NFPA® 2

Hydrogen Technologies Code

2016 Edition

NFPA, 1 Batterymarch Park, Quincy, MA 02169-7471
An International Codes and Standards Organization

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NFPA® 2

Hydrogen Technologies Code

2016 Edition

This edition of NFPA 2, *Hydrogen Technologies Code*, was prepared by the Technical Committee on Hydrogen Technology. It was issued by the Standards Council on May 26, 2015, with an effective date of June 15, 2015, and supersedes all previous editions.

A Tentative Interim Amendment (TIA) to 18.3.3 was issued on August 18, 2015. For further information on tentative interim amendments, see Section 5 of the Regulations Governing the Development of NFPA Standards, available at http://www.nfpa.org/regs.

This edition of NFPA 2 was approved as an American National Standard on June 15, 2015.

Origin and Development of NFPA 2

With the increased interest in hydrogen being used as a fuel source, the National Fire Protection Association was petitioned to develop an all-encompassing document that establishes the necessary requirements for hydrogen technologies. In 2006, the Technical Committee on Hydrogen Technology was formed and tasked to develop a document that addresses all aspects of hydrogen storage, use, and handling, that draws from existing NFPA codes and standards, and that identifies and fills technical gaps for a complete functional set of requirements for code users and enforcers. This document is also structured so that it works seamlessly with building and fire codes.

This code is largely extracted from other NFPA codes and standards (e.g., NFPA 52, NFPA 55, and NFPA 853) and is organized in a fashion that is specific for hydrogen. Paragraphs that have been extracted from other documents are shown with the extract reference brackets [] at the end of the paragraph. In some cases, modifications have been made to the extracted text to use terminology appropriate for this code, such as the terms GH2 instead of compressed gas and LH2 instead of cryogenic fluid. In those instances, brackets [] encase the modifying words. Similarly, where language was deleted to adhere to requirements based exclusively on hydrogen and no other changes were made to the paragraph, brackets that encompass a dash [-] are inserted into the paragraph to denote a change to the original material while retaining the extract to the source document. In short, added or modified text is shown with [] around the differing language and pure deletions of text are shown as [-].

The 2016 edition of NFPA 2 is more closely aligned with the requirements in NFPA 55 for gaseous and liquefied hydrogen systems. Both documents have been placed in the same revision cycle, which allowed the Technical Committees to work more closely together on revisions to the joint content. The requirements for hydrogen generation systems in NFPA 2 (Chapter 13) are no longer extracted from NFPA 55, and the requirements for hydrogen fueling systems (Chapters 10 and 11) are no longer extracted from NFPA 52. The Hydrogen Technologies Committee now has primary responsibility for those requirements.

The 2016 edition has the following changes:

(1) Significant revisions to Chapter 10, Gaseous Vehicle Fueling Facilities, that reflect a significant efforts by the Technical Committee in improving this chapter
(2) Clarification and organization of the requirements for gaseous hydrogen systems into three tiers based on the quantity of hydrogen stored: less than or equal to the MAQ (maximum allowable quantity), greater than the MAQ but less than the bulk quantity, and bulk systems
(3) Changes to the requirements in Chapter 7 for emergency isolation, consistent with the changes made to NFPA 55
(4) New requirements for hydrogen equipment enclosures, to address the growing use of these systems in a variety of field applications
(5) New chapters for parking garages and repair garages for hydrogen fuel cell vehicles

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This list represents the membership at the time the Committee was balloted on the final text of this edition. Since that time, changes in the membership may have occurred. A key to classifications is found at the back of the document.

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

Committee Scope: This committee shall have primary responsibility for documents on the storage, transfer, production, and use of hydrogen. The use of hydrogen would include stationary, portable, and vehicular applications.

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NFPA 2

Hydrogen Technologies Code

2016 Edition

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

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 M. 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 M.

Chapter 1 Administration

1.1 Scope. (Reserved)

1.2 Purpose. The purpose of this code shall be to provide fundamental safeguards for the generation, installation, storage, piping, use, and handling of hydrogen in compressed gas (GH_2) form or cryogenic liquid (LH_2) form.

1.3* Application.

1.3.1 This code shall apply to the production, storage, transfer, and use of hydrogen in all occupancies and on all premises.

1.3.2 The use of hydrogen shall include stationary, portable, and vehicular infrastructure applications.

1.3.3 The fundamental requirements of Chapters 1 through 8 shall apply in addition to the use-specific requirements provided in Chapters 9 through 18, as applicable.

1.3.4 Exemptions. This code shall not apply to the following:

(1) Onboard vehicle or mobile equipment components or systems, including the onboard GH_2 or LH_2 fuel supply
(2) Mixtures of GH_2 and other gases with a hydrogen concentration of less than 95 percent by volume when in accordance with NFPA 55
(3) The storage, handling, use, or processing of metal hydride materials outside of metal hydride storage systems defined in Chapter 3

1.4 Retroactivity. The provisions of this code reflect a consensus of the criteria 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.

1.5.1 Nothing in this code 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.

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

1.5.3 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 this code are presented first in U.S. customary units (inch-pound units). International System (SI) of Units follow the inch-pound units in parentheses.

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

1.6.6 If a value for measurement given in this standard is followed by an equivalent value in other units, the first stated shall be regarded as the requirement. The given equivalent value shall be considered to be approximate.

1.6.7 All pressures in this document are gauge pressures, unless otherwise indicated.

1.7 Enforcement.

1.7.1* This code shall be administered and enforced by the authority having jurisdiction designated by the governing authority under the administrative provisions of the adopted building or fire prevention code. *(See Annex C for sample wording for enabling legislation.)*

1.7.2 The administrative provisions of Annex B shall be allowed to be used when specifically adopted.

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,* 2015 edition.

NFPA 10, *Standard for Portable Fire Extinguishers,* 2013 edition.

NFPA 11, *Standard for Low-, Medium-, and High-Expansion Foam,* 2016 edition.

NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems,* 2015 edition.

NFPA 12A, *Standard on Halon 1301 Fire Extinguishing Systems,* 2015 edition.

NFPA 13, *Standard for the Installation of Sprinkler Systems,* 2016 edition.

NFPA 14, *Standard for the Installation of Standpipe and Hose Systems,* 2013 edition.

NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection,* 2012 edition.

NFPA 17, *Standard for Dry Chemical Extinguishing Systems,* 2013 edition.

NFPA 17A, *Standard for Wet Chemical Extinguishing Systems,* 2013 edition.

NFPA 24, *Standard for the Installation of Private Fire Service Mains and Their Appurtenances,* 2016 edition.

NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems,* 2014 edition.

NFPA 30, *Flammable and Combustible Liquids Code,* 2015 edition.

NFPA 30A, *Code for Motor Fuel Dispensing Facilities and Repair Garages,* 2015 edition.

NFPA 31, *Standard for the Installation of Oil-Burning Equipment,* 2011 edition.

NFPA 37, *Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines,* 2015 edition.

NFPA 45, *Standard on Fire Protection for Laboratories Using Chemicals,* 2015 edition.

NFPA 51, *Standard for the Design and Installation of Oxygen–Fuel Gas Systems for Welding, Cutting, and Allied Processes,* 2013 edition.

NFPA 51B, *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work,* 2014 edition.

NFPA 52, *Vehicular Natural Gas Fuel Systems Code,* 2013 edition.

NFPA 54, *National Fuel Gas Code,* 2015 edition.

NFPA 55, *Compressed Gases and Cryogenic Fluids Code,* 2016 edition.

NFPA 58, *Liquefied Petroleum Gas Code,* 2014 edition.

NFPA 68, *Standard on Explosion Protection by Deflagration Venting,* 2013 edition.

NFPA 69, *Standard on Explosion Prevention Systems,* 2014 edition.

NFPA 70®, National Electrical Code®, 2014 edition.

NFPA 72®, National Fire Alarm and Signaling Code, 2016 edition.

NFPA 79, *Electrical Standard for Industrial Machinery,* 2015 edition.

NFPA 80, *Standard for Fire Doors and Other Opening Protectives,* 2016 edition.

NFPA 82, *Standard on Incinerators and Waste and Linen Handling Systems and Equipment,* 2014 edition.

NFPA 86, *Standard for Ovens and Furnaces,* 2015 edition.

NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems,* 2015 edition.

NFPA 91, *Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids,* 2015 edition.

NFPA *101®, Life Safety Code®,* 2015 edition.

NFPA 110, *Standard for Emergency and Standby Power Systems,* 2016 edition.

NFPA 211, *Standard for Chimneys, Fireplaces, Vents, and Solid Fuel–Burning Appliances,* 2013 edition.

NFPA 259, *Standard Test Method for Potential Heat of Building Materials,* 2013 edition.

NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment,* 2013 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,* 2012 edition.

NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response,* 2012 edition.

NFPA 750, *Standard on Water Mist Fire Protection Systems,* 2015 edition.

NFPA 853, *Standard for the Installation of Stationary Fuel Cell Power Systems,* 2015 edition.

NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems,* 2015 edition.

2.3 Other Publications.

2.3.1 ANSI Publications. American National Standards Institute, Inc., 25 West 43rd Street, 4th Floor, New York, NY 10036.

ANSI A13.1, *Scheme for Identification of Piping Systems*, 2007.

ANSI C2, *National Electrical Safety Code*, 2012.

ANSI/CSA FC 1, *American National Standard for Fuel Cell Power Systems,* 2012.

ANSI/CSA FC 3, *American National Standard/CSA American Standard for Portable Fuel Cell Power Systems*, 2004.

ANSI Z535.2, *Environmental and Facility Safety Signs*, 2011.

ANSI Z535.3, *Criteria for Safety Symbols*, 2011.

ANSI Z535.4, *Product Safety Signs and Labels*, 2011.

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

ASME A13.1, *Scheme for the Identification of Piping Systems*, 2007.

ASME B31.3, *Process Piping*, 2012.

ASME B31.12, *Hydrogen Piping and Pipelines*, 2011.

ASME *Boiler and Pressure Vessel Code*, Section VIII, 2013.

ASME *International, Boiler and Pressure Vessel Code,* "Rules for the Construction of Unfired Pressure Vessels," Section VIII, 2013.

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

ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*, 2014.

ASTM E136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C*, 2012.

ASTM E1529, *Determining Effects of Large Hydrocarbon Pool Fire on Structural Members and Assemblies*, 2013.

ASTM E1591, *Standard Guide for Data for Fire Models*, 2013.

ASTM E2652, *Standard Test Method for Behavior of Materials in a Tube Furnace with a Cone-shaped Airflow Stabilizer, at 750°C*, 2012.

2.3.4 CGA Publications. Compressed Gas Association, 14501 George Carter Way, Suite 103, Chantilly, VA 20151-2923.

CGA C-7, *Guide to the Preparation of Precautionary Labeling and Marking of Compressed Gas Containers*, 2011.

CGA G-5.5, *Hydrogen Vent Systems*, 2014.

CGA P-1, *Safe Handling of Compressed Gases in Containers*, 2008.

CGA S-1.1, *Pressure Relief Device Standards — Part 1 — Cylinders for Compressed Gases*, 2011.

CGA S-1.2, *Pressure Relief Device Standards — Part 2 — Cargo and Portable Tanks for Compressed Gases*, 2009.

CGA S-1.3, *Pressure Relief Device Standards — Part 3 — Stationary Storage Containers for Compressed Gases*, 2008.

2.3.5* CTC Publications. Canadian Transport Commission, 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 ICC Publications. International Code Council, 500 New Jersey Avenue, NW, 6th Floor, Washington, DC 20001.

International Fire Code (IFC), 2015.

International Fuel Gas Code (IFGC), 2015.

2.3.7 SAE Publications. Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096, www.SAE.org.

SAE J2600, *Compressed Hydrogen Surface Refueling Connection Devices*, 2012.

2.3.8 UL Publications. Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096.

ANSI/UL 723, *Tests for Surface Burning Characteristics of Building Materials*, 2008.

2.3.9 U.S. Government Publications. U.S. Government Publishing Office, Washington, DC 20402.

Title 29, Code of Federal Regulations, Part 1910.1000.

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,* 2015 edition.

NFPA 13, *Standard for the Installation of Sprinkler Systems,* 2016 edition.

NFPA 30, *Flammable and Combustible Liquids Code,* 2015 edition.

NFPA 30A, *Code for Motor Fuel Dispensing Facilities and Repair Garages,* 2015 edition.

NFPA 45, *Standard on Fire Protection for Laboratories Using Chemicals,* 2015 edition.

NFPA 52, *Vehicular Natural Gas Fuel Systems Code,* 2013 edition.

NFPA 54, *National Fuel Gas Code,* 2015 edition.

NFPA 55, *Compressed Gases and Cryogenic Fluids Code,* 2016 edition.

NFPA 56, *Standard for Fire and Explosion Prevention During Cleaning and Purging of Flammable Gas Piping Systems,* 2014 edition.

NFPA 58, *Liquefied Petroleum Gas Code,* 2014 edition.

NFPA 70®, *National Electrical Code®*, 2014 edition.

NFPA 80, *Standard for Fire Doors and Other Opening Protectives,* 2016 edition.

NFPA 86, *Standard for Ovens and Furnaces,* 2015 edition.

NFPA 88A, *Standard for Parking Structures,* 2015 edition.

NFPA 91, *Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids,* 2015 edition.

NFPA *101®*, *Life Safety Code®*, 2015 edition.

NFPA 318, *Standard for the Protection of Semiconductor Fabrication Facilities,* 2015 edition.

NFPA 400, *Hazardous Materials Code,* 2016 edition.

NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids,* 2013 edition.

NFPA 801, *Standard for Fire Protection for Facilities Handling Radioactive Materials,* 2014 edition.

NFPA 820, *Standard for Fire Protection in Wastewater Treatment and Collection Facilities,* 2016 edition.

NFPA 853, *Standard for the Installation of Stationary Fuel Cell Power Systems,* 2015 edition.

NFPA 921, *Guide for Fire and Explosion Investigations,* 2014 edition.

NFPA 5000®, *Building Construction and Safety Code®*, 2015 edition.

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 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 Aboveground Storage Tank. See 3.3.228.4.1.

3.3.2 Aboveground Tank. See 3.3.228.1.

3.3.3 Absolute Pressure. See A.3.3.189.1.

3.3.4 Air.

3.3.4.1 *Auxiliary Air.* Supply or supplemental air delivered near the outside face of a chemical fume hood to reduce room air consumption. [**45,** 2015]

3.3.4.2 *Exhaust Air [Fuel Cell Power System].* Air removed from a space [-] and not reused. [**853,** 2015]

3.3.4.3 *Ventilation Air [Fuel Cell Power System].* The portion of supply air, the source of which is the outside/outdoors plus any recirculated air that has been treated and is acceptable for use [] that can be used for circulation, dilution, and/or primary air applications. [**853,** 2015]

3.3.5 Apparatus. Furniture, chemical fume hoods, centrifuges, refrigerators, and commercial or made-on-site equipment used in a laboratory. [**45,** 2015]

3.3.6 Area.

3.3.6.1 *Control Area.* A building or portion of a building or outdoor area, within which hazardous materials are allowed to be stored, dispensed, used, or handled, in quantities not exceeding the maximum allowable quantities (MAQ). [**400,** 2016]

3.3.6.2 *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 Section 6.6. *(See also 3.3.6.5, Outdoor Area.)* [**55,** 2016]

3.3.6.3 *Laboratory Work Area.* A room or space [regulated by Chapter 16 used] for testing, analysis, research, instruction, or similar activities that involve the use of chemicals. [**45,** 2015]

3.3.6.4 *Non-Laboratory Area.* Any space within a [laboratory] building not included in a laboratory unit. *(See also 3.3.13.2 and 3.3.235.1.)* [**45,** 2015]

3.3.6.5 *Outdoor Area.* An area that is not an indoor area. [**55,** 2016]

3.3.6.6* *Use Area.* A location inside or outside of a building or structure where the material placed into use is situated. [**55,** 2016]

3.3.7 ASME. American Society of Mechanical Engineers. [**58,** 2014]

3.3.8 ASTM. American Society for Testing and Materials. [**58,** 2014]

3.3.9 Automatic Emergency Shutoff Valve. See 3.3.241.1.1.

3.3.10 Automatic Fire Detection System. See 3.3.227.1.

3.3.11 Auxiliary Air. See 3.3.4.1.

3.3.12 Baffle. An object placed in an appliance to change the direction of or to retard the flow of air, air–gas mixtures, or flue gases. [**54,** 2015]

3.3.13 Building. Any structure used or intended for supporting or sheltering any use or occupancy. [***101,*** 2015]

3.3.13.1 *Detached Building.* A separate single-story building, without a basement or crawl space, used exclusively for the storage or use of hazardous materials and located an approved distance from other structures. [**55,** 2016]

3.3.13.2 *Laboratory Building.* A structure consisting wholly or principally of one or more laboratory units. *(See also 3.3.235.1)* [**45,** 2015]

3.3.14 Building Code. See 3.3.38.1.

3.3.15 Bulk Hydrogen Compressed Gas System. See 3.3.227.2.

3.3.16 Bulk Liquefied Hydrogen Gas System. See 3.3.227.3.

3.3.17 Bulk Oxygen System. See 3.3.227.4.

3.3.18 Burner. A device or group of devices used for the introduction of fuel, air, oxygen, or oxygen-enriched air into a furnace at the required velocities, turbulence, and concentration to maintain ignition and combustion of fuel. [**86,** 2015]

3.3.19 Burn-In. The procedure used in starting up a special atmosphere furnace to replace air within the heating chamber(s) and vestibule(s) with flammable special atmosphere. [**86,** 2015]

3.3.20 Burn-Out. The procedure used in shutting down or idling a special atmosphere to replace flammable atmosphere within the heating chamber(s) and vestibule(s) with nonflammable atmosphere. [**86,** 2015]

3.3.21 Bypass [Laboratory Hoods]. An airflow-compensating opening that maintains a relatively constant volume exhaust through a chemical fume hood regardless of sash position, serving to limit the maximum face velocity as the sash is lowered. [**45,** 2015]

3.3.22 Cabinet.

3.3.22.1* *Gas Cabinet.* A fully enclosed, noncombustible enclosure used to provide an isolated environment for compressed gas cylinders in storage or use. [**55,** 2016]

3.3.22.2 *Laminar Flow Cabinet.* A ventilated, partially enclosed cabinet primarily intended to provide filtered airflow over the work surface by use of laminar airflow methods. [**45,** 2015]

3.3.23 Canopy. A permanent structure or architectural projection of rigid construction over which a covering is attached that provides weather protection, identity, or decoration.

3.3.24 Canopy Hood. See 3.3.115.1.

3.3.25 Capacity [Vehicular Fuel Container]. The water volume of a container in gallons (liters). [**52,** 2013]

3.3.26 Cargo Transport Vehicle. A mobile unit designed to transport GH_2, or LH_2.

3.3.27 Cathodic Protection. See 3.3.194.1.

3.3.28 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. [**55,** 2016]

3.3.29 Ceiling Limit. See 3.3.138.1.

3.3.30 CFR. The Code of Federal Regulations of the United States Government. [**1,** 2015]

3.3.31 CGA. Compressed Gas Association. [**55,** 2016]

3.3.32* Chemical. A substance with one or more of the following hazard ratings as defined in NFPA 704: Health — 2, 3, or 4; Flammability — 2, 3, or 4; Instability — 2, 3, or 4. *(See also Section B.2.)*

3.3.33 Chemical Fume Hood. See 3.3.115.2.

3.3.34 Class 2 Unstable Reactive Gas. See 3.3.102.12.1.

3.3.35 Class 3 Unstable Reactive Gas. See 3.3.102.12.2.

3.3.36 Class 4 Unstable Reactive Gas. See 3.3.102.12.3.

3.3.37* Class C Furnace. An oven or furnace that has a potential hazard due to a flammable or other special atmosphere being used for treatment of material in process. [**86,** 2015]

3.3.38 Code.

3.3.38.1 ***Building Code.*** The building or construction code adopted by the jurisdiction. [**55,** 2016]

3.3.38.2 ***Fire Code.*** The fire prevention code adopted by the jurisdiction. [**55,** 2016]

3.3.38.3 ***Mechanical Code.*** The mechanical or mechanical construction code adopted by the jurisdiction. [**55,** 2016]

3.3.39 Combustible. Capable of undergoing combustion. [**853,** 2015]

3.3.39.1 ***Limited-Combustible Material.*** See 4.15.2.

3.3.40 Combustible Liquid. See 3.3.141.1.

3.3.41 Combustion Safeguard. A safety device or system that responds to the presence or absence of flame properties using one or more flame detectors and provides safe start-up, safe operation, and safe shutdown of a burner under normal and abnormal conditions. [**86,** 2015]

3.3.42 Compressed Gas. See 3.3.102.1.

3.3.43 Compressed Gas Container. See 3.3.47.1.

3.3.44 Compressed Gas System. See 3.3.227.5.

3.3.45 Compression Discharge Pressure. See 3.3.189.2.

3.3.46 Compressor. A mechanical device used to increase the pressure and the resultant density of a gas through the act of compression. [**55,** 2016]

3.3.47 Container. A vessel, such as a cylinder, portable tank, or stationary tank, that varies in shape, size, and material of construction. [**55,** 2016]

3.3.47.1 ***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. [**55,** 2016]

3.3.47.2 ***Fuel Supply Container.*** A container mounted on a vehicle to store LH_2, or GH_2 as the fuel supply to the vehicle.

3.3.48 Control.

3.3.48.1 ***Excess Flow Control.*** A fail-safe system or approved means designed to shut off flow due to a rupture in pressurized piping systems. [**55,** 2016]

3.3.48.2* ***Explosion Control.*** A means of [either] 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. [**55,** 2016]

3.3.48.3 ***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. [**55,** 2016]

3.3.49 Control Area. See 3.3.6.1.

3.3.50 Controller.

3.3.50.1 ***Excess Temperature Limit Controller.*** A device designed to cut off the source of heat if the operating temperature exceeds a predetermined temperature set point.

3.3.50.2 ***Temperature Controller.*** A device that measures the temperature and automatically controls the input of heat into the furnace. [**86,** 2015]

3.3.51 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. [**55,** 2016]

3.3.52 Corrosion Protection. See 3.3.194.2.

3.3.53 Corrosive Gas. See 3.3.102.2.

3.3.54 Court. An open, uncovered, unoccupied space, unobstructed to the sky, bounded on three or more sides by exterior building walls. [***101,*** 2015]

3.3.54.1 ***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,** 2015]

3.3.55 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). [**55,** 2016]

3.3.55.1 ***Flammable Cryogenic Fluid.*** A cryogenic fluid that forms flammable mixtures in air when in its vapor state. [**55,** 2016]

3.3.56 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. [**55,** 2016]

3.3.57* 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. [**55,** 2016]

3.3.58* Defueling. The controlled discharge of hydrogen from vehicle fuel storage tank systems according to the vehicle manufacturer's instructions, utilizing a nozzle or port supplied by the vehicle or test system manufacturer and equipment that has been listed and labeled, or approved for the intended use.

3.3.59 Detached Building. See 3.3.13.1.

3.3.60 Device.

3.3.60.1 ***Emergency Shutdown Device (ESD) [Vehicle Fueling].*** A device that closes all operations within the fueling facility from either local or remote locations. [**52,** 2013]

3.3.60.2 ***Pressure Relief Device.*** A device designed to open to prevent a rise of internal pressure in excess of a specified value. [**55,** 2016]

3.3.60.3 ***Safety Device [Furnaces].*** An instrument, a control, or other equipment that acts, or initiates action, to cause the furnace to revert to a safe condition in the event of equipment failure or other hazardous event. [**86,** 2015]

3.3.61* Distributed Integrated Controls (DIC). Systems or integrated controls used to monitor and control the functions of equipment, systems, or plants. [**853,** 2015]

3.3.62 Distributor. A business engaged in the sale or resale, or both, of compressed gases or cryogenic fluids, or both. [**55,** 2016]

3.3.63 DOT. U.S. Department of Transportation. [**52,** 2013]

3.3.64 Duct System. See 3.3.227.6.

3.3.65 Emergency Shutdown Device (ESD). See 3.3.60.1.

3.3.66 Emergency Shutoff Valve. See 3.3.241.1.

3.3.67 Enclosed Court. See 3.3.54.1.

3.3.68 Enclosed Parking Structure. See 3.3.178.1.

3.3.69 Engineered and Field-Constructed Fuel Cell Power System. See 3.3.227.7.

3.3.70 Evaluation.

3.3.70.1* ***Fire Risk Evaluation.*** A detailed engineering review of a plant's construction features and operating process conducted to ensure that applicable fire prevention and fire protection requirements for safeguarding life and physical property are met. [**853,** 2015]

3.3.71 Excess Flow Control. See 3.3.48.1.

3.3.72 Excess Temperature Limit Controller. See 3.3.50.1.

3.3.73 Exhaust Air. See 3.3.4.2.

3.3.74 Exhaust System. See 3.3.227.8.

3.3.75* 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. [**55,** 2016]

3.3.76 Exit Access. That portion of a means of egress that leads to an exit. [***101,*** 2015]

3.3.77 Explosion Control. See 3.3.48.2.

3.3.78 Face Velocity. The rate of flow or velocity of air moving into the chemical fume hood entrance or face, as measured at the plane of the chemical fume hood face. [**45,** 2015]

3.3.79 Facility.

3.3.79.1 ***Incidental Testing Facility.*** An area within a production facility set aside for the purpose of conducting in-process control tests that are related to the production process. [**45,** 2015]

3.3.79.2 ***Motor Fuel Dispensing Facility.*** That portion of a property where motor fuels are stored and dispensed from fixed equipment into the fuel tanks of motor vehicles or marine craft or into approved containers, including all equipment used in connection therewith. [**30A,** 2015]

3.3.79.2.1 ***Attended Self-Service Motor Fuel Dispensing Facility.*** A motor fuel dispensing facility that has an attendant or employee on duty whenever the facility is open for business. The attendant or employee on duty does not typically dispense motor fuels into fuel tanks or containers. The customer or vehicle operator usually conducts the dispensing. [**30A,** 2015]

3.3.79.2.2 ***Fleet Vehicle Motor Fuel Dispensing Facility.*** A motor fuel dispensing facility at a commercial, industrial, governmental, or manufacturing property where motor fuels are dispensed into the fuel tanks of motor vehicles that are used in connection with the business or operation of that property by persons within the employ of such business or operation. [**30A,** 2015]

3.3.79.2.3 ***Full-Service Motor Fuel Dispensing Facility.*** A motor fuel dispensing facility that has one or more attendants or supervisors on duty to dispense motor fuels into fuel tanks or containers whenever the facility is open for business. [**30A,** 2015]

3.3.79.2.4* ***Motor Fuel Dispensing Facility Located Inside a Building.*** That portion of a motor fuel dispensing facility located within the perimeter of a building or building structure that also contains other occupancies. [**30A,** 2015]

3.3.79.2.5 ***Unattended Self-Service Motor Fuel Dispensing Facility.*** A motor fuel dispensing facility that has no attendant or employee on duty. The customer or vehicle operator conducts the dispensing operation. This includes coin, currency, membership card, and credit card dispensing operations. [**30A,** 2015]

3.3.79.3 ***Residential GH_2 Fueling Facility (RFF-GH_2).*** An assembly with a capacity not exceeding 18 scf/min (0.5 scm/min) of GH_2 that generates and compresses hydrogen and that can be used for fueling a vehicle at a home or residence.

3.3.80* Fail-Safe. A design arrangement incorporating one or more features that automatically counteracts the effect of an anticipated source of failure or which includes a design arrangement that eliminates or mitigates a hazardous condition by compensating automatically for a failure or malfunction.

3.3.81 Fire Damper. A device, installed in an air-distribution system, that is designed to close automatically upon detection of heat to interrupt migratory airflow and to restrict the passage of flame. [**5000,** 2015]

3.3.82 Fire Prevention. Measures directed toward avoiding the inception of fire. [**801,** 2014]

3.3.83 Fire Protection. See 3.3.194.3.

3.3.84 Fire Risk Evaluation. See 3.3.70.1.

3.3.85 Flammable Cryogenic Fluid. See 3.3.55.1.

3.3.86 Flammable Gas. See 3.3.102.3.

3.3.87 Flammable Liquefied Gas. See 3.3.102.4.

3.3.88 Flammable Liquid. See 3.3.141.2.

3.3.89 Flammable Special Atmosphere. See 3.3.217.1.

3.3.90 Flash Point. The minimum temperature at which a liquid or a solid emits vapor sufficient to form an ignitable mixture with air near the surface of the liquid or the solid. [**853,** 2015]

3.3.91 Fleet Vehicle Motor Fuel Dispensing Facility. See 3.3.79.2.2.

3.3.92 Flow Switch. A switch that is activated by the flow of a fluid in a duct or piping system. [**86,** 2015]

3.3.93 Fuel Cell Cartridge. A removable article that contains and supplies fuel to the micro fuel cell power unit or internal reservoir.

3.3.94 Fuel Cell Power System. See 3.3.227.9.

3.3.95 Fuel Gas. See 3.3.102.5.

3.3.96 Fuel Line. The pipe, tubing, or hose on a vehicle, including all related fittings, through which [-] hydrogen passes. [**52,** 2013]

3.3.97 Fueling Nozzle. A mating device at the refueling station, including shutoff valves, that connects the fueling dispenser hose to the vehicle fuel filling system receptacle for the transfer of liquid or vapor. [**52,** 2013]

3.3.98 Fuel Supply Container. See 3.3.47.2.

3.3.99* Full Trycock. A valve connected to a line inserted into the inner tank of a cryogenic fluid tank and positioned such that liquid just begins to flow from the valve when opened.

3.3.100 Gallon, U.S. Standard. 1 U.S. gal = 0.833 Imperial gal = 231 in.^{3} = 3.785 L. [**58,** 2014]

3.3.101 Repair Garages.

3.3.101.1* ***Major Repair Garage.*** Hydrogen Fuel Cell Vehicle. A building or portions of a building for major repairs, such as work on the hydrogen storage system, the fuel cell system, the propulsion system, and repairs that require defueling of the hydrogen fuel cell vehicle, and maintenance or repairs that require open-flame cutting or welding.

3.3.101.2* ***Minor Repair Garage.*** Hydrogen Fuel Cell Vehicle. A building or portions of a building not used for work required to be performed in a major repair garage, such as lubrication, inspection, and minor automotive maintenance work, fluid changes (e.g., brake fluid, air conditioning refrigerants), brake system repairs, tire rotation, and similar routine maintenance work.

3.3.102 Gas.

3.3.102.1* ***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). [**55,** 2016]

3.3.102.2 ***Corrosive Gas.*** A gas that causes visible destruction of or irreversible alterations in living tissue by chemical action at the site of contact. [**55,** 2016]

3.3.102.3* ***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. [**55,** 2016]

3.3.102.4 ***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. [**55,** 2016]

3.3.102.5 ***Fuel Gas.*** A gas used as a fuel source, including natural gas, manufactured gas, sludge gas, liquefied petroleum gas–air mixtures, liquefied petroleum gas in the vapor phase, and mixtures of these gases. [**820,** 2016]

3.3.102.6* ***Inert Gas.*** A nonreactive, nonflammable, noncorrosive gas such as argon, helium, krypton, neon, nitrogen, and xenon. [**55,** 2016]

3.3.102.7 ***Nonflammable Gas.*** A gas that does not meet the definition of a flammable gas. [**55,** 2016]

3.3.102.8* ***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. [**55,** 2016]

3.3.102.9 ***Oxidizing Gas.*** A gas that can support and accelerate combustion of other materials more than air does. [**55,** 2016]

3.3.102.10 ***Pyrophoric Gas.*** A gas with an autoignition temperature in air at or below 130°F (54.4°C). [**55,** 2016]

3.3.102.11 ***Toxic Gas.*** A gas with a median lethal concentration (LC_{50}) 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. [**55,** 2016]

3.3.102.11.1 ***Highly Toxic Gas.*** A chemical that has a median lethal concentration (LC_{50}) 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. [**55,** 2016]

3.3.102.12* ***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. [**55,** 2016]

3.3.102.12.1 ***Class 2 Unstable Reactive Gas.*** Materials that readily undergo violent chemical change at elevated temperatures and pressures. [**55,** 2016]

3.3.102.12.2 ***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. [**55,** 2016]

3.3.102.12.3 ***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. [**55,** 2016]

3.3.103 Gas Analyzer. A device that measures concentrations, directly or indirectly, of some or all components in a gas or mixture. [**86,** 2015]

3.3.104 Gas Cabinet. See 3.3.22.1.

3.3.105 Gas Detection System. See 3.3.227.10.

3.3.106 Gas Manufacturer/Producer. A business that produces compressed gases or cryogenic fluids, or both, or fills portable or stationary gas containers, cylinders, or tanks. [**55,** 2016]

3.3.107 Gas Room. A separately ventilated, fully enclosed room in which only compressed gases, cryogenic fluids, associated equipment, and supplies are stored or used. [**55,** 2016]

3.3.108 Gaseous Hydrogen System. See 3.3.227.11.

3.3.109 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. [**55,** 2016]

3.3.110 GH_2. Hydrogen in the gas phase.

3.3.111* Handling. The deliberate movement of material in containers by any means to a point of storage or use. [**55,** 2016]

3.3.112* Hazard Rating. The numerical rating of the health, flammability, self-reactivity, and other hazards of the material, including its reaction with water. [**55,** 2016]

3.3.113 Hazardous Material (Chemical). See A.3.3.143.1.

3.3.114 Health Hazard Material. A chemical or substance classified as a toxic, highly toxic, or corrosive material in accordance with definitions set forth in this code. [**400,** 2016]

3.3.115 Hood.

3.3.115.1* ***Canopy Hood.*** A suspended ventilating device used only to exhaust heat, water vapor, odors, and other nonhazardous materials. [**45,** 2015]

3.3.115.2* ***Chemical Fume Hood.*** A ventilated enclosure designed to contain and exhaust fumes, gases, vapors, mists, and particulate matter generated within the hood interior. [**45,** 2015]

3.3.116 Hood Interior. The volume enclosed by the side, back, and top enclosure panels, the work surface, the access opening (called the face), the sash or sashes, and the exhaust plenum, including the baffle system for airflow distribution. [**45,** 2015]

3.3.117* Hydrogen Equipment Enclosure (HEE). A prefabricated area designed to protect hydrogen equipment that is confined by at least 3 walls, not routinely occupied, and has a total area less than 450 ft^2 (41.8 m^2).

