release of the fusible plugs.

**A.14.4.2.2** Welding is the preferred method of joining pipe. The use of welding is important in preventing leakage of ethylene oxide. For information on safety in cutting and welding, see NFPA 51B, *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work*.

**A.14.4.3** Cleaning the inside of lines used for ethylene oxide is necessary prior to opening the piping system to remove the combustible, oily ethylene oxide by-products (which also contain absorbed ethylene oxide), such as polymers or glycols. These by-products can build up gradually over time.

**A.14.4.6** For information on identification of piping, see ASME A13.1, *Scheme for the Identification of Piping Systems*.

**A.14.5.1.2** Additional detection at lower levels might be required to meet OSHA requirements (see 29 CFR 1910.1047, "Ethylene Oxide").

**A.14.5.1.3** Local exhaust hoods are an effective means used to control ethylene oxide levels at the source of potential release.

**A.14.5.4.2** Monitoring of temperature in the ethylene oxide vapor stream provides a means to detect liquid ethylene oxide downstream of the vaporizer. The vaporizer should be equipped with a controller to maintain the desired temperature range for vaporization of ethylene oxide or ethylene oxide mixtures.

**A.14.6.2** Sterilization is performed in a closed vessel under controlled conditions of temperature, humidity, pressure, and ethylene oxide gas concentration. The process is a single-pass, batch operation in which a number of steps are performed to complete the cycle. Process cycle parameters can vary widely to meet product sterilization requirements and can use flammable gas mixtures in the sterilizer.

**A.14.6.2.1** Lower concentrations of ethylene oxide are required by OSHA (see 29 CFR 1910.1047, "Ethylene Oxide") for personnel exposure.

The use of nitrogen in enclosed spaces can pose an asphyxiation hazard.

**A.14.6.2.2** Outgassing, depending on product characteristics, can be of sufficient magnitude to produce flammable mixtures of ethylene oxide.

**A.14.6.3.2** Ethylene oxide gas supply shutoff is a minimum requirement; other operations such as emergency ventilation might also be appropriate.

Additional detection at lower levels can be required to meet the requirements of OSHA (see 29 CFR 1910.1047, "Ethylene Oxide").

**A.14.7.2** For information on prevention of static electricity, see NFPA 77, *Recommended Practice on Static Electricity*.

**A.14.8.1** Flame arresters should be installed to prevent flame propagation from potential ignition sources external to the vessel. Locations for consideration are the vacuum pump suction line, air inbleed port, relief valve discharge, and other potential problem areas where flashbacks could occur.

**A.14.9.1** The emphasis of this section is on those issues specifically related to fire safety. Sterilization facilities are required to comply with federal, state, and local environmental health and safety regulations.

**A.14.9.5** Oxidizing emission control devices can include catalytic converters, flares, or other active sources of ignition.

**A.14.9.5.2.1.1** Engineering controls can include computer or programmable logic controllers and associated software and hardware that control the sterilization process, safety interlocks, purge systems, gas detection, and monitoring systems. The controls provided are to ensure that the concentration of ethylene oxide at the point where it is released to the emission control device is reduced below 25 percent of its LFL.

**A.14.9.5.2.1.1(C)** The mechanical code in use by the jurisdiction in which the installation is located is used to establish requirements for the design of the exhaust duct system. Requirements for the duct system can vary depending on the mechanical code in use as well as with the maximum concentration of ethylene oxide to be released to the duct system for any specific process.

**A.14.11.2.1.1(2)** For information on venting of deflagrations, see NFPA 68, *Standard on Explosion Protection by Deflagration Venting*.

**A.14.11.2.2** To comply with this requirement and OSHA (see 29 CFR 1910.1047, "Ethylene Oxide"), specific local exhaust ventilation might be necessary in storage and dispensing areas, on the sterilizer, and in aeration rooms.

**A.14.11.2.5** For information on venting of deflagrations, see NFPA 68, *Standard on Explosion Protection by Deflagration Venting*.

## Annex B Attended Operations

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

**B.1 Introduction.** Section 112(r) of the Clean Air Act (CAA) mandates that the U.S. Environmental Protection Agency (EPA) promulgate a regulatory program to prevent accidental releases of regulated toxic and flammable substances and reduce the severity of releases that do occur. The rule, published on June 20, 1996, formally appears in the Code of Federal Regulations as 40 CFR 68 and is officially titled "Accidental Release Prevention Requirements: Risk Management Programs Under Clean Air Act Section 112(r)(7)."

**B.1.1** In addition to qualified judgment and expertise, the following three resources must be considered in the selection of alternative release scenarios in evaluating the hazards of any system:

- (1) The five scenarios listed in Section 68.28 of 40 CFR 68
- (2) The 5-year accident history of all accidental releases from covered processes that resulted in deaths, injuries, or significant property damage on-site or all known off-site deaths, injuries, evacuations, sheltering-in-place, or property or environmental damage
- (3) The hazard review or process hazards analysis completed as part of the required prevention program

**B.1.2** The five scenarios encompassed in Section 68.28 of 40 CFR 68 of the regulation include the following:

- (1) Transfer hose releases due to splits or sudden hose uncoupling (typical of delivery operations)
- (2) Process piping releases from failures at flanges, joints, welds, valves and valve seals, and drains or bleeds
- (3) Process vessel or pump releases due to cracks, seal failure, or drain, bleed, or plug failure
- (4) Vessel overfilling and spill or overpressurization and venting through relief valves or rupture disks
- (5) Shipping container mishandling and breakage or puncturing leading to a spill

**B.1.3** Based on comparable analysis, it was determined that the most likely alternative release scenario having an off-site impact from compressed gas systems would be a process piping failure that either is outdoors or is indoors and entrained into an unspecified exhaust system. In either case, discharge results in a continuous emission resulting in a plume on-site or off-site. An accidental release of this type might occur due to mechanical failure, corrosion, failure of a piping component such as a joint or valve, or another cause.

**B.1.4** The flow rate through a pipe during a release is computed based on the pressure of the container, cylinder, or tank; the liquid head (if a liquid is involved); the fluid density; the line's resistance to flow (based primarily on diameter, length, and number of bends); and the open area available to flow at the exit.

**B.2 Parameters.** Each parameter, whether selected by the user or preselected, as is typical, is explained in B.2.1 through B.2.5.

**B.2.1 Container, Cylinder, or Tank Pressure.** The highest normal operating pressure should be used for the tank pressure.

**B.2.2 Liquid Head.** The liquid head is the amount of pressure exerted by the weight of the liquid column. For most small containers and cylinders, the liquid head is normally small and can usually be ignored.

**B.2.3 Fluid Density.** Fluid density is the density of the fluid under consideration.

**B.2.4 Line Length and Configuration.** Line configuration is specific to the configuration under consideration.

**B.2.5 Pipe Break Flow Area.** Most piping breaks result in less than the full pipe diameter being open to flow. For example, a full-guillotine break is not nearly as likely as a reduced-flow area break or a small leak. It is unlikely that small leaks will have an off-site impact. Therefore, it is appropriate to select as an alternative release case a piping failure characterized by a fraction of the full-open area that is typical of the majority of piping failures while significantly greater than that of a small leak.

For the purposes of calculation, a 20 percent flow rate versus a full bore line break should be used. Statistics indicate that piping failures of this magnitude would be expected to occur between 2 and 10 times as often as a full-guillotine break.

**B.3** Calculations to demonstrate the "maximum credible worst-case leak" must be engineered, and factors to include the nature of flow must be considered, including whether the gas or vapor flowing is gaseous, liquid, or a two-phase-type flow. Detailed air dispersion models and methods of calculation are available. The choice of the model or methodology, or both, must be established by engineering principles and applied by those versed in such matters.

## Annex C Physical Properties of Hydrogen

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

**C.1 Physical Properties.** Hydrogen is a flammable gas. It is colorless, odorless, tasteless, and nontoxic. It is the lightest gas known, having a specific gravity of 0.0695 (air = 1.0). Hydrogen diffuses rapidly in air and through materials not normally considered porous.

**C.1.1** Hydrogen burns in air with a pale blue, almost invisible flame. At atmospheric pressure, the ignition temperature of hydrogen-air mixtures has been reported by the U.S. Bureau of Mines to be as low as 932°F (500°C). The flammable limits of hydrogen-air mixtures depend on pressure, temperature, and water vapor content. At atmospheric pressure, the flammable range is approximately 4 percent to 75 percent by volume of hydrogen in air.

**C.1.2** Hydrogen remains a gas even at high pressures. It is liquefied when cooled to its boiling point of -423°F (-253°C).

**C.1.3** Hydrogen is nontoxic, but it can cause anoxia (asphyxiation) when it displaces the normal 21 percent oxygen in a confined area without ventilation that will maintain an oxygen content exceeding 19.5 percent. Because hydrogen is colorless, odorless, and tasteless, its presence cannot be detected by the human senses.

**C.2 Physical Properties.** Liquefied hydrogen is transparent, odorless, and not corrosive or noticeably reactive. The boiling point at atmospheric pressure is -423°F (-253°C). It is only  $1/14$  as heavy as water. Liquefied hydrogen converted to gaseous hydrogen at standard conditions expands approximately 850 times.

## Annex D Significant Properties of Ethylene Oxide

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

**D.1 Hazards of Ethylene Oxide.** Figure D.1 illustrates the hazards of ethylene oxide.

SYNONYMS: di-methylene oxide; EO; EtO;  
1,2-epoxyethane; oxirane

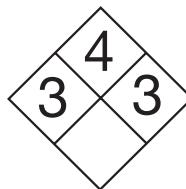
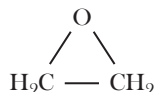


FIGURE D.1 Hazards of Ethylene Oxide.



FORMULA:  $(\text{CH}_2)_2\text{O}$



DOT CLASS: Class 2.3, Poisonous gas

SHIPPING LABEL: POISON GAS and FLAMMABLE GAS

ID NO.: UN 1040

CAS NO.: 75-21-8

MOL. WT.: 44.0

STATEMENT OF HAZARDS: Flammable gas. Low ignition energy. Explosive decomposition can occur. Hazardous polymerization can occur. Serious health hazard.

EMERGENCY RESPONSE PERSONAL PROTECTIVE EQUIPMENT: Wear special protective clothing and positive pressure self-contained breathing apparatus.

SPILL OR LEAK PROCEDURES: Eliminate all ignition sources. Releases might require isolation or evacuation. Approach release from upwind. Stop or control the leak, if it can be done without undue risk. Use water spray to cool and disperse vapors, protect personnel, and dilute spills to form nonflammable mixtures. Water solutions are no longer flammable in open areas when diluted to 1 part in 22 parts water. In enclosed areas such as sewers, dilution to 1 part in 100 parts water can be required to eliminate flash potential. Control runoff and isolate discharged material for proper disposal.

FIRE-FIGHTING PROCEDURES: Use flooding quantities of water as fog. Use water spray, dry chemical, “alcohol-resistant” foam, or carbon dioxide. Use water spray to keep fire-exposed containers cool. Explosive decomposition can occur under fire conditions. Fight fire from protected location or maximum possible distance.

HEALTH HAZARDS: Serious health hazard. Can be harmful if absorbed through skin or inhaled. Pulmonary edema can result. Irritating to skin, eyes, and respiratory system.

FIRE AND EXPLOSION HAZARDS: Flammable gas. Volatile flammable liquid below room temperature. Explosive decomposition can occur in vapor or liquid phases. Vapor forms explosive mixtures with air over a wide range. Vapors are heavier than air and can travel to a source of ignition and flash back. Closed containers can rupture violently when heated.

FLASH POINT:  $-4^{\circ}\text{F}$  ( $-20^{\circ}\text{C}$ )

AUTOIGNITION TEMPERATURE:  $804^{\circ}\text{F}$  ( $429^{\circ}\text{C}$ ) [AIT in the absence of air:  $1058^{\circ}\text{F}$  ( $570^{\circ}\text{C}$ )]

FLAMMABLE LIMITS: LOWER, 3.0 percent; UPPER, 100.0 percent

INSTABILITY AND REACTIVITY HAZARDS: Highly reactive. Hazardous polymerization can occur, especially if contaminated. Reacts with acids, alkalies, salts, combustible materials. Can undergo runaway reaction with water. Many materials can accelerate this reaction.

STORAGE RECOMMENDATIONS: Store in a cool, dry, well-ventilated location. Store away from heat, oxidizing materials, and sunlight. Separate from acids, alkalies, salts, and combustible materials. Outside or detached storage is preferred. Can react in insulation, forming low-molecular-weight polyethylene glycols that can spontaneously heat and ignite at less than  $212^{\circ}\text{F}$  ( $100^{\circ}\text{C}$ ).

USUAL SHIPPING CONTAINERS: Insulated steel cylinders; pressurized tanks on trucks, rail cars, barges. Safety relief valves required.

PHYSICAL PROPERTIES: Colorless gas with sweet ether-like odor.

MELTING POINT:  $-170^{\circ}\text{F}$  ( $-112^{\circ}\text{C}$ )

BOILING POINT:  $51^{\circ}\text{F}$  ( $11^{\circ}\text{C}$ )

SPECIFIC GRAVITY: 0.89 at  $0^{\circ}\text{C}$

SOLUBILITY IN WATER: Soluble

VAPOR DENSITY: 1.51

VAPOR PRESSURE: 1095 mm Hg at  $20^{\circ}\text{C}$

ELECTRICAL EQUIPMENT: Class I, Group B (C)

**D.2 Nonflammable Mixtures of Ethylene Oxide.** Ethylene oxide is often mixed with a second, inert component and shipped as a liquefied gas mixture for use by sterilizer operators. Several of these mixtures are nonflammable. Table D.2 indicates the maximum amount of ethylene oxide that a nonflammable mixture can contain, as well as typical ethylene oxide contents of commercially available nonflammable mixtures. Figure D.2(a) through Figure D.2(c) show how the flammable range for ethylene oxide varies as a function of pressure in nitrogen and air atmospheres.

Table D.2 Nonflammable Mixtures of Ethylene Oxide

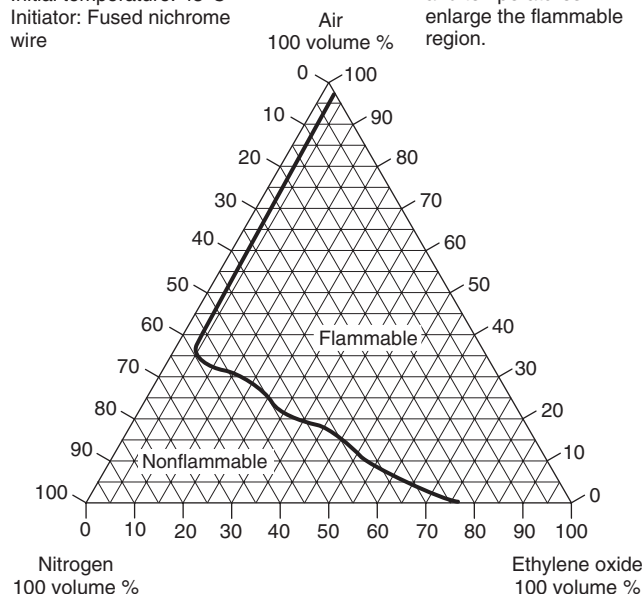
Second Component Chemical Name	Common Name	Chemical Formula	Maximum Ethylene Oxide by Weight (percent)	Typical Ethylene Oxide by Weight (percent)	Maximum Ethylene Oxide by Volume (percent)
Dichloro difluoromethane	CFC-12	$\text{CF}_2\text{Cl}_2$	12.5	12.0	28.0
Carbon dioxide	—	$\text{CO}_2$	9.0	8.5	9.0
2 Chloro-2,1,1,1 Tetrafluoroethane	HCFC-124	$\text{CHClF-CF}_3$	9.3	8.6	24.2
2,1,1,1 Tetrafluoroethane	HFC-134a	$\text{CH}_2\text{FCF}_3$	6.1	N/A	13.0
2,2,1,1,1 Pentafluoroethane	HFC-125	$\text{CHF}_2\text{CF}_3$	8.5	N/A	21.2

Note: Mixtures measured in accordance with ASTM E 681, *Standard Test Method for Concentration Limits of Flammability of Chemicals*, with an ignition energy of 40 J.



Initial pressure: 1 ATM  
Initial temperature: 45°C  
Initiator: Fused nichrome wire

Caution: Higher pressure and temperatures will enlarge the flammable region.

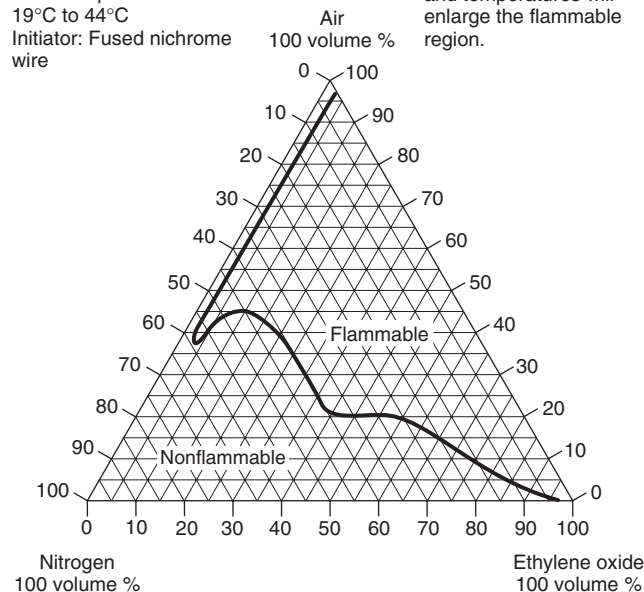


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**FIGURE D.2(a) Flammability of Ethylene Oxide-N<sub>2</sub>-Air Mixtures at 1 Atmosphere. (45°C = 113°F) (Source: Allied Signal Inc.)**

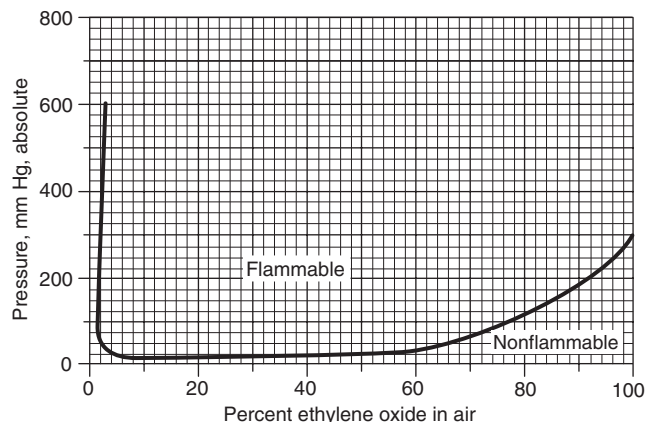
Initial pressure: ½ ATM  
Initial temperature: 19°C to 44°C  
Initiator: Fused nichrome wire

Caution: Higher pressure and temperatures will enlarge the flammable region.