3.3.118 Hydrogen Generation System. See 3.3.227.12.

3.3.119 Hydrogen Generator. A packaged or factory- matched hydrogen gas generation device that (1) uses electrochemical reactions to electrolyze water to produce hydrogen and oxygen gas (electrolyzer) or (2) converts hydrocarbon fuel to a hydrogen-rich stream of composition and conditions suitable for the type of device (e.g., fuel cells) using the hydrogen (reformer).

3.3.120 Incidental Testing Facility. See 3.3.79.1.

3.3.121 Indoor Area. See 3.3.6.2.

3.3.122* Indoor Installation. See 3.3.124.1.

3.3.123 Inert Gas. See 3.3.102.6.

3.3.124 Installation [Fuel Cell Power System]. The location where a fuel cell power system [other than a portable micro fuel cell power system] is sited as a unit or built as an assembly. [**853,** 2015]

3.3.124.1 ***Indoor Installation [Fuel Cell Power System].*** A fuel cell power system [other than a portable or micro fuel cell power system] completely surrounded and enclosed by walls, a roof, and a floor. [**853,** 2015]

3.3.124.2 ***Outside or Outdoor Installation [Fuel Cell Power System].*** A power system installation (other than a portable or micro fuel cell power system) that is not located inside a building or that has only partial weather protection (maximum coverage of a roof and up to 25 percent enclosing walls).

3.3.124.3 ***Portable Fuel Cell [Power System] Installation.*** A fuel cell [power system] generator [other than a micro fuel cell power system] of electricity that is not fixed in place. A portable appliance utilizes a cord and plug connection to a grid-isolated load and has an integral fuel supply. [**853,** 2015]

3.3.124.4 ***Rooftop Installation.*** A power system installation located on the roof of a building. [**853,** 2015]

3.3.125 Instructional Laboratory Unit. See 3.3.235.1.1.

3.3.126 Interactive System. See 3.3.227.15.

3.3.127 Interlock.

3.3.127.1 ***1400°F (760°C) Bypass Interlock.*** A device designed to permit specific permitted logic when the combustion chamber is proved to be above 1400°F (760°C). [**86,** 2015]

3.3.127.2 ***Excess Temperature Limit Interlock.*** A device designed to cut off the source of heat if the operating temperature exceeds a predetermined temperature set point. [**86,** 2015]

3.3.127.3 ***Safety Interlock.*** A device required to ensure safe startup and safe operation and to cause safe equipment shutdown. [**86,** 2015]

3.3.128* ISO Module. An assembly of tanks or tubular cylinders permanently mounted in a frame conforming to International Organization for Standardization (ISO) requirements. [**55,** 2016]

3.3.129 Laboratory. A laboratory is a facility regulated by Chapter 16 that provides controlled conditions in which scientific research, experiments, or measurements are performed.

3.3.130 Laboratory Building. See 3.3.13.2.

3.3.131 Laboratory Equipment. See 3.3.5, Apparatus.

3.3.132 Laboratory Unit. See 3.3.235.1.

3.3.133* Laboratory Work Area. See 3.3.6.3.

3.3.134 Laminar Flow Cabinet. See 3.3.22.2.

3.3.135 Lecture Bottle. A small compressed gas cylinder up to a size of approximately 2 in. × 13 in. (5 cm × 33 cm). [**45,** 2015]

3.3.136* LH_2. Hydrogen in the liquid phase.

3.3.137 LH_2 System. An assembly of equipment designed to contain, distribute, or transport LH_2.

3.3.138 Limit.

3.3.138.1* ***Ceiling Limit.*** The maximum concentration of an airborne contaminant to which one can be exposed. [**5000,** 2015]

3.3.138.2 ***Exposure Limit.***

3.3.138.2.1* ***Permissible Exposure Limit (PEL).*** The maximum permitted 8-hour, time-weighted average concentration of an airborne contaminant. [**55,** 2016]

3.3.138.2.2* ***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). [**55,** 2016]

3.3.138.3 ***Lower Flammability Limit (LFL).*** That concentration of a combustible material in air below which ignition will not occur. [**52,** 2013]

3.3.139 Limited Combustible. See 3.3.39.1.

3.3.140 Liquefied Hydrogen System. See 3.3.227.16.

3.3.141 Liquid.

3.3.141.1* ***Combustible Liquid.*** Any liquid that has a closed-cup flash point at or above 100°F (37.8°C), as determined by the test procedures and apparatus set forth in [NFPA 30.] Combustible liquids are classified according to Section 4.3 [of NFPA 30]. [**30,** 2015]

3.3.141.2* ***Flammable Liquid (Class I).*** Any liquid having a closed-cup flash point not exceeding 100°F (37.8°C). [**55,** 2016]

3.3.142 Lower Flammability Limit (LFL). See 3.3.138.3.

3.3.143 Material.

3.3.143.1* ***Hazardous Material.*** A chemical or substance that is classified as a physical hazard material or a health hazard material, whether the chemical or substance is in usable or waste condition. *(See also 3.3.114, Health Hazard Material, and 3.3.180, Physical Hazard Material).* [**400,** 2016]

3.3.143.2 ***Noncombustible Material.*** See 4.15.1.

3.3.144 Material Safety Data Sheet (MSDS). Written or printed material concerning a hazardous material that is prepared in accordance with the provisions of OSHA 29 CFR 1910.1200. [**1,** 2015]

3.3.145 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. [**55,** 2016]

3.3.146 Maximum Allowable Working Pressure (MAWP). See 3.3.189.3.

3.3.147* Maximum Operating Pressure. See 3.3.189.5.1.

3.3.148 Mechanical Code. See 3.3.38.3.

3.3.149 Mechanical Connection. A non-welded or brazed connection.

3.3.150 Mechanical Ventilation. See 3.3.245.2.

3.3.151 Metal Hydride. A generic name for compounds composed of metallic element(s) and hydrogen. [**55,** 2016]

3.3.152 Metal Hydride Storage System. See 3.3.227.17.

3.3.153 Metallic Hose. A hose whose strength depends primarily on the strength of its metallic parts; it can have metallic liners or covers, or both. [**52,** 2013]

3.3.154 Micro Fuel Cell. A fuel cell that is wearable or easily carried by hand providing a direct current output that does not exceed 60 VDC and power output that does not exceed 240 VA.

3.3.155* Mobile [Refueling]. The use of a DOT-approved vehicle or mobile equipment on site with tank(s) and/or pump(s) that dispenses engine fuel directly to vehicles, storage vessels/cylinders, or secondary refueling equipment. [**52,** 2013]

3.3.156 Mobile Supply Unit. See 3.3.235.2.

3.3.157 Motor Fuel Dispensing Facility. See 3.3.79.2.

3.3.158 Motor Fuel Dispensing Facility Located Inside a Building. See 3.3.79.2.4.

3.3.159 Natural Ventilation. See 3.3.245.3.

3.3.160 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). [**55,** 2016]

3.3.161* Nonbulk Hydrogen Compressed Gas. Gaseous hydrogen (GH_2) packaged in cylinders, containers, or tanks with a contained volume not exceeding 5000 scf (141.6 Nm^3) each at NTP that are either not interconnected by manifolds or piping systems or that when interconnected have an aggregate contained volume of less than 5000 scf (141.6 Nm^3).

3.3.162 Noncombustible. Not capable of igniting and burning when subjected to a fire. [**80,** 2016]

3.3.163 Noncombustible Material. See 3.3.143.2.

3.3.164 Nonflammable Gas. See 3.3.102.7.

3.3.165 Non-Laboratory Area. See 3.3.6.4.

3.3.166 Normal Cubic Meter (Nm^3) of Gas. A cubic meter of gas at an absolute pressure of 14.7 psi (101.3 kPa) and a temperature of 70°F (21°C). [**55,** 2016]

3.3.167 Normal Temperature and Pressure (NTP). See 3.3.189.4.

3.3.168 Open Parking Structure. See 3.3.178.2.

3.3.169 Operating Pressure. See 3.3.189.5.

3.3.170 Operator [Furnace]. An individual trained and responsible for the start-up, operation, shutdown, and emergency handling of the furnace and associated equipment. [**86,** 2015]

3.3.171 OSHA. The Occupational Safety and Health Administration of the U.S. Department of Labor. [**55,** 2016]

3.3.172 Other Gas. See 3.3.102.8.

3.3.173 Outdoor Area. See 3.3.6.5.

3.3.174 Outside or Outdoor Installation. See 3.3.124.2.

3.3.175 Oven. See 3.3.37, Class C Furnace.

3.3.176 Overpressure. See 3.3.189.6.

3.3.177 Oxidizing Gas. See 3.3.102.9.

3.3.178* Parking Structure. A building, structure, or portion thereof used for the parking, storage, or both, of motor vehicles. [**88A,** 2015]

3.3.178.1 ***Enclosed Parking Structure.*** Any parking structure that is not an open parking structure. [**88A,** 2015]

3.3.178.2 ***Open Parking Structure.*** A parking structure that meets the requirements of 17.3.3.1. [**88A,** 2015]

3.3.179 Permissible Exposure Limit (PEL). See 3.3.138.2.1.

3.3.180 Physical Hazard Material. A chemical or substance classified as a combustible liquid, explosive, flammable cryogen, flammable gas, flammable liquid, flammable solid, organic peroxide, oxidizer, oxidizing cryogen, pyrophoric, unstable (reactive), or water-reactive material. [**400,** 2016]

3.3.181 Pilot. A flame that is used to light the main burner. [**86,** 2015]

3.3.182 Pilot Plant. An experimental assembly of equipment for exploring process variables or for producing semicommercial quantities of materials. [**45,** 2015]

3.3.183 Piping System. See 3.3.227.20.

3.3.184 Point of Transfer. The location where connections and disconnections are made. [**52,** 2013]

3.3.185 Portable Fuel Cell [Power System] Installation. See 3.3.124.3.

3.3.186 Portable Tank. See 3.3.228.2.

3.3.187 Pre-Engineered and Matched Modular Components Fuel Cell Power System. See 3.3.227.21.

3.3.188 Prepackaged, Self-Contained Fuel Cell Power System. See 3.3.227.22.

3.3.189 Pressure.

3.3.189.1* ***Absolute Pressure.*** Pressure based on a zero reference point, the perfect vacuum. [**55,** 2016]

3.3.189.2 ***Compression Discharge Pressure.*** The varying pressure at the point of discharge from the compressor. [**52,** 2013]

3.3.189.3 ***Maximum Allowable Working Pressure (MAWP) [GH_2 Fueling Facilities].*** The maximum pressure to which any component or portion of the pressure system can be subjected over the entire range of design temperatures. This value is 1.1 × 1.25 × the service pressure. [**52,** 2013]

3.3.189.4* ***Normal Temperature and Pressure (NTP).*** A temperature of 70°F (21°C) at an absolute pressure of 14.7 psi (101.3 kPa). [**55,** 2016]

3.3.189.5 ***Operating Pressure.*** The varying pressure in a fuel supply container during normal container use. [**52,** 2013]

3.3.189.5.1 ***Maximum Operating Pressure [GH_2 Vehicular Fueling].*** The steady-state gauge pressure at which a part or system normally operates. This value is 1.25 × the pressure. [**52,** 2013]

3.3.189.6 ***Overpressure.*** The pressure in a blast wave above atmospheric pressure, or a pressure within a containment structure that exceeds the maximum allowable working pressure of the containment structure. [**52,** 2013]

3.3.189.7 ***Service Pressure.*** The settled gas pressure at a uniform gas temperature [-] 59°F (15°C) for GH_2 systems when the equipment is fully charged with gas. [**52,** 2013]

3.3.189.8 ***Set Pressure.*** The start-to-discharge pressure for which a relief valve is set and marked. [**52,** 2013]

3.3.189.9 ***Settled Pressure.*** The pressure in a container after the temperature of the gas reaches equilibrium. [**52,** 2013]

3.3.189.10 ***Storage Pressure.*** The varying pressure in the storage containers. [**52,** 2013]

3.3.190 Pressure Regulator. See 3.3.203.1.

3.3.191 Pressure Relief Device. See 3.3.60.2.

3.3.192 Pressure Relief Device Channels. The passage or passages beyond the operating parts of the pressure relief device through which fluid passes to reach the atmosphere. [**52,** 2013]

3.3.193 Pressure Vessel. A container or other component designed in accordance with the ASME *Boiler and Pressure Vessel Code* or the CSA B51, *Boiler, Pressure Vessel and Pressure Piping Code.* [**52,** 2013]

3.3.194 Protection.

3.3.194.1* ***Cathodic Protection.*** A technique to resist the corrosion of a metal surface by making the surface the cathode of an electrochemical cell. [**55,** 2016]

3.3.194.2 ***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. [**55,** 2016]

3.3.194.3 ***Fire Protection.*** Methods of providing for fire control or fire extinguishment. [**801,** 2014]

3.3.195* 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. [**55,** 2016]

3.3.196* Purge [Special Atmosphere Applications]. The replacement of a flammable, indeterminate, or high-oxygen-bearing atmosphere with another gas that, when complete, results in a nonflammable final state. [**86,** 2015]

3.3.197 Purging. A method used to free the internal volume of a piping system of unwanted contents that results in the existing contents being removed or replaced. [**55,** 2016]

3.3.198 Pyrophoric Gas. See 3.3.102.10.

3.3.199 Qualified Individual. An individual knowledgeable in the hazards of compressed gases and cryogenic fluids through training and work experience. [**55,** 2016]

3.3.200 Qualified Person. A person who, by possession of a recognized degree, certificate, professional standing, or skill, and who, by knowledge, training, and experience, has demonstrated the ability to deal with problems relating to a particular subject matter, work, or project. [**45,** 2015]

3.3.201 Ramp-Type Parking Structure. See 3.3.178.

3.3.202 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. [**55,** 2016]

3.3.203 Regulator.

3.3.203.1 ***Pressure Regulator.*** A device, either adjustable or nonadjustable, for controlling and maintaining, within acceptable limits, a uniform outlet pressure. [**52,** 2013]

3.3.204 Remotely Located, Manually Activated Shutdown Control. See 3.3.48.3.

3.3.205 Residential GH_2 Fueling Facility (RFF-GH_2). See 3.3.79.3.

3.3.206 Rooftop Installation. See 3.3.124.4.

3.3.207* Safety Device. See 3.3.60.3.

3.3.208 Safety Interlock. A device required to ensure safe startup and safe operation and to cause safe equipment shutdown. [**86,** 2015]

3.3.209 Safety Shutoff Valve. See 3.3.241.2.1.

3.3.210 Sash. A movable panel or panels set in the hood entrance. [**45,** 2015]

3.3.211* Self-Service Motor Fuel Dispensing Facility. A property where liquids or gases used as motor fuels are stored and dispensed from fixed, approved dispensing equipment into the fuel tanks of motor vehicles by persons other than the facility attendant.

3.3.212 Service Pressure. See 3.3.189.7.

3.3.213 Set Pressure. See 3.3.189.8.

3.3.214 Settled Pressure. See 3.3.189.9.

3.3.215 Short-Term Exposure Limit (STEL). See 3.3.138.2.2.

3.3.216 Source Valve. See 3.3.241.3.

3.3.217 Special Atmosphere. A prepared gas or a gas mixture that is introduced into the work chamber of a furnace to replace air, generally to protect or intentionally change the surface of the material undergoing heat processing (heat treatment). [**86,** 2015]

3.3.217.1 ***Flammable Special Atmosphere.*** A special atmosphere in which gases are known to be flammable and predictably ignitible where mixed with air. [**86,** 2015]

3.3.217.2 ***Synthetic Special Atmosphere.*** A special atmosphere such as those of anhydrous ammonia, hydrogen, nitrogen, or inert gases obtained from compressed gas cylinders or bulk storage tanks and those derived by chemical dissociation or mixing of hydrocarbon fluids, including mixtures of synthetic and generated atmospheres. [**86,** 2015]

3.3.218 Special Provisions. Controls required when the maximum allowable quantity in the control area is exceeded. [**55,** 2016]

3.3.219 Sprinkler System. See 3.3.227.23.

3.3.220 Standard Cubic Foot (scf) of Gas. An amount of gas that occupies one cubic foot at an absolute pressure of 14.7 psi (101 kPa) and a temperature of 70°F (21°C). [**55,** 2016]

3.3.221 Stationary. Permanently connected and fixed in place. [**853,** 2015]

3.3.222 Stationary Tank. See 3.3.228.3.

3.3.223 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. [**55,** 2016]

3.3.224 Storage Pressure. See 3.3.189.10.

3.3.225 Storage Tank. See 3.3.228.4.

3.3.226 Synthetic Special Atmosphere. See 3.3.217.2.

3.3.227 System.

3.3.227.1 ***Automatic Fire Detection System.*** A fire detection system that senses the presence of fire, smoke, or heat and activates a [fire suppression] system [and/]or an automatic alarm system. [**853,** 2015]

3.3.227.2* ***Bulk Hydrogen Compressed Gas System.*** A GH_2 system with a storage capacity of more than 5000 scf (141.6 Nm^3) of compressed hydrogen gas. [**55,** 2016]

3.3.227.3* ***Bulk Liquefied Hydrogen (LH_2) System.*** An LH_2 system with a storage capacity of more than 39.7 gal (150 L) of liquefied hydrogen. [**55,** 2016]

3.3.227.4* ***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 scf (566 Nm^3) of oxygen, and that terminates at the source valve. [**55,** 2016]

3.3.227.5 ***Compressed Gas System.*** An assembly of equipment designed to contain, distribute, or transport compressed gases. [**318,** 2015]

3.3.227.6 ***Duct System.*** A continuous passageway for the transmission of air that, in addition to ducts, includes duct fittings, dampers, fans, and accessory air-managing equipment and appliances. [**853,** 2015]

3.3.227.7* ***Engineered and Field-Constructed Fuel Cell Power System.*** A fuel cell power system that is not preassembled or does not have factory-matched components. [**853,** 2015]

3.3.227.8 ***Exhaust System.*** An air-conveying system for moving materials from a source to a point of discharge. [**91,** 2015]

3.3.227.9* ***Fuel Cell Power System.*** A generator system that converts the chemical energy of reactants (a fuel and oxidant) by an electrochemical process to electric energy (direct current or alternating current electricity) and thermal energy. [**853,** 2015]

3.3.227.10 ***Gas Detection System.*** One or more sensors capable of detecting [hydrogen] at specified concentrations and activating alarms and safety systems. [**52,** 2013]

3.3.227.11* ***Gaseous Hydrogen (GH_2) System.*** An assembly of equipment that consists of, but is not limited to, storage containers, pressure regulators, pressure relief devices, compressors, manifolds, and piping and that terminates at the source valve. [**55,** 2016]

3.3.227.12 ***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. [**55,** 2016]

3.3.227.13 ***Hydrogen Storage System.*** That portion of a closed system used for retention of hydrogen gas or liquid upstream of the source valve.

3.3.227.14 ***Hydrogen Use System.*** Placing hydrogen into action through the use of piping, pressure or control systems downstream of the source valve.

3.3.227.15 ***Interactive System.*** A fuel cell [power] system that operates in parallel with and may deliver power to an electrical production and distribution network. For the purpose of this definition, an energy storage subsystem of a fuel cell [power] system, such as a battery, is not another electrical production source. [**70:**692.2]

3.3.227.16* ***Liquefied Hydrogen (LH_2) 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 and that terminates at the source valve. [**55,** 2016]

3.3.227.17 ***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. [**55,** 2016]

3.3.227.18 ***Micro Fuel Cell Power System.*** A micro fuel cell power unit and associated fuel cartridges that is wearable or that is easily carried by hand.

3.3.227.19* ***Non-Bulk Flammable Gas System.*** A system consisting of cylinders or other storage systems, with each individual cylinder and each individual set of connected cylinders having less than 5000 scf (141.6 Nm^3). [**55,** 2016]

3.3.227.20* ***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. [**55,** 2016]

3.3.227.21* ***Pre-Engineered and Matched Modular Components Fuel Cell Power System.*** A fuel cell power system that has components that are assembled in a factory in separate modules, such as the fuel cell [power system] stack, reformer, and inverter. [**853,** 2015]

3.3.227.22 ***Prepackaged, Self-Contained Fuel Cell Power System.*** A fuel cell power system that is designed as one unit, assembled in a factory, and shipped to site. [**853,** 2015]

3.3.227.23 ***Sprinkler System.*** A system that consists of an integrated network of piping designed in accordance with fire protection engineering standards that includes a water supply source, a water control valve, a waterflow alarm, and a drain. The portion of the sprinkler system above ground is a network of specially sized or hydraulically designed piping installed in a building, structure, or area, generally overhead, and to which sprinklers are attached in a systematic pattern. The system is commonly activated by heat from a fire and discharges water over the fire area. [**13,** 2016]

3.3.227.24 ***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. [**55,** 2016]

3.3.228 Tank (flammable or combustible liquid).

3.3.228.1 ***Aboveground Tank.*** A storage tank that is installed above grade, at grade, or below grade without backfill. [**30,** 2015]

3.3.228.2 ***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. [**55,** 2016]

3.3.228.3* ***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. [**55,** 2016]

3.3.228.4 ***Storage Tank.*** Any vessel having a liquid capacity that exceeds 60 gal (230 L), is intended for fixed installation, and is not used for processing. [**30,** 2015]

3.3.228.4.1 ***Aboveground Storage Tank [Flammable or Combustible Liquids].*** A horizontal or vertical tank that is listed and intended for fixed installation, without backfill, above or below grade and is used within the scope of its approval or listing. [**30A,** 2015]

3.3.229 Temperature Controller. See 3.3.50.2.

3.3.230* Thermal Spraying. A coating process in which melted (or heated) materials are sprayed onto a surface. The "feedstock" (coating precursor) is heated by electrical (plasma or arc) or chemical means (combustion flame).

3.3.231 Toxic Gas. See 3.3.102.11.

3.3.232 Transport Canada (TC). [**55,** 2016]

3.3.233 Treatment System. See 3.3.227.24.

3.3.234* 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. [**55,** 2016]

3.3.235 Unit.

3.3.235.1* ***Laboratory Unit.*** An enclosed space [within a laboratory building] used for experiments or tests. [**45,** 2015]

3.3.235.1.1 ***Instructional Laboratory Unit.*** A laboratory unit under the direct supervision of an instructor that is used for the purposes of instruction for students beyond the twelfth grade. [**45,** 2015]

3.3.235.2* ***Mobile Supply Unit.*** Any supply source that is equipped with wheels so it is able to be moved around. [**55,** 2016]

3.3.236 Unpierced Wall. A wall that is allowed to have pipes or conduits passing through it, or unopenable windows, glazed with safety glass or wired glass, set in it, but such openings are sealed to prevent the flow of air between adjacent rooms. [**55,** 2016]

3.3.237 Unstable Reactive Gas. See 3.3.102.12.

3.3.238 Use. To place a material into action, including solids, liquids, and gases. [**55,** 2016]

3.3.239* Vacuum Jacket. A term used to describe the construction of double walled pressure vessel consisting of an inner and outer vessel which has been constructed in a manner similar to a thermos bottle where the atmosphere between the inner and outer vessels has been removed by mechanical means.

3.3.240 Vacuum Pump. A compressor for exhausting air and noncondensable gases from a space that is to be maintained at subatmospheric pressure. [**86,** 2015]

3.3.241 Valve.

3.3.241.1 ***Emergency Shutoff Valve.*** A designated valve designed to shut off the flow of gases or liquids. [**55,** 2016]

3.3.241.1.1 ***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. [**55,** 2016]

3.3.241.2 ***Shutoff Valve.***

3.3.241.2.1* ***Safety Shutoff Valve.*** A normally closed valve installed in the piping that closes automatically to shut off the fuel, atmosphere gas, or oxygen in the event of abnormal conditions or during shutdown. [**86,** 2015]

3.3.241.3* ***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. [**55,** 2016]

3.3.242* Vaporizer. A heat exchanger that transfers heat from an outside source to a liquid, typically a cryogenic fluid contained within a closed piping system, in order to transform the fluid from its liquid phase to the gaseous phase.

3.3.243 Vehicle. A device or structure for transporting persons or things; a conveyance (e.g., automobiles, trucks, marine vessels, railroad trains). [**52,** 2013]

3.3.244 Vehicle Fueling Appliance (VFA). A listed, self-contained system that compresses natural gas or that generates and compresses hydrogen and dispenses [-] to a vehicle's engine fueling system. [**52,** 2013]

3.3.245 Ventilation.

3.3.245.1 ***Fixed Natural Ventilation.*** The movement of air into and out of a space through permanent openings that are arranged in such a way that the required ventilation cannot be reduced by operating windows, doors, louvers, or similar devices. [**55,** 2016]

3.3.245.2 ***Mechanical Ventilation.*** The flow of air or gas created by a fan, blower, or other mechanical means that will push or induce the gas stream through a ventilation system. [**853,** 2015]

3.3.245.3 ***Natural Ventilation.*** The flow of air or gases created by the difference in the pressures or gas densities between the outside and inside of a vent, room, or space. [**853,** 2015]

3.3.246 Ventilation Air. See 3.3.4.3.

3.4 Definitions for Performance-Based Designs.

3.4.1 Alternative Calculation Procedure. A calculation procedure that differs from the procedure originally employed by the design team but that provides predictions for the same variables of interest. [***101,*** 2015]

3.4.2 Analysis.

3.4.2.1 ***Sensitivity Analysis.*** An analysis performed to determine the degree to which a predicted output will vary given a specified change in an input parameter, usually in relation to models. [**5000,** 2015]

3.4.2.2 ***Uncertainty Analysis.*** An analysis performed to determine the degree to which a predicted value will vary. [**5000,** 2015]

3.4.3 Data Conversion. The process of developing the input data set for the assessment method of choice. [***101,*** 2015]

3.4.4 Design Fire Scenario. See 3.4.9.1.

3.4.5 Design Specification. See 3.4.20.1.

3.4.6 Design Team. A group of stakeholders including, but not limited to, representatives of the architect, client, and any pertinent engineers and other designers. [***101,*** 2015]

3.4.7* Exposure Fire. A fire that starts at a location that is remote from the area being protected and grows to expose that which is being protected. [***101,*** 2015]

3.4.8* Fire Model. A structured approach to predicting one or more effects of a fire. [***101,*** 2015]

3.4.9* Fire Scenario. A set of conditions that defines the development of fire, the spread of combustion products throughout a building or portion of a building, the reactions of people to fire, and the effects of combustion products. [***101*** 2015]

3.4.9.1 ***Design Fire Scenario.*** A fire scenario selected for evaluation of a proposed design. [***101,*** 2015]

3.4.10 Fuel Load. The total quantity of combustible contents of a building, space, or fire area, including interior finish and trim, expressed in heat units or the equivalent weight in wood. [**921,** 2014]

3.4.11 Incapacitation. A condition under which humans do not function adequately and become unable to escape untenable conditions. [***101,*** 2015]

3.4.12 Input Data Specification. See 3.4.20.2.

3.4.13 Occupant Characteristics. The abilities or behaviors of people before and during a fire. [***101,*** 2015]

3.4.14* Performance Criteria. Threshold values on measurement scales that are based on quantified performance objectives. [***101,*** 2015]

3.4.15* Proposed Design. A design developed by a design team and submitted to the authority having jurisdiction for approval. [***101,*** 2015]

3.4.16 Safe Location. A location remote or separated from the effects of a fire so that such effects no longer pose a threat. [***101,*** 2015]

3.4.17 Safety Factor. A factor applied to a predicted value to ensure that a sufficient safety margin is maintained. [***101,*** 2015]

3.4.18 Safety Margin. The difference between a predicted value and the actual value where a fault condition is expected. [***101,*** 2015]

3.4.19 Sensitivity Analysis. See 3.4.2.1.

3.4.20 Specification.

3.4.20.1* ***Design Specification.*** A building characteristic and other conditions that are under the control of the design team. [**5000,** 2015]

3.4.20.2 ***Input Data Specification.*** Information required by the verification method. [***101,*** 2015]

3.4.21 Stakeholder. An individual, or representative of same, having an interest in the successful completion of a project. [***101,*** 2015]

3.4.22 Uncertainty Analysis. See 3.4.2.2.

3.4.23 Verification Method. A procedure or process used to demonstrate or confirm that the proposed design meets the specified criteria. [***101,*** 2015]

Chapter 4 General Fire Safety Requirements

4.1 Application. Sections 4.1 and 4.2 shall establish the minimum goals and objectives commensurate with public safety to be considered in the application of this code.

4.1.1 For applications where buildings or structures are to be provided, this code and the building code adopted by the jurisdiction shall be used to regulate matters of construction, including requirements for life safety in the building or structure in which hydrogen is stored, handled, or used.

4.1.2* For applications in facilities located outdoors, the proximity of hydrogen storage systems and systems that use or produce hydrogen shall be regulated by this code in addition to the requirements of building or local zoning regulations that address matters of location, quantity restrictions, or matters that are the subject of local, state, or federal regulations.

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

4.1.4 Subsection 4.4.1 shall be the default design option applicable to facilities when hydrogen is stored, handled, used, or produced.

4.1.4.1 The use of 4.4.2 shall be permitted at the option of the permittee with the approval of the authority having jurisdiction.

4.1.4.2 Performance-based designs shall be in accordance with the requirements of Chapter 5.

4.2* Goals and Objectives. *(Also see Section 4.3.)*

4.2.1* Goals. The goals of this code shall be to provide a reasonable level of safety, property protection, and public welfare from the hazards created by fire, explosion, and other hazardous conditions. [**1:**4.1.1]

4.2.2* Objectives. To achieve the goals stated in 4.2.1, the goals and objectives of 4.2.3 through 4.2.5 shall be used to determine the intent of this code. [**1:**4.1.2]

4.2.3* Safety. This code shall provide for life safety by reducing the probability of injury or death from fire, explosions, or events involving [GH_2 or LH_2]. [**1:**4.1.3]

4.2.3.1 Safety from Fire.

4.2.3.1.1* Safety-from-Fire Goals. The fire safety goals of this code shall be as follows:

(1) To provide an environment for the occupants in a building or facility and for the public near a building or facility that is reasonably safe from fire and similar emergencies
(2) To protect fire fighters and emergency responders [**1:**4.1.3.1.1]

4.2.3.1.2 Safety-from-Fire Objectives.

4.2.3.1.2.1 Buildings and facilities shall be designed, constructed, and maintained to protect occupants who are not intimate with the initial fire development for the amount of time needed to evacuate, relocate, or defend in place. [**1:**4.1.3.1.2.1]

4.2.3.1.2.2* Buildings shall be designed and constructed to provide reasonable safety for fire fighters and emergency responders during search and rescue operations. [**1:**4.1.3.1.2.2]

4.2.3.1.2.3 Buildings shall be designed, located, and constructed to reasonably protect adjacent persons from injury or death as a result of a fire. [**1:**4.1.3.1.2.3]

4.2.3.1.2.4 Buildings shall be designed, located, and constructed to provide reasonable access to the building for emergency responders. [**1:**4.1.3.1.2.4]

4.2.3.1.2.5* Operations shall be conducted at facilities in a safe manner that minimizes, reduces, controls, or mitigates the risk of fire injury or death for the operators, while protecting the occupants not intimate with initial fire development for the amount of time needed to evacuate, relocate, or defend in place. [**1:**4.1.3.1.2.5]

4.2.3.2 Safety During Building Use.

4.2.3.2.1* Safety-During-Building-Use Goal. The safety-during-building-use goal of this code shall be to provide an environment for the occupants of the building that is reasonably safe during the normal use of the building. [**1:**4.1.3.2.1]

4.2.3.2.2 Safety-During-Building-Use Objectives. Performance-based building design shall be in accordance with the requirements of the adopted building code.

4.2.3.3* Safety from Hydrogen Hazards.