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**FIGURE D.2(b) Flammability of Ethylene Oxide-CO<sub>2</sub>-Air Mixtures at 1 Atmosphere. (19°C to 44°C = 66°F to 111°F) (Source: Allied Signal Inc.)**



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**FIGURE D.2(c) Flammability of Ethylene Oxide Mixtures at Subatmospheric Pressures. (Source: Allied Signal Inc.)**

## Annex E Determination of Separation Distances for Bulk Gaseous Hydrogen Systems

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

*This annex is a paper by William Houf and Robert Schefer, "Description of Hazard Models Used in the Development of Separation Distance Tables for NFPA 55 and NFPA 2" (Sandia National Laboratories, P.O. Box 969, Livermore, CA 94551-0969).*

*The informational references found in Section H.2 will assist code users in gaining further understanding of the methodologies used in the development of the separation distance tables for bulk gaseous hydrogen systems. Two key references are the work by LaChance et al., which provides the technical rationale used as the basis in the development of a risk-informed approach to separation distances, and the work of Houf and Schefer, which provides information relative to the determination of the physical effects of an ignited and an unignited release.*

**E.1 Introduction.** Separation distances in NFPA 55 and NFPA 2 are based on the prediction of the characteristics of unignited jets or ignited jet flames from hydrogen leaks. Because the characteristics of hydrogen jets and jet flames depend on the source pressure and effective diameter of the leak the separation distance table for was broken into four pressure ranges. The effective leak diameter for each pressure range was based on a characteristic pipe diameter (I.D. = inside diameter), where the leak flow area was taken to be 3% of the flow area of the pipe (based on I.D. of the pipe). For a round leak the effective diameter of the leak is

$$d_{\text{leak}} = (0.03)^{1/2} d_{\text{pipe(I.D.)}}$$

where  $d_{\text{leak}}$  is the effective leak diameter and  $d_{\text{pipe(I.D.)}}$  is the inside diameter of the pipe. Table E.1(a) lists the pressure ranges for the separation distances table and the associated inside pipe diameter of the characteristic pipe used to determine the leak effective diameter for each pressure range.

When using the separation distance table one must first determine the storage pressure. The storage pressure determines what pressure range in the table is to be used in the determination of separation distances. The storage pressure is defined as the maximum pressure of a storage array with volume greater than 400 scf (standard cubic feet) in the system. If the system has more than one storage array with a volume

**Table E.1(a) Pressure Ranges for Separation Distances Table and the Associated System Characteristic Pipe Diameter**

Storage Pressure Range	Characteristic Pipe Diameter (I.D.)
>103 to ≤ 1724 kPa (gauge) (>15 to ≤250 psig)	52.50 mm (2.067 in)
>1724 to ≤ 20684 kPa (gauge) (>250 to ≤3000 psig)	18.97 mm (0.75 in)
>20684 to ≤ 51711 kPa (gauge) (>3000 to ≤7500 psig)	7.92 mm (0.312 in)
>51711 to ≤ 103421 kPa (gauge) (>7500 to ≤15000 psig)	7.16 mm (0.282 in)

greater than 400 scf then a storage pressure must be determined for each array. The next parameter that must be determined is the largest diameter (I.D.) of the piping within the system or portion of the system downstream of the stored volume. If the largest pipe diameter associated with the storage pressure is less than the characteristic pipe diameter listed in Table E.1(a) for that pressure range, then the values listed in separation distance table may used, or alternately the formulas at the bottom of the table may be applied using the determined value of largest pipe diameter (I.D.).

If the value of the largest pipe diameter (I.D.) is greater than the characteristic pipe diameter for the storage pressure range of interest then the formulas at the bottom of separation distance table must be used to determine separation distances. These formulas reproduce the numeric values in the separation distance tables for the pipe diameters shown in Table E.1(a).

The formulas are based on performing curve-fits to hazard distance calculations performed over a range of pipe diameters (assuming 3% flow area leak) and pressures using the hazard models discussed in Section E.2. The formulas are simple enough that they can easily be entered into an Excel spreadsheet program or programmable calculator for computation of separation distances for any value of pipe diameter (I.D.). An Excel spreadsheet based on these formulas was developed and distributed to the NFPA Hydrogen Technology Committee members as part of the development of separation distance tables.

If a system contains multiple storage arrays (greater than 400 scf) at different pressures then storage pressures and largest pipe diameters must be determined for each storage array in the system. The separation distance table and formula procedure outlined above is then applied to each storage array in the system and the largest separation distance for each storage array defines the value of the separation distance for the overall system.

A description of the models used to determine the values of the separation distances are discussed in the sections that follow. More detailed descriptions of the models and the experiments used in their development and validation can be found in the publications (Houf and Schefer, 2007, 2008; Schefer et al. 2006, 2007). The models consider either the concentration decay of an unignited high-momentum hydrogen leak or in the case where the mixture ignites, a high-momentum hydrogen jet flame, its visible length, and the radiation heat flux from the flame. Table E.1(b) lists the hazard criteria that were used with the unignited jet and jet flames models to create a risk informed consequence-based separation distance table for NFPA 55 and NFPA 2.

**E.2 Description of Engineering Hazard Models: Nomenclature.** See Table E.2 for specification of the parameters used in engineering hazard models.

The development of an infrastructure for hydrogen utilization requires safety codes and standards that establish guidelines for building the components of this infrastructure. Based on a recent workshop on unintended hydrogen releases, one release case of interest involves leaks from pressurized hydrogen-handling equipment (Schefer et al., 2004). These leaks range from small-diameter, slow-release leaks originating from holes in delivery pipes to larger, high-volume releases resulting from accidental breaks in the tubing from high-pressure storage tanks. In all cases, the resulting hydrogen jet represents a potential fire hazard, and the buildup of a combustible cloud poses a hazard if ignited downstream of the leak.

A case in which a high-pressure leak of hydrogen is ignited at the source is best described as a classic turbulent-jet flame, shown schematically in Figure E.2. The distances of importance are the radial distance from the geometrical flame centerline,  $r$ , and the distance downstream of the jet exit,  $x$ . Other variables of interest are the jet exit diameter,  $d_j$ , and the jet exit velocity and density,  $u_j$  and  $\rho_j$ , respectively. Schefer et al. (2006, 2007) reported experimental measurements of large-scale hydrogen jet flames and verified that measurements of flame length, flame width, radiative heat flux, and radiant fraction are in agreement with non-dimensional flame correlations reported in the literature. This work verifies that such correlations can be used to predict the radiative heat flux from a wide variety of hydrogen flames. The present analysis builds upon this work by incorporating the experimentally verified correlations into an engineering model that predicts flame length, flame width, and the radiative heat flux at an axial position,  $x$ , and radial distance,  $r$ . The engineering model is then used to predict radiative heat fluxes for hydrogen flames.

For cases where the high-pressure leak of hydrogen is unignited, a classic high-momentum turbulent jet is formed that can be described using the same coordinate system shown in Figure E.2. The hydrogen concentration within the jet varies with axial and radial position due to entrainment and turbulent mixing with the ambient air. The concentration contour beyond which the hydrogen-air mixture

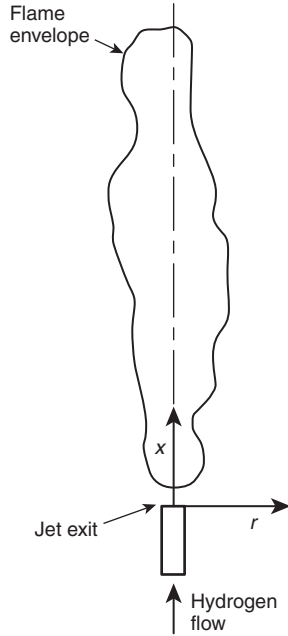
**Table E.1(b) Hazard Parameters for Separation Distances Tables**

Hydrogen unignited jet	Distance to point where concentration has decayed to 4% mole fraction hydrogen in air
Hydrogen jet flame	Visible flame length
Hydrogen jet flame	Distance to radiation heat flux level of 1577 W/m <sup>2</sup> (500 Btu/hr · ft <sup>2</sup> )
Hydrogen jet flame	Distance to radiation heat flux level of 4732 W/m <sup>2</sup> (1500 Btu/hr · ft <sup>2</sup> ) exposure to employees for a maximum of 3 minutes
Hydrogen jet flame	Distance to combustible heat flux level of 20,000 W/m <sup>2</sup> (6340 Btu/hr · ft <sup>2</sup> )
Hydrogen jet flame	Distance to non-combustible equipment heat flux level of 25,237 W/m <sup>2</sup> (8000 Btu/hr · ft <sup>2</sup> )

**Table E.2 Parameters Used in Hazard Models**

$b$	Coefficient for hydrogen in the Abel-Nobel equation of state ( $7.691 \times 10^{-3} \text{ m}^3/\text{kg}$ )
Btu	British thermal unit
$C^*$	Non-dimensional radiant power
$\text{CH}_4$	Methane
$\text{C}_2\text{H}_2$	Acetylene
$\text{C}_2\text{H}_4$	Ethylene
$\text{C}_3\text{H}_8$	Propane
$d_{\text{eff}}$	The effective diameter, m
$d_j$	Jet exit diameter, m
$d^*$	Jet momentum diameter, m
$D_{\text{rad}}$	Radiation distance, m
$\text{Fr}_f$	Froude number (dimensionless parameter based on the ratio of momentum effects to buoyancy effects)
$f_s$	Mass fraction of fuel at stoichiometric conditions
$g$	Acceleration due to gravity ( $9.8 \text{ m/sec}^2$ )
$\text{H}_2$	Molecular hydrogen
hr	hour
$K$	The entrainment constant
$K_c$	The entrainment constant for a round jet
$L_{\text{vis}}$	Visible flame length, m
$L^*$	Non-dimensional flame length
LFL	Lower flammability limit
$\text{LFL}_{\text{DPF}}$	Lower flammability limit for a downward propagating flame
$\text{LFL}_{\text{UPF}}$	Lower flammability limit for an upward propagating flame
$m_{\text{fuel}}$	Total fuel mass flow rate, kg/sec
$m_{\text{fuel}}\Delta H_c$	Total heat released due to chemical reaction, W
$p_j$	The jet exit pressure, bar
$p_{\text{supply}}$	The pressure in the supply, bar
$p_{\text{tank}}$	The pressure in the tank, bar
$p_{\infty}$	The ambient pressure, bar
$q_{\text{rad}}(x,r)$	The radiant heat flux measured at a particular axial location, $x$ , and radial location, $r$ , $\text{W/m}^2$
$r$	Radial position, m
$R_{\text{H}_2}$	Gas constant for hydrogen ( $4124.18 \text{ J/kg/K}$ )
$R_u$	Universal gas constant ( $8314.34 \text{ J/kmol/K}$ )
$R_{\text{max}}$	The maximum radial position from the flame centerline for the given heat flux level, m
$S_{\text{rad}}$	The total emitted radiative power, W
$T_{\text{ad}}$	Adiabatic flame temperature of hydrogen in air (2390K)
$u_j$	Jet exit velocity, m/sec
$u_{\text{eff}}$	The effective velocity at the end of expansion, m/sec
$x$	Axial position, m
$x_o$	The virtual origin of the jet, m
$X(R_{\text{max}})$	The axial location at which the maximum heat flux level occurs, m
$X_{\text{rad}}$	The radiant fraction or the fraction of the total chemical heat release that is radiated to the surroundings
$W_f$	Flame width, m
$W_{\text{mix}}$	Mean molecular weight of the products of stoichiometric combustion of hydrogen in air ( $24.54 \text{ kg/kmol}$ )
$Z$	The compressibility factor [ $Z = p/(\rho RT)$ ]
$\Delta H_c$	Heat of combustion, J/kg
$\Delta T_f$	Peak flame temperature rise due to combustion heat release, K
$\pi$	Pi
$\rho_f$	Flame density, $\text{kg/m}^3$
$\rho_{\text{gas}}$	The density of the exiting gas evaluated at ambient temperature and pressure, $\text{kg/m}^3$
$\rho_j$	Jet exit density, $\text{kg/m}^3$
$(\rho_j/\rho_{\infty})$	Ratio of jet gas density to ambient gas density
$\rho_{\infty}$	Density of the ambient fluid, $\text{kg/m}^3$
$\bar{\eta}_{cl}$	Volume fraction (mole fraction) along the centerline of the jet
$\tau_f$	Global flame residence time, sec

is no longer ignitable is of importance to hydrogen ignition studies. The present study develops an engineering model for the concentration decay of a high-momentum turbulent jet based on experimentally-measured entrainment rates and similarity scaling laws for turbulent jets. The model is then verified by comparing simulations for high-pressure natural gas leaks with the experimental data of Birch (1984) for the concentration decay of high-pressure natural gas jets. The engineering model is then applied to hydrogen and used to predict unignited jet mean (time-averaged over turbulent fluctuations) concentration contours for high-pressure hydrogen leaks.



**FIGURE E.2** Coordinate System for Turbulent Jet Flame and Unignited Jet.

### E.2.1 Flame Radiation Heat Flux and Flame Length Model.

Gaseous flame radiation is the primary heat transfer mechanism from hydrogen flames. The flame radiation heat flux model follows the approach of Sivathanu and Gore (1993) where the flame properties of importance are the visible flame length,  $L_{vis}$ , total radiative power emitted from the flame,  $S_{rad}$ , and total heat released due to chemical reaction,  $m_{fuel}\Delta H_c$  where  $m_{fuel}$  and  $\Delta H_c$  are the total fuel mass flow rate and the heat of combustion, respectively. The radiant fraction,  $X_{rad}$ , is defined as the fraction of the total chemical heat release that is radiated to the surroundings and is given by an expression of the form

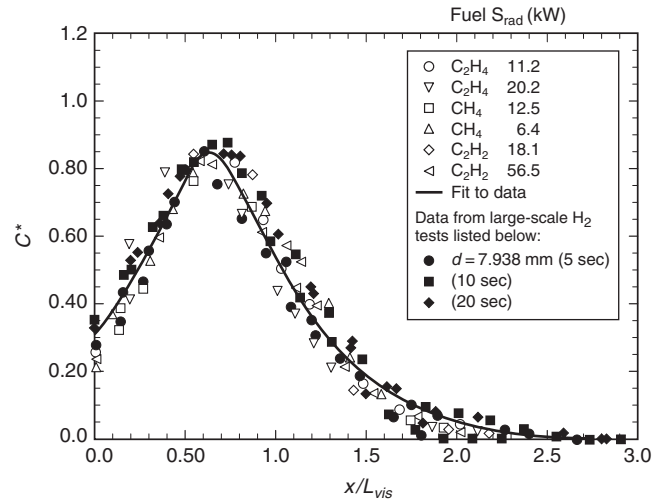
$$X_{rad} = S_{rad} / m_{fuel} \Delta H_c \quad (\text{E.2.1a})$$

For turbulent-jet flames, the radiative heat flux at an axial position  $x$  and radial position  $r$  can be expressed in terms of the non-dimensional radiant power,  $C^*$ , and,  $S_{rad}$ , the total emitted radiative power. The radiative heat flux is given by an expression of the form (Sivathanu and Gore, 1993)

$$q_{rad}(x, r) = C^*(x/L_{vis}) S_{rad} / 4\pi r^2 \quad (\text{E.2.1b})$$

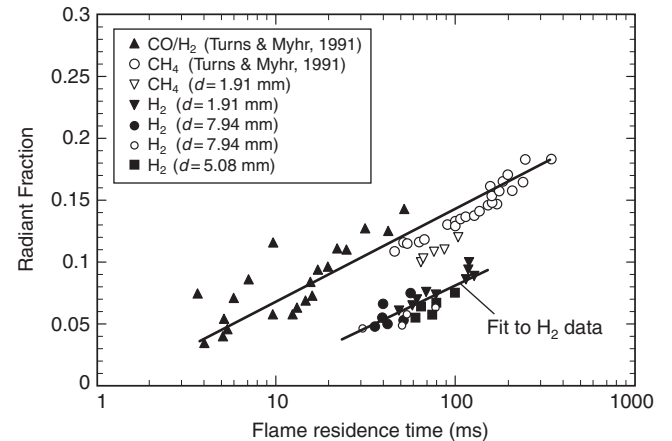
where  $q_{rad}(x, r)$  is the radiant heat flux measured at a particular axial location,  $x$ , and radial location,  $r$ . Experimental data further show that  $C^*$  may be expressed in non-dimensionalized

form as a function of burner diameter, flow rate and fuel type and, for turbulent-jet flames, is dependent only on the normalized axial distance. Figure E.2.1(a) shows typical profiles of  $C^*$  measured in six different turbulent-jet flames using  $\text{CH}_4$ ,  $\text{C}_2\text{H}_2$  and  $\text{C}_2\text{H}_4$  as the fuel (Sivathanu and Gore, 1993) as well as the measurements of Schefer *et al.* (2006, 2007) for large-scale  $\text{H}_2$  jet flames.



**FIGURE E.2.1(a)** Axial Variation of Normalized Radiative Heat Flux.

The use of Equation E.2.1b to calculate flame radiation heat flux levels requires knowledge of the flame radiant fraction. Turns and Myhr (1991) measured the radiant fraction from turbulent jet flames using four hydrocarbon fuels with a wide variety of sooting tendencies. These fuels included methane, ethylene, propane, and a 57%  $\text{CO}/43\% \text{H}_2$  mixture. A plot of the radiant fraction data from Turns and Myhr (1991) along with the radiant fraction data for large-scale  $\text{H}_2$  flames is shown in Figure E.2.1(b). The radiant fraction data,  $X_{rad}$ , is



**FIGURE E.2.1(b)** Radiant Fraction as a Function of Flame Residence Time (lab  $\text{H}_2$  flame data for diameters of 1.905 and 3.75 mm, large-scale  $\text{H}_2$  flame test data at diameter of 7.94 mm).



plotted versus the global flame residence time where the residence time is given by an expression of the form

$$\tau_f = (\rho_f W_f^2 L_{vis} f_s) / (3 \rho_j d_j^2 u_j) \quad (\text{E.2.1c})$$

where  $\rho_f$ ,  $W_f$  and  $L_{vis}$  are the flame density, width, and length, and  $f_s$  is the mass fraction of hydrogen in a stoichiometric mixture of hydrogen and air. For turbulent-jet flames, the flame width,  $W_f$  is approximately equal to  $0.17 L_{vis}$  (Schefer *et al.*, 2006). This definition of residence time takes into account the actual flame density and models the flame as a cone. The flame density,  $\rho_f$ , is calculated from the expression  $\rho_f = p_\infty W_{mix} / (R_u T_{ad})$ , where  $p_\infty$  is the ambient pressure,  $W_{mix}$  is the mean molecular weight of the stoichiometric products of hydrogen combustion in air,  $R_u$  is the universal gas constant, and  $T_{ad}$  is the adiabatic flame temperature for hydrogen. The figure suggests that for flames with a lower sooting tendency, there is a well-defined relationship between radiant fraction and global flame residence time. Both methane and the  $\text{CO}/\text{H}_2$  mixture show a well-behaved dependence on residence time and nearly collapse onto the same curve over the range of conditions studied. Values for the large-scale hydrogen jet flames are approximately a factor of two lower than the hydrocarbon flames for the same flame residence time.