4.2.3.3.1 Safety-from-Hydrogen Hazards Goal. The safety-from- [hydrogen hazards] goal of this code shall be to provide an environment for the occupants in a building or facility and to those adjacent to a building or facility that is reasonably safe from exposures to adverse affects from [hydrogen hazards] present therein. [**1:**4.1.3.3.1]

4.2.3.3.2 Safety-from-Hydrogen Hazards Objectives.

4.2.3.3.2.1 The storage, use, or handling of [hydrogen] in a building or facility shall be accomplished in a manner that provides a reasonable level of safety for occupants and for those adjacent to a building or facility from health hazards, illness, injury, or death during normal storage, use, or handling operations and conditions. [**1:**4.1.3.3.2.1]

4.2.3.3.2.2* The storage, use, or handling of [hydrogen] in a building or facility shall be accomplished in a manner that provides a reasonable level of safety for occupants and for those adjacent to a building or facility from illness, injury, or death due to the following conditions:

(1) An unplanned release of [hydrogen]
(2) A fire impinging upon the [hydrogen piping or containment system] or the involvement of [hydrogen] in a fire
(3) The application of an external force on the [hydrogen piping or containment system] that is likely to result in an unsafe condition

[**1:**4.1.3.3.2.2]

4.2.4 Property Protection.

4.2.4.1 Property Protection Goal. The property protection goal of this code shall be to limit damage created by a fire, explosion, or event associated with [GH_2 or LH_2] to a reasonable level to the building or facility and adjacent property. [**1:**4.1.4.1]

4.2.4.2 Property Protection Objectives.

4.2.4.2.1* Prevention of Ignition. The facility shall be designed, constructed, and maintained, and operations associated with the facility shall be conducted, to prevent unintentional explosions and fires that result in failure of or damage to adjacent compartments, emergency life safety systems, adjacent properties, adjacent outside storage, and the facility's structural elements. [**1:**4.1.4.2.1]

4.2.4.2.2* Fire Spread and Explosions. In the event that a fire or explosion occurs, the building or facility shall be sited, designed, constructed, or maintained, and operations associated with the facility shall be conducted and protected, to reasonably reduce the impact of unwanted fires and explosions on the adjacent compartments, emergency life safety systems, adjacent properties, adjacent outside storage, and the facility's structural elements. [**1:**4.1.4.2.2]

4.2.4.2.3 Structural Integrity. The facility shall be designed, constructed, protected, and maintained, and operations associated with the facility shall be conducted, to provide a reasonable level of protection for the facility, its contents, and adjacent properties from building collapse due to a loss of structural integrity resulting from a fire. [**1:**4.1.4.2.3]

4.2.4.2.4 Hydrogen Hazards. The facility shall be designed, constructed, and maintained, and operations associated with the facility shall be conducted, to provide reasonable property protection from damage resulting from fires, explosions, and other unsafe conditions associated with the storage, use, and handling of [hydrogen] therein. [**1:**4.1.4.2.4]

4.2.5 Public Welfare.

4.2.5.1* Public Welfare Goal. The public welfare goal of this code shall be to maintain a high probability that buildings and facilities that provide a public welfare role for a community continue to perform the function for their intended purpose following a fire, explosion, or hazardous materials event. [**1:**4.1.5.1]

4.2.5.2* Public Welfare Objective. Buildings and facilities that provide a public welfare role for a community shall be designed, constructed, maintained, and operated to provide reasonable assurance of continued function following fire, explosion or hazardous materials event. [**1:**4.1.5.2]

4.3 Assumptions.

4.3.1* Single Fire Source.

4.3.1.1 The fire protection methods of this code shall assume multiple simultaneous fire incidents will not occur. [**1:**4.2.1.1]

4.3.1.2 The single fire source assumption shall not preclude the evaluation of multiple design fire scenarios as required by Section 5.4. [**1:**4.2.1.2]

4.3.2* Single Hazardous Material Release.

4.3.2.1 The protection methods of this code shall assume that multiple simultaneous unauthorized releases of hazardous materials from different locations will not occur. [**1:**4.2.2.1]

4.3.2.2 The single hazardous material release assumption shall not preclude the evaluation of multiple design scenarios as required by Section 5.4. [**1:**4.2.2.2]

4.3.3* Incidents Impinging on Hazardous Materials. The protection methods of this code shall assume that a fire, explosion, hazardous materials release, or external force that creates a dangerous condition has the potential to impinge on hazardous materials being stored, handled, or used in the building or facility under normal conditions. *(See Section 5.4 for performance-based design scenarios.)* [**1:**4.2.3]

4.4 Compliance Options. Compliance with the goals and objectives of Section 4.2 shall be provided in accordance with either of the following: [**1:**4.3]

(1) The prescriptive-based provisions per 4.4.1 [**1:**4.3]
(2) The performance-based provisions per 4.4.2 [**1:**4.3]

4.4.1 Prescriptive-Based Option.

4.4.1.1 A prescriptive-based option shall be in accordance with Chapters 1 through 4 and Chapters 6 through 18 of this code as applicable.

4.4.2 Performance-Based Option.

4.4.2.1 A performance-based option shall be in accordance with Chapter 1 through Chapter 5 of this code. [**1:**4.3.2.1]

4.4.2.2 Prescriptive requirements shall be permitted to be used as part of the performance approach, if they, in conjunction with the performance features, meet the overall goals and objectives of this code. [**1:**4.3.2.2]

4.5 Permits. Permits shall be obtained in accordance with the requirements of the jurisdiction in which the facility operates. [**55:**4.1]

4.6 Emergency Plan.

4.6.1 An emergency plan shall be prepared and updated wherever [GH_2 or LH_2] 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). [**55:**4.2.1.1]

4.6.2 The plan shall be available for inspection by the AHJ 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 GH_2 or LH_2 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 GH_2 and LH_2 stored or used
   (c) Accessing MSDSs
   (d) Knowing the site emergency procedures
(7) A list of the types and quantities of GH_2 and LH_2 found within the facility

4.7 Facility Closure.

4.7.1 Where required by the AHJ, no facility storing hazardous materials listed in 1.1.1 of NFPA 400 shall close or abandon an entire storage facility without notifying the AHJ at least 30 days prior to the scheduled closing. [**400:**1.9.1]

4.7.2 The AHJ shall be permitted to reduce the 30-day period specified in 4.7.1 where there are special circumstances requiring such reduction. [**400:**1.9.2]

4.7.3 Facilities Out of Service.

4.7.3.1 Temporarily Out-of-Service Facilities. Facilities that are temporarily out of service shall continue to maintain a permit and be monitored and inspected. [**400:**1.9.3.1]

4.7.3.2 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 4.7.4. [**400:**1.9.3.2]

4.7.4 Closure Plan.

4.7.4.1 Where required by the AHJ, the permit holder or applicant shall submit a plan to the fire department to terminate storage, dispensing, handling, or use of [GH_2 or LH_2] at least 30 days prior to facility closure. [**400:**1.9.4.1]

4.7.4.2 The plan shall demonstrate that [GH_2 or LH_2] that was stored, dispensed, handled, or used in the facility has been transported, disposed of, or reused in a manner that eliminates the need for further maintenance and any threat to public health and safety. [**400:**1.9.4.2]

4.7.4.3 The plan shall be submitted with a permit application for facility closure in accordance with Section 4.5. [**55:**4.3.3.3]

4.8* 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 a serviceable condition.
(4) Security shall be maintained in accordance with 7.1.7. [**55:**4.4]

4.9 Management Plan and Hazardous Materials Documentation.

4.9.1 Hazardous Materials Management Plan. Where required by the AHJ, a hazardous materials management plan (HMMP) shall be submitted to the AHJ. [**55:**4.5.1]

4.9.1.1 The HMMP shall comply with the requirements of the [adopted] fire code [**55:**4.5.1.1]

4.9.2 Hazardous Materials Inventory Statement. When required by the AHJ, a hazardous materials inventory statement (HMIS) [addressing the GH_2 or LH_2 present] shall be completed and submitted to the AHJ. [**400:**1.12.1]

4.9.3 Safety Data Sheets. Safety data sheets (SDS) shall be readily available on the premises for [GH_2 or LH_2]. When approved, SDSs shall be permitted to be retrievable by electronic access. [**400:**6.1.2]

4.10 Release of GH_2 or LH_2.

4.10.1* Prohibited Releases. [GH_2 or LH_2] shall not be released into a sewer, storm drain, ditch, drainage canal, lake, river, or tidal waterway; upon the ground, sidewalk, street, or highway unless such release is permitted by the following: [**400:**6.1.3.1]

(1) Federal, state, or local governing regulations [**400:**6.1.3.1(1)]
(2) Permits of the jurisdictional air quality management board [**400:**6.1.3.1(2)]
(3) National Pollutant Discharge Elimination System Permit [**400:**6.1.3.1(3)]
(4) Waste discharge requirements established by the jurisdictional water quality control board [**400:**6.1.3.1(4)]
(5) Sewer pretreatment requirements for publicly owned treatment works [**400:**6.1.3.1(5)]
(6) Pressure relief devices and vents designed as part of a system

4.10.2 Control and Mitigation of Unauthorized Releases. Provisions shall be made for controlling and mitigating unauthorized releases. [**400:**6.1.3.2]

4.10.3* Records of Unauthorized Releases. Accurate records of the unauthorized releases of [GH_2 or LH_2] shall be kept by the permittee. [**400:**6.1.3.3]

4.10.4 Notification of Unauthorized Releases. The fire department shall be notified immediately or in accordance with approved emergency procedures when an unauthorized release becomes reportable under state, federal, or local regulations. [**400:**6.1.3.4]

4.10.5 Container Failure. When an unauthorized release due to primary container failure is discovered, the involved primary container shall be repaired or removed from service. [**400:**6.1.3.5]

4.10.6 Responsibility for Cleanup of Unauthorized Releases.

4.10.6.1 The person, firm, or corporation responsible for an unauthorized release shall institute and complete all actions necessary to remedy the effects of such unauthorized release, whether sudden or gradual, at no cost to the AHJ. [**400:**6.1.3.7.1]

4.10.6.2 When deemed necessary by the AHJ, cleanup of an unauthorized release 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 release. [**400:**6.1.3.7.2]

4.11* Personnel Training. Persons in areas where [GH_2 or LH_2] are stored, dispensed, handled, or used shall be trained in the hazards of the materials employed and actions required by the emergency plan. The level of training to be conducted shall be consistent with the responsibilities of the persons to be trained in accordance with 4.11.1 through 4.11.4. [**400:**6.1.4]

4.11.1 Awareness. The training provided for persons designated in Section 4.11 shall include awareness training in accordance with 4.11.1 through 4.11.3. [**400:**6.1.4.1]

4.11.1.1 Completion. Initial training shall be completed prior to beginning work in the work area. [**400:**6.1.4.1.1]

4.11.1.2 Hazard Communications. Training shall be provided prior to beginning work in the work area to enable personnel to recognize and identify [GH_2 or LH_2] stored, dispensed, handled, or used on site and where to find hazard safety information pertaining to the materials employed. [**400:**6.1.4.1.2]

4.11.1.3 Emergency Plan. Training shall be provided prior to beginning work in the work area to enable personnel to implement the emergency plan. [**400:**6.1.4.1.3]

4.11.2 Operations Personnel. Persons engaged in storing, using, or handling [GH_2 or LH_2] shall be designated as operations personnel and shall be trained in accordance with 4.11.1 and 4.11.2.1 through 4.11.3.2. [**400:**6.1.4.2]

4.11.2.1 Physical and Health Hazard Properties. Operations personnel shall be trained in the chemical nature of the materials, including their physical hazards and the symptoms of acute or chronic exposure as provided by the Safety Data Sheet (SDS) furnished by the manufacturer or other authoritative sources. [**400:**6.1.4.2.1]

4.11.2.2 Dispensing, Using, and Processing. Operations personnel shall be trained in the specific safeguards applicable to the dispensing, processing, or use of the materials and the equipment employed. [**400:**6.1.4.2.2]

4.11.2.3 Storage. Operations personnel shall be trained in the application of storage arrangements and site-specific limitations on storage for the materials employed. [**400:**6.1.4.2.3]

4.11.2.4 Transport (Handling). Operations personnel involved in materials handling shall be trained in the requirements for on-site transport of the materials employed. [**400:**6.1.4.2.4]

4.11.2.5 Actions in an Emergency. Operations personnel shall be trained in the necessary actions to take in the event of an emergency, including the operation and activation of emergency controls prior to evacuations. [**400:**6.1.4.2.5]

4.11.2.6 Changes. Training shall be provided whenever a new hazardous material is introduced into the work area that presents a new physical or health hazard, or when new information is obtained pertaining to physical or health hazards of an existing hazardous material that has not been included in previous training, and when there are changes in one of the following:

(1) Equipment
(2) Operations
(3) Hazardous Materials

[**400:**6.1.4.2.6]

4.11.3 Emergency Response Liaison. [400:6.1.4.3]

4.11.3.1 Responsible persons shall be designated and trained to be emergency response (ER) liaison personnel. [**400:**6.1.4.3.1]

4.11.3.2 Emergency response liaison personnel shall do the following:

(1) Aid emergency responders in pre-planning responses to emergencies
(2) Identify locations where [GH_2 or LH_2] are located
(3) Have access to material safety data sheets
(4) Be knowledgeable in the site emergency response procedures

[**400:**6.1.4.3.2]

4.11.4* Emergency Responders. Emergency responders shall be trained to be competent in the actions to be taken in an emergency event. [**400:**6.1.4.4]

4.11.4.1* Emergency Response Team Leader. Persons acting as ER team leaders shall be trained under the Incident Command System concept or equivalent. [**400:**6.1.4.4.1]

4.11.4.2* Response to Incipient Events. Responses to incidental releases of [GH_2 or LH_2] where the material can be absorbed, neutralized, or otherwise controlled at the time of release by employees in the immediate release area, or by maintenance personnel, shall not be considered emergency responses as defined with the scope of this code. [**400:**6.1.4.4.2]

4.11.4.3* On-Site Emergency Response Team. When an on-site emergency response team is provided, emergency responders shall be trained in accordance with the requirements of the specific site emergency plan or as required by federal, state, or local governmental agencies. [**400:**6.1.4.4.3]

4.11.4.4 Training Mandated by Other Agencies. Training required by federal, state, or local regulations that is required based on the quantity or type of [GH_2 or LH_2] stored, dispensed, handled, or used shall be conducted in accordance with the requirements of and under the jurisdiction of the governing agency. [**400:**6.1.4.5]

4.11.4.5 Documentation. Training shall be documented and made available to the AHJ upon written request. [**400:**6.1.4.6]

4.12 Ignition Source Controls.

4.12.1 Smoking. Smoking shall be prohibited in the following locations:

(1) Within 25 ft (7.6 m) of outdoor storage or areas, dispensing areas, or open use areas.
(2) In rooms or areas where [GH_2 or LH_2] are stored, dispensed, or used in open systems in amounts requiring a permit in accordance with Section 4.5

[**400:**6.1.5.1]

4.12.2 Open Flames and High-Temperature Devices. Open flames and high-temperature devices shall not be used in a manner that creates a hazardous condition. [**400:**6.1.5.2]

4.12.3 Energy-Consuming Equipment. Energy-consuming equipment with the potential to serve as a source of ignition shall be listed or approved for use with [GH_2 or LH_2]. [**400:**6.1.5.3]

4.12.4 Powered Industrial Trucks. Powered industrial trucks shall be operated and maintained in accordance with NFPA 505. [**1:**10.17]

4.12.5 Laboratories. Equipment in laboratories shall be in accordance with Chapter 16.

4.13 Signs.

4.13.1 General.

4.13.1.1 Design and Construction. Signs shall be durable, and the size, color, and lettering of signs shall be in accordance with nationally recognized standards. [**400:**6.1.8.1.1]

4.13.1.2 Language. Signs shall be in English as the primary language or in symbols allowed by this code. [**400:**6.1.8.1.2]

4.13.1.3 Maintenance. Signs shall meet the following criteria:

(1) They shall not be obscured.
(2) They shall be maintained in a legible condition.
(3) They shall not be removed, unless for replacement. [**400:**6.1.8.1.3]

4.13.2 Hazard Identification Signs.

4.13.2.1 Visible hazard identification signs in accordance with NFPA 704 shall be placed at the following locations, except where the AHJ has received a hazardous materials management plan and a hazardous materials inventory statement in accordance with 4.9.1 through 4.9.2 and has determined that omission of such signs is consistent with safety:

(1) On stationary aboveground tanks
(2) On 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 [**400:**6.1.8.2.1]

4.13.2.2 Identification of Containers, Cartons, and Packages. Individual containers, cartons, or packages shall be conspicuously marked or labeled in accordance with nationally recognized [codes and] standards. [**1:**6.1.8.2.2]

4.13.2.3 Identification of Gas Rooms and Cabinets. Rooms or cabinets containing compressed gases shall be conspicuously labeled as follows: COMPRESSED GAS
[**55:**4.10.2.3]

4.13.3 No Smoking Signs. Where "no smoking" is not applicable to an entire site or building, signs shall be provided as follows:

(1) In rooms or areas where [GH_2 or LH_2] is stored or dispensed or used in open systems in amounts requiring a permit in accordance with Section 1.8 of NFPA 400
(2) Within 25 ft (7.6 m) of outdoor storage, dispensing, or open-use areas

[**400:**6.1.8.3]

4.14 Protection From Vehicular Damage.

4.14.1 Where required, guard posts in accordance with 4.14.1.2 or other approved means shall be provided to protect against physical damage.

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

(1)*Storage tanks and connected piping, valves, and fittings
(2) Storage areas containing tanks or portable containers except where the exposing vehicles are powered industrial trucks used for transporting the [GH_2 or LH_2]
(3) Use areas

[**400:**6.1.9.1]

4.14.1.2 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.

[**400:**6.1.9.2]

4.15* Building Construction Materials.

4.15.1* Noncombustible Material. A material that complies with any of the following shall be considered a noncombustible material:

(1)*A material that, in the form in which it is used and under the condition anticipated, will not ignite, burn, support combustion, or release flammable vapors, when subjected to fire or heat.
(2) A material that is reported as passing ASTM E136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750 Degrees C.*
(3) A material that is reported as complying with the pass/fail criteria of ASTM E136 when tested in accordance with the test method and procedure in ASTM E2652, *Standard Test Method for Behavior of Materials in a Tube Furnace with a Cone-shaped Airflow Stabilizer, at 750 Degrees C.*

[***101:***4.6.13.1]

4.15.2* Limited-Combustible Material. A material shall be considered a limited-combustible material where all the conditions of 4.15.2.1 and 4.15.2.2, and the conditions of either 4.15.2.3 or 4.15.2.4 are met. [***101:***4.6.14]

4.15.2.1 The material shall not comply with the requirements for a noncombustible material, in accordance with 4.15.1. [***101:***4.6.14.1]

4.15.2.2 The material, in the form which it is used, shall exhibit a potential heat value not exceeding 3500 Btu/lb (8141 kJ/kg), where tested in accordance with NFPA 259. [***101:***4.6.14.2]

4.15.2.3 The material shall have a structural base of a noncombustible material with a surfacing not exceeding a thickness of ⅛ in. (3.2 mm) where the surfacing exhibits a flame spread index not greater than 50 when tested in accordance with ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*, or ANSI/UL 723, *Standard for Test for Surface Burning Characteristics of Building Materials.* [***101:***4.6.14.3]

4.15.2.4 The material shall have composed of materials that, in the form and thickness used, neither exhibit a flame spread index greater than 25 nor evidence of continued progressive combustion when tested in accordance with ASTM E84 or ANSI/UL 723, and are of such composition that all surfaces that would be exposed by cutting through the material on any plane with neither exhibit a flame spread index greater than 25 nor evidence of continued progressive combustion when tested in accordance with ASTM E84 or ANSI/UL 723. [***101***:4.6.14.4]

4.15.2.5 Where the term *limited-combustible* is used in this code, it shall also include the term *noncombustible*. [***101***:4.6.14.5]

Chapter 5 Performance-Based Option

5.1* General.

5.1.1 Application. The requirements of this chapter shall apply to facilities designed to the performance-based option permitted by Section 4.4. [**1:**5.1.1]

5.1.2 Goals and Objectives. The performance-based design shall meet the goals and objectives of this Code in accordance with Section 4.3.

5.1.3* Approved Qualifications. The performance-based design shall be prepared by a person with qualifications acceptable to the AHJ. [**1:**5.1.3]

5.1.4* Plan Submittal Documentation. When a performance-based design is submitted to the AHJ for review and approval, the owner shall document, in an approved format, each performance objective and applicable scenario, including any calculation methods or models used in establishing the proposed design's fire and life safety performance. [**1:**5.1.4]

5.1.5* Independent Review. The AHJ shall be permitted to require an approved, independent third party to review the proposed design and provide an evaluation of the design to the AHJ at the expense of the owner. [**1:**5.1.5]

5.1.6 Sources of Data. Data sources shall be identified and documented for each input data requirement that is required to be met using a source other than a required design scenario, an assumption, or a facility design specification. [**1:**5.1.6]

5.1.6.1 The degree of conservatism reflected in such data shall be specified, and a justification for the source shall be provided. [**1:**5.1.6.1]

5.1.6.2 Copies of all references relied upon by the performance-based design to support assumptions, design features, or any other part of the design shall be made available to the AHJ if requested. [**1:**5.1.6.2]

5.1.7 Final Determination. The AHJ shall make the final determination as to whether the performance objectives have been met. [**1:**5.1.7]

5.1.8* Operations and Maintenance Manual. An approved Operations and Maintenance (O&M) Manual shall be provided by the owner to the AHJ and the fire department [for review] and shall be maintained at the facility in an approved location. [**1:**5.1.8]

5.1.9* Information Transfer to the Fire Service. Where a performance-based design is approved and used, the designer shall ensure that information regarding the operating procedures of the performance-based designed fire protection system is transferred to the owner and to the local fire service for inclusion in the pre-fire plan. [**1:**5.1.9]

5.1.10* Design Feature Maintenance.

5.1.10.1 The design features required for the facility to meet the performance goals and objectives shall be maintained by the owner and be readily accessible to the AHJ for the life of the facility. [**1:**5.1.10.1]

5.1.10.2 The facility shall be maintained in accordance with all documented assumptions and design specifications. [**1:**5.1.10.2]

5.1.10.2.1 Any proposed changes or variations from the approved design shall be approved by the AHJ prior to the actual change. [**1:**5.1.10.2.1]

5.1.10.2.2 Any approved changes to the original design shall be maintained in the same manner as the original design. [**1:**5.1.10.2.2]

5.1.11* Annual Certification. Where a performance-based design is approved and used, the property owner shall annually certify that the design features and systems have been maintained in accordance with the approved original performance-based design and assumptions and any subsequent approved changes or modifications to the original performance-based design. [**1:**5.1.11]

5.1.12 Hazardous Materials.

5.1.12.1 Performance-based designs for facilities containing high hazard contents shall identify the properties of hazardous materials to be stored, used, or handled and shall provide adequate and reliable safeguards to accomplish the following objectives, considering both normal operations and possible abnormal conditions:

(1) Minimize the potential occurrence of unwanted releases, fire, or other emergency incidents resulting from the storage, use, or handling of hazardous materials
(2) Minimize the potential failure of buildings, equipment, or processes involving hazardous materials by ensuring that such buildings, equipment, or processes are reliably designed and are suitable for the hazards present
(3) Minimize the potential exposure of people or property to unsafe conditions or events involving an unintended reaction or release of hazardous materials
(4) Minimize the potential for an unintentional reaction that results in a fire, explosion, or other dangerous condition
(5) Provide a means to contain, treat, neutralize, or otherwise handle plausible releases of hazardous materials to minimize the potential for adverse impacts to persons or property outside of the immediate area of a release
(6) Provide appropriate safeguards to minimize the risk of and limit damage and injury that could result from an explosion involving hazardous materials that present explosion hazards
(7) Detect hazardous levels of gases or vapors that are dangerous to health and alert appropriate persons or mitigate the hazard when the physiological warning properties for such gases or vapors are inadequate to warn of danger prior to personal injury
(8) Maintain power to provide for continued operation of safeguards and important systems that are relied upon to prevent or control an emergency condition involving hazardous materials
(9) Maintain ventilation where ventilation is relied upon to minimize the risk of emergency conditions involving hazardous materials

(10) Minimize the potential for exposing combustible hazardous materials to unintended sources of ignition and for exposing any hazardous material to fire or physical damage that can lead to endangerment of people or property

[**1:**5.1.12.1]

5.1.12.2 A process hazard analysis and off-site consequence analysis shall be conducted when required by the AHJ to ensure that people and property are satisfactorily protected from potentially dangerous conditions involving hazardous materials. The results of such analyses shall be considered when determining active and passive mitigation measures used in accomplishing the objectives of 4.2.3.3.2 and 4.2.4.2. [**1:**5.1.12.2]

5.1.12.3 Written procedures for pre-start-up safety reviews, normal and emergency operations, management of change, emergency response, and accident investigation shall be developed prior to beginning operations at a facility [-]. Such procedures shall be developed with the participation of employees. [**1:**5.1.12.3]

5.1.13 Special Definitions. A list of special terms used in this chapter shall be as follows:

(1) Design Fire Scenario *(See 3.4.4.)*
(2) Design Specification *(See 3.4.5.)*
(3) Design Team *(See 3.4.6.)*
(4) Exposure Fire *(See 3.4.7.)*
(5) Fire Model *(See 3.4.8.)*
(6) Fire Scenario *(See 3.4.9.)*
(7) Fuel Load *(See 3.4.10.)*
(8) Input Data Specification *(See 3.4.12.)*
(9) Occupant Characteristics *(See 3.4.13.)*
(10) Performance Criteria *(See 3.4.14.)*
(11) Proposed Design *(See 3.4.15.)*
(12) Safety Factor *(See 3.4.17.)*
(13) Safety Margin *(See 3.4.18.)*
(14) Sensitivity Analysis *(See 3.4.19.)*
(15) Stakeholder *(See 3.4.21.)*
(16) Uncertainty Analysis *(See 3.4.22.)*
(17) Verification Method *(See 3.4.23.)*

[**1:**5.1.13]

5.2 Performance Criteria.

5.2.1 General. A design shall meet the objectives specified in Section 4.2 if, for each required design scenario, assumption, and design specification, the performance criteria of 5.2.2 are met. [**1:**5.2.1]

5.2.2* Specific Performance Criteria.

5.2.2.1* Fire Conditions. No occupant who is not intimate with ignition shall be exposed to instantaneous or cumulative untenable conditions. [**1:**5.2.2.1]

5.2.2.2* Explosion Conditions. The facility design shall provide an acceptable level of safety for occupants and for individuals immediately adjacent to the property from the effects of unintentional detonation or deflagration. [**1:**5.2.2.2]

5.2.2.3* Hazardous Materials Exposure. The facility design shall provide an acceptable level of safety for occupants and for individuals immediately adjacent to the property from the effects of an unauthorized release of hazardous materials or the unintentional reaction of hazardous materials. [**1:**5.2.2.3]

5.2.2.4* Property Protection. The facility design shall limit the effects of all required design scenarios from causing an unacceptable level of property damage. [**1:**5.2.2.4]

5.2.2.5* Public Welfare. For facilities that serve a public welfare role as defined in 4.2.5, the facility design shall limit the effects of all required design scenarios from causing an unacceptable interruption of the facility's mission. [**1:**5.2.2.5]

5.2.2.6 Occupant Protection from Untenable Conditions. Means shall be provided to evacuate, relocate, or defend in place occupants not intimate with ignition for sufficient time so that they are not exposed to instantaneous or cumulative untenable conditions from smoke, heat, or flames. [**1:**5.2.2.6]

5.2.2.7 Emergency Responder Protection. Buildings shall be designed and constructed to reasonably prevent structural failure under fire conditions for sufficient time to enable fire fighters and emergency responders to conduct search and rescue operations. [**1:**5.2.2.7]

5.2.2.8 Occupant Protection from Structural Failure. Buildings shall be designed and constructed to reasonably prevent structural failure under fire conditions for sufficient time to protect the occupants. [**1:**5.2.2.8]

5.3 Retained Prescriptive Requirements.

5.3.1 Systems and Features. All fire protection systems and features of the building shall comply with applicable NFPA standards for those systems and features. [**1:**5.3.1]

5.3.2 Electrical Systems. Electrical systems shall comply with applicable NFPA standards for those systems. [**1:**5.3.2]

5.3.3 General. The design shall comply with the following requirements in addition to the performance criteria of Section 5.2 and the methods of Sections 5.4 through 5.7:

(1) General requirements for precautions against fire from the adopted fire code
(2) Emergency evacuation drill requirements from the adopted fire code
(3) Smoking prohibitions of 4.12.1
(4) Fire service feature requirements of the adopted fire code
(5) Requirements for fire safety during construction and demolition from the adopted fire code

5.3.4 Means of Egress. The design shall comply with the adopted building code in addition to the performance criteria of Section 5.2 and the methods of Sections 5.4 through 5.7.

5.3.5 Equivalency. Equivalent designs for the features covered in the retained prescriptive requirements mandated by 5.3.1 through 5.3.4 shall be addressed in accordance with the equivalency provisions of Section 1.5. [**1:**5.3.5]

5.4* Design Scenarios.

5.4.1 General.

5.4.1.1 The proposed design shall be considered to meet the goals and objectives if it achieves the performance criteria for each required design scenario. The AHJ shall approve the parameters involved with required design scenarios. [**1:**5.4.1.1]

5.4.1.2* Design scenarios shall be evaluated for each required scenario using a method acceptable to the AHJ and appropriate for the conditions. Each scenario shall be as challenging and realistic as any that could realistically occur in the building. [**1:**5.4.1.2]

5.4.1.3* Scenarios selected as design scenarios shall include, but not be limited to, those specified in 5.4.2 through 5.4.5. [**1:**5.4.1.3]

5.4.1.3.1 Design fire scenarios demonstrated by the design team to the satisfaction of the AHJ as inappropriate for the building use and conditions shall not be required to be evaluated fully. [**1:**5.4.1.3.1]

5.4.1.4 Each design scenario used in the performance-based design proposal shall be translated into input data specifications, as appropriate for the calculation method or model. [**1:**5.4.1.4]

5.4.1.5 Any design scenario specifications that the design analyses do not explicitly address or incorporate and that are, therefore, omitted from input data specifications shall be identified, and a sensitivity analysis of the consequences of that omission shall be performed. [**1:**5.4.1.5]

5.4.1.6 Any design scenario specifications modified in input data specifications, because of limitations in test methods or other data generation procedures, shall be identified, and a sensitivity analysis of the consequences of the modification shall be performed. [**1:**5.4.1.6]

5.4.2* Required Design Scenarios — Fire. Performance-based building design for life safety affecting the egress system shall be in accordance with this code and the requirements of the adopted building code.

5.4.3 Required Design Scenarios — Explosion.

5.4.3.1 Explosion Design Scenario 1 — Hydrogen Pressure Vessel Burst Scenario. Explosion Design Scenario 1 shall be the prevention or mitigation of a ruptured hydrogen pressure vessel.

5.4.3.1.1 Explosion Design Scenario 1 shall identify the various pressure vessel failure prevention measures in relation to both expected and potential abnormal vessel fill and operating conditions.

5.4.3.1.2 Mitigation measures, if applicable, shall address the safety of individuals at various distances from the pressure vessel.

5.4.3.2 Explosion Design Scenario 2 — Hydrogen Deflagration. Explosion Design Scenario 2 shall be the deflagration of a hydrogen-air or hydrogen-oxidant mixture within an enclosure such as a room or within large process equipment containing hydrogen.

5.4.3.2.1 Explosion Design Scenario 2 shall identify the specific gas mixture formed in relation to both expected and potential abnormal operating conditions and ventilation in the enclosure.

5.4.3.2.2 Mitigation measures, such as deflagration venting, shall address the hazards to any individuals within the enclosure and in the vicinity of the enclosure.

5.4.3.3 Explosion Design Scenario 3 — Hydrogen Detonation. Explosion Design Scenario 3 shall be the detonation of a hydrogen-air or hydrogen-oxidant mixture within an enclosure such as a room or a process vessel or within piping containing hydrogen.

5.4.3.3.1 The specific enclosure selected shall be the enclosure that has the greatest potential for a detonation.

5.4.3.3.2 Explosion Design Scenario 3 shall identify the specific gas mixture formed in relation to both expected and potential abnormal operating conditions and ventilation in the enclosure.

5.4.3.3.3 Mitigation measures, such as detonation containment, shall address the hazards to any individuals in the vicinity of the enclosure.

5.4.4* Required Design Scenarios — Hazardous Materials.

5.4.4.1 Hazardous Materials Design Scenario 1. Hazardous Materials Design Scenario 1 involves an unauthorized release of hazardous materials from a single control area. This design scenario shall address the concern regarding the spread of hazardous conditions from the point of release. [**1:**5.4.4.1]

5.4.4.2 Hazardous Materials Design Scenario 2. Hazardous Materials Design Scenario 2 involves an exposure fire on a location where hazardous materials are stored, used, handled, or dispensed. This design scenario shall address the concern regarding how a fire in a facility affects the safe storage, handling, or use of hazardous materials. [**1:**5.4.4.2]

5.4.4.3 Hazardous Materials Design Scenario 3. Hazardous Materials Design Scenario 3 involves the application of an external factor to the hazardous material that is likely to result in a fire, explosion, toxic release, or other unsafe condition. This design scenario shall address the concern regarding the initiation of a hazardous materials event by the application of heat, shock, impact, or water onto a hazardous material being stored, used, handled, or dispensed in the facility. [**1:**5.4.4.3]

5.4.4.4 Hazardous Materials Design Scenario 4.

5.4.4.4.1 Hazardous Materials Design Scenario 4 involves an unauthorized discharge with each protection system independently rendered ineffective. This set of design hazardous materials scenarios shall address concern regarding each protection system or protection feature, considered individually, being unreliable or becoming unavailable. [**1:**5.4.4.4.1]

5.4.4.4.2* Hazardous Materials Design Scenario 4 shall not be required to be applied to protection systems or features for which both the level of reliability and the design performance in the absence of the system are acceptable to the AHJ. [**1:**5.4.4.4.2]

5.4.5 Required Design Scenarios — Safety During Building Use.

5.4.5.1* Building Use Design Scenario 1. Building Use Design Scenario 1 involves an event in which the maximum occupant load is in the assembly building and an emergency event occurs blocking the principal exit/entrance to the building. This design scenario shall address the concern of occupants having to take alternative exit routes under crowded conditions. [**1:**5.4.5.1]

5.4.5.2 Building Use Design Scenario 2. Building Use Design Scenario 2 involves a fire in an area of a building undergoing construction or demolition while the remainder of the building is occupied. The normal fire suppression system in the area undergoing construction or demolition has been taken out of service. This design scenario shall address the concern regarding the inoperability of certain building fire safety features during construction and demolition in a partially occupied building. [**1:**5.4.5.2]

5.5 Evaluation of Proposed Designs.

5.5.1 General.

5.5.1.1 A proposed design's performance shall be assessed relative to each performance objective in Section 4.2 and each applicable scenario in Section 5.4, with the assessment conducted through the use of appropriate calculation methods. [**1:**5.5.1.1]

5.5.1.2 The choice of assessment methods shall require the approval of the AHJ. [**1:**5.5.1.2]

5.5.2 Use. The design professional shall use the assessment methods to demonstrate that the proposed design achieves the goals and objectives, as measured by the performance criteria in light of the safety margins and uncertainty analysis, for each scenario, given the assumptions. [**1:**5.5.2]

5.5.3 Input Data.

5.5.3.1 Data.

5.5.3.1.1 Input data for computer fire models shall be obtained in accordance with ASTM E1591, *Standard Guide for Data for Fire Models*. [**1:**5.5.3.1.1]

5.5.3.1.2 Data for use in analytical models that are not computer-based fire models shall be obtained using appropriate measurement, recording, and storage techniques to ensure the applicability of the data to the analytical method being used. [**1:**5.5.3.1.2]

5.5.3.2 Data Requirements. A complete listing of input data requirements for all models, engineering methods, and other calculation or verification methods required or proposed as part of the performance-based design shall be provided. [**1:**5.5.3.2]

5.5.3.3 Uncertainty and Conservatism of Data. Uncertainty in input data shall be analyzed and, as determined appropriate by the AHJ, addressed through the use of conservative values. [**1:**5.5.3.3]

5.5.4 Output Data. The assessment methods used shall accurately and appropriately produce the required output data from input data based on the design specifications, assumptions, and scenarios. [**1:**5.5.4]

5.5.5 Validity. Evidence shall be provided confirming that the assessment methods are valid and appropriate for the proposed facility, use, and conditions. [**1:**5.5.5]

5.6* Safety Factors. Approved safety factors shall be included in the design methods and calculations to reflect uncertainty in the assumptions, data, and other factors associated with the performance-based design. [**1:**5.6]

5.7 Documentation Requirements.

5.7.1* General.