The visible flame length,  $L_{vis}$ , is required for computing the global flame residence time,  $\tau_f$  to determine the flame radiant fraction. Based on an analysis of the transition from momentum-controlled to buoyancy-controlled turbulent jet flame dynamics, Delichatsios (1993) developed a useful correlation for turbulent flame lengths. The correlation is based on a non-dimensional Froude number that measures the ratio of buoyancy to momentum forces in jet flames. Using the nomenclature of Turns (2000) the Froude number is defined as:

$$Fr_f = \frac{u_j f_s^{3/2}}{(\rho_j / \rho_\infty)^{1/4} \left[ \frac{\Delta T_f}{T_\infty} g d_j \right]^{1/2}} \quad (\text{E.2.1d})$$

where  $u_j$  is the jet exit velocity,  $f_s$  is the mass fraction of fuel at stoichiometric conditions,  $(\rho_j / \rho_\infty)$  is the ratio of jet gas density to ambient gas density,  $d_j$  is the jet exit diameter, and  $\Delta T_f$  is the peak flame temperature rise due to combustion heat release. Small values of  $Fr_f$  correspond to buoyancy-dominated flames while large values of  $Fr_f$  correspond to momentum-dominated flames. Note that the parameters known to control turbulent flame length such as jet diameter, flow rate, stoichiometry, and  $(\rho_j / \rho_\infty)$  are included in  $Fr_f$ . Further, a non-dimensional flame length,  $L^*$ , can be defined as

$$L^* = \frac{L_{vis} f_s}{d_j (\rho_j / \rho_\infty)^{1/2}} = \frac{L_{vis} f_s}{d^*} \quad (\text{E.2.1e})$$

where  $L_{vis}$  is the visible flame length and  $d^*$  is the jet momentum diameter. Figure E.2.1(c) shows the resulting correlation of flame length data for a range of fuels ( $\text{H}_2$ ,  $\text{C}_3\text{H}_8$  and  $\text{CH}_4$ ) and inlet flow conditions. In the buoyancy-dominated regime,  $L^*$  is correlated by the expression

$$L^* = \frac{13.5 Fr_f^{2/5}}{(1 + 0.07 Fr_f^2)^{1/5}} \quad \text{for } Fr_f < 5 \quad (\text{E.2.1f})$$

and in the momentum-dominated regime by the expression

$$L^* = 23 \quad \text{for } Fr_f > 5 \quad (\text{E.2.1g})$$

The flame length data of Schefer *et al.* (2006, 2007) for large-scale hydrogen flames is shown on the plot and is found to be in good agreement with the  $L^*$  correlations given by Eqs. (E.2.1f) and (E.2.1g). For choked flow conditions the concept of a notional expansion and effective source diameter (see next section) was used to reduce the hydrogen flame length measurements for plotting in terms of  $L^*$  in Figure E.2.1(c). The simulation also uses this same effective diameter approach to recover the visible flame length,  $L_{vis}$ , from the values of  $L^*$  computed from Eqs. (E.2.1f) and (E.2.1g).

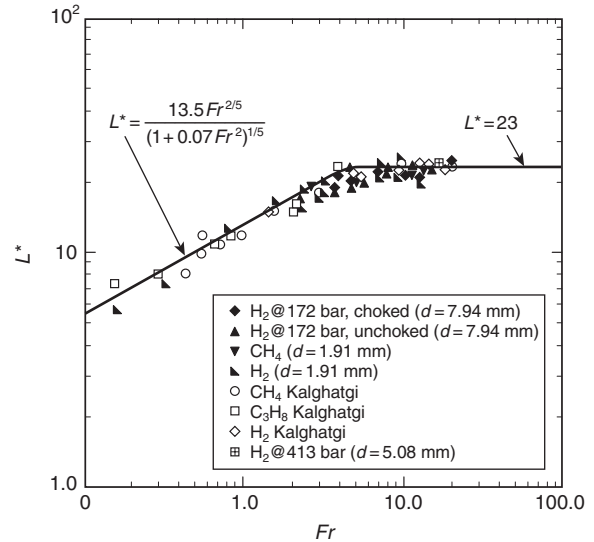


FIGURE E.2.1(c) Variation of Dimensionless Visible Flame Length with Flame Froude Number.

If the jet exit velocity and density of a hydrogen flame are known, then Eq. (E.2.1d) can be used to calculate the flame Froude number and Eq. (E.2.1e) and both Eq. (E.2.1f) and Eq. (E.2.1g) can then be used to compute the visible length of the flame,  $L_{vis}$ . The flame width,  $W_f$ , can be computed from the expression  $W_f = 0.17 L_{vis}$  and used in Eq. (E.2.1c) to compute the global flame residence time,  $\tau_f$ . Knowing the flame residence time, a curve-fit to the hydrogen radiant fraction data in Figure E.2.1(b) can be used to determine the radiant fraction of the hydrogen flame. Knowing the radiant fraction and using a curve-fit to the  $C^*$  curve shown in Figure E.2.1(a), Eq. E.2.1b can be used to compute the radiant heat flux from the hydrogen flame at any axial position,  $x$ , and radial position  $r$ .

**E.2.2 Unignited Jet Concentration Decay Model.** For cases where the high-pressure leak of hydrogen is unignited, a classic high-momentum turbulent jet is formed that can be described using the same coordinate system shown in Figure E.2. The hydrogen concentration within the jet varies with axial position,  $x$ , and radial position,  $r$ , due to entrainment and turbulent mixing with the ambient air.

The nature of the concentration field of subsonic, momentum-dominated incompressible turbulent free jets is well documented in the literature (Chen and Rodi, 1980). The decay of the mean volume fraction,  $\bar{\eta}_{cl}$ , (or mean mole

fraction) along the centerline of the jet is given by an expression of the form

$$\eta_d(x) = \frac{Kd_j}{x + x_o} \left( \frac{\rho_\infty}{\rho_{gas}} \right)^{1/2} \quad (\text{E.2.2a})$$

where  $K$  is the entrainment constant,  $\rho_\infty$  is the density of the ambient fluid,  $\rho_{gas}$  is the density of the exiting gas evaluated at ambient temperature and pressure, and  $x_o$  is the virtual origin of the jet (Chen and Rodi, 1980).

For high-pressure leaks of hydrogen, the exit flow chokes at the sonic velocity if the pressure ratio across the leak is greater than the critical pressure ratio (approximately 1.9 for hydrogen). At pressure ratios higher than the critical value, the exit velocity remains locally sonic. For these supercritical releases, the flow leaves the exit to form an underexpanded jet that quickly expands to ambient pressure through a complex flow structure involving one or more shocks. As a result, the concentration field behaves as if it were produced by a larger source than the actual exit diameter and the diameter of this effective source is referred to as the effective diameter,  $d_{eff}$ . The work of Birch (1984, 1987) for natural gas jets indicates that the classical laws for concentration decay for turbulent jets in pressure equilibrium [i.e., Eq. (E.2.2a)] can be applied to underexpanded jets resulting from supercritical releases provided that the jet exit diameter,  $d_j$ , is replaced by the effective diameter  $d_{eff}$ . The reports of Britter (1994, 1995) discuss various approaches for computing effective diameter source models for underexpanded jets.

The effective source diameter model used in this work is formulated by considering a notional expansion (Birch, 1987) that conserves both mass and momentum while retaining the assumption that the pressure is reduced to ambient pressure at the end of the expansion. Based on the work of Birch (1987), the equation for the effective source diameter is

$$d_{eff} = \left( \frac{\rho_j u_j}{\rho_{gas} u_{eff}} \right)^{1/2} d_j \quad (\text{E.2.2b})$$

where  $\rho_j$  is the jet exit density,  $u_j$  is the jet exit velocity,  $\rho_{gas}$  is the density of the exiting gas evaluated at ambient pressure and temperature,  $d_j$  is the jet exit diameter, and  $u_{eff}$  is the velocity at the end of the expansion. The effective velocity at the end of the expansion is given by an expression of the form

$$u_{eff} = u_j + (P_j - P_\infty) / (\rho_j u_j) \quad (\text{E.2.2c})$$

where  $p_j$  is the jet exit pressure and  $p_\infty$  is the ambient pressure. Equations (E.2.2b) and (E.2.2c) can be used to compute the effective source diameter for supercritical releases and are valid for real gas as well as ideal gas models as long as the jet exit conditions are computed properly. For hydrogen at 200 bar and 300K the compressibility factor  $Z$  (where  $Z = p/(\rho RT)$ ) is approximately 1.12; at a pressure of 800 bar and the same temperature the compressibility factor is approximately 1.51. For an ideal gas,  $Z$  is equal to unity.

For supercritical releases the effective source diameter replaces the jet diameter in Eq. (E.2.2a) and centerline concentration decay equation becomes

$$\eta_d(x) = \frac{Kd_{eff}}{x + x_o} \left( \frac{\rho_\infty}{\rho_{gas}} \right)^{1/2} \quad (\text{E.2.2d})$$

At each axial position,  $x$ , the radial variation of the concentration is computed from the expression

$$\eta(x, r) = \eta_d(x) e^{-K_c (r/x + x_o)^2} \quad (\text{E.2.2e})$$

where the value of  $K_c = 57$  for a round jet (Chen and Rodi, 1980). Equations (E.2.2b), (E.2.2c), (E.2.2d), and (E.2.2e) can be used to compute the concentration field from a high-momentum turbulent jet resulting from the supercritical release of hydrogen. For the studies performed in this paper, a value of the entrainment coefficient equal to  $K=5.40$  (Birch, 1987) was used for the simulations. The value of the virtual origin,  $x_o$ , is typically a small multiple (less than 5) of the jet exit diameter and was set to zero for these studies in accordance with the work of Birch (1987).

### E.3 Comparison of Models with Experimental Data.

#### E.3.1 Flame Radiation Heat Flux and Flame Length Model.

The hydrogen flame radiation and flame length models were compared against the large-scale hydrogen jet flame experiments of Schefer *et al.* (2006, 2007). In these experiments, hydrogen gas was released from a “six-pack” of high-pressure cylinders, each connected to a central manifold with a common outlet. Typical pressure in the full cylinders was 137.9 bar (2000 psia) to 172.3 bar (2500 psia).

To obtain jet exit conditions, a network flow model of the piping and high-pressure cylinders used in the experiment was developed using the Sandia developed Topaz code (Winters, 1984). The network flow model considers the non-ideal gas behavior of hydrogen through an Abel-Nobel equation of state (Chenoweth, 1983) of the form

$$p = \frac{\rho R_{H_2} T}{(1 - b\rho)} \quad (\text{E.3.1})$$

where the values of  $R_{H_2} = 4,124.18 \text{ J/kg}\cdot\text{K}$  and  $b = 7.691 \times 10^{-3} \text{ m}^3/\text{kg}$  were used for hydrogen. The model can also be used with an ideal-gas equation of state by setting the value  $b$  equal to zero.

The tank blow-down and network flow model was used to predict the flow and pressure drop through the piping leading to the jet exit. These jet exit conditions were then used with the flame length and radiant fraction correlations described in the previous section to predict the hydrogen jet flame characteristics. Comparisons of the measured and predicted pressure history curves in the high-pressure cylinders were used to validate the tank blow-down network flow model (Schefer *et al.*, 2006). Simulations with the network flow model indicated that significant pressure drop occurred in the piping of the experiment with the total pressure at the jet exit being approximately 16.4 bar (226 psig) or a static pressure of approximately 13.6 bar (182 psig) at 0.1 second into the blow-down.

Figure E.3.1(a) shows a comparison of the flame length predictions from the model with the large-scale hydrogen jet flame length data. Because an approximate  $\pm 10\%$  scatter occurs in the data around the  $L^*$  correlation [see Figure E.2.1(c)] used in the model, an uncertainty analysis was performed where the  $L^*$  correlation was increased and then decreased by 10% from its nominal value. Calculations are shown in Figure E.3.1(a) for the nominal  $L^*$  correlation, and an increase in  $L^*$  of 10% and a decrease in  $L^*$  of  $-10\%$ . Predictions from the model are found to be in good agreement with the measured hydrogen flame lengths.

Figure E.3.1(b) shows a comparison of simulations and measured radiation heat flux data along the axis of a hydrogen

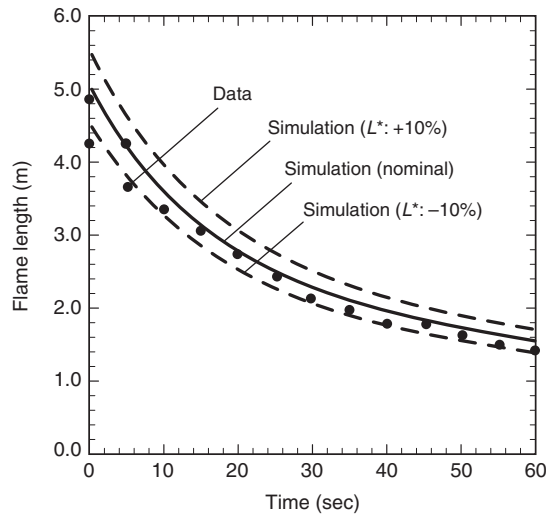


FIGURE E.3.1(a) Comparison of Simulation of Hydrogen Visible Flame Length with the Hydrogen Jet Flame Data of Schefer et al. (2006).

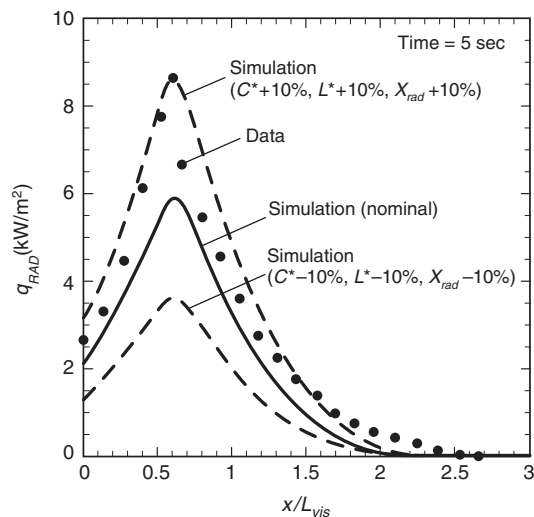


FIGURE E.3.1(b) Comparison of Simulation of Radiative Heat Flux from a Hydrogen Flame at a Radial Position of  $r=1.83$  m with the Data at 5 Seconds into the Blow-Down.

jet flame at a radial distance of 1.82 m (6 ft) from the flame centerline at a time 5 seconds into the blow-down of the high-pressure hydrogen cylinders. An approximate  $\pm 10\%$  scatter occurs in the data around the  $L^*$  correlation [see Figure E.2.1(c)], the  $C^*$  correlation [see Figure E.2.1(a)], and the radiant fraction correlation [see Figure E.2.1(b)],  $X_{rad}$ . Hence, an uncertainty analysis was performed where model calculations were performed with the nominal values of these correlations, and an increase of 10% to each of the 3 correlations (upper bound on radiative heat flux), and a decrease of -10% to each of the correlations (lower bound on radiative heat flux). The results of these calculations are shown in Figure E.3.1(b). An additional comparison with data using the same approach is shown in Figure E.3.1(c) at a time of 10 seconds into the blow-down. The range of the calculations

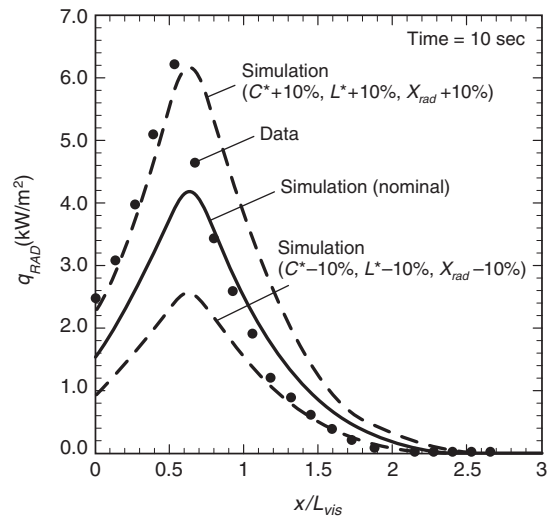
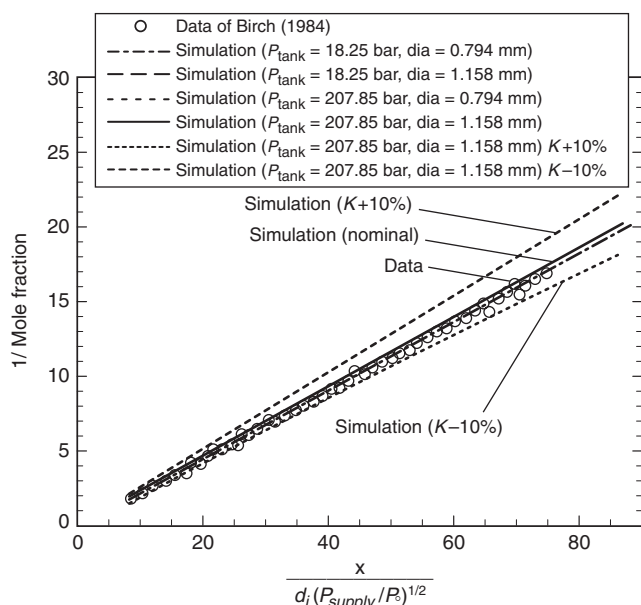


FIGURE E.3.1(c) Comparison of Simulation of Radiative Heat Flux from a Hydrogen Flame at a Radial Position of  $r=1.83$  m with the Data at 10 Seconds into the Blow-Down.

with either an increase of 10% or decrease of 10% in each of the correlations for  $L^*$ ,  $C^*$ , and  $X_{rad}$  are able to bound the range of experimental data adequately at both times.

**E.3.2 Unignited Jet Concentration Decay Model.** There appears to be a lack of data in the literature for the concentration decay of momentum-dominated, choked flow, unignited turbulent hydrogen jets resulting from supercritical releases. Hence the unignited jet model was compared with the jet concentration decay data of Birch (1984) for supercritical releases of natural gas. Birch measured the concentration decay of natural gas into air for a 2.7 mm diameter round nozzle connected to a regulated high-pressure natural gas supply. The method of concentration measurement in the experiment integrated the turbulent concentration fluctuations in the flow and resulted in a time-averaged concentration measurement at each axial location. Measurements of the mean concentration level at different axial positions along the jet centerline were made for supply pressures ranging from 3.5 to 71 bar. Birch found if the mean concentration decay along centerline was plotted in terms of the non-dimensional coordinate  $x/(d_j(p_{supply}/p_{\infty})^{0.5})$ , then the data collapsed onto a single curve.