5.7.1.1 All aspects of the design, including those described in 5.7.2 through 5.7.14, shall be documented. [**1:**5.7.1.1]

5.7.1.2 The format and content of the documentation shall be acceptable to the AHJ. [**1:**5.7.1.2]

5.7.2* Technical References and Resources.

5.7.2.1 The AHJ shall be provided with sufficient documentation to support the validity, accuracy, relevance, and precision of the proposed methods. [**1:**5.7.2.1]

5.7.2.2 The engineering standards, calculation methods, and other forms of scientific information provided shall be appropriate for the particular application and methodologies used. [**1:**5.7.2.2]

5.7.3 Facility Design Specifications. All details of the proposed facility design that affect the ability of the facility to meet the stated goals and objectives shall be documented. [**1:**5.7.3]

5.7.4 Performance Criteria. Performance criteria, with sources, shall be documented. [**1:**5.7.4]

5.7.5 Occupant Characteristics. Assumptions about occupant characteristics shall be documented. [**1:**5.7.5]

5.7.6 Design Scenarios. Descriptions of design hazards scenarios shall be documented. [**1:**5.7.6]

5.7.7 Input Data. Input data to models and assessment methods, including sensitivity analysis, shall be documented. [**1:**5.7.7]

5.7.8 Output Data. Output data from models and assessment methods, including sensitivity analysis, shall be documented. [**1:**5.7.8]

5.7.9 Safety Factors. Safety factors utilized shall be documented. [**1:**5.7.9]

5.7.10 Prescriptive Requirements. Retained prescriptive requirements shall be documented. [**1:**5.7.10]

5.7.11* Modeling Features.

5.7.11.1 Assumptions made by the model user, and descriptions of models and methods used, including known limitations, shall be documented. [**1:**5.7.11.1]

5.7.11.2 Documentation shall be provided that the assessment methods have been used validly and appropriately to address the design specifications, assumptions, and scenarios. [**1:**5.7.11.2]

5.7.12 Evidence of Modeler Capability. The design team's relevant experience with the models, test methods, databases, and other assessment methods used in the performance-based design proposal shall be documented. [**1:**5.7.12]

5.7.13 Performance Evaluation. The performance evaluation summary shall be documented. [**1:**5.7.13]

5.7.14 Use of Performance-Based Design Option. Design proposals shall include documentation that provides anyone involved in ownership or management of the facility with all of the following notification:

(1) The facility was approved as a performance-based design with certain specified design criteria and assumptions.
(2) Any remodeling, modification, renovation, change in use, or change in the established assumptions requires a re-evaluation and re-approval.

[**1:**5.7.14]

Chapter 6 General Hydrogen Requirements

6.1 General.

6.1.1 Occupancies containing GH_2 or LH_2 shall comply with this chapter in addition to other applicable requirements of this code.

6.1.1.1 When specific requirements are provided in other chapters, those specific requirements shall apply.

6.1.1.2 Where there is a conflict between a general requirement and a specific requirement, the specific requirement shall be applicable.

6.1.1.3 The occupancy of a building or structure, or portion of a building or structure, [where hydrogen is stored or used], shall be classified in accordance with the [adopted] building code. [**55:**6.1.1.2]

6.1.1.4 Quantities Less than or Equal to the MAQ. Indoor control areas with [GH_2 or LH_2] stored or used in quantities less than or equal to those shown in Table 6.4.1.1 shall be in accordance with 6.4.1.5 and Sections 6.1,6.7, 6.8, 6.12, 6.16, and 6.17. [**55:**6.2.4]

6.1.1.5 Quantities Greater than the MAQ. Building-related controls in areas with [GH_2 or LH_2] stored or used within an indoor area in quantities greater than those shown in Table 6.4.1.1 shall be in accordance with the requirements of Chapter 6. [**55:**6.3.1.2]

6.2 Design and Construction. Buildings, or portions thereof, shall be designed, located, and constructed in accordance with the adopted building code.

6.3 Control Areas.

6.3.1 Construction Requirements. Control areas shall be separated from each other's fire barriers in accordance with the adopted building code.

6.3.2 Number of Control Areas. The maximum number of control areas within a building shall be in accordance with the adopted building code.

6.3.3 Where only one control area is present in a building, no special construction provisions shall be required. [**400:**5.2.2.2]

6.4 Occupancy Classification.

6.4.1 Quantity Thresholds for GH_2 or LH_2 Requiring Special Provisions.

6.4.1.1 Threshold Exceedences. Where the quantities of [GH_2 or LH_2] stored or used within an indoor control area exceed those shown in Table 6.4.1.1, the area shall meet the requirements for [the occupancy classification] in accordance with the [adopted] building code, based on the requirements of 6.4.2. [**55:**6.3.1.1]

Table 6.4.1.1 Maximum Allowable Quantity of Hydrogen per Control Area (Quantity Thresholds Requiring Special Provisions)

	Unsprinklered Areas		Sprinklered Areas	
Material	**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**
LH_2	0 gal (0 L)	45 gal (170 L) †	45 gal (170 L)	45 gal (170 L)
GH_2	1000 ft^3 (28 m^3)	2000 ft^3 (56 m^3)	2000 ft^3 (56 m^3)	4000 ft^3 (112 m^3)

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 or stationary or portable containers shall be vented directly outdoors or to an exhaust hood. *(See 8.1.4.6.)*

6.4.1.2 Aggregate Allowable Quantities. The aggregate quantity in use and storage shall not exceed the quantity listed for storage. [**55:**6.3.1.3]

6.4.1.3 Incompatible Materials. When the classification of materials in individual containers requires the area to be placed in more than one [occupancy classification], the separation of [occupancies] shall not be required, providing the area is constructed to meet the requirements of the most restrictive [occupancy classification] and that the incompatible materials are separated as required by 7.2.1.1. [**55:**6.3.1.4]

6.4.1.4 Multiple Hazards. GH_2 blended with other gases having multiple hazards shall also comply with NFPA 55.

6.4.1.5 GH_2.

6.4.1.5.1* [GH_2] shall not be stored or used in other than industrial and storage occupancies. [**55:**6.3.1.6.1]

6.4.1.5.1.1 Cylinders, containers, or tanks not exceeding 250 scf (7.1 Nm^3) content at normal temperature and pressure (NTP) and used for maintenance purposes, patient care, or operation of equipment shall be permitted. [**55:**6.3.1.6.2]

6.4.1.5.1.2 Piping systems used to supply GH_2 in accordance with 7.1.15.1 shall be permitted.

6.4.2 Classification of Occupancy. The occupancy classification required shall be based on the hazard class of the material involved as indicated in 6.4.2.1.

6.4.2.1 Occupancy Classification. Occupancies used for the storage or use of GH_2 or LH_2 in quantities that exceed the quantity thresholds for gases requiring special provisions shall be classified in accordance with the adopted building code.

6.5 Gas Rooms. Where a gas room is used to increase the threshold quantity for a gas requiring special provisions or where otherwise required by the material or application specific requirements of Chapters 10 through 18, the room shall meet the requirements of 6.5.1 through 6.5.5. [**55:**6.4]

6.5.1 Pressure Control. Gas rooms shall operate at a negative pressure in relationship to the surrounding area. [**55:**6.4.1]

6.5.2 Exhaust Ventilation. Gas rooms shall be provided with an exhaust ventilation system. [**55:**6.4.2]

6.5.3 Construction. Gas rooms shall be constructed in accordance with the [adopted] building code. [**55:**6.4.3]

6.5.4 Separation. Gas rooms shall be separated from other occupancies by a minimum of 1-hour fire resistance. [**55:**6.4.4]

6.5.5 Limitation on Contents.

6.5.5.1 The function of compressed gas rooms shall be limited to storage and use of compressed gases and associated equipment and supplies. [**55:**6.4.5]

6.5.5.2 Where GH_2 or LH_2 is stored and used in gas rooms it shall comply with 6.5.5.1.

6.6 Weather Protection.

6.6.1 Classification of Weather Protection as an Indoor Versus Outdoor Area.

6.6.1.1 A weather protection structure shall be permitted to be used for sheltering hydrogen in outdoor storage or use areas, without requiring these areas to be classified as indoor storage.

6.6.1.2 Weather protected areas constructed in accordance with 6.6.1.4 shall be regulated as outdoor storage or use. [**55:**6.6.2]

6.6.1.3 Weather protected areas that are not constructed in accordance with 6.6.1.4 shall be regulated as indoor storage or use. [**55:**6.6.2.1]

6.6.1.4 Buildings or structures used for weather protection shall be in accordance with the following:

(1) The building or structure shall be constructed of noncombustible materials.
(2) Walls shall not obstruct more than one side of the structure.
(3) Walls shall be permitted to obstruct portions of multiple sides of the structure, provided that the obstructed area does not exceed 25 percent of the structure's perimeter area.
(4) The building or structure shall be limited to a maximum area of 1500 ft^2 (140 m^2), with increases in area allowed by the building code based on occupancy and type of construction.
(5) The distance from the structure constructed as weather protection 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 based on the hazard classification of the materials contained.
(6) Reductions in 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 and 8.

[**55:**6.6.3]

6.7* Electrical Equipment. Electrical wiring and equipment shall be in accordance with Section 6.7 and *NFPA 70*. [**55:**6.7]

6.7.1 Standby Power.

6.7.1.1 Where the following systems are required by this code for the storage or use of [GH_2 or LH_2] 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*:

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

[**55:**6.7.1.1]

6.7.1.2 The requirements of 6.7.1.1 shall not apply where emergency power is provided in accordance with 6.7.2 and *NFPA 70*. [**55:**6.7.1.2]

6.7.2 Emergency Power. When emergency power is required, the system shall meet the requirements for a Level 2 system in accordance with NFPA 110. [**55:**6.7.2]

6.8* 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 4.6.1, or for reaction time for safe egress of employees from the workplace or the immediate work area, or both. [**55:**6.8]

6.9* Explosion Control.

6.9.1 Explosion control shall be provided where the quantity of GH_2 or LH_2 in storage or use exceed the quantity thresholds requiring special provisions as listed in Table 6.4.1.1 or where otherwise required.

6.9.2 When explosion control is required, it shall be provided by one or both of the following methods:

(1) Explosion prevention in accordance with 6.9.3
(2) Deflagration venting in accordance with 6.9.4

6.9.3* Explosion Prevention. When provided, explosion prevention shall be in accordance with one or more of the methods specified in NFPA 69.

6.9.4 Deflagration Venting. When provided, explosion protection by the use of deflagration venting shall be in accordance with NFPA 68.

6.10 Fire Protection Systems. Buildings, or portions thereof, required to comply with the requirements for hazardous occupancies shall be protected by an approved automatic fire sprinkler system complying with NFPA 13.

6.10.1 Sprinkler System Design. When sprinkler protection is required, the area in which [GH_2 or LH_2] is stored or used shall be protected with a sprinkler system designed to be not less than that required by 11.2.3.11 of NFPA 13 for the Extra Hazard Group 1 density/area curve. [**55:**6.10.2.2]

6.11 Fire Alarm Systems.

6.11.1 A manual fire alarm system shall be provided.

6.11.2 The system shall be designed, installed, and maintained in accordance with *NFPA 72*.

6.12* GH_2 Detection Systems.

6.12.1 Gas detection equipment shall be listed or approved.

6.12.2 Where GH_2 detection systems are installed, they shall be designed, installed, tested, inspected, calibrated, and maintained in accordance with the following:

(1) Manufacturer's requirements
(2) Equipment listing requirements

6.12.2.1 Maintenance, inspection, calibration, and testing shall be conducted by trained personnel.

6.12.2.1.1* Testing shall be conducted at least annually.

6.12.2.1.2 Maintenance, inspection, calibration, and testing records shall be retained for a minimum of 3 years.

6.13* Lighting. Approved lighting by natural or artificial means shall be provided for areas of storage or use. [**55:**6.11]

6.14 Spill Control, Drainage, and Secondary Containment.

6.14.1 GH_2. Spill control, drainage, and secondary containment shall not be required for [GH_2]. [**55:**6.13]

6.14.2 LH_2. Diking shall not be used to contain an [LH_2] spill. [**55:**11.3.1.2]

6.15 Shelving.

6.15.1 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. [**55:**6.14.1]

6.15.2 In seismically active areas, shelves and containers shall be secured from overturning. [**55:**6.14.2]

6.16* Vent Pipe Termination. Hydrogen venting systems serving pressure relief devices discharging hydrogen to the atmosphere shall be in accordance with CGA G-5.5, *Hydrogen Vent Systems*. [**55:**10.2.3]

6.17* Ventilation. Indoor storage and use areas and storage buildings for [GH_2 and LH_2] shall be provided with mechanical exhaust ventilation or fixed natural ventilation, where natural ventilation is shown to be acceptable for [GH_2 or LH_2]. [**55:**6.16]

6.17.1 Ventilation Rate. Mechanical exhaust or fixed natural ventilation shall be at a rate of not less than 1 scf/min/ft^2 (0.3048 Nm^3/min/m^2) of floor area over the area of storage or use. [**55:**6.16.3.2]

6.17.2 Mechanical Exhaust Ventilation.

6.17.2.1 Ventilation Systems. In addition to the requirements of Section 6.17, ventilation systems shall be designed and installed in accordance with the requirements of the [adopted] mechanical code. [**55:**6.16.2]

6.17.2.1.1 Continuous Operation. When operation of ventilation systems is required, systems shall operate continuously unless an alternative design is approved by the AHJ. [**55:**6.16.3.1]

6.17.2.1.2 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. [**55:**6.16.5]

6.17.2.1.3 Manual Shutoff Switch. The switch shall be the breakglass or equivalent type and shall be labeled as follows:

WARNING:

VENTILATION SYSTEM EMERGENCY SHUTOFF

[**55:**16.3.3.1]

6.17.2.1.4 Inlets to the Exhaust System.

6.17.2.1.4.1 The exhaust ventilation system design shall take into account the density of the potential gases released. [**55:**6.16.4.1]

6.17.2.1.4.2 For gases that are lighter than air, exhaust shall be taken from a point within 12 in. (305 mm) of the ceiling. The use of supplemental inlets shall be allowed to be installed at points below the 12 in. (305 mm) threshold level. [**55:**6.16.4.3]

6.17.2.1.4.3* For [LH_2 systems], exhaust shall be taken from a point within 12 in. (305 mm) of the floor. The use of supplemental inlets shall be allowed to be installed at points above the 12 in. (305 mm) threshold level. [**55:**6.16.4.2]

6.17.2.1.5 Recirculation of 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 ceiling of the room or area to prevent the accumulation of [hydrogen] within the ventilated space. [**55:**6.16.4.4]

6.17.2.1.6 Ventilation Discharge. Ventilation discharge systems shall terminate at a point not less than 50 ft (15 m) from intakes of air-handling systems, air-conditioning equipment, and air compressors. [**55:**6.16.6]

6.17.2.1.7 Air Intakes. Storage and use of GH_2 or LH_2 shall be located not less than 50 ft (15 m) from air intakes.

6.18 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 6.18.1 through 6.18.4. [**55:**6.17]

6.18.1 Construction.

6.18.1.1 Materials of Construction. The gas cabinet shall be constructed of not less than 0.097 in. (2.46 mm) (12 gauge) steel. [**55:**6.17.1.1]

6.18.1.2 Access to Controls. The gas cabinet shall be provided with self-closing limited access ports or noncombustible windows to give access to equipment controls. [**55:**6.17.1.2]

6.18.1.3 Self-Closing Doors. The gas cabinet shall be provided with self-closing doors. [**55:**6.17.1.3]

6.18.2 Ventilation Requirements. The gas cabinet shall be provided with an exhaust ventilation system designed to operate at a negative pressure relative to the surrounding area. [**55:**6.17.2.1]

6.18.3 Quantity Limits. Gas cabinets shall contain not more than three cylinders, containers, or tanks. [**55:**6.17.4]

6.18.4 Separation of Incompatibles. Incompatible gases, as defined by Table 7.2.1.1, shall be stored or used within separate gas cabinets. [**55:**6.17.5]

6.19 Exhausted Enclosures.

6.19.1 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. [**55:**6.18.1]

6.19.2 Separation of Incompatible Gases within Enclosures.

6.19.2.1 Cylinders, containers, and tanks within enclosures shall be separated in accordance with Table 7.2.1.1. [**55:**6.18.1.2]

6.19.2.2 Incompatible gases, as defined by Table 7.2.1.1, shall be stored or used within separate exhausted enclosures. [**55:**6.18.2]

6.19.3 Fire Protection. Exhausted enclosures shall be internally sprinklered. [**55:**6.18.1.3]

6.20* Source Valve. Bulk gas systems shall be provided with a source valve. [**55:**6.19]

6.20.1 The source valve shall be marked. [**55:**6.19.1]

6.20.2 The source valve shall be designated on the design drawings for the installation. [**55:**6.19.2]

6.21 Cleaning and Purging of Piping Systems.

6.21.1 General.

6.21.1.1 [Hydrogen] systems shall be cleaned and purged in accordance with the requirements of Section 6.21 when one or more of the following conditions exist:

(1) The system is installed and prior to being placed into service.
(2) There is a change in service.
(3)*There are alterations or repair of the system, involving the replacement of parts or addition to the piping system and prior to returning the system to service.
(4)*The design standards or written procedures specify cleaning or purging.
[**55:**7.1.18.1.1]

6.21.1.2 Cleaning and purging of the internal surfaces of [hydrogen] systems shall be conducted by qualified individuals trained in cleaning and purging operations and procedures, including the recognition of potential hazards associated with cleaning and purging. [**55:**7.1.18.1.2]

6.21.1.3* A written cleaning or purging procedure shall be provided to establish the requirements for the cleaning and purging operations to be conducted. [**55:**7.1.18.1.3]

6.21.1.3.1* An independent or third-party review of the written procedure shall be conducted after the procedure has been written and shall accomplish the following:

(1) Evaluate hazards, errors, and malfunctions related to each step in the procedure
(2) Review the measures prescribed in the procedure for applicability
(3) Make recommendations for additional hazard mitigation measures if deemed to be necessary
[**55:**7.1.18.1.3.1]

6.21.1.3.2 The completed written procedure shall be:

(1) Maintained on site by the facility owner/operator
(2) Provided to operating personnel engaged in cleaning or purging operations
(3) Made available to the AHJ upon request
[**55:**7.1.18.1.3.2]

6.21.1.3.3 Where generic cleaning or purging procedures have been established, a job-specific operating procedure shall not be required. [**55:**7.1.18.1.3.3]

6.21.1.3.4 Generic procedures shall be reviewed when originally published or when the procedure or operation is changed. [**55:**7.1.18.1.3.4]

6.21.1.4 Written procedures to manage change to process materials, technology, equipment, procedures, and facilities shall be established and implemented. [**654:**4.3]

6.21.1.4.1 The management-of-change procedures shall ensure that the following topics are addressed prior to any change:

(1) The technical basis for the proposed change
(2) The safety and health implications
(3) Whether the change is permanent or temporary
(4) Modifications to the cleaning and purging procedures
(5) Employee training requirements
(6) Authorization requirements for the proposed change
[**56:**4.6.1]

6.21.1.4.2* Implementation of the management-of-change procedures shall not be required for replacements-in-kind. [**56:**4.6.2]

6.21.1.4.3 The written cleaning and purging procedure, as required by 6.21.1.3, shall be updated to incorporate the change. [**56:**4.6.3]

6.21.1.5 Prior to cleaning or purging [in, hydrogen] piping systems shall be inspected and tested to determine that the installation, including the materials of construction, and method of fabrication, comply with the requirements of the design standard used and the intended application for which the system was designed. [**55:**7.1.18.1.5]

6.21.1.5.1 Inspection and testing of piping systems shall not be required to remove a system from service. [**55:**7.1.18.1.5.1]

6.21.1.5.2* Personnel in the affected area(s), as determined by the cleaning or purging procedure, shall be informed of the hazards associated with the operational activity and notified prior to the initiation of any such activity. [**55:**7.1.18.1.5.3]

Chapter 7 Gaseous Hydrogen

7.1 General.

7.1.1 The storage, use, and handling of GH_2 shall comply with this chapter in addition to other applicable requirements of this code.

7.1.1.1 Where specific requirements are provided in other chapters, those specific requirements shall apply.

7.1.1.2 Where there is a conflict between a general requirement and a specific requirement, the specific requirement shall be applicable.

7.1.1.3 The occupancy of a building or structure, or portion thereof, where hydrogen is stored or used shall be classified in accordance with the adopted building code.

7.1.2* GH_2 Systems.

7.1.2.1 [System] Design. [GH_2] systems shall be designed for the intended use and shall be designed by persons competent in such design. [**55:**7.1.2.2]

7.1.2.2 Installation. Installation of bulk [GH_2] systems shall be supervised by personnel knowledgeable in the application of the standards for their construction and use. [**55:**7.1.2.2]

7.1.2.3 Controls.

7.1.2.3.1 [GH_2] system controls shall be designed to prevent materials from entering or leaving the process at an unintended time, rate, or path. [**55:**7.3.1.2.1]

7.1.2.3.2 Automatic controls shall be designed to be fail-safe. [**55:**7.3.1.2.2]

7.1.3 Listed or Approved Hydrogen Equipment. Listed or approved hydrogen-generating and hydrogen-consuming equipment shall be in accordance with the listing requirements and manufacturers' instructions. [**55:**10.2.8.1]

7.1.4* Metal Hydride Storage Systems.

7.1.4.1 General.

7.1.4.1.1 The storage and use of metal hydride storage systems shall be in accordance with 7.1.4. [**55:**10.2.9.1.1]

7.1.4.1.2 Metal Hydride Systems Storing or Supplying GH_2. Those portions of the system that are used as a means to store or supply [GH_2] shall also comply with Sections 7.2 or 7.3 as applicable. [**55:**10.2.9.1.2]

7.1.4.1.3 Classification. The hazard classification of the metal hydride storage system shall be based on the [GH_2] stored without regard to the metal hydride content. [**55:**10.2.9.1.3]

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. [**55:**10.2.9.1.4]

7.1.4.1.5 Design and Construction of Containers. [GH_2] cylinders, containers, and tanks used for metal hydride storage systems shall be designed and constructed in accordance with 7.1.5.1. [**55:**10.2.9.1.5]

7.1.4.1.6 Service Life and Inspection of Containers. Metal hydride storage system cylinders, containers, and tanks shall be inspected, tested, and requalified for service at not less than 5-year intervals. [**55:**10.2.9.1.6]

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. [**55:**10.2.9.1.7]

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
[**55:**10.2.9.1.7.1]

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
[**55:**10.2.9.1.7.2]

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
[**55:**10.2.9.1.7.3]

(A) 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. [**55:**10.2.9.1.7.3(A)]

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
[**55:**10.2.9.1.7.4]

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. [**55:**10.2.9.1.8]

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. [**55:**10.2.9.1.9]

7.1.4.1.10 Refilling of Containers. The refilling of listed or approved metal hydride storage systems shall be in accordance with the listing requirements and manufacturers' instructions. [**55:**10.2.9.1.11]

7.1.4.1.10.1 Industrial Trucks. The refilling of metal hydride storage systems serving powered industrial trucks shall be in accordance with the requirements of Chapter 10.

7.1.4.1.10.2 Hydrogen Purity. The purity of [GH_2] used for the purpose of refilling containers shall be in accordance with the listing and the manufacturers' instructions. [**55:**10.2.9.1.11.2]

7.1.4.1.11 Electrical. Electrical components for metal hydride storage systems shall be designed, constructed, and installed in accordance with *NFPA 70*. [**55:**10.2.9.1.12]

7.1.4.2 Portable Containers or Systems.

7.1.4.2.1 Securing Containers. Cylinders, containers, and tanks shall be secured in accordance with 7.1.7.4. [**55:**10.2.9.2.1]

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 cylinders, containers, or tanks from dislodgement, slipping, or rotating when the equipment is in motion. [**55:**10.2.9.2.1.1]

7.1.4.2.1.2 Motorized Equipment.

(A) 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. [**55:**10.2.9.2.1.2]

(B) Metal hydride storage systems, including cylinders, containers, tanks, and fittings, shall not extend beyond the platform of the mobile equipment. [**55:**10.2.9.2.1.2(A)]

7.1.4.2.2 Valves. Valves on cylinders, containers, and tanks shall remain closed except when containers are connected to closed systems and ready for use. [**55:**10.2.9.2.2]

7.1.5 Cylinders, Containers, and Tanks.

7.1.5.1 Design and Construction. Cylinders, containers, 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. [**55:**7.1.5.1]

7.1.5.2 Defective Cylinders, Containers, and Tanks.

7.1.5.2.1 Defective cylinders, containers, and tanks shall be returned to the supplier. [**55:**7.1.5.2.1]

7.1.5.2.2 Suppliers shall repair the cylinders, containers, and tanks, remove them from service, or dispose of them in an approved manner. [**55:**7.1.5.2.2]

7.1.5.3 Supports. Stationary cylinders, containers, and tanks shall be provided with engineered supports of noncombustible material on noncombustible foundations. [**55:**7.1.5.3]

7.1.5.4 Cylinders, Containers, and Tanks Containing Residual Gas. [GH_2] cylinders, containers, and tanks containing residual product shall be treated as full except when being examined, serviced, or refilled by a gas manufacturer, authorized cylinder requalifier, or distributor. [**55:**7.1.5.4]

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 [GH_2] from rupture in the event of overpressure from thermal exposure. [**55:**7.1.5.5.1]

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. [**55:**7.1.5.5.2]

7.1.5.5.3 Pressure relief devices shall be sized in accordance with the specifications to which the container was fabricated. [**55:**7.1.5.5.3]

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. [**55:**7.1.5.5.4]

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 scf (0.057 Nm^3) or less. [**55:**7.1.5.5.5]

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. [**55:**7.1.5.5.6]

7.1.6 Labeling Requirements.

7.1.6.1 Containers. Individual [GH_2] cylinders, containers, and tanks shall be marked or labeled in accordance with DOT requirements or those of the applicable regulatory agency. [**55:**7.1.7.1]

7.1.6.2 Label Maintenance. The labels applied by the gas manufacturer to identify the liquefied or nonliquefied [GH_2] cylinder contents shall not be altered or removed by the user. [**55:**7.1.7.2]

7.1.6.3 Stationary GH_2 Cylinders, Containers, and Tanks.

7.1.6.3.1 Stationary [GH_2] cylinders, containers, and tanks shall be marked in accordance with NFPA 704. [**55:**7.1.7.3.1]

7.1.6.3.2 Markings shall be visible from any direction of approach. [**55:**7.1.7.3.2]

7.1.6.4 Piping Systems.

7.1.6.4.1 Except as provided in 7.1.6.4.2, piping systems shall be marked in accordance with ASME A13.1, *Scheme for the Identification of Piping Systems*, or other applicable approved [codes and] 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

[**55:**7.1.7.4.1]

7.1.6.4.2 Piping within gas manufacturing plants, gas processing plants, refineries, and similar occupancies shall be marked in an approved manner. [**55:**7.1.7.4.2]

7.1.6.5 Marking.

7.1.6.5.1 Hazard identification signs shall be provided in accordance with 4.13.2. [**55:**10.2.1.1]

7.1.6.5.2 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

[**55:**10.2.1.2]

7.1.7 Security.

7.1.7.1 General. [GH_2] cylinders, containers, tanks, and systems shall be secured against accidental dislodgement and against access by unauthorized personnel. [**55:**7.1.8.1]

7.1.7.2* Security of Areas. Storage, use, and handling areas shall be secured against unauthorized entry. [**55:**7.1.8.2]

7.1.7.2.1 Administrative controls shall be allowed to be used to control access to individual storage, use, and handling areas located in secure facilities not accessible by the general public. [**55:**7.1.8.2.1]

7.1.7.3 Physical Protection.

7.1.7.3.1 [GH_2] cylinders, containers, tanks, and systems that could be exposed to physical damage shall be protected. [**55:**7.1.8.3.1]

7.1.7.3.2 Guard posts or other means shall be provided to protect [GH_2] cylinders, containers, tanks, and systems indoors and outdoors from vehicular damage in accordance with. Section 4.14. [**55:**7.1.8.3.2]

7.1.7.3.3 Where guard posts are installed, they shall be in accordance with 4.14.1.2.

7.1.7.4 Securing GH_2 Cylinders, Containers, and Tanks. [GH_2] cylinders, containers, 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 7.1.7.4.1 and 7.1.7.4.2. [**55:**7.1.8.4]

7.1.7.4.1 [GH_2] cylinders, containers, and tanks in the process of examination, servicing, and refilling shall not be required to be secured. [**55:**7.1.8.4.1]

7.1.7.4.2 At cylinder-filling plants, authorized cylinder requalifier's facilities, and distributors' warehouses, the nesting of cylinders shall be permitted as a means to secure cylinders. [**55:**7.1.8.4.2]

7.1.8 Valve Protection.

7.1.8.1* General. [GH_2] cylinder, container, and tank valves shall be protected from physical damage by means of protective caps, collars, or similar devices. [**55:**7.1.9.1]

7.1.8.1.1 Valve protection of individual valves shall not be required to be installed on individual cylinders, containers, or tanks installed on tube trailers or similar transportable bulk gas systems equipped with manifolds that are provided with a means of physical protection that will protect the valves from physical damage when the equipment is in use. Protective systems required by DOT for over the road transport shall provide an acceptable means of protection. [**55:**7.1.9.1.1]

7.1.8.1.1.1 Valve protection of individual valves shall not be required to be installed on individual cylinders, containers, or tanks that comprise bulk or non-bulk gas systems where the containers are stationary, or portable equipped with manifolds that are provided with physical protection in accordance with 4.1.4 and 7.1.7.3 or other approved means. Protective systems required by DOT for over the road transport shall provide an acceptable means of protection. [**55:**7.1.9.1.1.1]

7.1.8.2 Valve-Protective Caps. Where [GH_2] cylinders, containers, and tanks are designed to accept valve-protective caps, the user shall keep such caps on the [GH_2] cylinders, containers, and tanks at all times, except when empty, being processed, or connected for use. [**55:**7.1.9.2]

7.1.9 Separation from Hazardous Conditions.

7.1.9.1 General. [GH_2] cylinders, containers, tanks, and systems in storage or use shall be separated from materials and conditions that present exposure hazards to or from each other. [**55:**7.1.10.1]

7.1.9.1.1* Clearance from Combustibles and Vegetation. Combustible waste, vegetation, and similar materials shall be kept a minimum of 10 ft (3.1 m) from [GH_2] cylinders, containers, tanks, and systems. [**55:**7.1.10.3]

7.1.9.1.1.1 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. [**55:**7.1.10.3.1]

7.1.9.1.1.2 The noncombustible partition shall either be an independent structure or the exterior wall of the building adjacent to the storage area. [**55:**7.1.10.3.2]

7.1.9.1.2 Ledges, Platforms, and Elevators. [GH_2] cylinders, containers, and tanks shall not be placed near elevators, unprotected platform ledges, or other areas where [GH_2] cylinders, containers, or tanks could fall distances exceeding one-half the height of the cylinder, container, or tank. [**55:**7.1.10.4]

7.1.9.1.3 Temperature Extremes. [GH_2] cylinders, containers, 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. [**55:**7.1.10.5]

7.1.9.1.3.1 [GH_2] cylinders, containers, and tanks that have not been designed for use under elevated temperature conditions shall not be exposed to direct sunlight outdoors where ambient temperatures exceed 125°F (52°C). The use of a weather protected structure or shaded environment for storage or use shall be permitted as a means to protect against direct exposure to sunlight. [**55:**7.1.10.5.1]

7.1.9.1.4 Falling Objects. [GH_2] cylinders, containers, and tanks shall not be placed in areas where they are capable of being damaged by falling objects. [**55:**7.1.10.6]

7.1.9.1.5 Heating. [GH_2] cylinders, containers, and tanks, whether full or partially full, shall not be heated by devices that could raise the surface temperature of the cylinder, container, or tank to above 125°F (52°C). [**55:**7.1.10.7]

7.1.9.1.5.1 Electrically Powered Heating Devices. Electrical heating devices shall be in accordance with *NFPA 70*. [**55:**7.1.10.7.1]

7.1.9.1.5.2 Fail-Safe Design. Devices designed to maintain individual [GH_2] cylinders, containers, or tanks at constant temperature shall be designed to be fail-safe. [**55:**7.1.10.7.2]

7.1.9.1.6 Sources of Ignition. Open flames and high-temperature devices shall not be used in a manner that creates a hazardous condition. [**55:**7.1.10.8]

7.1.9.1.7 Exposure to Chemicals. [GH_2] cylinders, containers, and tanks shall not be exposed to corrosive chemicals or fumes that could damage cylinders, containers, tanks, or valve-protective caps. [**55:**7.1.10.9]

7.1.9.1.8 Exposure to Electrical Circuits. [GH_2] containers, cylinders, and tanks shall not be placed where they could become a part of an electrical circuit. [**55:**7.1.10.10]

7.1.9.1.8.1* Electrical devices mounted on [GH_2] piping, cylinders, containers, or tanks shall be installed, grounded, and bonded in accordance with the methods specified in *NFPA 70* (NEC). [**55:**7.1.10.10.1]

7.1.10 Service and Repair. Service, repair, modification, or removal of valves, pressure relief devices, or other [GH_2] cylinder, container, or tank appurtenances shall be performed by trained personnel and with the permission of the container owner. [**55:**7.1.11]

7.1.11 Unauthorized Use. [GH_2] cylinders, containers, 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. [**55:**7.1.12]

7.1.12 Cylinders, Containers, and Tanks Exposed to Fire. [GH_2] cylinders, containers, 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. [**55:**7.1.13]

7.1.13 Leaks, Damage, or Corrosion.

7.1.13.1* Removal from Service. Leaking, damaged, or corroded [GH_2] cylinders, containers, and tanks shall be removed from service. [**55:**7.1.14.1]

7.1.13.2 Replacement and Repair. Leaking, damaged, or corroded [GH_2] systems shall be replaced or repaired. [**55:**7.1.14.2]

7.1.13.3* Handling of Cylinders, Containers, and Tanks Removed from Service. [GH_2] cylinders, containers, and tanks that have been removed from service shall be handled in an approved manner. [**55:**7.1.14.3]

7.1.14 Surfaces.

7.1.14.1 To prevent bottom corrosion, cylinders, containers, and tanks shall be protected from direct contact with soil or surfaces where water might accumulate. [**55:**7.1.15.1]

7.1.14.2 Surfaces shall be graded to prevent accumulation of water. [**55:**7.1.15.2]

7.1.15 Piping.

7.1.15.1* Piping Systems. Piping, tubing, fittings, and related components shall be designed, fabricated, and installed in accordance with applicable parts of ASME B31.3, *Code for Process Piping*, 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.

7.1.15.1.1 Prior to acceptance and initial operation, all piping installations shall be inspected and pressure tested in accordance with ASME B31.12, *Hydrogen Piping and Pipelines*, and ICC *International Fuel Gas Code (IFGC)*, Section 705. [**55:**10.2.2.1]

7.1.15.1.2 In addition to the requirements of 7.1.15.1, brazing materials used for joints in piping and tubing systems shall have a melting point about 1000°F (538°C). [**55:**10.2.2.2]

7.1.15.1.3 Underground piping system shall be in accordance with 7.1.15.3. [**55:**10.2.2.3]

7.1.15.1.4 Integrity. Piping, tubing, pressure regulators, valves, and other apparatus shall be kept gastight to prevent leakage. [**55:**7.3.1.3.1]

7.1.15.1.5 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. [**55:**7.3.1.3.2]

7.1.15.2 Equipment Assembly.

7.1.15.2.1 Valves, gauges, regulators, and other accessories used for hydrogen compressed gas systems shall be specified for hydrogen service by the manufacturer or the hydrogen supplier. [**55:**10.2.4.1]

7.1.15.2.2 Storage containers, piping, valves, regulating equipment, and appurtenances serving hydrogen compressed gas systems shall be protected against physical damage and tampering. [**55:**10.2.4.1.1]

7.1.15.2.3 Cabinets or enclosures containing hydrogen control or operating equipment shall be ventilated to prevent the accumulation of hydrogen. [**55:**10.2.4.2]

7.1.15.2.4 Mobile hydrogen supply units used as part of a hydrogen compressed gas system shall be secured to prevent movement. [**55:**10.2.4.3]

7.1.15.2.5 Mobile hydrogen supply units shall be electrically bonded to the storage system before hydrogen is discharged from the supply unit. [**55:**10.3.2.1]

7.1.15.3 Underground Piping.

7.1.15.3.1 Underground piping shall be of welded construction without valves, unwelded mechanical joints, or connections installed underground. [**55:**7.1.17.1]

7.1.15.3.1.1 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. [**55:**7.1.17.1.1]

7.1.15.3.1.2 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 [adopted] building code for areas designated as vehicular driveways and yards, subject to trucking. [**55:**7.1.17.1.1.1]

7.1.15.3.1.3* Piping installed in trench systems located below grade where the trench is open to above shall not be considered to be underground. [**55:**7.1.17.1.2]

7.1.15.3.2 Contact with Earth.

7.1.15.3.2.1 Gas piping in contact with earth or other material that could corrode the piping shall be protected against corrosion in an approved manner. [**55:**7.1.17.2]

7.1.15.3.2.2 When cathodic protection is provided, it shall be in accordance with 7.1.18. [**55:**7.1.17.2.1]

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

7.1.15.3.4 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]

7.1.15.3.5 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]

7.1.15.3.6 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]

7.1.15.3.7 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. [**55:**7.1.17.7]

7.1.15.3.8 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]

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

7.1.15.3.10 Two or more levels of piping 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]

7.1.15.3.11 "As-built" drawings of the underground piping installation shall be maintained by the owner and shall be available upon request by the AHJ.

7.1.16 Valves.

7.1.16.1 Valves utilized on [GH_2] systems shall be designed for the gas or gases and pressure intended and shall be accessible. [**55:**7.3.1.4.1]

7.1.16.2 Valve handles or operators for required shutoff valves shall not be removed or otherwise altered to prevent access. [**55:**7.3.1.4.2]

7.1.17 GH_2 Venting Systems. Hydrogen-venting systems serving pressure relief devices discharging [GH_2] to the atmosphere shall be in accordance with CGA G-5.5, *Hydrogen Vent Systems*. [**55:**10.2.3]

7.1.17.1 Venting from the relief vents from the hydrogen supply piping serving listed fuel cell power 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. [**55:**10.2.3.1]

7.1.17.2 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. [**55:**10.2.3.1.1]

7.1.17.3 Vent Pipe Termination.

7.1.17.3.1 Venting of [GH_2] shall be directed to an approved location. [**55:**7.3.1.5.1]

7.1.17.3.2 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 6.16. [**55:**7.3.1.5.2]

7.1.18 Cathodic Protection. Where required, cathodic protection shall be in accordance with 7.1.18. [**55:**7.1.6]

7.1.18.1 Operation. Where installed, cathodic protection systems shall be operated and maintained to continuously provide corrosion protection. [**55:**7.1.6.1]

7.1.18.2 Inspection. Container systems equipped with cathodic protection shall be inspected for [proper] operation by a cathodic protection tester. The frequency of inspection shall be determined by the designer of the cathodic protection system. [**55:**7.1.6.2]

7.1.18.2.1 The cathodic protection tester shall be certified as being qualified by the National Association of Corrosion Engineers, International (NACE). [**55:**7.1.6.2.1]

7.1.18.3 Impressed Current Systems. Systems equipped with impressed current cathodic protection systems shall be inspected in accordance with the requirements of the design and 7.1.18.2. [**55:**7.1.6.3]

7.1.18.3.1 The design limits of the cathodic protection system shall be available to the AHJ upon request. [**55:**7.1.6.3.1]

7.1.18.3.2 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 [**55:**7.1.6.3.2]

7.1.18.4 Corrosion Expert. Repairs, maintenance, or replacement of a cathodic protection system shall be under the supervision of a corrosion expert certified by NACE. [**55:**7.1.6.4]

7.1.18.4.1 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. [**55:**7.1.6.4.1]

7.1.19 Transfer. Transfer of [GH_2] between cylinders, containers, 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.* [**55:**7.3.1.9]

7.1.20 Compression and Processing Equipment. Compression and gas processing equipment integral to hydrogen compressed gas storage systems shall be designed for use with GH_2 and for maximum pressures and temperatures to which it can be subjected under normal operating conditions. [**55:**10.2.5]

7.1.20.1 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. [**55:**10.2.5.1]

7.1.20.2 Where GH_2 compression equipment is operated unattended, it shall be equipped with a high discharge and a low suction pressure automatic shutdown control. [**55:**10.2.5.2]

7.1.20.3 Control circuits that automatically shut down shall remain down until manually activated or reset after a safe shutdown is performed. [**55:**10.2.5.3]

7.1.21 Stationary Compressors.

7.1.21.1 Valves.

(A) Valves shall be installed such that each compressor is able to be isolated for maintenance. [**55:**10.2.5.4.1.1]

(B) 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. [**55:**10.2.5.4.1.2]

7.1.21.2 Foundations.

(A) Foundations used for supporting equipment shall be designed and constructed to prevent frost heaving. [**55:**10.2.5.5.1]

(B) The structural aspects of such foundations shall be designed and constructed in accordance with the provisions of the [adopted] building code. [**55:**10.2.5.5.2]

7.1.21.3 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 gas installation. [**55:**10.2.5.6]

7.1.21.4 Relief Valves.

(A) Each compressor shall be provided with a vent or relief device that will prevent overpressurizing of the compressor under normal or upset conditions. [**55:**10.2.5.7.1]

(B) Pressure relief devices used to serve pumps or compression equipment shall be connected to a vent pipe system in accordance with 7.1.17. [**55:**10.2.5.7.2]

7.1.21.5 Pressure Monitoring. The pressure on the compressor discharge shall be monitored by a control system. [**55:**10.2.5.8]

7.1.21.5.1 Discharge pressures in excess of the equipment design pressures shall cause the compressor to shut down. [**55:**10.2.5.8.1]

7.1.21.6 Protection. Transfer piping and compressors shall be protected from vehicular damage. [**55:**10.2.5.9]

7.1.22 Use of GH_2 for Inflation. Inflatable equipment, devices, or balloons shall not be pressurized or filled with GH_2.

7.1.23 Hydrogen Equipment Enclosures.

7.1.23.1 Hydrogen equipment enclosures (HEE) shall be in accordance with 7.1.23 when the total quantity of hydrogen stored in the enclosure or piped into the enclosure exceeds 1000 scf (28.3 Nm^3) or the enclosure contains hydrogen processing or generating equipment.

7.1.23.1.1 Subsection 7.1.23 does not apply to:

(1) Gas cabinets in accordance with Section 6.18
(2) Exhausted enclosures in accordance with 6.19

(3) Enclosures integral to fuel cell systems that are listed or approved in accordance with Chapter 12
(4) Enclosures integral to hydrogen generators that are listed or approved in accordance with Chapter 13

7.1.23.1.2 HEE shall be constructed of noncombustible materials.

7.1.23.2 Bonding and Grounding.

7.1.23.2.1 HEE grounding and equipment bonding within the enclosure shall comply with all of the following:

(1) The HEE structure shall be grounded in accordance with *NFPA 70*.
(2) All conductive parts of the enclosure shall be grounded or bonded.
(3) Hydrogen piping and equipment shall be bonded to the HEE structure to prevent static discharge.

7.1.23.3 GH_2 shall not be vented within the HEE or to compartments within a HEE.

7.1.23.3.1 Vent pipes shall be in accordance with Section 7.1.17.3.

7.1.23.3.2 Pressure relief devices and valves discharging to the atmosphere shall be vented in accordance with 7.1.5.5.5.

7.1.23.4 A HEE that can be entered and contains or is connected to a source of GH_2 shall be evaluated for the potential of an oxygen-deficient atmosphere during normal or off-normal conditions.

7.1.23.4.1 Where the potential exists for an oxygen-deficient atmosphere, detection and notification appliances shall be provided to warn personnel of an oxygen-deficient atmosphere.

7.1.23.4.1.1 Notification appliances shall produce a distinctive audible and visual alarm and be located outside the entrance to all locations where the oxygen-deficient condition could exist.

7.1.23.4.1.2 If a GH_2 detection system is provided in accordance with Section 6.12, oxygen detectors are not required.

7.1.23.5 Security.

7.1.23.5.1 Exterior access doors for a HEE shall be secured against unauthorized entry.

7.1.23.5.1.1 Exterior access doors shall not be required to be secured if a secured perimeter fence or wall is provided to prevent unauthorized entry.

7.1.23.5.2 Locks or latches shall not require the use of a key, a tool, or special knowledge or effort for the operation from the egress side.

7.1.23.6* Means of egress for a HEE shall be in accordance with 7.1.23.6.1, unless the HEE cannot be entered.

7.1.23.6.1 Not fewer than two means of egress shall be provided from each equipment enclosure or equipment compartment, unless all of the following criteria are met:

(1) Undivided HEE or equipment compartments do not exceed 200 ft^2 (18.6 m^2), and
(2) HEE or equipment compartments have a travel distance to the room or compartment exit door(s) not exceeding 15 ft (4.6 m).

7.1.23.6.1.1 The means of egress shall have:

(1) A minimum of 28 in. (710 mm) clear width, and
(2) A minimum headroom of not less than 6 ft, 8 in. (2030 mm) along the entire designated means of egress path

7.1.23.7 Hydrogen piping and equipment shall be isolated, depressurized, and made safe prior to replacement.

7.1.23.8 A HEE shall be secured to a structure or foundation in a manner approved by the AHJ.

7.1.23.9 Isolation of GH_2 Storage.

7.1.23.9.1 Where required by Table 7.1.23.9.1, a means for isolation of GH_2 storage shall be provided in accordance with 7.1.23.9.

7.1.23.9.2* GH_2 storage shall be equipped with automatic emergency shutoff valves to isolate the source of hydrogen from the delivery piping system.

7.1.23.9.3 Automatic emergency shutoff valves shall be located within the same compartment as the hydrogen storage.

7.1.23.9.4 Automatic emergency shutoff valves shall operate on GH_2 detection alarms, fire alarms, and emergency shutdown system activations.

7.1.23.9.5 Automatic emergency shutoff valves shall be fail-safe to close upon loss of power or air pressure.

7.1.23.9.6 GH_2 generation and compression equipment within a HEE which supplies hydrogen to storage containers shall be equipped with either an external automatic emergency shutoff valve or non-return valve on the exit piping outside the enclosure or compartment.

7.1.23.10 Ventilation.

7.1.23.10.1 Where required by Table 7.1.23.9.1, ventilation shall be provided in accordance with 7.1.23.10.

7.1.23.10.2 A HEE and compartments within a HEE that contain GH_2 storage, equipment, or piping shall be provided with ventilation in accordance with 7.3.2.2.2.2.

7.1.23.10.3 Natural ventilation openings and air intakes for mechanical ventilation systems shall be separated from nonbulk sources of GH_2 in accordance with 7.2.2.3.2.2 and from bulk sources of GH_2 in accordance with 7.3.2.3.1.1.

7.1.23.10.3.1 Air intakes and ventilation openings shall not be required to meet the requirements of 7.1.23.10.3 where the compartment is provided with GH_2 detection in accordance with 7.1.23.14, which deactivates power to all electrical equipment within the enclosure upon detection of 25 percent of the LFL.

7.1.23.11 Storage Area Separation.

7.1.23.11.1 Where required by Table 7.1.23.9.1, storage area separation shall be provided in accordance with 7.1.23.11.

7.1.23.11.2 Fuel cell equipment, compressors, hydrogen generators, electrical distribution equipment, and similar appliances shall be separated from GH_2 storage areas within the HEE by a one-hour fire rated barrier that is also capable of preventing gas transmission.

7.1.23.12 Electrical Equipment.

7.1.23.12.1 All electrical equipment in a HEE that has GH_2 piping, storage, generation, or processing equipment shall be in accordance with Chapter 5 of *NFPA 70*.

Table 7.1.23.9.1 Protection Features Based on Use

HEE or a Compartment in a HEE Contains:	GH_2 Storage	GH_2 Storage	Hydrogen Generation, Compression and/or Processing Equipment	Support Equipment Room (in a HEE)
Enclosure Volume:	<200 ft^3	≥200 ft^3	Not limited	Not limited
Contains or is connected to a source of hydrogen:	Yes	Yes	Yes	No
Automatic isolation from GH_2 storage	Not required	Not required	Required	Not applicable
Ventilation	Natural or mechanical	Natural for 3-walls HEE/mechanical for 4-walls HEE	Mechanical	No additional requirement
Storage compartment separation	Not applicable	Not applicable	Required	Required
Electrical equipment	Per *NFPA 70*, Chapter 5	Per *NFPA 70*, Chapter 5	Per *NFPA 70*, Chapter 5	Unclassified
Bonding/grounding	Required	Required	Required	Per *NFPA 70*
Explosion control	Not required	Required	Required	Not required
Detection	Loss of ventilation*	GH_2, Loss of ventilation*	GH_2, Fire and Loss of ventilation	GH_2 if necessary to meet the requirements of 7.1.23.10.3.1

*When mechanical ventilation is provided.

7.1.23.12.2 Electrical equipment within 15 ft (4.6 m) of any natural ventilation opening or required exhaust discharge of a HEE shall comply with the requirements of Chapter 5 of *NFPA 70*.

7.1.23.13 Emergency Shutdown System.

7.1.23.13.1 An emergency shutdown system (ESS) shall be provided for the HEE.

7.1.23.13.1.1 The ESS shall operate on GH_2 detection alarms, fire alarms, and loss of ventilation alarms, where these are required by Table 7.1.23.9.1.

7.1.23.13.1.2 The ESS shall operate upon activation of a manual emergency shutdown device (ESD).

7.1.23.13.1.3 The ESS shall operate across all interconnected HEE at a common site.

7.1.23.13.1.4 Where activated, the ESS shall de-energize unclassified electrical equipment inside compartments containing hydrogen or other flammable gases and close all automatic shutoff control valves on piping into and from interconnected HEE and HEE compartments containing hydrogen equipment.

7.1.23.13.1.5 A manual ESD shall be located on the exterior of each HEE that is interconnected to the hydrogen system.

(A) The ESD shall be identified by a sign located at the exterior of the equipment enclosure.

7.1.23.13.1.6 A remote emergency shutdown shall be located not less than 25 ft (7.6 m) and not more than 100 ft (30 m) from HEE equipped with individual ESDs.

7.1.23.14 Detection.

7.1.23.14.1 Where required by Table 7.1.23.9.1, GH_2 detection, fire detection, and loss of ventilation detection shall be provided in accordance with 7.1.23.14.

7.1.23.14.2 GH_2 detection shall be provided in accordance with Section 6.12.

7.1.23.14.2.1 Detection of hydrogen above 25 percent of the LFL shall result in activation of the ESS, and shall be indicated by a visible notification device mounted on the exterior of the HEE.

7.1.23.14.3 Heat detectors or flame detectors shall be provided and installed in accordance in *NFPA 72*.

7.1.23.14.4 A device shall be provided to detect failure of the ventilation system.

7.1.23.14.4.1 The device shall activate the ESS when airflow drops below 75 percent of the required flow.

7.1.23.15 Explosion Control.

7.1.23.15.1 Where required by Table 7.1.23.9.1, explosion control shall be provided in accordance with Section 6.9.

7.1.23.15.1.1 Explosion vents, where used, shall not discharge into adjacent HEE compartments.

7.1.24 Emergency Shutoff Valves.

7.1.24.1 Accessible manual or automatic emergency shutoff valves shall be provided to shut off the flow of GH_2 in case of emergency. [**55:**7.3.1.11.1]

7.1.24.1.1* Manual emergency shutoff valves or the device that activates an automatic emergency shutoff valve on a bulk source or piping systems serving the bulk supply shall be identified by means of a sign. [**55:**7.3.1.11.1.1]

7.1.24.2 Emergency shutoffs shall be located at the point of use and at the tank, cylinder, or bulk source, and at the point where the system piping enters the building. [**55:**7.3.1.11.2]

7.1.25 Emergency Isolation.

7.1.25.1 Where [GH_2] [-] is carried in pressurized piping above a gauge pressure of 15 psi (103 kPa), an approved means of emergency isolation shall be provided [-]. [**55:**7.3.1.12.1]

7.1.25.2 Approved means of meeting the requirements for emergency isolation shall include any of the following:

(1) Automatic shutoff valves located as close to the bulk source as practical tied to leak detection systems
(2) Attended control stations where trained personnel can monitor alarms or supervisory signals and can trigger emergency responses
(3) A constantly monitored control station with an alarm and remote shutoff of the gas supply system
(4) Excess flow valves at the bulk source
[**55:**7.3.1.12.2]

7.1.25.3 The requirements of 7.1.25 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 6.4.1.1
[**55:**7.3.1.12.3]

7.1.25.4 Location Exemptions. The requirements of 7.1.25.1 shall not apply to the following:

(1) Piping for inlet connections designed to prevent backflow
(2) Piping for pressure relief devices
(3) Systems containing 430 scf (12.7 Nm^3) or less of [GH_2]
[**55:**7.3.1.12.4]

7.1.26 Ignition Source Control. Ignition sources in areas containing [GH_2] shall be in accordance with 7.1.26. [**55:**7.6.3]

7.1.26.1 Static Producing Equipment. Static producing equipment located in [GH_2] areas shall be grounded. [**55:**7.6.3.1]

7.1.26.2 No Smoking or Open Flame. Signs shall be posted in areas containing [GH_2] 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. [**55:**7.6.3.2]

7.1.27 Operating Instructions.

(A) 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. [**55:**10.2.6.1.1]

(B) Instructions shall be maintained at the operating site at a location acceptable to the authority having jurisdiction. [**55:**10.2.6.1.2]

7.1.28 Maintenance.

7.1.28.1 Maintenance shall be performed annually by a qualified representative of the equipment owner. [**55:**10.2.6.2.1]

7.1.28.2 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. [**55:**10.2.6.2.2]

7.1.28.3 Scheduled maintenance and retest activities shall be formally documented and records shall be maintained a minimum of 3 years. [**55:**10.2.6.2.3]

7.2 Non-Bulk GH_2.

7.2.1 Non-Bulk GH_2 General.

7.2.1.1* Incompatible Materials. [GH_2] cylinders, containers, and tanks shall be separated in accordance with Table 7.2.1.1. [**55:**7.1.10.2]

Table 7.2.1.1 Separation of Gas Cylinders, Containers, and Tanks by Hazard Class [from Non-Bulk GH_2 Cylinders, Containers, Tanks, and Systems]

	GH_2*	
Gas Category	**ft**	**m**
Toxic or highly toxic	20	6.1
Pyrophoric	20	6.1
Flammable	—	—
Oxidizing	20	6.1
Corrosive	20	6.1
Unstable reactive Class 2, Class 3, or Class 4	20	6.1
Other gas	NR	NR

NR: No separation required.
[**55:**7.1.10.2]
*Extract of flammable gas column from Table 7.1.10.2 of NFPA 55.

7.2.1.1.1 GH_2 systems in outdoor storage or use shall be separated from other compressed gases in accordance with Table 7.3.2.3.1.1(a).

7.2.1.1.2 Subparagraph 7.2.1.1.1 shall not apply to [GH_2] contained within closed piping systems. [**55:**7.1.10.2.1]

7.2.1.1.3 The distances shown in Table 7.2.1.1 shall be permitted to be reduced without limit [when GH_2] cylinders, containers, and tanks are separated by a barrier of noncombustible construction that has a fire resistance rating of at least 0.5 hour and interrupts the line of sight between the containers. [**55:**7.1.10.2.2]

7.2.1.1.4 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. [**55:**7.1.10.2.3]

7.2.1.1.5 Cylinders without pressure relief devices shall not be stored without separation from flammable and pyrophoric gases with pressure relief devices. [**55:**7.1.10.2.4]

7.2.1.1.6 Spatial separation shall not be required between cylinders deemed to be incompatible in gas production facilities where cylinders are connected to manifolds for the purposes of filling, analysis of compressed gases, or manufacturing procedures, assuming the prescribed controls for the manufacture of gas mixtures are in place. [**55:**7.1.10.2.5]

7.2.1.2 Bonding and Grounding. The hydrogen compressed gas system shall be electrically bonded and grounded. [**55:**10.3.2]

7.2.1.2.1 Mobile hydrogen supply units shall be electrically bonded to the storage system before hydrogen is discharged from the supply unit. [**55:**10.3.2.1]

7.2.2 Non-Bulk GH_2 Storage.

7.2.2.1 General.

7.2.2.1.1 Applicability. The storage of [GH_2] exceeding the quantity thresholds for gases requiring special provisions as specified in Table 6.4.1.1 shall be in accordance with Chapters 1 through 6 [as applicable] and Sections 7.1 through 7.2. [**55:**7.6.1.1]

7.2.2.1.2 Classification of Weather Protection as an Indoor Versus 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. [**55:**7.2.1.3]

7.2.2.2 Indoor Storage. Indoor storage of [GH_2] shall be in accordance with the [applicable] provisions of Section 7.1. [**55:**7.2.2.1]

7.2.2.2.1 Indoor GH_2 systems in control areas with less than the maximum allowable quantities per control area shown in Table 6.4.1.1 shall be located in accordance with the applicable provisions of Table 7.3.2.2.1.

7.2.2.2.2 Indoor Hydrogen System Location.

7.2.2.2.2.1 Hydrogen systems of less than 5000 scf (141.6 Nm^3) and greater than the MAQ, where located inside buildings, shall be in accordance with the following:

(1) In a ventilated area in accordance with the provisions of Section 6.17
(2) Separated from incompatible materials in accordance with the provisions of 7.2.1.1
(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 located in the same room or area as the hydrogen system
   (a) The distance shall be permitted to be reduced to 10 ft (3.1 m) where the room or area in which the hydrogen system is installed is protected by a listed detection system as per Article 500.7(K) of *NFPA 70* and the detection system shall shut down the fuel supply in the event of a leak that results in a concentration that exceeds 25 percent of the LFL.
   (b) Emergency shutoff valves shall be provided in accordance with 7.1.24.
(5) A distance of 50 ft (15 m) from other flammable gas storage
(6) Protected against damage in accordance with the provisions of 7.1.7.3
[**55:**10.3.4.1]

7.2.2.2.2.2 Systems Installed in One Room.

(A) More than one system of 5000 scf (141.6 Nm^3) 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. [**55:**10.3.4.2.1]

(B) The separation distance between multiple systems of 5000 scf (141.6 Nm^3) 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 6.10. [**55:**10.3.4.2.2]

(C) The required separation distance between individual portable systems in the process of being filled or serviced in facilities associated with the manufacture or distribution of hydrogen and its mixtures shall not be limited by 7.2.2.2.2.2(A) or 7.2.2.2.2.2(B) when such facilities are provided with Protection Level 2 controls and the applicable requirements of Chapters 1 through 7. [**55:**10.3.4.2.3]

7.2.2.3 Outdoor Storage.

7.2.2.3.1 General. Exterior storage of [GH_2] shall be in accordance with 7.2.1, 7.2.2.1, and 7.2.2.3. [**55:**7.2.2.2.1]

7.2.2.3.2 Distance to Exposures. The outdoor storage or use of [GH_2] shall be located from lot lines, public streets, public alleys, public ways, or buildings not associated with the manufacture or distribution of [GH_2] in accordance with Table 7.2.2.3.2. [**55:**7.6.2]

7.2.2.3.2.1 Fire Barriers.

(A)* Where a fire barrier is used to protect [GH_2] systems, the system shall terminate downstream of the source valve. [**55:**7.5.2.1.1]

(B) The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage or use area. [**55:**7.5.2.1.2]

(C) The fire barrier wall shall be without openings or penetrations. [**55:**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 [adopted] building code. [**55:**8.7.2.1.1.1]

(D) The configuration of the [fire barrier] shall be designed to allow natural ventilation to prevent the accumulation of hazardous gas concentrations. [**55:**7.6.2.3]

7.2.2.3.2.2 Air Intakes. Storage and use of [GH_2] shall not be located within 50 ft (15.2 m) of air intakes. [**55:**7.6.2.4]

7.2.2.3.2.3 Building Openings. Storage and use of [GH_2] 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. [**55:**7.6.2.5]

7.2.3 Non-Bulk GH_2 Use.

7.2.3.1 General.

7.2.3.1.1 Applicability. The storage or use of [GH_2] exceeding the quantity thresholds for gases requiring special provisions as specified in Table 6.4.1.1 shall be in accordance with Chapters 1 through 6 [as applicable] and Sections 7.1 and 7.2. [**55:**7.6.1.1]

7.2.3.2 Indoor Use. Indoor use of [GH_2] shall be in accordance with the requirements of Section 7.1. [**55:**7.3.2.1]

7.2.3.3 Outdoor Use. Exterior use of [GH_2] shall be in accordance with the [applicable] requirements of Section 7.1. [**55:**7.3.2.2.1]

7.2.4 Non-Bulk GH_2 Handling.

7.2.4.1 Applicability. The storage or use of [GH_2] exceeding the quantity thresholds for gases requiring special provisions as specified in Table 6.4.1.1 shall be in accordance with Chapters 1 through 6 [as applicable] and Sections 7.1 and 7.2. [**55:**7.6.1.1]

7.2.4.2 Carts and Trucks.

7.2.4.2.1 Cylinders, containers, and tanks shall be moved using an approved method. [**55:**7.3.3.2.1]

7.2.4.2.2 Where cylinders, containers, and tanks are moved by hand cart, hand truck, or other mobile device, such carts,

Table 7.2.2.3.2 Distance to Exposures for Non-Bulk [GH_2]

Maximum Amount per Storage Area (ft^3)	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 scf = 0.02832 Nm^3.

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.

[**55:** Table 7.6.2]

trucks, or devices shall be designed for the secure movement of cylinders, containers, and tanks. [**55:**7.3.3.2.2]

7.2.4.3 Lifting Devices. Ropes, chains, or slings shall not be used to suspend [GH_2] cylinders, containers, and tanks unless provisions at time of manufacture have been made on the cylinder, container, or tank for appropriate lifting attachments, such as lugs. [**55:**7.3.3.3]

7.2.4.4 Cargo Transport Unloading. Cargo transport unloading shall be in accordance with 7.3.4.2.

7.3 Bulk GH_2 Systems.

7.3.1 Bulk GH_2 Systems — General.

7.3.1.1 Applicability. The storage, use, and handling of bulk [GH_2] systems shall be in accordance with the applicable provisions of Chapters 1 through 6, and Section 7.3. [**55:**10.1]

7.3.1.2 Bonding and Grounding. The [bulk] hydrogen compressed gas system shall be electrically bonded and grounded. [**55:**10.3.2]

7.3.2 Bulk GH_2 Systems Storage.

7.3.2.1 General Requirements.

7.3.2.1.1 Systems located above ground either at grade or above grade shall be in accordance with 7.3.2. [**55:**10.4.2]

7.3.2.1.2* Fire Protection. Fire protection shall be in accordance with the requirements of Section 6.10. [**55:**10.4.5.1.2]

7.3.2.1.3 Installation in Vaults Above and Below Ground. Generation, compression, storage and dispensing equipment for compressed gases shall be allowed to be located in either abovegrade or belowgrade vaults in accordance with IFC 5303.16.

7.3.2.2 Indoor Storage.

7.3.2.2.1 The location of bulk [GH_2] systems shall be in accordance with Table 7.3.2.2.1. [**55:**10.4.5.1.1].

Table 7.3.2.2.1 Location of [GH_2] Systems

Location	Quantity of Hydrogen	
	≥5000 scf to <15,000 scf (≥142 Nm^3 to <425 Nm^3)	≥15,000 scf (≥425 Nm^3)
In a detached building	A	A
In a gas room, in accordance with Section 6.4	A	Detached building required
Not in a gas room	NA	Detached building required

A: Allowed. NA: Not allowed.