Calculations with the unignited jet model discussed in the previous section were performed using natural gas properties and generating jet exit conditions for a large high-pressure supply attached to a short round nozzle. The Topaz network flow code with an ideal gas equation of state for natural gas was used to generate jet exit conditions for this geometry. Calculations were performed at pressures of 18.25 bar (250 psig) and 207.85 bar (3000 psig) for jet exit diameters of 0.794 mm and 1.158 mm. The axial variation of the reciprocal of the mean concentration ( $1/\bar{\eta}_r$ ) on jet centerline was plotted in terms of the non-dimensional axial coordinate,  $x/(d_j(p_{supply}/p_{\infty})^{0.5})$ , where  $d_j$  is the jet exit diameter,  $p_{supply}$  is the pressure in high-pressure supply,  $p_{\infty}$  is the ambient pressure. Comparison of the calculations from the model with the data of Birch (1984) using the nominal value of the turbulent entrainment constant ( $K = 5.40$ ) is shown in Figure E.3.2. Based on data reported by Birch (1984, 1987) there appears to be approximately  $\pm 10\%$  variation in the value of the turbulent



**FIGURE E.3.2 Comparison of Simulation of Centerline Concentration Decay for Gas Unignited Jets with the Data of Birch [3].**

entrainment constant,  $K$ . Hence, in addition to using the nominal value of  $K$ , calculations were performed for the 207.85 bar 1.158 diameter nozzle by varying  $K \pm 10\%$  from the nominal value. Results of the calculations using the nominal value of  $K$  are in excellent agreement with the data of Birch. Moreover the calculations at 207.8 bar, which are well beyond the maximum pressure of 71 bar used in Birch's experiments, are found to be in excellent agreement with the collapsed data curve plotted in terms of  $x/(d_j(P_{\text{supply}}/P_{\infty})^{0.5})$ . The work of Ruffin *et al.* (1996) also appears to confirm the notional expansion concentration decay model of Birch for supercritical jets of methane and hydrogen at a pressure of 40 bar.

#### E.4 Simulation of Unintended Releases.

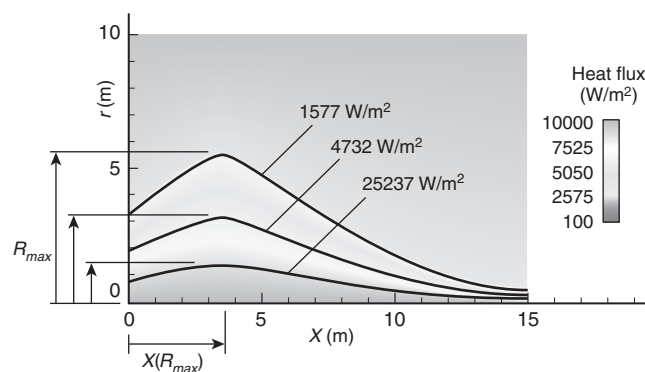
**E.4.1 Hydrogen Jet Flame Radiation and Unignited Jet Concentration Decay.** Simulations for unintended releases of hydrogen were performed by considering a break in the tubing directly connected to a large hydrogen storage container. Based on a survey of a panel of experts (ICC, 2003) familiar with current and intended uses of hydrogen, pressures in the range from 18.25 bar (250 psig) to 1,035.21 bar (15,000 psig) and leak diameters in the range from 9.525 mm ( $3/8$  inch) to 0.25 mm were suggested for analysis.

For the simulations reported in this section a storage tank volume of  $29.7 \text{ m}^3$  was used based on the recommendation of the expert panel. Calculations are reported for pressures of 18.25 bar (250 psig), 207.85 bar (3000 psig), 518.11 bar (7500 psig), and 1,035.21 bar (15,000 psig) and leak diameters ranging between 1.587 mm ( $1/16$  inch) and 6.35 mm ( $1/4$  inch). Jet exit conditions were computed using the Topaz network flow code with an Abel-Nobel equation of state for hydrogen to simulate a large tank of hydrogen connected to a short length of tubing (3.175 mm) with a diameter equal to the diameter of the leak under consideration. The tank temperature was assumed to be initially at ambient temperature (294K) with the end of the tubing exiting to the ambient environment (1.0133 bar, 294K). Calculations were per-

formed for hydrogen jet flames and unignited jets with the results for radiative heat flux and concentration decay being reported at 1 second into the tank blow-down for each case. At 1 second, the tank pressure has not changed significantly from its initial value and the radiative and concentration length scales are at their largest values.

For the hydrogen jet flames, radiative heat flux contours were recorded for heat flux levels of  $1577 \text{ W/m}^2$  (500 Btu/hr-ft<sup>2</sup>),  $4732 \text{ W/m}^2$  (1500 Btu/hr-ft<sup>2</sup>), and  $25237 \text{ W/m}^2$  (8000 Btu/hr-ft<sup>2</sup>). These heat flux levels corresponding to values listed in the 2003 International Fire Code (2002) for exposure at property line, exposure for employees for a maximum of 3 minutes, and exposure for noncombustible equipment, respectively. Figure E.4.1(a) shows results for the radiative heat flux from a hydrogen jet flame with a tank pressure of 207.85 bar (3000 psig) and a leak diameter of 3.175 mm ( $1/8$  inch). Important safety related information recorded from the simulations includes the maximum radial position from the flame centerline for the given heat flux level,  $R_{\text{max}}$ , the axial location at which the maximum occurs,  $X(R_{\text{max}})$ , the combination of these two distances,  $D_{\text{rad}} = (R_{\text{max}} + X(R_{\text{max}}))$ , and the visible flame length,  $L_{\text{vis}}$ . Figure E.4.1(b) shows a plot of  $D_{\text{rad}}$  and the visible flame length for various leak diameters for a tank pressure of 207.85 bar. Also included on the plot are the upper and lower bounds for  $D_{\text{rad}}$  and  $L_{\text{vis}}$  assuming an uncertainty of  $\pm 10\%$  in each of the values of  $C^*$ ,  $L^*$ , and  $X_{\text{rad}}$ . Figure E.4.1(c) shows a plot of  $R_{\text{max}}$  and  $X(R_{\text{max}})$  for various leak diameters for a tank pressure of 207.85 bar, including the upper and lower bounds for  $R_{\text{max}}$  and  $X(R_{\text{max}})$  assuming  $\pm 10\%$  uncertainty in each of the values of  $C^*$ ,  $L^*$ , and  $X_{\text{rad}}$ . At this pressure the value of  $D_{\text{rad}}$  can be computed to approximately  $\pm 14\%$  to  $\pm 18\%$  depending on the jet diameter, while the flame length can be computed to approximately  $\pm 10\%$ .

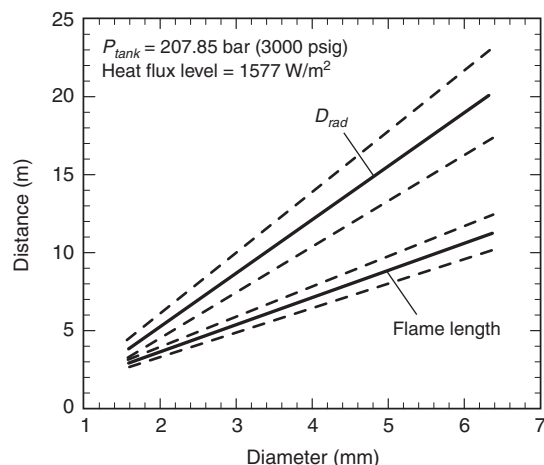
Figure E.4.1(d) shows mole fraction contours for the simulation of the concentration decay of an unignited jet of hydrogen for a tank pressure of 207.85 bar (3000 psig) and a leak diameter of 3.175 mm ( $1/8$  inch). Important safety information recorded from the simulations is the distance from the jet exit to where the mean concentration decays to a given concentration level on the jet centerline. Although the generally accepted value for the upward-propagating lower flammability limit of hydrogen in air is 0.04 mole fraction, experimental data in the literature indicate that the limit may be as high as 0.072 mole fraction for horizontal-propagating flames and 0.095 mole fraction for downward-propagating flames (Zebetakis, 1965, Coward and Jones, 1952). For the unignited hydrogen jet simulations,



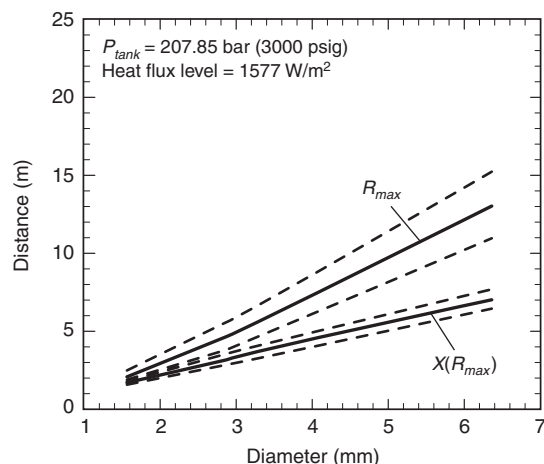
**FIGURE E.4.1(a) Simulation of Radiation Heat Flux from a Hydrogen Jet Flame with a Leak Diameter of 3.175 mm and a Tank Pressure of 207.85 bar (3000 psig).**



distances from the origin to jet centerline concentration levels of 0.08, 0.06, 0.04, and 0.02 mole fraction were recorded, and these distances are referred to as x8%, x6%, x4%, and x2% respectively. Figure E.4.1(e) shows a plot of unignited jet concentration decay distances for a tank pressure of 207.85 bar (3000 psig) for various leak diameters. Upper and lower bounds for the concentration decay distances are also shown on the plot assuming a  $\pm 10\%$  uncertainty in the turbulent jet entrainment constant  $K$ .