[**55:** Table 10.4.5.1.1]

7.3.2.2.2 Detached Buildings.

7.3.2.2.2.1 Detached buildings shall be constructed of noncombustible or limited-combustible materials in accordance with the requirements of Section 6.5. [**55:**10.4.5.2.1]

7.3.2.2.2.2 Ventilation shall be provided in accordance with the requirements of Section 6.17. [**55:**10.4.5.2.2]

(A) Outlet openings shall be located at the high point of the room in exterior walls or roof. [**55:**10.4.5.2.2.1]

(B) Inlet and outlet openings shall each have a minimum total area of 1 ft^2/1000 ft^3 (1 m^2 /305 m^3) of room volume. [**55:**10.4.5.2.2.2]

(C) Discharge from outlet openings shall be directed or conducted to the atmosphere. [**55:**10.4.5.2.2.3]

7.3.2.2.2.3* Explosion control shall be provided in accordance with the requirements of Section 6.9. [**55:**10.4.5.2.3]

7.3.2.2.2.4 Electrical equipment shall be in accordance with Article 501 of *NFPA 70* for Class I, Division 2 locations. [**55:**10.4.5.2.4]

7.3.2.2.2.5 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 7.3.2.2.2.4. [**55:**10.4.5.2.5]

7.3.2.2.3 Hydrogen Gas Rooms.

7.3.2.2.3.1 Floors, walls, and ceilings shall be constructed of noncombustible or limited-combustible materials in accordance with the requirements of the [adopted] building code. [**55:**10.4.5.3.1]

(A) 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. [**55:**10.4.5.3.1.1]

(B) Not less than 25 percent of the perimeter wall shall be an exterior wall. [**55:**10.4.5.3.1.2]

(C) Openings to other parts of the building shall not be permitted. [**55:**10.4.5.3.1.3]

(D) Windows and doors shall be in exterior walls only. [**55:**10.4.56.3.1.4]

7.3.2.2.3.2 Ventilation shall be as provided in Section 6.17. [**55:**10.4.5.3.2]

7.3.2.2.3.3 Explosion control shall be provided in accordance with the requirements of Section 6.9. [**55:**10.4.5.3.3]

7.3.2.2.3.4 There shall be no sources of ignition from open flames, electrical equipment, or heating equipment. [**55:**10.4.5.3.4]

7.3.2.2.3.5* Electrical equipment shall be in accordance with Article 501 of *NFPA 70* for Class I, Division 2 locations. [**55:**10.4.5.3.5]

7.3.2.2.3.6 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 7.3.2.2.3.5. [**55:**10.4.5.3.6]

7.3.2.3 Outdoor Storage.

7.3.2.3.1 Aboveground Locations.

7.3.2.3.1.1* Minimum Distance for Aboveground Locations. The minimum distance from a [GH_2] system located outdoors to specified exposures shall be in accordance with Table 7.3.2.3.1.1(a), Table 7.3.2.3.1.1(b), or Table 7.3.2.3.1.1(c). [**55:**10.4.2.2.1]

(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 be required to be in accordance with the values shown in Table 7.3.2.3.1.1(a) when in accordance with Table 7.3.2.3.1.1(b) or Table 7.3.2.3.1.1(c). [**55:**10.4.2.2.2]
   (a) The separation distance for piping systems with internal diameters other than those specified in Table 7.3.2.3.1.1(a) for the pressure range selected shall be permitted with tabular distances determined based on the use of the equations in Table 7.3.2.3.1.1(b) or Table 7.3.2.3.1.1(c). [**55:**10.4.2.2.1.1]
   (b) Separation distances determined based on the use of Table 7.3.2.3.1.1(b) or Table 7.3.2.3.1.1(c) shall be subject to review and approval by the AHJ. [**55:**10.4.2.2.2.2]
   (c)* **Determination of Internal Diameter.** The internal diameter of the piping system shall be determined by the diameter of the piping serving that portion of a storage array with content greater than 5000 scf (141.6 Nm^3). The piping system size used in the application of Table 7.3.2.3.1.1(a), Table 7.3.2.3.1.1(b), or Table 7.3.2.3.1.1(c) and shall be determined based on that portion of the system with the greatest maximum internal diameter. [**55:**10.4.2.2.2.1]
   (d)* **Determination of System Pressure.** The system pressure shall be determined by the maximum operating pressure of the storage array with content greater than 5000 scf (141.6 Nm^3), irrespective of those portions of the system elevated to a higher pressure. [**55:**10.4.2.2.3]

7.3.2.3.1.2* Reduction of Distance by Mitigation Means.

(A)* Except for distances to air intakes, the distances to Group 1 and 2 exposures shown in Table 7.3.2.3.1.1(a), Table 7.3.2.3.1.1(b), and Table 7.3.2.3.1.1(c) shall be permitted to be reduced by one-half and shall not apply to Group 3 exposures where fire barrier walls are located between the system and the exposure and constructed in accordance with the following: [**55:**10.4.2.2.4.1]

(1) The fire barrier wall shall be without openings or penetrations. [**55:**8.7.3.2.1]
   (a) 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 [adopted] building code. [**55:**8.7.3.2.1.1]
(2) Fire barrier walls shall have a minimum fire resistance rating of not less than 2 hours. [**55:**10.4.2.2.4.1(1)]
(3) The fire barrier wall shall interrupt the line of sight between the bulk hydrogen compressed gas system and the exposure. [**55:**10.4.2.2.4.1(2)]
(4) The configuration of the fire barrier shall allow natural ventilation to prevent the accumulation of hazardous gas concentrations. [**55:**10.4.2.2.4.1(3)]
(5) The number of fire barrier walls used to separate individual systems shall be limited to three. [**55:**10.4.2.2.4.1(4)]
(6) The fire barrier wall shall not have more than two sides at 90 degrees (1.57 rad) directions or not more than three sides with connecting angles of 135 degrees (2.36 rad). [**55:**10.4.2.2.4.1(5)]
   (a) The connecting angles between fire barrier walls shall be permitted to be reduced to less than 135 degrees (2.3 rad) for installations consisting of three walls when in accordance with 8.3.2.3.1.5(E). [**55:**10.4.2.2.4.1(5)(a)]
(7) Fire barrier walls shall be designed and constructed as a structure in accordance with the requirements of the building code without exceeding the specified allowable stresses for the materials of construction utilized. Structures shall be designed to resist the overturning effects caused by lateral forces due to wind, soil, flood, and seismic events. [**55:**10.4.2.2.4.1(6)]
(8) Where clearance is required between bulk hydrogen compressed gas system and the barrier wall for the performance of service or maintenance-related activities, a minimum horizontal clearance of 5 ft (1.5 m) shall be provided between the structure and the system. [**55:**10.4.2.2.4.1(7)]

Table 7.3.2.3.1.1(a) Minimum Distance (D) from Outdoor [GH_2] Systems to Exposures — Typical Maximum Pipe Size

Pressure	**>15 to ≤250 psig**		**>250 to ≤3000 psig**		**>3000 to ≤7500 psig**		**>7500 to ≤15000 psig**	
Internal Pipe Diameter (ID) d_{mm}	**>103.4 to ≤1724 kPa** $d = 52.5_{mm}$		**>1724 to ≤20,684 kPa** $d = 18.97_{mm}$		**>20,684 to ≤51,711 kPa** $d = 7.31_{mm}$		**>51,711 to ≤103,421 kPa** $d = 7.16_{mm}$	
Group 1 Exposures	**m**	**ft**	**m**	**ft**	**m**	**ft**	**m**	**ft**
(a) Lot lines (b) Air intakes (HVAC, compressors, other) (c) Operable openings in buildings and structures (d) Ignition sources such as open flames and welding	12	40	14	46	9	29	10	34
Group 2 Exposures	**m**	**ft**	**m**	**ft**	**m**	**ft**	**m**	**ft**
(a) Exposed persons other than those servicing the system (b) Parked cars	6	20	7	24	4	13	5	16
Group 3 Exposures	**m**	**ft**	**m**	**ft**	**m**	**ft**	**m**	**ft**
(a) Buildings of noncombustible non-fire-rated construction (b) Buildings of combustible construction (c) Flammable gas storage systems above or below ground (d) Hazardous materials storage systems above or below ground (e) Heavy timber, coal, or other slow-burning combustible solids (f) 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 (g) Unopenable openings in building and structures (h) Encroachment by overhead utilities (horizontal distance from the vertical plane below the nearest overhead electrical wire of building service) (i) Piping containing other hazardous materials (j) Flammable gas metering and regulating stations such as natural gas or propane	5	17	6	19	4	12	4	14

[**55:** Table 10.4.2.2.1(a)]

(9) The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage or use area when the exterior building wall meets the requirements for fire barrier walls. [**55:**10.4.2.2.4.1(8)]

(B)* Active Means. Active control systems that mitigate the rise of system leaks and failures shall be permitted to be used as a means to reduce separation distances where approved by the AHJ under the authority as granted by Section 1.5. [**55:**10.4.2.2.4.2]

7.3.2.3.1.3 Required Separation Distance for All Systems. Separation distances shall be required for bulk hydrogen compressed gas systems independent of system pressure or internal diameter of piping systems in accordance with Sections 7.3.2.3.1.3(A) through 7.3.2.3.1.3(C). [**55:**10.4.2.2.5]

(A) Unloading connections on delivery equipment shall not be positioned closer to any of the exposures cited in Table 7.3.2.3.1.1(a), Table 7.3.2.3.1.1(b), or Table 7.3.2.3.1.1(c) than the distances given for the storage system. [**55:**10.4.2.2.5]

(B) The minimum separation distance between gaseous and liquid systems integrated into a single system where the liquid source is vaporized, compressed, and stored in the gaseous state shall be 15 ft (4.6 m). [**55:**10.4.2.2.5.2]

(C) 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 the liquids under the system. [**55:**10.4.2.2.5.3]

7.3.2.3.1.4 Bulk hydrogen compressed gas systems shall be allowed to integrate or co-locate other nonliquefied flammable gas systems as a component of the hydrogen gas system without separation, 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. [**55:**10.4.2.2.6]

Table 7.3.2.3.1.1(b) Minimum Distance (D) from Outdoor [GH_2] Systems to Exposures by Maximum Pipe Size with Pressures >15 to ≤3000 psig

Pressure		>15 to ≤250 psig >103.4 to ≤1724 kPa						>250 to ≤3000 psig >17.24 to ≤20,684 kPa					
		Exposures*†						Exposures*†					
Internal Pipe Diameter (ID)		Group 1		Group 2		Group 3		Group 1		Group 2		Group 3	
		D = 0.231d		D = 0.12584d – 0.47126		D = 0.096d		D = 0.738d		D = 0.43616d – 0.91791		D = 0.307d	
ID (in.)	d (mm)	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft
0.2	5.1	1	4	0	1	0	2	4	12	1	4	2	5
0.3	7.6	2	6	0	2	1	2	6	18	2	8	2	8
0.4	10.2	2	8	1	3	1	3	7	25	4	12	3	10
0.5	12.7	3	10	1	4	1	4	9	31	5	15	4	13
0.6	15.2	4	12	1	5	1	5	11	37	6	19	5	15
0.7	17.8	4	13	2	6	2	6	13	43	7	22	5	18
0.8	20.3	5	15	2	7	2	6	15	49	8	26	6	20
0.9	22.9	5	17	2	8	2	7	17	55	9	30	7	23
1.0	25.4	6	19	3	9	2	8	19	62	10	33	8	26
1.1	27.9	6	21	3	10	3	9	21	68	11	37	9	28
1.2	30.5	7	23	3	11	3	10	22	74	12	41	9	31
1.3	33	8	25	4	12	3	10	24	80	13	44	10	33
1.4	35.6	8	27	4	13	3	11	26	86	15	48	11	36
1.5	38.1	9	29	4	14	4	12	28	92	16	52	12	38
1.6	40.6	9	31	5	15	4	13	30	98	17	55	12	41
1.7	43.2	10	33	5	16	4	14	32	105	18	59	13	43
1.8	45.7	11	35	5	17	4	14	34	111	19	62	14	46
1.9	48.3	11	37	6	18	5	15	36	117	20	66	15	49
2.0	50.8	12	39	6	19	5	16	37	123	21	70	16	51
2.1	53.3	12	40	6	20	5	17	39	129	22	73	16	54

Note: Linear interpolation of internal pipe diameters and distances between table entries is allowed.

*For a list of exposures in each exposure group, see Column 1 of Table 7.3.2.3.1.1(a).

†When calculating the minimum separation distance (D) using the formulas indicated, based on the exposure group and pressure indicated, the internal pipe diameter (d) is entered in millimeters (mm). The calculated distance (D) is expressed in units of measure in meters (m). To convert distance (D) to units of measure in feet, multiply the value of (D) in meters by 3.2808 and round to the nearest whole foot.

[**55:** Table 10.4.2.2.1(b)]

Table 7.3.2.3.1.1(c) Minimum Distance (D) from Outdoor [GH_2] Systems to Exposures by Maximum Pipe Size with Pressures >3000 to ≤15,000 psig

Pressure		>3000 to ≤7500 psig >20,684 to ≤51,711 kPa						>7500 to ≤15,000 psig >51,711 to ≤103,421 kPa					
		Exposures*†						Exposures*†					
Internal Pipe Diameter (ID)		Group 1		Group 2		Group 3		Group 1		Group 2		Group 3	
ID (in.)	d (mm)	D = 1.105d		D = 0.68311d – 1.3123		D = 0.459d		D = 1.448d		D = 1.448d		D = 0.602d	
		m	ft	m	ft	m	ft	m	ft	m	ft	m	ft
0.2	5.1	6	18	2	7	2	8	7	24	3	10	3	10
0.3	7.6	8	28	4	13	3	11	11	36	5	18	5	15
0.4	10.2	11	37	6	18	5	15	15	48	8	25	6	20
0.5	12.7	14	46	7	24	6	19	18	60	10	33	8	25
0.6	15.2	17	55	9	30	7	23	22	72	12	41	9	30
0.7	17.8	20	64	11	36	8	27	26	84	15	49	11	35
0.8	20.3	22	74	13	41	9	31	29	97	17	56	12	40
0.9	22.9	25	83	14	47	10	34	33	109	20	64	14	45
1.0	25.4	28	92	16	53	12	38	37	121	22	72	15	50
1.1	27.9	31	101	18	58	13	42	40	133	24	80	17	55
1.2	30.5	34	111	20	64	14	46	44	145	27	87	18	60
1.3	33.0	36	120	21	70	15	50	48	157	29	95	20	65
1.4	35.6	39	129	23	75	16	54	51	169	31	103	21	70
1.5	38.1	42	138	25	81	17	57	55	181	34	111	23	75
1.6	40.6	45	147	26	87	19	61	59	193	36	118	24	80
1.7	43.2	48	157	28	92	20	65	63	205	38	126	26	85
1.8	45.7	51	166	30	98	21	69	66	217	41	134	28	90
1.9	48.3	53	175	32	104	22	73	70	229	43	142	29	95
2.0	50.8	56	184	33	110	23	77	74	241	46	149	31	100

Note: Linear interpolation of internal pipe diameters and distances between table entries is allowed.
*For a list of exposures in each exposure group, see Column 1 of Table 7.3.2.3.1.1(a).
†When calculating the minimum separation distance (D) using the formulas indicated, based on the exposure group and pressure indicated, the internal pipe diameter (d) is entered in millimeters (mm). The calculated distance (D) is expressed in units of measure in meters (m). To convert distance (D) to units of measure in feet, multiply the value of (D) in meters by 3.2808 and round to the nearest whole foot.
[**55:** Table 10.4.2.2.1(c)]

7.3.2.3.1.5 Electrical Equipment. Electrical wiring and equipment shall be in accordance with Article 500 of *NFPA 70*. [**55:**10.4.2.1.2] *(See Table 7.3.2.3.1.5.)*

Table 7.3.2.3.1.5 Electrical Area Classification

Location	Classification	Extent of Classified Area
Within 3 ft (1 m) of any vent outlet and any points where hydrogen is vented to the atmosphere under normal conditions	Class I, Division 1	Between 0 ft (0 m) and 3 ft (0.9 m) and measured spherically from the outlet
Between 3 ft (1 m) and 15 ft (4.6 m) of any vent outlet and any points where hydrogen is vented to the atmosphere under normal operations	Class I, Division 2	Between 3 ft (0.9 m) and 15 ft (4.6 m) and measured spherically from the vent outlet
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) and measured spherically from the source

7.3.2.4 Underground Systems. Bulk hydrogen compressed gas systems installed underground where [GH_2] containers are to be buried in contact with earth or fill shall be in accordance with 7.3.2.4. [**55:**10.4.3.1]

7.3.2.4.1 Container Design. Pressure [GH_2] containers installed underground using burial methods shall be of seamless construction in accordance with Part UF or Appendix 22 of the ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1. [**55:**10.4.3.1.1]

7.3.2.4.1.1* [GH_2] containers shall be designed to include cyclic pressure life calculations using fracture mechanics methods. [**55:**10.4.3.1.1.1]

7.3.2.4.1.2 GH_2 Container Examination.

(A) [GH_2] containers shall be examined for internal and external surface flaws and inclusions before burial, or at the time of manufacture. [**55:**10.4.1.1.2 (A)]

(B) [GH_2] 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. [**55:**10.4.1.1.2 (B)]

7.3.2.4.1.3 Composite Containers. (Reserved)

7.3.2.4.2 Corrosion Protection. [GH_2] containers and underground piping shall be protected from corrosion in accordance with 7.1.9.1.7, 7.1.14, [and] 7.1.15.3 as applicable. [**55:**10.4.3.1.3]

7.3.2.4.3* Outlet Connections.

7.3.2.4.3.1 Threaded [GH_2] container outlet connections shall be designed with primary and secondary seals that shall be tested for functionality. [**55:**10.4.3.1.4.1]

7.3.2.4.3.2 The seal design shall include a method of detecting a leak in the primary seal. [**55:**10.4.3.1.4.2]

7.3.2.4.4 Piping Systems.

7.3.2.4.4.1 Joints in the piping system shall be installed and inspected in accordance with the requirements of ASME B31.12, *Hydrogen Piping and Pipelines*, or other approved standards. [**55:**10.4.3.1.5.1]

7.3.2.4.4.2 Valves, controls, safety devices, and instrumentation shall be above ground and accessible to authorized personnel. [**55:**10.4.3.1.5.2]

7.3.2.4.5 Location. [GH_2] containers shall be located in accordance with 7.3.2.4.5.1 through 7.3.2.4.5.6. [**55:**10.4.3.1.6]

7.3.2.4.5.1 Underground [GH_2] containers shall not be located beneath buildings. [**55:**10.4.3.1.6.1]

7.3.2.4.5.2 [GH_2] 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. [**55:**10.4.3.1.6.2]

7.3.2.4.5.3 The distance from any part of the [GH_2] container to the nearest wall of a basement, pit, cellar, or lot line shall not be less than 10 ft (3.1 m). [**55:**10.4.3.1.6.3]

7.3.2.4.5.4 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. [**55:**10.4.3.1.6.4]

7.3.2.4.5.5 A minimum distance of 1 ft (0.3 m), shell to shell, shall be maintained between adjacent underground containers. [**55:**10.4.3.1.6.5]

7.3.2.4.5.6* A minimum distance of 3 ft (0.9 m) shall be maintained between [GH_2] containers and buried utilities. [**55:**10.4.3.1.6.6]

7.3.2.4.6 Foundations. Underground [GH_2] containers shall be set on foundations constructed in accordance with the [adopted] building code, and surrounded with not less than 6 in. (152 mm) of noncorrosive inert material. [**55:**10.4.3.1.7]

7.3.2.4.6.1 The concrete shall extend a minimum of 1 ft (0.3 m) horizontally beyond the footprint of the tank in all directions. [**55:**10.4.3.1.7.1]

7.3.2.4.7 Depth, Cover, and Fill.

7.3.2.4.7.1 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. [**55:**10.4.3.1.8]

7.3.2.4.8* Anchorage and Security. [GH_2] 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. [**55:**10.4.3.1.9]

7.3.2.4.9 Venting of Underground GH_2 Containers. Vent pipes for underground [GH_2] containers shall be in accordance with 7.1.15. [**55:**10.4.3.1.10]

7.3.2.4.10 Overfill Protection and Prevention Systems. An approved means or method shall be provided to prevent the overfilling of the storage containers. [**55:**10.4.3.1.11]

7.3.2.4.11 Physical Protection. Piping and control equipment ancillary to underground containers that is located above ground shall be protected from physical damage in accordance with 7.1.7.3. [**55:**10.4.3.1.12]

7.3.3 Bulk GH_2 Systems Use.

7.3.3.1 The use of bulk GH_2 systems shall be in accordance with Section 7.1.

7.3.3.2 Good Practice Standards. Where nationally recognized good practices or standards have been established for the processes employed, such practices and standards shall be followed. [**55:**8.14.1.5.1]

7.3.4 Handling of Bulk GH_2 Systems.

7.3.4.1 The handling of GH_2 shall be in accordance with 7.2.4.

7.3.4.2 Cargo Transport Unloading.

7.3.4.2.1 Personnel conducting transfer operations from the bulk transport vehicle shall be trained.

7.3.4.2.2 Unloading connections on delivery equipment shall not be positioned closer to any of the exposures than distances given for the bulk GH_2 compressed gas storage system. [**55:**10.3.3.2]

7.3.4.2.3 During transfer of hydrogen from cargo vehicles to the bulk [GH_2] compressed gas storage system, the hand or emergency brake of the vehicle shall be set, and chock blocks shall be used to prevent the vehicle from moving. [**55:**10.3.3.3]

7.3.4.2.4 Cargo vehicles equipped with air-brake interlock in front of the unloading connection to protect against driveaways shall be engaged such that the interlock is activated. [**55:**10.3.3.4]

7.3.4.2.5 Mobile hydrogen supply units shall be electrically bonded to the bulk hydrogen gas storage system before hydrogen is discharged from the supply unit. [**55:**10.3.3.5]

7.3.4.2.6 Transfer System Depressurization.

7.3.4.2.6.1 The transfer systems shall be capable of depressurizing to facilitate disconnection. [**55:**10.3.3.6.1]

7.3.4.2.6.2 Bleed connections shall be connected to a hydrogen venting system in accordance with 7.1.17. [**55:**10.3.3.6.2]

7.3.4.2.7 Where required, check valves on delivery systems shall be in accordance with 7.1.15.1.5. [**55:**10.3.3.7]

7.3.4.2.8 Prohibitions on smoking or the use of open flame shall be in accordance with 7.1.26.2. [**55:**10.3.3.8]

7.3.4.2.9 An emergency shutoff valve shall be provided in accordance with 7.1.24. [**55:**10.3.3.9]

Chapter 8 Liquefied Hydrogen

8.1 General. The storage, use, and handling of LH_2 in LH_2 storage systems shall comply with this chapter in addition to other applicable requirements of this code.

8.1.1 Where specific requirements are provided in other chapters, those specific requirements shall apply.

8.1.1.1 Where there is a conflict between a general requirement and a specific requirement, the specific requirement shall be applicable.

8.1.1.2 The occupancy of a building or structure, or portion thereof, where hydrogen is stored or used, shall be classified in accordance with the adopted building code.

8.1.2* Containers — Design, Construction, and Maintenance. Containers employed for the storage or use of [LH_2] 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. [**55:**8.2]

8.1.3 Design. [LH_2] systems shall be designed for the intended use and shall be designed by persons competent in such design. [**55:**7.1.2.1]

8.1.3.1 Piping Systems. Piping, tubing, fittings, and related components shall be designed, fabricated, and tested in accordance with the requirements of ASME B31.12, *Hydrogen Piping and Pipelines*, or other approved standards and shall be in accordance with 8.1.3.1.1.

8.1.3.1.1 Piping and Appurtenances.

8.1.3.1.1.1 Piping systems shall be designed for the use intended through the full range of pressure and temperature to which they will be subjected. [**55:**8.14.2.1]

8.1.3.1.1.2 Piping or tubing used at operating temperatures below –20°F (–29°C) shall be fabricated from materials meeting the impact test requirements of ASME B31.12, *Hydrogen Piping and Pipelines*. [**55:**11.2.3.2]

8.1.3.1.1.3 Piping systems shall be designed and constructed to allow for expansion, contraction, vibration, settlement, and fire exposure. [**55:**8.14.2.2]

8.1.3.1.2 Joints. Joints in piping and tubing shall be in accordance with the requirements of ASME B31.12, *Hydrogen Piping and Pipelines*. [**55:**11.2.3.3]

8.1.3.1.2.1 Brazing materials, where used, shall have a melting point above 1000°F (538°C). [**11:**2.3.4]

8.1.3.1.3 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. [**55:**8.14.4]

8.1.3.1.4 Shutoff Valves on Containers. Shutoff valves shall be provided on all container connections, except for pressure relief devices. [**55:**8.14.5]

8.1.3.1.4.1 Shutoff valves for containers with multiple pressure relief devices shall be permitted in accordance with 8.1.4.7. [**55:**8.14.5.1]

8.1.3.1.4.2 Shutoff valves shall be accessible and located as close as practical to the container. [**55:**8.14.5.2]

8.1.3.1.5 Shutoff Valves on Piping.

8.1.3.1.5.1 Shutoff valves shall be installed in piping containing [LH_2] where needed to limit the volume of liquid discharged in the event of piping or equipment failure. [**55:**8.14.6.1]

8.1.3.1.5.2* Pressure relief valves shall be installed where liquid or cold gas can be trapped between shutoff valves in the piping system. *(See 8.1.4.)* [**55:**8.14.6.2]

8.1.3.1.6 Physical Protection and Support.

8.1.3.1.6.1 Aboveground piping systems shall be supported and protected from physical damage. [**55:**8.14.7.1]

8.1.3.1.6.2 Piping passing through walls shall be protected from mechanical damage. [**55:**8.14.7.2]

8.1.3.1.7 Corrosion Protection.

8.1.3.1.7.1 Aboveground piping that is subject to corrosion shall be protected against corrosion. [**55:**8.14.8.1]

8.1.3.1.7.2 Belowground piping shall be protected against corrosion. [**55:**8.14.8.2]

8.1.3.1.8 Cathodic Protection. Where required, cathodic protection shall be in accordance with 8.1.3.1.8. [**55:**8.14.9]

8.1.3.1.8.1 Operation. Where installed, cathodic protection systems shall be operated and maintained to continuously provide corrosion protection. [**55:**8.14.9.1]

8.1.3.1.8.2 Inspection.

(A) Container systems equipped with cathodic protection shall be inspected for the intended operation by a cathodic protection tester. [**55:**8.14.9.2.1]

(B) The cathodic protection tester shall be certified as being qualified by the National Association of Corrosion Engineers, International (NACE). [**55:**8.14.9.2.2]

8.1.3.1.8.3 Impressed Current Systems.

(A) Systems equipped with impressed current cathodic protection systems shall be inspected in accordance with the requirements of the design and 8.1.3.1.8.2. [**55:**8.14.9.3.1]

(B) The design limits shall be available to the AHJ upon request. [**55:**8.14.9.3.2]

(C) 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 [**55:**8.14.9.3.3]

8.1.3.1.8.4 Corrosion Expert.

(A) Repairs, maintenance, or replacement of a cathodic protection system shall be under the supervision of a corrosion expert certified by NACE. [**55:**8.14.9.4]

(B) 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. [**55:**8.14.9.4.1]

8.1.3.1.9 Testing.

8.1.3.1.9.1 Piping systems shall be tested and proved free of leaks after installation as required by the codes and standards to which they are designed and constructed. [**55:**8.14.10.1]

8.1.3.1.9.2 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. [**55:**8.14.10.2]

8.1.4 Pressure-Relief Devices.

8.1.4.1 General.

8.1.4.1.1 Pressure relief devices shall be provided to protect containers and systems containing [LH_2] from rupture in the event of overpressure. [**55:**8.2.4.1.1]

8.1.4.1.2 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. [**55:**8.2.4.1.2]

8.1.4.2 Containers Open to the Atmosphere. Portable containers that are open to the atmosphere and are designed to contain [LH_2] at atmospheric pressure shall not be required to be equipped with pressure relief devices. [**55:**8.2.4.2]

8.1.4.2.1 Containers shall be equipped with approved controls to prevent the condensation of air within the container.

8.1.4.2.2 Containers located indoors shall be within a zone of local exhaust using a mechanical exhaust system.

8.1.4.2.2.1 The exhaust system shall operate continuously when LH_2 is present and shall be designed in accordance with the mechanical code for the removal of flammable vapors.

8.1.4.2.2.2 The duct system used to exhaust the hydrogen released from open containers shall be considered to be a hazardous exhaust system.

8.1.4.3 Equipment Other Than Containers. Heat exchangers, vaporizers, insulation casings surrounding containers, vessels, and coaxial piping systems in which [LH_2] could be trapped due to leakage from the primary container shall be provided with a pressure relief device. [**55:**8.2.4.3]

8.1.4.4 Sizing.

8.1.4.4.1 Pressure relief devices shall be sized in accordance with the specifications to which the container was fabricated. [**55:**8.2.4.4.1]

8.1.4.4.2 The pressure relief device shall have the capacity to prevent the maximum design pressure of the container or system from being exceeded. [**55:**8.2.4.4.2]

8.1.4.5 Accessibility. Pressure relief devices shall be located such that they are accessible for inspection and repair. [**55:**8.2.4.5]

8.1.4.5.1* ASME pressure relief valves shall be made to be tamper resistant in order to prevent adjusting of the set pressure by other than authorized personnel. [**55:**8.2.4.5.1]

8.1.4.5.2 Non-ASME pressure relief valves shall not be field adjusted. [**55:**8.2.4.5.2]

8.1.4.6 Arrangement.

8.1.4.6.1 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. [**55:**8.2.4.6.1]

8.1.4.6.2 Portable Containers with Volume Less than 2.0 scf^3 (0.057 Nm^3).

8.1.4.6.2.1 The arrangement of the discharge from pressure relief devices from DOT-specified containers with an internal water volume of 2.0 scf (0.057 Nm^3) or less shall be incorporated in the design of the container. [**55:**8.2.4.6.2.1]

8.1.4.6.2.2 Additional safeguards regarding placement or arrangement shall not be required. [**55:**8.2.4.6.2.2]

8.1.4.7 Shutoffs Between Pressure Relief Devices and Containers.

8.1.4.7.1 General. Shutoff valves installed between pressure relief devices and containers shall be in accordance with 8.1.4.7. [**55:**8.2.4.7.1]

8.1.4.7.2 Location. Shutoff valves shall not be installed between pressure relief devices and containers unless the valves or their use meet the requirements of 8.1.4.7.2.1 or 8.1.4.7.2.2. [**55:**8.2.4.7.2]

8.1.4.7.2.1 Security. Shutoff valves shall be locked in the open position, 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*. [**55:**8.2.4.7.2.1]

8.1.4.7.2.2 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 relief devices at all times. [**55:**8.2.4.7.2.2]

8.1.4.8 Temperature Limits. Pressure relief devices shall not be subjected to [LH_2] fluid temperatures except when operating. [**55:**8.2.4.8]

8.1.5 Pressure Relief Vent Piping.

8.1.5.1 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 8.1.5. [**55:**8.3.1]

8.1.5.2 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. [**55:**8.3.2]

8.1.5.3 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. [**55:**8.3.3]

8.1.5.4 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. [**55:**8.3.4]

8.1.5.5 Overfilling. Controls shall be provided to prevent overfilling of stationary containers. [**55:**8.3.5]

8.1.6 Marking.

8.1.6.1 General. [LH_2] containers and systems shall be marked in accordance with nationally recognized standards and in accordance with 8.1.6. [**55:**8.4.1]

8.1.6.1.1 Portable Containers.

8.1.6.1.1.1 Portable [LH_2] containers shall be marked in accordance with CGA C-7, *Guide to the Preparation of Precautionary Labeling and Marking of Compressed Gas Containers*. [**55:**8.4.1.1.1]

8.1.6.1.1.2* All DOT-4L/TC-4LM liquid cylinders shall have product identification visible from all directions with minimum 2 in. (51 mm) high letters. [**55:**8.4.1.1.2]

8.1.6.1.2 Stationary Tanks. Stationary tanks shall be marked in accordance with NFPA 704. [**55:**8.4.1.2]

8.1.6.1.3 Identification Signs. Visible hazard identification signs shall be provided in accordance with NFPA 704 at entrances to buildings or areas in which [LH_2] is stored, handled, or used. [**55:**8.4.1.3]

8.1.6.2 Identification of Contents. Stationary containers shall be placarded with the identity of their contents to indicate the name of the material contained. [**55:**8.4.2]

8.1.6.3 Container Specification. Stationary containers shall be marked with the manufacturing specification and maximum allowable working pressure on a permanent nameplate. [**55:**8.4.3]

8.1.6.3.1 The nameplate shall be installed on the container in an accessible location. [**55:**8.4.3.1]

8.1.6.3.2 The nameplate shall be marked in accordance with nationally recognized standards. [**55:**8.4.3.2]

8.1.6.4 Identification of Container Connections.

8.1.6.4.1 Container inlet and outlet connections, liquid-level limit controls, valves, and pressure gauges shall be identified using one of the methods prescribed by 8.1.6.4.1.1 through 8.1.6.4.1.2. [**55:**8.4.4.1]

8.1.6.4.1.1 They shall be marked with a permanent tag or label identifying their function. [**55:**8.4.4.1.1]

8.1.6.4.1.2 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. [**55:**8.4.4.1.2]

(A) When a schematic drawing is provided, it shall be attached to the container and maintained in a legible condition. [**55:**8.4.4.1.2.1]

8.1.6.5 Identification of Piping Systems. Piping systems shall be identified in accordance with ASME A13.1, *Scheme for the Identification of Piping Systems*. [**55:**8.4.5]

8.1.6.6 Identification of Emergency Shutoff Valves. Emergency shutoff valves on stationary containers shall be identified, visible, and indicated by means of a sign. [**55:**8.4.6]

8.1.7 Security.

8.1.7.1 General. [LH_2] containers and systems shall be secured against accidental dislodgement and against access by unauthorized personnel in accordance with 8.1.7. [**55:**8.6.1]

8.1.7.2* Security of Areas. User storage sites shall be fenced or otherwise secured and posted to prevent entry by unauthorized personnel. [**55:**11.4.1.3]

8.1.7.2.1 Administrative controls shall be allowed to be used to control access to individual storage, use, and handling areas located in secure facilities not accessible by the general public. [**55:**11.4.1.3.1]

8.1.7.3 Securing of Containers. Stationary containers shall be secured to foundations in accordance with the [adopted] building code. [**55:**8.6.3]

8.1.7.3.1 Portable containers subject to shifting or upset shall be secured. [**55:**8.6.3.1]

8.1.7.3.2 Nesting shall be permitted as a means of securing portable containers. [**55:**8.6.3.2]

8.1.7.4 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. [**55:**8.6.4]

8.1.7.5 Physical Protection. Containers, piping, valves, pressure relief devices, regulating equipment, and other appurtenances shall be protected against physical damage and tampering. [**55:**8.6.5]

8.1.8 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 [LH_2] in the container. [**55:**8.7.2.3]

8.1.9 Electrical Wiring and Equipment.

8.1.9.1 General. Electrical wiring and equipment shall be in accordance with *NFPA 70* and 8.1.9. [**55:**8.8.1]

8.1.9.2 Location. Containers and systems shall not be located where they could become part of an electrical circuit. [**55:**8.8.2]

8.1.9.3 Electrical Ground and Bonding. Containers and systems shall not be used for electrical grounding. [**55:**8.8.3]

8.1.9.3.1 When electrical grounding and bonding are required, the system shall be in accordance with *NFPA 70.* [**55:**8.8.3.1]

8.1.9.3.2 The grounding system shall be protected against corrosion, including corrosion caused by stray electrical currents. [**55:**8.8.3.2]

8.1.10 Service and Repair. Service, repair, modification, or removal of valves, pressure relief devices, or other container appurtenances shall be in accordance with nationally recognized codes and standards. [**55:**8.9]

8.1.10.1 Containers. Containers that have been removed from service shall be handled in an approved manner. [**55:**8.9.1]

8.1.10.1.1 Testing. Containers, out of service in excess of 1 year shall be inspected and tested as required in 8.1.10.1.2. [**55:**8.9.1.1]

8.1.10.1.2 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. [**55:**8.9.1.2]

8.1.10.1.3 Containers that have previously been used for [LH_2] and have been removed from service shall be purged with an inert gas to remove residual [LH_2] and stored with all valves closed and the valve outlets plugged. [**55:**8.9.1.3]

8.1.10.2 Systems. Service and repair of containers or systems shall be performed by trained personnel in accordance with nationally recognized [codes and] standards and with the permission of the container owner. [**55:**8.9.2]

8.1.11 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. [**55:**8.10]

8.1.12 Leaks, Damage, and Corrosion.

8.1.12.1 Leaking, damaged, or corroded containers shall be removed from service. [**55:**8.11.1]

8.1.12.2 Leaking, damaged, or corroded systems shall be replaced, repaired, or removed from service. [**55:**8.11.2]

8.1.13 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. [**55:**8.12]

8.1.14 Emergency Shutoff Valves.

8.1.14.1 Accessible manual or automatic emergency shutoff valves shall be provided to shut off the LH_2 supply in case of emergency.

8.1.14.1.1 Emergency shutoff valves on a bulk source or piping systems serving the bulk supply shall be identified by means of a sign.

8.1.14.1.2 Emergency shutoff valves shall be located at the point of use, at the source of supply, and at the point where the system piping enters the building.

8.1.15 Dispensing Areas. Dispensing of [LH_2] associated with physical or health hazards shall be conducted in approved locations. [**55:**8.14.11.3.2]

8.1.15.1 Indoor Dispensing Areas. Dispensing indoors shall be conducted in areas constructed in accordance with the [adopted] building code. [**55:**8.14.11.3.2.1]

8.1.15.2 Ventilation. Indoor areas in which [LH_2] are dispensed shall be ventilated in accordance with the requirements of Section 6.17 and the [adopted] mechanical code. [**55:**8.14.11.3.2.2]

8.1.15.3 Piping Systems. Piping systems utilized for filling or dispensing of [LH_2] shall be designed and constructed in accordance with 8.1.3.1.1. [**55:**8.14.11.3.2.3]

8.1.16 Operation.

8.1.16.1 Securing Equipment. Mobile LH_2 supply units used as part of a hydrogen system shall be restrained to resist movement.

8.1.16.2 Bonding and Grounding. The [mobile LH_2 supply units] shall be electrically bonded and grounded. [**55:**11.2.7]

8.2 Nonbulk LH_2.

8.2.1 Nonbulk LH_2 General. The storage, use, and handling of LH_2 in LH_2 storage systems shall be in accordance with the provisions of Chapters 1 through 6, and Chapter 8 as applicable.

8.2.1.1 Containers and systems having a total LH_2 content of more than 39.7 gal (150 L) shall be in accordance with Section 8.3.

8.2.2 Nonbulk LH_2 Storage.

8.2.2.1 General. (Reserved)

8.2.2.2 Indoor Storage.

8.2.2.2.1 Installation. Containers stored indoors shall be installed in accordance with Sections 8.1 and 8.2.

8.2.2.2.2 [Storage Locations LH_2.] [LH_2] in stationary or portable containers stored indoors shall be stored in buildings, rooms, or areas constructed in accordance with the [adopted] building code. [**55:**8.13.1.3]

8.2.2.2.3 Ventilation. Ventilation shall be in accordance with Section 6.17. [**55:**8.13.1.4]

8.2.2.2.4 Installation of LH_2 Inside Buildings Other Than Detached Buildings and Gas Rooms. Portable LH_2 containers of 39.7 gal (150 L) or less capacity 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.
(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 the storage or use of other flammable gases or the storage or use of incompatible gases.
(5) Containers shall be protected against physical damage in accordance with the requirements of 8.1.7.5.
(6) Containers shall be secured in accordance with the requirements of 8.1.7.3.
(7) Welding or cutting operations and smoking shall be prohibited while hydrogen is in the room, and signs shall be provided as required by 4.13.3.
(8) Ventilation shall be provided in accordance with the requirements of Section 6.17.
(9) Pressure-relief devices on stationary or portable containers shall be vented directly outdoors or to an exhaust hood. (*See 8.1.4.6*)

[**55:**11.3.3]

8.2.2.3 Outdoor Storage.

8.2.2.3.1 General.

8.2.2.3.1.1 [LH_2] in stationary or portable containers stored outdoors shall be in accordance with 8.2.2.3. [**55:**8.13.2.1]

8.2.2.3.2 Distance to Exposures.

8.2.2.3.2.1 General. [LH_2] 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 8.2.2.3.2. [**55:**8.7.1]

8.2.2.3.3 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 [LH_2] in the container. [**55:**8.7.2.3]

8.2.2.3.4 Separation Distance. Non-bulk portable containers of liquefied hydrogen shall be separated from exposure hazards in accordance with Table 8.2.2.3.4. [**55:**8.7.3.1]

8.2.2.3.4.1 Fire Barriers. A 2-hour fire barrier wall shall be permitted in lieu of the distances specified by Table 8.2.2.3.4 when in accordance with the provisions of 8.2.2.3.4.1(A) through 8.2.2.3.4.1(E). [**55:**8.7.3.2]

(A) The fire barrier wall shall be without openings or penetrations. [**55:**8.7.3.2.1]

(B) 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. [**55:**8.7.3.2.1.1]

(C) The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage system. [**55:**8.7.3.2.2]

(D) The fire barrier wall shall be located not less than 5 ft (1.5 m) from any exposure. [**55:**8.7.3.2.3]

(E) 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). [**55:**8.7.3.2.4]

8.2.2.3.4.2 Air Intakes. Storage and use of [LH_2] shall not be located within 50 ft (15.2 m) of air intakes. [**55:**7.6.2.4]

8.2.2.3.4.3 Building Openings. Storage and use of [LH_2] 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. [**55:**7.6.2.5]

Table 8.2.2.3.4 Distance to Exposures for Non-Bulk Liquefied Hydrogen [LH_2]

Maximum Amount per Storage Area (gal)	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
0–39.7	5	5	5	5	0	0
39.8–186.9	10	10	10	10	5	0
187–448.7	10	15	15	20	5	0
448.8–747.8	10	20	20	20	5	0
>747.8	20	25	25	20	5	0

For SI units: 1 ft = 305 mm.
Notes:
(1) For requirements on minimum distance to air intakes, see 8.2.2.3.4.2.
(2) For requirements on minimum distance to building openings including exits, see 8.2.2.3.4.3.
(3) When 8.2.2.3.4.1 is used as a means of distance reduction, the configuration of the fire barriers should be designed to allow natural ventilation to prevent the accumulation of hazardous gas concentrations.
[**55:** Table 8.7.3.1]

8.2.2.3.5 Access.

8.2.2.3.5.1 Stationary containers shall be located to provide access by mobile supply equipment and authorized personnel. [**55:**8.13.2.2]

8.2.2.3.5.2 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). [**55:**8.13.2.2.1]

8.2.2.3.6 Physical Protection.

8.2.2.3.6.1 [LH_2] cylinders, containers, tanks, and systems that could be exposed to physical damage shall be protected. [**55:**8.13.2.3]

8.2.2.3.6.2 Guard posts or other means shall be provided to protect [LH_2] cylinders, containers, tanks, and systems indoors and outdoors from vehicular damage. *(See Section 4.14.)* [**55:**8.13.2.3.1]

8.2.2.3.7 Diked Areas Containing Other Hazardous Materials. Containers of [LH_2] shall not be located within diked areas with other hazardous materials. [**55:**8.13.2.4]

8.2.2.3.8* 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 [adopted] building code. [**55:**8.13.2.5]

8.2.2.3.8.1 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. [**55:**8.13.2.5.1]

8.2.2.3.8.2 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. [**55:**8.13.2.5.2]

8.2.2.3.9 Drainage.

8.2.2.3.9.1 The area surrounding stationary and portable containers shall be provided with a means to prevent accidental discharge of [LH_2] from endangering personnel, containers, equipment, and adjacent structures and from entering enclosed spaces in accordance with [the adopted fire prevention code]. [**55:**8.13.2.6.1]

8.2.2.3.9.2 The stationary container shall not be placed where spilled or discharged [LH_2] will be retained around the container. *(See 8.2.2.3.7.)* [**55:**8.13.2.6.2]

8.2.2.3.9.3 The provisions of 8.2.2.3.9.2 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 [LH_2]
[**55:**8.13.2.6.3]

8.2.2.3.9.4 Grade.

(A) The grade for a distance of not less than 50 ft (15.2 m) from where [LH_2] storage or delivery systems are installed shall be higher than the grade on which flammable or combustible liquids are stored or used. [**55:**8.13.2.6.4]

(B)* Drainage Control.

(1) When the grade differential between the storage or delivery system and the flammable or combustible liquids storage or use area is not in accordance with 8.2.2.3.9.4(A), diversion curbs or other means of drainage control shall be used to divert the flow of flammable or combustible liquids away from the [LH_2] system. [**55:**8.13.2.6.4.1(A)]
(2) 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. [**55:**8.13.2.6.4.1(B)]

8.2.3 Non-bulk LH_2 Use.

8.2.3.1 General.

8.2.3.1.1 Use and handling of containers and systems shall be in accordance with 8.2.3.1.1 through 8.2.3.1.10.2. [**55:**8.14.1]

8.2.3.1.1.1 Operating Instructions. Operating instructions shall be provided for installations that require the operation of equipment. [**55:**8.14.1.1]

8.2.3.1.1.2 Attended Delivery. A qualified person shall be in attendance at all times [LH_2] is transferred from mobile supply units to a storage system. [**55:**8.14.1.2]

8.2.3.1.1.3 Inspection.

(A) [LH_2] storage systems shall be inspected and maintained by a qualified representative of the equipment owner [-]. [**55:**8.14.1.4.1]

(1) The interval between inspections [-] shall be based on nationally recognized good practices or standards. [**55:**8.14.1.4.1.1]
(2) A record of the inspection shall be prepared and provided to the user or the authority having jurisdiction upon request. [**55:**8.14.1.4.2]

8.2.3.1.1.4 Design.

(A) Nationally Recognized Good Practices. Where nationally recognized good practices or [codes and] standards have been established for the process employed, such practices and [codes and] standards shall be followed. [**55:**8.14.1.5.1]

(B) 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 8.2.3.1.2. [**55:**8.14.1.5.2]

8.2.3.1.2 Piping and Appurtenances.

8.2.3.1.2.1 Piping systems shall be designed for the use intended through the full range of pressure and temperature to which they will be subjected. [**55:**8.14.2.1]

8.2.3.1.2.2 Piping systems shall be designed and constructed to allow for expansion, contraction, vibration, settlement, and fire exposure. [**55:**8.14.2.2]

8.2.3.1.3 Joints. Joints in piping and tubing shall be in accordance with the requirements of ANSI/ASME B31.3, *Process Piping*, or other approved standards. [**55:**8.14.3]

8.2.3.1.4 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. [**55:**8.14.4]

8.2.3.1.5 Shutoff Valves on Containers. Shutoff valves shall be provided on all container connections, except for pressure relief devices. [**55:**8.14.5]

8.2.3.1.5.1 Shutoff valves for containers with multiple pressure relief devices shall be permitted in accordance with 8.1.4.7. [**55:**8.14.5.1]

8.2.3.1.5.2 Shutoff valves shall be accessible and located as close as practical to the container. [**55:**8.14.5.2]

8.2.3.1.6 Shutoff Valves on Piping.

8.2.3.1.6.1 Shutoff valves shall be installed in piping containing [LH_2] where needed to limit the volume of liquid discharged in the event of piping or equipment failure. [**55:**8.14.6.1]

8.2.3.1.6.2 Pressure relief valves shall be installed where liquid or cold gas can be trapped between shutoff valves in the piping system. *(See 8.1.4.)* [**55:**8.14.6.2]

8.2.3.1.7 Physical Protection and Support.

8.2.3.1.7.1 Aboveground piping systems shall be supported and protected from physical damage. [**55:**8.14.7.1]

8.2.3.1.7.2 Piping passing through walls shall be protected from mechanical damage. [**55:**8.14.7.2]

8.2.3.1.8 Corrosion Protection.

8.2.3.1.8.1 Aboveground piping that is subject to corrosion shall be protected against corrosion. [**55:**8.14.8.1]

8.2.3.1.8.2 Belowground piping shall be protected against corrosion. [**55:**8.14.8.2]

8.2.3.1.9 Cathodic Protection. Where required, cathodic protection shall be in accordance with 8.2.3.1.9. [**55:**8.14.9]

8.2.3.1.9.1 Operation. Where installed, cathodic protection systems shall be operated and maintained to continuously provide corrosion protection. [**55:**8.14.9.1]

8.2.3.1.9.2 Inspection.

(A) Container systems equipped with cathodic protection shall be inspected for the intended operation by a cathodic protection tester. [**55:**8.14.9.2.1]

(B) The cathodic protection tester shall be certified as being qualified by the National Association of Corrosion Engineers, International (NACE). [**55:**8.14.9.2.2]

8.2.3.1.9.3 Impressed Current Systems.

(A) Systems equipped with impressed current cathodic protection systems shall be inspected in accordance with the requirements of the design and 8.2.3.1.9.2. [**55:**8.14.9.3.1]

(B) The design limits shall be available to the AHJ upon request. [**55:**8.14.9.3.2]

(C) 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 [**55:**8.14.9.3.3]

8.2.3.1.9.4 Corrosion Expert.

8.2.3.1.9.5 Repairs, maintenance, or replacement of a cathodic protection system shall be under the supervision of a corrosion expert certified by NACE. [**55:**8.14.9.4]

(A) 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. [**55:**8.14.9.4.1]

8.2.3.1.10 Testing.

8.2.3.1.10.1 Piping systems shall be tested and proven free of leaks after installation as required by the codes and standards to which they are designed and constructed. [**55:**8.14.10.1]

8.2.3.1.10.2 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. [**55:**8.14.10.2]

8.2.3.2 Indoor Use.

8.2.3.2.1 Filling and Dispensing.

8.2.3.2.1.1 General. A qualified person shall be in attendance at all times [LH_2] is transferred from mobile supply units to a storage system. [**55:**8.14.1.2]

8.2.3.2.1.2 Indoor Dispensing Areas. Dispensing indoors shall be conducted in areas constructed in accordance with the [adopted] building code. [**55:**8.14.11.3.2.1]

8.2.3.2.1.3 Ventilation. Indoor areas in which [LH_2 is] dispensed shall be ventilated in accordance with the requirements of Section 6.17 and the [adopted mechanical code]. [**55:**8.14.11.3.2.2]

8.2.3.3 Outdoor Use. (Reserved)

8.2.4 Nonbulk LH_2 Handling.

8.2.4.1 Nonbulk LH_2. Handling of [LH_2] containers shall be in accordance with 8.2.4. [**55:**8.14.11.4.1]

8.2.4.2 Carts and Trucks.

8.2.4.2.1 [LH_2] containers shall be moved using an approved method. [**55:**8.14.11.4.2.1]

8.2.4.2.2 Where [LH_2] containers are moved by hand cart, hand truck, or other mobile device, that device shall be designed for the secure movement of the container. [**55:**8.14.11.4.2.2]

8.2.4.3 Design. Carts and trucks used to transport [LH_2] 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. [**55:**8.14.11.4.3]

8.2.4.4 Closed Containers.

8.2.4.4.1 Pressurized containers shall be closed while transported. [**55:**8.14.11.4.4.1]

8.2.4.4.2 Containers designed for use at atmospheric conditions shall be transported with appropriate loose-fitting covers in place to prevent spillage. [**55:**8.14.11.4.4.2]

8.3 Bulk LH_2 Systems.

8.3.1 Bulk LH_2 Systems — General. The storage, use, and handling of LH_2 in LH_2 storage systems shall be in accordance with the provisions of Chapters 1 through 6 and Chapter 8, as applicable.

8.3.1.1 Section 8.3 shall not apply to individual systems using containers having a total hydrogen content of less than 39.7 gal (150 L).

8.3.1.2 Design of LH_2 Systems.

8.3.1.2.1 Fire Protection of Structural Supports.

8.3.1.2.1.1* Steel supports in excess of 18 in. (457 mm) in height shall have a minimum 2-hour fire resistance rating in accordance with ASTM E1529, *Determining the Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies.* [**55:**11.2.1.1]

8.3.1.2.2 Pressure Relief Devices. Stationary and portable containers and tanks shall be provided with pressure relief devices in accordance with the requirements of 8.1.4 and 8.3.1.2.2.1 through 8.3.1.2.2.3. [**55:**11.2.2]

8.3.1.2.2.1 Pressure relief valves or vent piping shall be designed or located so that moisture cannot collect and freeze in a manner that would interfere with the operation of the device. [**55:**11.2.2.1]

8.3.1.2.2.2 Pressure relief devices serving stationary containers shall be in accordance with the provisions of 8.1.4.6.1 and arranged to discharge unobstructed to the outdoors. [**55:**11.2.2.2]

8.3.1.2.2.3 Hydrogen venting systems discharging to the atmosphere shall be in accordance with CGA G-5.5, *Hydrogen Vent Systems.* [**55:**11.2.2.3]

8.3.1.2.2.4 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. [**55:**11.2.2.4]

8.3.1.2.3* Piping, Tubing, and Fittings.

8.3.1.2.3.1 Piping and tubing shall be in accordance with the requirements of ASME B31.12, *Hydrogen Piping and Pipelines.* [**55:**11.2.3.1]

8.3.1.2.3.2* 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 ASME B31.12, *Hydrogen Piping and Pipelines.* [**55:**11.2.3.2]

8.3.1.2.3.3 Piping and tubing materials that have a minimum design metal temperature (MDMT) of −425°F (−254°C) or lower, as defined and specified in ASME B31.12, *Hydrogen Piping and Pipelines*, shall be permitted to be used without impact testing. [**55:**11.2.3.2.1]

8.3.1.2.3.4 Piping and tubing materials that have a MDMT greater than −425°F (−254°C) shall be permitted to be used after impact testing has been performed and the materials have passed. [**55:**11.2.3.3.2]

8.3.1.2.3.5 Joints in piping and tubing shall be in accordance with the requirements of ASME B31.12, *Hydrogen Piping and Pipelines.* [**55:**11.2.3.3]

8.3.1.2.3.6 Brazing materials, where used, shall have a melting point above 1000°F (538°C). [**55:**11.2.3.4]

8.3.1.2.3.7 Aluminum piping systems and components external to the storage vessel shall not be used with LH_2 except for ambient air vaporizers. [**55:**11.2.3.5]

8.3.1.2.3.8* 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 [LH_2] temperatures. [**55:**11.2.3.6]

(A) Insulation on piping systems used to convey [LH_2] 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. [**55:**11.2.3.6.1]

(B) The insulation material and outside shield shall be designed to prevent deterioration of the insulation due to normal operating conditions. [**55:**11.2.3.6.2]

8.3.1.2.3.9 Uninsulated piping and equipment that operates at LH_2 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. [**55:**11.2.3.7]

8.3.1.2.3.10 Drip pans shall be allowed to be installed under uninsulated piping and equipment to retain and vaporize condensed liquid air. [**55:**11.2.3.8]

8.3.1.2.3.11 Cleaning and purging of piping systems shall be in accordance with Section 6.21.

8.3.1.2.4 Equipment Assembly.

8.3.1.2.4.1 Installation of bulk LH_2 systems shall be supervised by personnel knowledgeable about the applicable [codes] and the construction and use of the system to be installed. [**55:**11.2.4.1]

8.3.1.2.4.2 Storage containers, piping, valves, regulating equipment, and other accessories shall be accessible and shall be protected against physical damage and tampering. [**55:**11.2.4.2]

(A) Emergency shutoff valves shall be located in liquid and vapor use lines as close to the container as practical to terminate all flow to use lines during an emergency. [**55:**11.2.4.2.1]

(B) Containers exceeding 2000 gal (7570 L) capacity shall be provided with an automatic emergency shutoff valve. [**55:**11.2.4.2.2]

(1) The remotely operated emergency isolation valve shall be operated by a remotely located, manually activated shutdown control. [**55:**11.2.4.2.2.1]
(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. [**55:**11.2.4.2.2.2]
(3) Connections downstream of the shutoff valve shall be in accordance with ASME B31.12 *Hydrogen Piping and Pipelines.* [**55:**11.2.4.2.2.3]

8.3.1.2.4.3 Cabinets or enclosures containing hydrogen control equipment shall be ventilated to prevent any accumulation of hydrogen gas. [**55:**11.2.4.3]

8.3.1.2.5 LH_2 Vaporizers.

8.3.1.2.5.1* Heat supplied to a [LH_2] vaporizer shall be by indirect means utilizing a transfer medium. [**55:**11.2.5.1]

8.3.1.2.5.2* A low-temperature shutoff switch or valve shall be provided in the vaporizer discharge piping to prevent flow of LH_2 downstream of the vaporizer in the event that liquid is discharged from the vaporizer. [**55:**11.2.5.2]

8.3.1.2.6 Electrical Systems. Electrical wiring and equipment shall be in accordance with Table 8.3.1.2.6 and Article 500 of *NFPA 70.* [**55:**11.2.6]

Table 8.3.1.2.6 Electrical Area Classification

Location	Division	Extent of Classified Area
The bulk liquefied hydrogen system fill connection, pressure relief vent outlets, or other points on the system where hydrogen is vented to the atmosphere under the designed operating conditions	1	Within 3 ft (1 m) measured spherically from the system fill connection, system pressure relief vent outlets or, other points of release when the system is operating as designed
	2	Between 3 ft (1 m) and 25 ft (7.6 m) measured spherically from the system fill connection, any vent outlet, and within 25 ft (7.6 m) of any portion of the bulk supply system that contains liquefied hydrogen

[**55:** Table 11.2.6.2]

8.3.1.2.6.1 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
(2) Intrinsically safe
[**55:**11.2.6.1]

8.3.1.2.6.2 Electrical equipment installed on mobile supply trucks or tank cars from which the storage container is filled shall not be subject to 8.3.1.2.6.1. [**55:**11.2.6.4]

8.3.1.2.7 Bonding and Grounding. The [LH_2] system shall be electrically bonded and grounded. [**55:**11.2.7]

8.3.1.2.8 Stationary Pumps and Compressors.

8.3.1.2.8.1 Valve Isolation.

(A) Valves shall be installed such that each pump or compressor can be isolated for maintenance. [**55:**11.2.8.1.1]

(B) 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. [**55:**11.2.8.1.2]

8.3.1.2.8.2 Foundation Design and Construction.

(A) Foundations used for supporting pumps and equipment shall be designed and constructed to prevent frost heaving. [**55:**11.2.8.2.1]

(B) The structural aspects of such foundations shall be designed and constructed in accordance with the provisions of the [adopted] building code. [**55:**11.2.8.2.2]

8.3.1.2.8.3 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. [**55:**11.2.8.3]

8.3.1.2.8.4 Pump and Compressor Venting.

(A) 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. [**55:**11.2.8.4.1]

(B) Pressure relief devices used to serve pumps or compression equipment shall be connected to a vent pipe system in accordance with 8.3.1.2.2.3. [**55:**11.2.8.4.2]

8.3.1.2.8.5* Pressure Monitoring. The pressure on the pump or compressor discharge shall be monitored by a control system. [**55:**11.2.8.5]

(A) Discharge pressures in excess of the equipment design pressures shall cause the pump or compressor to shut down. [**55:**11.2.8.5.1]

8.3.1.2.8.6 Protection of Transfer Piping, Pumps, and Compressors. Transfer piping, pumps, and compressors shall be protected from vehicular damage. [**55:**11.2.8.6]

8.3.1.2.9 Emergency Shutdown System.

8.3.1.2.9.1 Emergency isolation shall comply with 7.1.25.1, 8.3.1.2.4.2, and 8.3.1.2.9.

8.3.1.2.9.2 An emergency shutdown (ESD) system shall be provided at the bulk source to stop the flow of liquid and gas into the use line when activated. [**55:**11.2.9.2]

8.3.1.2.9.3 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. [**55:**11.2.9.3].

8.3.1.2.9.4 Reactivation of the ESD system after ESD shall require that the ESD system be manually reset. [**55:**11.2.9.4]

8.3.1.2.9.5 The ESD system shall be identified by means of a sign. [**55:**11.2.9.5]

8.3.1.3 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 8.3.2.3.1.6(A). [**55:**8.7.2.2]

8.3.2 Bulk LH_2 Systems Storage.

8.3.2.1 General.

8.3.2.1.1 Stationary storage containers shall be located so that they are accessible from mobile supply equipment. [**55:**11.3.1.1]

8.3.2.1.2* Diking shall not be used to contain a LH_2 spill. [**55:**11.3.1.2]

8.3.2.1.3 Storage sites shall be placarded as follows:

WARNING:

LIQUEFIED HYDROGEN

FLAMMABLE GAS

NO SMOKING — NO OPEN FLAMES

[**55:**11.3.1.3]

8.3.2.1.4 Aboveground Tanks. Aboveground tanks for the storage of [LH_2] shall be in accordance with 8.3.2.1.4. [**55:**8.2.1]

8.3.2.1.4.1 Construction of the Inner Vessel. The inner vessel of storage tanks in [LH_2] 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 8.3.2.1.4.2. [**55:**8.2.1.1]

8.3.2.1.4.2 Construction of the Vacuum Jacket (Outer Vessel).

(A) The vacuum jacket used as an outer vessel for storage tanks in [LH_2] 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 and outer vessel. [**55:**8.2.1.2.1]

(B) The jacket shall be designed to withstand a minimum collapsing pressure differential of 30 psi (207 kPa). [**55:**8.2.1.2.2]

(C) Vacuum Level Monitoring.

(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 the outer vessel. [**55:**8.2.1.2.3.1]
(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. [**55:**8.2.1.2.3.2]

8.3.2.1.4.3 Nonstandard Containers.

(A) 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. [**55:**8.2.2.1]

(B) 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 [**55:**8.2.2.2]

8.3.2.1.4.4 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 8.3.2.1.4.4(A) through 8.3.2.1.4.4(E) also shall apply. [**55:**8.2.3]

(A) Excessive Loads. Stationary tanks shall be supported to prevent the concentration of excessive loads on the supporting portion of the shell. [**55:**8.2.3.1]

(B) Expansion and Contraction. Foundations for horizontal containers shall be constructed to accommodate expansion and contraction of the container [**55:**8.2.3.2]

(C)* Support of Ancilliary Equipment.

(1) Foundations shall be provided to support the weight of the vaporizers or heat exchangers. [**55:**8.2.3.3.1]
(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. [**55:**8.2.3.3.2]

(D) 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°F (–90°C), the foundations or supports shall be constructed of materials that are capable of withstanding the low-temperature effects of [LH_2] spillage. [**55:**8.2.3.4]

(E) Corrosion Protection. Portions of stationary tanks in contact with foundations or saddles shall be painted to protect against corrosion. [**55:**8.2.3.5]

8.3.2.1.5 Underground Tanks. Underground tanks shall not be located under buildings. *(See 8.3.2.3.1.7.)*

8.3.2.2 Indoor Storage.

8.3.2.2.1 Installation. Stationary containers stored indoors shall be installed in accordance with Sections 8.1 and 8.3.

8.3.2.2.1.1 Stationary Containers. Stationary containers shall be in accordance with 8.1.2. [**55:**8.13.1.2]

8.3.2.2.1.2 LH_2 Fluids. [LH_2] in stationary or portable containers stored indoors shall be stored in buildings, rooms, or areas constructed in accordance with the [adopted] building code. [**55:**8.13.1.3]

8.3.2.2.1.3 Ventilation. Ventilation shall be in accordance with Section 6.17. [**55:**8.13.1.4]

8.3.2.2.1.4 Specific Locations. The location of bulk LH_2 storage systems, as determined by the [maximum total quantity of LH_2], shall be in accordance with Table 8.3.2.2.1.4. [**55:**11.3.2.1]

Table 8.3.2.2.1.4 Location of [LH_2] Systems

	Quantity of Hydrogen			
Location	**MAQ**	**>MAQ to 300 gal (>170.32 L to 1135.5 L)**	**>300 to 600 gal (>1135.5 L 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. [**55:** Table 11.3.2.1]

8.3.2.2.2 Detached Buildings.

8.3.2.2.2.1 Explosion Control.

(A) Detached buildings containing more than 300 gal (1136 L) of [LH_2] shall be constructed of noncombustible or limited-combustible materials in accordance with the requirements of the [adopted] building code. [**55:**11.4.4.1.1]

(B) Explosion control shall be provided in accordance with the requirements of Section 6.9. [**55:**11.4.4.1.2]

8.3.2.2.2.2 Ventilation. Ventilation shall be provided in accordance with the requirements of Section 6.17 and 8.3.2.2.2.2(A) through 8.3.2.2.2.2(D). [**55:**11.4.4.2]

(A) Inlet openings shall be located within 18 in. (0.46 m) of the floor in exterior walls only. [**55:**11.4.4.2.1]

(B) Outlet openings shall be located at the high point of the room in exterior walls or the roof. [**55:**11.4.4.2.2]

(C) Both the inlet and outlet vent openings shall have a minimum total area of 1 ft^2/1000 scf (1 m^2/300 Nm^3) of room volume. [**55:**11.4.4.2.3]

(D) 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. [**55:**11.4.4.2.4]

8.3.2.2.2.3* Ignition Sources. There shall be no sources of ignition within the room or area where the hydrogen system is installed. [**55:**11.4.4.3]

8.3.2.2.2.4 Heating.

(A) Heating, if provided, shall be by indirect means such as steam or hot water. [**55:**11.4.4.4.1]

(B) Electrical heating in accordance with 8.1.9 shall be allowed. [**55:**11.4.4.4.2]

8.3.2.2.3 Gas Rooms.

8.3.2.2.3.1 Heating, if provided, shall be by steam, hot water, or other indirect means. [**55:**11.4.5.1]

8.3.2.2.3.2 Explosion control shall be provided in accordance with the requirements of Section 6.9. [**55:**11.4.4.1.2]

8.3.2.2.3.3 Electrical heating in accordance with 8.1.9 shall be allowed. [**55:**11.4.5.2]

8.3.2.3 Outdoor Storage. [LH_2] in stationary or portable containers stored outdoors shall be in accordance with 8.3.2.3. [**55:**8.13.2.1]

8.3.2.3.1 Aboveground Tanks.

8.3.2.3.1.1 Access.

(A) Stationary containers shall be located to provide access by mobile supply equipment and authorized personnel. [**55:**8.13.2.2]

(B) 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). [**55:**8.13.2.2.1]

8.3.2.3.1.2 Physical Protection.

(A) [LH_2] cylinders, containers, tanks, and systems that could be exposed to physical damage shall be protected. [**55:**8.13.2.3]

(B) Guard posts or other means shall be provided to protect [LH_2] cylinders, containers, tanks, and systems indoors and outdoors from vehicular damage. *(See Section 4.14.)* [**55:**8.13.2.3.1]

8.3.2.3.1.3* 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 [adopted] building code. [**55:**8.13.2.5]

(A) 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. [**55:**8.13.2.5.1]

8.3.2.3.1.4 Drainage.

(A) 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 [the adopted fire prevention code]. [**55:**8.13.2.6.1]

(B) The stationary container shall not be placed where spilled or discharged [LH_2] will be retained around the container. [**55:**8.13.2.6.2]

(C) The provisions of 8.3.2.3.1.4(B) 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
[**55:**8.13.2.6.3]

(D) Grade. 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. [**55:**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 8.3.2.3.1.4(D), diversion curbs or other means of drainage control shall be used to divert the flow of flammable or combustible liquids away from the [LH_2]. [**55:**8.13.2.6.4.1(A)]
   (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. [**55:**8.13.2.6.4.1(B)]

8.3.2.3.1.5 Design Considerations at Specific Locations.

(A) Outdoor Locations. Roadways and yard surfaces located below [LH_2] 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. [**55:**11.4.1.1]

(1) The area of noncombustible surfacing provided under liquid mobile supply equipment shall have a width not less than 12 ft (3.7 m) and a length not less than 12 ft (3.7 m) in the direction of the vehicle axis. [**55:**11.4.1.1.1]
(2) Asphalt and bitumastic paving shall be assumed to be combustible. [**55:**11.4.1.1.2]
(3) Expansion joints and fillers used in the construction of concrete slabs shall be of noncombustible materials. [**55:**11.4.1.1.3]

(B) Weather protection shall be constructed in accordance with the requirements of the adopted building code.

(C) Enclosed Courts. Stationary containers shall not be installed within enclosed courts. [**55:**8.13.2.7.1]

(D)* Open 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 8.3.2.3.1.6(A). [**55:**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. [**55:**8.13.2.7.2.1]

(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. [**55:**8.13.2.7.2.2]

(E) Fenced Areas.