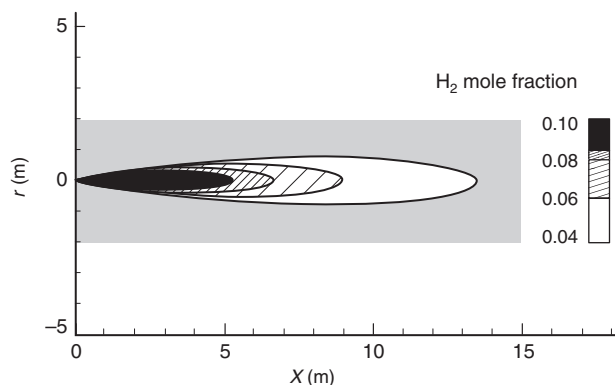


**FIGURE E.4.1(b)** Simulations of Hydrogen Jet Flame Radiation from a Tank at Pressure 207.85 bar (3000 psig) for Various Diameter Leaks. Results showing radiation distance,  $D_{rad} = (X(R_{max}) + R_{max})$ , for a heat flux level of  $1577 \text{ W/m}^2$  and the visible flame length. Solid lines show distances using nominal values of  $C^*$ ,  $L^*$ , and  $X_{rad}$ . Dashed lines show upper and lower bounds for  $D_{rad}$  and visible flame length with  $\pm 10\%$  uncertainty in each of the values of  $C^*$ ,  $L^*$ , and  $X_{rad}$ .

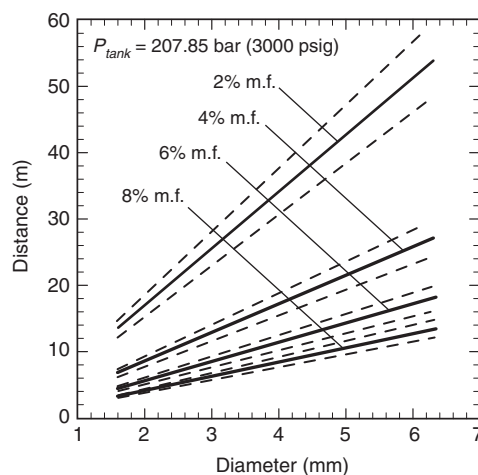


**FIGURE E.4.1(c)** Simulations of Hydrogen Jet Flame Radiation from a Tank at Pressure 207.85 bar (3000 psig) for Various Diameter Leaks. Results showing maximum radial distance from the flame centerline,  $R_{max}$ , for a heat flux level of  $1577 \text{ W/m}^2$  and the axial location on centerline,  $X(R_{max})$ , where the maximum occurs. Solid lines show distances using nominal values of  $C^*$ ,  $L^*$ , and  $X_{rad}$ . Dashed lines show upper and lower bounds for  $R_{max}$  and  $X(R_{max})$  with  $\pm 10\%$  uncertainty in each of the values of  $C^*$ ,  $L^*$ , and  $X_{rad}$ .

Table E.4.1(a) shows a summary of radiation distances recorded from hydrogen jet flame simulations for tank pressures of 18.25 bar (250 psig), 207.85 bar (3000 psig), 518.11 bar (7500 psig), and 1035.21 bar (15,000 psig) for selected leak diameters using the nominal values of  $C^*$ ,  $L^*$ , and  $X_{rad}$ . Table E.4.1(b) shows a summary of concentration decay distances for unignited hydrogen jets for the same tank pressures and selected leak diameters using the nominal value of the entrainment constant  $K$ . Detailed plots of radiation and concentration decay distances for the range of parameters considered are presented in E.7.



**FIGURE E.4.1(d)** Simulations of Concentration Decay of an Unignited Hydrogen Jet with a Diameter of 3.175 mm ( $\frac{1}{8}$  inch) and a Tank Pressure of 207.85 bar (3000 psig). Contour lines correspond to mole fraction levels shown in the color legend.



**FIGURE E.4.1(e)** Simulations of Concentration Decay for a Turbulent High-Momentum Supercritical Unignited Hydrogen Jet from a Tank at Pressure 207.85 bar (3000 psig) for Various Diameter Leaks. Results showing axial distance from jet origin to the point where jet concentration reaches 2.0%, 4.0%, 6.0%, and 8.0% mole fraction on jet centerline. Solid lines show distances using the nominal value of the turbulent jet entrainment constant,  $K = 5.40$ . Dashed lines show upper and lower bounds for distances with  $\pm 10\%$  uncertainty in the value of  $K$ .

**Table E.4.1(a) Hydrogen Jet Flame Radiation Distances for Selected Leak Diameters and Tank Pressures (Note: Assuming worst case of no pressure loss in tubing).**

$P_{\text{tank}}$ (bar)	$d_j$ (mm)	$X(R_{\text{max}})$ (m)	$R_{\text{max}}$ (m)	$D_{\text{rad}}$ (m)	$L_{\text{vis}}$ (m)	Heat Flux (W/m <sup>2</sup> )
18.25	1.00	0.35	0.10	0.45	0.55	1577
18.25	1.00	0.35	0.059	0.41	0.55	4732
18.25	1.00	0.35	0.026	0.38	0.55	25237
18.25	2.3810	0.84	0.52	1.36	1.32	1577
18.25	2.3810	0.84	0.30	1.14	1.32	4732
18.25	2.3810	0.84	0.13	0.97	1.32	25237
18.25	4.2333	1.49	1.59	3.09	2.35	1577
18.25	4.2333	1.49	0.92	2.41	2.35	4732
18.25	4.2333	1.49	0.39	1.89	2.35	25237
18.25	6.35	2.24	2.90	5.14	3.52	1577
18.25	6.35	2.24	1.67	3.91	3.52	4732
18.25	6.35	2.24	0.72	2.96	3.52	25237
207.85	1.00	1.13	0.96	2.08	1.77	1577
207.85	1.00	1.13	0.55	1.68	1.77	4732
207.85	1.00	1.13	0.24	1.36	1.77	25237
207.85	2.3810	2.68	3.75	6.43	4.22	1577
207.85	2.3810	2.68	2.16	4.84	4.22	4732
207.85	2.3810	2.68	0.93	3.61	4.22	25237
207.85	4.2333	4.76	7.94	12.71	7.50	1577
207.85	4.2333	4.76	4.58	9.35	7.50	4732
207.85	4.2333	4.76	1.98	6.75	7.50	25237
207.85	6.35	7.14	13.09	20.23	11.25	1577
207.85	6.35	7.14	7.55	14.70	11.25	4732
207.85	6.35	7.14	3.27	10.42	11.25	25237
518.11	1.00	1.68	1.91	3.60	2.65	1577
518.11	1.00	1.68	1.10	2.79	2.65	4732
518.11	1.00	1.68	0.48	2.16	2.65	25237
518.11	2.3810	4.01	6.46	10.47	6.31	1577
518.11	2.3810	4.01	3.73	7.74	6.31	4732
518.11	2.3810	4.01	1.61	5.62	6.31	25237
518.11	4.2333	7.13	13.27	20.40	11.23	1577
518.11	4.2333	7.13	7.66	14.79	11.23	4732
518.11	4.2333	7.13	3.31	10.45	11.23	25237
518.11	6.35	10.69	21.58	32.28	16.84	1577
518.11	6.35	10.69	12.46	23.16	16.84	4732
518.11	6.35	10.69	5.39	16.09	16.84	25237
1035.21	1.00	2.21	2.89	5.10	3.48	1577
1035.21	1.00	2.21	1.67	3.88	3.48	4732
1035.21	1.00	2.21	0.72	2.93	3.48	25237
1035.21	2.3810	5.26	9.30	14.56	8.29	1577
1035.21	2.3810	5.26	5.37	10.63	8.29	4732
1035.21	2.3810	5.26	2.32	7.59	8.29	25237

Figure E.4.1(f) shows a comparison of hydrogen jet flame radiation hazard distances with unignited jet concentration decay distances for a range of tank pressures and leak diameters. Results are shown for the visible flame length and the radiation hazard distance,  $D_{\text{rad}}$ , for heat flux levels of 1577 W/m<sup>2</sup> and 4732 W/m<sup>2</sup>. These radiation hazard distances are compared with unignited jet concentration decay distances from origin to jet centerline mean concentration levels of 0.08, 0.06, 0.04 mole fractions. For the range of pressures studied, the unignited jet concentration decay distance to the generally accepted lower flammability limit of hydrogen in air (0.04 mole fraction) is greater than the radiation jet flame hazard distance ( $D_{\text{rad}}$ ) for exposure at property line (1577 W/m<sup>2</sup>).

**E.5 Summary and Conclusions.** The previous sections presented methods by which the radiant heat flux from hydrogen jet flames and the concentration decay of supercritical high-momentum unignited hydrogen jets may be computed. If the jet exit conditions can be computed at the leak (Chernicoff *et al.*, 2005), then these methods can be used to compute hydrogen jet flame radiation and unignited jet concentration decay based on the models.

An uncertainty analysis of the hydrogen jet flame radiation model (207.85 bar case) using an uncertainty of  $\pm 10\%$  in each of the three experimentally measured correlations ( $C^*$ ,  $L^*$ ,  $X_{\text{rad}}$ ), indicates that the radiation distance,  $D_{\text{rad}}$ , can be computed to approximately  $\pm 14\%$  to  $\pm 18\%$  for the jet diameters