(1)*User storage sites shall be fenced or otherwise secured and posted to prevent entry by unauthorized personnel. [**55:**11.4.1.3]

(a) Administrative controls shall be allowed to be used to control access to individual storage, use, and handling areas located in secure facilities not accessible by the general public. [**55:**11.4.1.3.1]

(b) At least two means of egress shall be provided from any fenced area. [**55:**11.4.1.3.2]

8.3.2.3.1.6 Siting Locations.

(A)* The minimum distance from [LH_2] systems of indicated capacity shall be in accordance with Table 8.3.2.3.1.6(A). [**55:**11.3.2.2]

(1) The distances in 1, 7, 8, 10, 11, and 12 in Table 8.3.2.3.1.6(A) 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. [**55:**11.3.2.2.1]

(2)***Fire Barrier Walls.** The distances in 1, 7, 8, 10, 11 and 12 in Table 8.3.2.3.1.6(A) 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 8.3.2.3.1.6(A). [**55:**11.3.2.2.2]

(a) The fire barrier or the insulated [LH_2] tank shall interrupt the line of sight between uninsulated portions of the [LH_2] storage system and the exposure. [**55:**11.3.2.2.3]

(b) 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). [**55:**11.3.2.2.4]

i.*The connecting angles between fire barrier walls shall be permitted to be reduced to less than 135 degrees (2.36 rad) for installations consisting of three walls when in accordance with 8.3.2.3.1.5(D). [**55**:11.3.2.2.4.1]

(c)*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. [**55:**11.3.2.2.4.2]

i. Vertical tanks shall be located at a distance not less than one tank diameter from the enclosing walls. [**55:**11.3.2.2.4.2(A)]

ii. Where horizontal tanks are used, the distance to any enclosing wall shall be not less than one-half the length of the tank. [**55:**11.3.2.2.4.2(B)]

(d) The fire barrier wall shall be without openings or penetrations. [**55:**8.7.2.1.1]

i. Penetrations of the fire barrier wall by conduit or piping shall be permitted provided that the penetration is protected with a fire stop system in accordance with the [adopted] building code. [**55:**8.7.2.1.1.1]

(e) The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage system. [**55:**8.7.2.1.2]

(f) The fire barrier wall shall not be located less than 5 ft (1.5 m) from any exposure. [**55:**8.7.2.1.3]

(g) Where the requirement of 8.3.2.3.1.6(A) is met, the bulk system shall be a minimum distance of 1 ft (0.3 m) from the fire barrier wall. [**55:**8.7.2.1.5]

(B) Unloading connections on delivery equipment shall not be positioned closer to any of the exposures cited in Table 8.3.2.3.1.6(A) than the distances given for the storage system. [**55:**11.3.2.3]

8.3.2.3.1.7 Underground Tanks. Underground tanks for the storage of [LH_2] shall be in accordance with this subsection. [**55:**11.4.3]

(A) 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 8.3.2.3.1.7(A). [**55:**11.4.3.1]

(1) Vacuum Jacket Construction.

(a) 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. [**55:**11.4.3.1.1.1]

(b) Portions of the vacuum jacket installed below grade shall be designed to withstand anticipated soil, hydrostatic, and seismic loading. [**55:**11.4.3.1.1.2]

(c) The vacuum jacket shall be constructed of stainless steel or other approved corrosion-resistant material. [**55:**11.4.3.1.1.2(A)]

(d) 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. [**55:**11.4.3.1.1.2(B)]

(B) Location. Tanks shall be located in accordance with 8.3.2.3.1.7(B)(1) through 8.3.2.3.1.7(B)(4). [**55:**11.4.3.2]

(1) Underground storage tanks shall not be located beneath buildings. [**55:**11.4.3.2.1]

(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. [**55:**11.4.3.2.2]

(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). [**55:**11.4.3.2.3]

(4) A minimum distance of 1 ft (0.3 m), shell to shell, shall be maintained between adjacent underground tanks. [**55:**11.4.3.2.4]

(C) Depth, Cover, and Fill.

(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. [**55:**11.4.3.3.1]

(2) The concrete shall extend a minimum of 1 ft (0.3 m) horizontally beyond the footprint of the tank in all directions. [**55:**11.4.3.3.2]

Table 8.3.2.3.1.6(A) Minimum Distance from Bulk Liquefied Hydrogen [LH_2] Systems to Exposures

	Total Bulk Liquefied Hydrogen [LH_2] 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
Type of Exposure	**ft**	**m**	**ft**	**m**	**ft**	**m**
Group 1						
1. Lot lines	25	7.6	50	15	75	23
2. Air intakes [heating, ventilating, or air conditioning equipment (HVAC, compressors, other]	75	23	75	23	75	23
3. Wall openings						
Operable openings in buildings and structures	75	23	75	23	75	23
4. Ignition sources such as open flames and welding	50	15	50	15	50	15
Group 2						
5. Places of public assembly	75	23	75	23	75	23
6. Parked cars (distance shall be measured from the container fill connection)	25	7.6	25	7.6	25	7.6
Group 3						
7. Building or structure						
(a) Buildings constructed of noncombustible or limited-combustible materials						
(1) Sprinklered building or structure or unsprinklered building or structure having noncombustible contents	5[a]	1.5	5[a]	1.5	5[a]	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[b]	5	1.5	5	1.5	5	1.5
(b) Buildings of combustible construction						
(1) Sprinklered building or structure	50	15	50	15	50	15
(2) Unsprinklered building or structure	50	15	75	23	100	30.5
8. Flammable gas storage or systems (other than hydrogen) above or below ground	50	15	75	23	75	23
9. Between stationary liquefied hydrogen containers	5	1.5	5	1.5	5	1.5
10. All classes of flammable and combustible liquids (above ground and vent or fill openings if below ground)[c]	50	15	75	23	100	30.5
11. Hazardous materials storage or systems including liquid oxygen storage and other oxidizers, above or below ground	75	23	75	23	75	23
12. Heavy timber, coal, or other slow-burning combustible solids	50	15	75	23	100	30.5
13. Wall openings						
Unopenable openings in buildings and structures	25	7.6	50	15	50	15
14. Inlet to underground sewers	5	1.5	5	1.5	5	1.5
15. Utilities overhead, including electric power, building services, or hazardous materials piping systems						
(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
16. Flammable gas metering and regulating stations above grade	15	4.6	15	4.6	15	4.6

[a] Portions of wall less than 10 ft (3.1 m) (measured horizontally) from any part of a system must have a fire resistance rating of not less than 1 hour.
[b] Exclusive of windows and doors.
[c] The separation distances for Class IIIB combustible liquids shall be permitted to be reduced to 15 ft (4.6 m).
[**55:** Table 11.3.2.2]

(3) Underground tanks shall be set on foundations constructed in accordance with the [adopted] building code and surrounded with not less than 6 in. (152 mm) of noncorrosive inert material. [**55:**11.4.3.3.3]
(4) The vertical extension of the vacuum jacket required for service connections shall be allowed to extend above grade. [**55:**11.4.3.3.4]

(D) Anchorage and Security. Tanks and systems shall be secured against accidental dislodgment due to seismic events or flooding. [**55:**11.4.3.4]

(1)*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 [adopted] building code. [**55:**8.13.2.5]
   (a) 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. [**55:**8.13.2.5.2]

(E) Venting of Underground Tanks. Vent pipes for underground storage tanks shall be in accordance with 8.3.1.2.2.3. [**55:**11.4.3.5]

(F) Underground LH_2 Piping.

(1) Underground [LH_2] piping shall be vacuum jacketed. [**55:**11.4.3.6.1]
(2) Unjacketed piping shall not be buried and shall exit the tank annular space above grade. [**55:**11.4.3.6.2]

(G) Overfill Protection and Prevention Systems. An approved means or method shall be provided to prevent the overfilling of storage tanks. [**55:**11.4.3.7]

(H) Vacuum Level Monitoring. An approved monitoring method shall be provided to indicate vacuum degradation within the vacuum jacket(s). [**55:**11.4.3.8]

(I) Physical Protection. Piping and control equipment ancillary to the underground tank located above ground shall be protected from physical damage in accordance with 8.1.7.5. [**55:**11.4.3.9]

(J) Tanks Not in Service.

(1)*Tanks not in service shall be maintained in accordance with 8.3.2.3.1.7(J). [**55:**11.4.3.10]
(2) Corrosion protection shall be maintained in operation. [**55:**11.4.3.10.1]

8.3.3 Bulk LH_2 Systems Use.

8.3.3.1 General.

8.3.3.1.1 General. Use [-] of containers and systems shall be in accordance with 8.3.3. [**55:**8.14.1]

8.3.3.1.2 Nationally Recognized Good Practices. Where nationally recognized good practices or codes and standards have been established for the process employed, such practices and codes and standards shall be followed.

8.3.3.1.3 Operating Instructions. Operating instructions shall be provided for installations that require the operation of equipment. [**55:**8.14.1.1]

8.3.3.1.4 Attended Delivery. A qualified person shall be in attendance at all times [LH_2 is] transferred from mobile supply units to a storage system. [**55:**8.14.1.2]

8.3.3.1.4.1 Cleaning and Purging of Gas Piping Systems. Cleaning and purging of piping systems shall be in accordance with Section 6.21.

8.3.3.1.5 Inspection.

8.3.3.1.5.1 [LH_2] storage systems shall be inspected and maintained by a qualified representative of the equipment owner [-]. [**55:**8.14.1.4.1]

(A) The interval between inspections [-] shall be based on nationally recognized good practices or standards. [**55:**8.14.1.4.1.1]

8.3.3.1.5.2 A record of the inspection shall be prepared and provided to the user or the authority having jurisdiction upon request. [**55:**8.14.1.4.2]

8.3.3.2 Indoor Use.

8.3.3.2.1 Filling and Dispensing.

8.3.3.2.1.1 General. Filling and dispensing of [LH_2] shall be in accordance with 8.3.3.1.4. [**55:**8.14.11.3.1]

8.3.3.2.1.2 Indoor Dispensing Areas. Dispensing indoors shall be conducted in areas constructed in accordance with the [adopted] building code. [**55:**8.14.11.3.2.1]

8.3.3.2.1.3 Ventilation. Indoor areas in which [LH_2] is dispensed shall be ventilated in accordance with the requirements of Section 6.17 and the [adopted mechanical code]. [**55:**8.14.11.3.2.2]

8.3.3.3 Outdoor Use. (Reserved)

8.3.4 Bulk LH_2 Systems Handling.

8.3.4.1 Bulk LH_2 Systems. Handling of [LH_2] containers shall be in accordance with 8.3.4. [**55:**8.14.11.4.1]

8.3.4.2 Carts and Trucks.

8.3.4.2.1 [LH_2] containers shall be moved using an approved method. [**55:**8.14.11.4.2.1]

8.3.4.2.2 Where [LH_2] containers are moved by hand cart, hand truck, or other mobile device, that device shall be designed for the secure movement of the container. [**55:**8.14.11.4.2.2]

8.3.4.3 Design. Carts and trucks used to transport [LH_2] 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. [**55:**8.14.11.4.3]

8.3.4.4 Closed Containers.

8.3.4.4.1 Pressurized containers shall be closed while being transported. [**55:**8.14.11.4.4.1]

8.3.4.4.2 Containers designed for use at atmospheric conditions shall be transported with appropriate loose-fitting covers in place to prevent spillage. [**55:**8.14.11.4.4.2]

8.3.4.5 Cargo Transport Unloading.

8.3.4.5.1 Personnel conducting transfer operations from the bulk transport vehicle shall be trained.

8.3.4.5.2 Unloading connections on delivery equipment shall not be positioned closer to any of the exposures cited in Table 8.3.2.3.1.6(A) than the distances given for the storage system. [**55:**11.5.1]

8.3.4.5.3 Prior to connection, a cargo transport vehicle's wheels shall be rendered immobile.

8.3.4.5.4 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. [**55:**11.5.2]

8.3.4.5.5 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. [**55:**11.5.3]

8.3.4.5.6 Mobile hydrogen supply units shall be electrically bonded to the storage system before hydrogen is discharged from the supply unit. [**55:**11.5.4]

8.3.4.5.7 The cargo transport vehicle's engine shall be shut off while the transfer hose or piping is being connected or disconnected. If required for LH_2 trailer pumping transfer, the engine pump drive motor shall be permitted to be started and used during the liquid transfer operations.

8.3.4.5.8 When transfers are made into fueling facility containers, the LH_2 shall be transferred at a pressure that shall not overpressurize the receiving tank.

8.3.4.5.9 The transfer piping shall be equipped with a check valve to prevent backflow from the container being filled to the transport vehicle.

8.3.4.5.10* When the tank to be filled is directly buried or installed in an inaccessible, sealed, and corrosion-resistant area that does not create a confined space as defined by applicable occupational safety and health regulations, the following shall apply:

(1) Controls shall be provided and visible to the operator to prevent overfilling of the tank
(2) The controls shall be provided in the unloading area and as a minimum shall include a liquid level indicator, pressure indicator, and a fill termination device

8.3.4.5.11 The transfer systems shall be capable of depressurizing to facilitate disconnection. Bleed connections shall be connected to a hydrogen venting system in accordance with 8.3.1.2.2.3. [**55:**11.5.5]

8.3.4.5.12 Prohibitions on smoking or the use of open flame shall be in accordance with 8.3.2.1.3. [**55:**11.5.7]

8.3.4.5.13 Sources of ignition shall not be permitted in the unloading area while transfer is in progress.

8.3.4.5.14 An emergency shutoff valve shall be provided in accordance with 8.1.14.1. [**55:**11.5.9]

8.3.4.6 Filling Controls. A pressure gauge and full trycock valve shall be provided and shall be visible from the delivery point to allow the delivery operator to monitor the internal pressure and liquid level of stationary containers during filling. [**55:**8.14.11.3.5]

8.3.4.6.1 When the containers being filled are remote from the delivery point and pressure gauges or full trycock valves are not visible, redundant gauges and valves shall be installed at the filling connection. [**55:**8.14.11.3.5.1]

Chapter 9 Explosion Protection (Reserved)

9.1 Reserved.

Chapter 10 GH_2 Vehicle Fueling Facilities

10.1 Scope. This chapter shall apply to the design, construction, and installation of GH_2 systems to be utilized for vehicle fueling.

10.1.1 Application. The requirements of this chapter shall apply to fueling operations, irrespective of the system capacity of either the fueling source or the vehicle being fueled.

10.1.1.1 Hydrogen dispensing systems for vehicular fueling shall comply with Chapter 10.

10.1.1.2 The storage, use, and handling of GH_2 in any quantity shall also comply with the requirements of Chapters 1 through 4 and the applicable requirements of Chapters 5 through 8.

10.1.1.3 Hydrogen generation systems shall be designed in accordance with Chapter 13.

10.1.1.4 Chapters 4, 6, and 7 contain fundamental requirements that shall apply to all GH_2 systems.

10.1.1.4.1 The use-specific requirements of this chapter for GH_2 fueling applications shall apply.

10.1.1.4.2 Where there is a conflict between a fundamental requirement and a use-specific requirement, the use-specific requirement shall apply.

10.2 General.

10.2.1 System Approvals.

10.2.1.1 Dispensing facilities shall be certified as meeting the requirements of this code by qualified engineer(s) with expertise and competence in the design, fabrication, and construction of hydrogen containers, piping systems, site fire protection, gaseous detection, emergency shutdown provisions, isolation, drainage, site spacing, fire protection equipment, operating procedures, worker protection, and other components of the facility.

10.2.1.2* A hazard analysis shall be conducted on every hydrogen fueling system installation by a qualified engineer(s) with proven expertise in hydrogen fueling systems, installations, and hazard analysis techniques.

10.3 Dispensing.

10.3.1 General.

10.3.1.1* System Component Qualifications. The following systems and system components shall be listed or approved:

(1) Pressure relief devices, including pressure relief valves
(2) Pressure gauges
(3) Pressure regulators
(4) Valves
(5) Hose and hose connections
(6) Vehicle fueling connections (nozzle)
(7) Electrical equipment used with GH_2 systems
(8) Gas detection equipment and alarms
(9) Hydrogen dispensers
(10) Pressure switches
(11) Flow meters
(12) Breakaway devices
(13) Dispenser enclosure

10.3.1.2 Devices not otherwise specifically provided for shall be constructed to provide safety equivalent to that required for other parts of a system.

10.3.1.3* Design and Construction of Cylinders, Containers, and Tanks.

10.3.1.3.1 Cylinders, containers, and tanks shall be fabricated, installed, and maintained in accordance with Chapters 6, 7, and 8 of this document.

10.3.1.4 Pressure Relief Devices.

10.3.1.4.1 Pressure relief valves for GH_2 service shall not be fitted with lifting devices.

10.3.1.4.1.1 The adjustment, if external, shall be provided with a means for sealing the adjustment to prevent tampering.

10.3.1.4.1.2 If at any time it is necessary to break such a seal, the valve shall be removed from service until it has been reset and sealed.

10.3.1.4.1.3 Adjustments shall be made only by the manufacturer or other companies having competent personnel and facilities for the repair, adjustment, and testing of such valves.

10.3.1.4.1.4 The organization making such adjustment shall attach a permanent tag with the setting, capacity, and date.

10.3.1.4.1.5 Pressure relief valves protecting ASME pressure vessels shall be repaired, adjusted, and tested in accordance with the ASME *Boiler and Pressure Vessel Code*.

10.3.1.4.2 Installation of Pressure Relief Devices on Dispensing Systems.

10.3.1.4.2.1 An overpressure protection device, other than a rupture disc, shall be installed in the fueling transfer system to prevent overpressure in the vehicle.

10.3.1.4.2.2 The set pressure of the overpressure protection device for the dispensing system shall not exceed 138 percent of the service pressure of the fueling nozzle it supplies.

10.3.1.4.2.3* Pressure relief devices installed on hydrogen dispensers shall exceed the full flow capacity of the dispenser supply.

10.3.1.4.2.4 A relief device is not required on a hydrogen dispenser if there are equivalent means of protecting for overpressure upstream of the dispenser.

10.3.1.4.3 Pressure relief valves shall be tested at least every 5 years.

10.3.1.4.3.1 Pressure relief devices designed and installed in accordance with 7.1.5.5.2 shall be examined and tested in accordance with the requirements of the applicable design standard.

(A) Pressure relief valves or reclosing pressure relief devices designed in accordance with CGA S-1.3, *Pressure Relief Device Standards—Part 3—Stationary Storage Containers for Compressed Gases,* shall be examined and tested at least every 5 years or as otherwise provided by the standard.

(B) Pressure relief devices designed and installed in accordance with 10.3.1.4.1.5 shall be examined and tested in accordance with the applicable requirements of the ASME *Boiler and Pressure Vessel Code*.

10.3.1.5 Pressure Gauges.

10.3.1.5.1 A pressure gauge, if provided, shall be capable of reading at least 1.2 times the system MAWP.

10.3.1.5.2 Installation of Pressure Gauges on Dispensing Systems. Gauges or other suitable readout devices shall be installed to indicate dispenser discharge pressure.

10.3.1.5.3 Pressure gauges shall be constructed such that the gauge will protect personnel under overpressure conditions (e.g., blow-out back or secondary containment and release).

10.3.1.6 Pressure Regulators.

10.3.1.6.1 A pressure regulator inlet and each chamber shall be designed for its service pressure with a safety factor of at least 3.

10.3.1.6.2 Low-pressure chambers shall provide for overpressure relief or shall be able to withstand the service pressure of the upstream pressure chamber.

10.3.1.6.3 Installation of Pressure Regulators on Dispensing Systems.

10.3.1.6.3.1 Components shall be designed, installed, or protected so their operation is not affected by freezing rain, sleet, snow, ice, mud, insects, or debris.

10.3.1.6.4 The regulator protection in 10.3.1.6.3.1 shall be permitted to be integral with the regulator.

10.3.1.7 Fuel Lines and Piping Systems.

10.3.1.7.1 Pipe, tubing, and fittings shall be suitable for hydrogen service and for maximum pressures and minimum and maximum temperatures.

10.3.1.7.1.1 Wetted piping, tubing, fittings, gaskets, and packing material shall be compatible with hydrogen service conditions.

10.3.1.7.1.2 Gray, ductile, and cast iron pipe and fittings shall not be used.

10.3.1.7.2 Pipe, tubing, fittings, and other components shall be designed with a minimum safety factor of 3.

10.3.1.7.3* Hydrogen gas piping shall be fabricated and tested in accordance with ANSI/ASME B31.3, *Process Piping*.

10.3.1.7.4 Piping joints made with tapered threaded pipe and sealant shall not be used downstream of the source valve in hydrogen service above 3000 psi (20.7 MPa).

10.3.1.7.4.1 Tapered joints shall be allowed on systems exceeding 3000 psi (20.7 MPa) under the following conditions:

(1) Where valves or instrumentation are not available with straight threads
(2) Where tapered joints are seal welded in accordance with the requirements of ANSI/ASME B31.3, *Process Piping*.

10.3.1.7.5 Piping components such as strainers, snubbers, and expansion joints shall be permanently marked by the manufacturer to indicate the service ratings.

10.3.1.7.6 Installation of Piping and Hoses on Dispensing Systems.

10.3.1.7.6.1 Piping and hose shall be run as directly as practical and with provisions to protect the piping from the effects of expansion, contraction, jarring, vibration, and settling.

10.3.1.7.6.2 Exterior piping shall be protected against mechanical damage.

10.3.1.7.6.3 A pipe thread jointing material impervious to the action of the hydrogen used in the system shall be applied to all male pipe threads prior to assembly.

10.3.1.7.6.4 Threaded piping and fittings shall be clear and free from cutting or threading burrs and scales, and the ends of all piping shall be reamed.

10.3.1.7.6.5* Mechanical connections in hydrogen piping shall not be buried.

10.3.1.7.6.6 A bend in piping or tubing shall have the pressure rating reduced according to ANSI/ASME B31.3, *Process Piping*.

10.3.1.7.6.7 Mechanical joints shall be located in an accessible location.

10.3.1.7.7* Hydrogen shall be vented in accordance with Section 6.16.

10.3.1.8 Hose and Hose Connections.

10.3.1.8.1 Hose shall be constructed of or lined with materials that are resistant to corrosion and exposure to hydrogen.

10.3.1.8.2 Hose, metallic hose, flexible metal hose, tubing, and their connections shall be designed or selected for the most severe pressures and temperatures expected under normal operating conditions with a burst pressure of at least three times the MAWP.

10.3.1.8.3 Prior to use, hose assemblies shall be tested by the component OEM or its designated representative at a pressure at least twice the maximum allowable pressure.

10.3.1.8.4 Hose and metallic hose shall be distinctly marked by the manufacturer, either by the manufacturer's permanently attached tag or by distinct markings indicating the manufacturer's name or trademark, applicable service identifier, design pressure, and flow direction.

10.3.1.8.5 The use of hose in a hydrogen dispensing system shall be limited to vehicle fueling hose.

10.3.1.8.5.1 Each section shall be installed so that it is protected against mechanical damage and accessible for inspection.

10.3.1.8.6 A breakaway device that causes hydrogen gas flow to stop shall be installed between the connection of the hose to the dispenser and the filling nozzle. Where a separate vent hose is used, the vent hose connection also shall be equipped with a breakaway device.

10.3.1.8.6.1 Such devices shall be arranged to separate using a force not greater than 150 lb (68 kg) when applied in any direction that the vehicle would move.

10.3.1.8.6.2 All other connections shall not prevent the operation of the gas flow breakaway devices.

10.3.1.9 Valves.

10.3.1.9.1 All system components shall be listed or approved for the hydrogen service pressures, internal and external temperatures, and operating environment of the hydrogen dispensing system.

10.3.1.9.1.1 Shutoff valves shall have a rated service pressure not less than the rated service pressure of the entire system and shall be designed with a minimum safety factor of 3.

10.3.1.9.1.2 Leakage shall not occur when tested in accordance with the requirements of ANSI/ASME B31.12, *Hydrogen Piping and Pipelines,* either pneumatically or hydrostatically. The test pressure shall be not less than 110 percent of the rated service pressure when tested pneumatically, using an inert gas as the medium, nor less than 150 percent of the rated service pressure when tested hydrostatically.

10.3.1.9.2 Valves of a design that allows the valve stem to be removed without removal of the complete valve bonnet or without disassembly of the valve body shall not be used.

10.3.1.10 System Testing.

10.3.1.10.1* Hydrogen dispensing systems shall be leak tested after final installation to prove them free from leaks at a pressure equal to at least the normal service pressure of that portion of the system.

10.3.1.10.2 This leak test shall be in addition to the ANSI/ASME B31.3, *Process Piping,* testing required by 10.3.1.7.3.

10.3.1.10.3 The assembly shall be leak tested using hydrogen or helium.

10.3.1.10.3.1 This leak test shall be conducted following any maintenance that involves breaking a connection or, at a minimum, annually.

10.3.1.10.4* Where hydrogen is to be used as the leak test media, the system shall first be purged with an inert gas to ensure that all oxygen is removed.

10.3.1.11 System Maintenance.

10.3.1.11.1 Hydrogen dispensing systems shall be maintained in accordance with the manufacturers' instructions.

10.3.1.11.2 Hose Assembly Maintenance.

10.3.1.11.2.1 Hoses, nozzles, and breakaways shall be examined according to the manufacturers' recommendations or at least monthly and shall be maintained in accordance with the manufacturers' instructions.

10.3.1.11.2.2 Hose shall be tested for leaks according to the manufacturer's requirements. Leakage or surface cracks shall be reason for rejection and replacement.

10.3.1.11.2.3 Testing shall be carried out using an inert gas as the test medium or where this is not practical, with hydrogen using suitable precautions.

10.3.1.11.3 Maintenance, Modification, and Calibration Documentation.

10.3.1.11.3.1 The hydrogen dispensing system operator (station owner, contractor, station operator, etc.) shall develop a management of change (MOC) system to ensure system modifications are documented and any necessary revisions to system documents are identified and marked completed (system documents can include hazard analysis, site plans, emergency procedures, first responder pre-plans, etc.).

10.3.1.11.3.2 Each hydrogen dispensing system shall indicate the last maintenance date and date of the next scheduled maintenance.

10.3.1.11.3.3 If testing is required, each hydrogen dispensing system shall indicate the last test date and the date of the next scheduled test.

10.3.1.11.3.4 If calibration is required, each hydrogen dispensing system shall indicate expiration date of the current calibration.

(A) The calibration indicator shall be readily visible to the hydrogen dispensing system user and shall not obscure other display functions of the dispenser.

10.3.1.11.4* Controllers on hydrogen dispensing systems shall be designed to verify the integrity of the fuel hose, breakaway, nozzle, and receptacle by pressurizing these components to at least the vehicle back pressure and monitoring pressure decay over a period of at least 5 seconds prior to the start of fueling.

10.3.1.11.5 Hydrogen dispensing integrity checks shall be as follows:

(1) Hydrogen fueling events of 350 bar shall have an integrity check repeated at 85 percent of the dispenser nozzle service pressure by stopping flow and checking the pressure decay over a period of 5 seconds.
(2) Hydrogen fueling events of 700 bar shall have an integrity check repeated at 45 percent and 85 percent of the dispenser nozzle service pressure by stopping flow and checking the pressure decay over a period of at least 5 seconds.

10.3.1.11.6* Maintenance personnel shall be trained in leak detection procedures.

10.3.1.11.7 Personnel performing maintenance on hydrogen installations shall be trained and wear personal protective equipment as prescribed in the material safety data sheets.

10.3.1.12 Hydrogen dispensing systems shall be protected to prevent damage from vehicles and to minimize physical damage and vandalism.

10.3.1.13 Vehicle Fueling Dispenser System Operation.

10.3.1.13.1 A hydrogen container shall not be charged in excess of the service pressure that is stamped on the container and displayed on a label near the filling connection when compensated for differences in temperature from 59°F (15°C).

10.3.1.13.1.1 A hydrogen container shall not be subjected to pressure in excess of 125 percent of its marked service pressure.

10.3.1.13.2 Communications Protocol.

10.3.1.13.2.1 Dispensers using a communications protocol to control the fueling shall abort the fill or revert to a noncommunication fueling strategy in the event of a communications failure.

10.3.1.13.3 GH_2 dispensing systems shall be equipped to stop fuel flow automatically when a fuel supply container reaches the temperature-corrected fill pressure.

10.3.1.13.4 Where an overpressure incident that results in operation of the overpressure protection system occurs, the dispenser pressure control system shall be examined and certified by a qualified technician prior to being returned to service.

10.3.1.13.5 The transfer of GH_2 into a fuel supply container shall be performed in accordance with instructions posted at the dispensing station.

10.3.1.13.6 Transfer systems shall be capable of depressurizing to facilitate disconnection.

10.3.1.13.7 Bleed connections shall lead to a safe point of discharge.

10.3.1.13.8 GH_2 shall not be used to operate any device or equipment that has not been designed or modified for GH_2 service.

10.3.1.13.9 Sources of ignition shall not be permitted within 10 ft (3.0 m) of any filling connection during a transfer operation.

10.3.1.13.10 A warning sign with the words "STOP MOTOR, NO SMOKING, FLAMMABLE GAS, HYDROGEN HAS NO ODOR" shall be posted at each dispenser.

10.3.1.13.10.1 The lettering on the sign shall be large enough to be visible and legible from each point of transfer.

10.3.1.13.11 Pneumatic gas supply systems for control devices shall be designed to prevent internal and external freezing. Fuel gas controls shall be installed to prevent external freezing.

10.3.1.13.12 Vehicles shall not be considered a source of ignition with respect to the provisions of this chapter.

10.3.1.13.12.1 Vehicles containing fuel-fired equipment (e.g., recreational vehicles and catering trucks) shall be considered a source of ignition unless this equipment is shut off completely before entering an area in which ignition sources are not permitted.

10.3.1.13.13 A means shall be provided to bring the system to a safe condition in the event of failure of the hydrogen dispensing system logic controller.

10.3.1.13.13.1 The means of protection shall stop the dispensing of hydrogen if the dispenser pressure or dispenser fuel temperature deviate from the operating parameters.

10.3.1.13.14 The dispenser gas temperature shall be measured as close to the hose breakaway as possible and shall not be less than −40°F (−40°C).

10.3.1.13.15 A dispenser shall only dispense hydrogen when the ambient temperature is between −40°F (−40°C) and 122°F (50°C).

10.3.1.13.16* The flowrate of a hydrogen dispenser for light duty vehicles shall not exceed 0.1323 lb (60 g) of hydrogen per second.

10.3.1.13.16.1 The limit of 0.1323 lb (60 g) per second does not include transient excursions due to valve actuation.

10.3.1.13.17 The dispenser shall not exceed the service pressure, temperature, or maximum fuel density of the container over the range of dispenser operating conditions.

10.3.1.14 Vehicle Fueling Connection.

10.3.1.14.1 Fueling nozzles for GH_2 service shall be listed or approved in accordance with SAE J2600, *Compressed Hydrogen Surface Refueling Connection Devices*.

10.3.1.14.2 The use of adapters shall be prohibited.

10.3.1.14.3 The fueling connection shall prevent the escape of gas where the connector is not properly engaged or becomes separated.

10.3.1.15 Installation of Electrical Equipment.

10.3.1.15.1 Fixed electrical equipment and wiring within areas specified in Table 10.3.1.15.1 shall comply with Table 10.3.1.15.1 and shall be installed in accordance with *NFPA 70*.

10.3.1.15.1.1 The electrical area classification shall not apply to vehicles.

10.3.1.15.2 With the approval of the authority having jurisdiction, the classified areas specified in Table 10.3.1.15.1 shall be permitted to be reduced or eliminated by positive pressure ventilation from a source of clean air or inert gas in conjunction with effective safeguards against ventilator failure by purging methods recognized in NFPA 496.

Table 10.3.1.15.1 Electrical Installations

Location	Division or Zone	Extent of Classified Area
Outdoor dispenser enclosure — exterior and interior	2	Up to 5 ft (1.5 m) from dispenser
Indoor dispenser enclosure — exterior and interior	2	15 ft (4.6 m) from the point of transfer in accordance with 10.3.3.2.2.3
Outdoor discharge from relief valves or vents	1	5 ft (1.5 m) from source
Outdoor discharge from relief valves or vents	2	15 ft (4.6 m) from source
Discharge from relief valves within 15 degrees of the line of discharge	1	15 ft (4.6 m) from source

10.3.1.15.2.1 Modifications shall be approved by a qualified engineer with expertise in fire safety and gaseous fuels.

10.3.1.15.3 Classified areas shall not extend beyond an unpierced wall, roof, or gastight partition.

10.3.1.15.4 Space around welded pipe and equipment without flanges, valves, or fittings shall be a nonhazardous location.

10.3.1.15.4.1 Listed dispensers shall be permitted to be installed using classified areas in accordance with the terms of the listing.

10.3.1.16 Stray or Impressed Currents and Bonding.

10.3.1.16.1* Where stray or impressed currents are used or can be present on dispensing systems, such as cathodic protection, protective measures to prevent ignition shall be taken.

10.3.1.16.2 Additional static protection shall not be required where GH_2 is transferred by conductive hose, flexible metallic tubing, or pipe connections where both halves of the metallic coupling are in continuous contact.

10.3.1.16.3 Vehicle fueling areas shall be constructed with a length and width to accommodate the types of vehicles to be fueled.

10.3.1.17 Installation of Emergency Shutdown Equipment.

10.3.1.17.1 Manually Operated Container Valve.

10.3.1.17.1.1 Each group of storage vessels up to a maximum combined capacity of 10,000 scf (283 m^3) shall be provided with a manually operated shutoff valve.

10.3.1.17.1.2 A manually operated shutoff valve shall be installed in a manifold as close to a container or group of containers as practical.

10.3.1.17.1.3 The valve in 10.3.1.17.1.2 shall be located downstream of the backflow check valve specified in 10.3.1.17.2.

10.3.1.17.2 The compressor discharge line supplying the storage container shall be equipped with a backflow check valve near the container to prevent discharge of hydrogen from the container in case of the rupture of the line, hose, or fittings.

10.3.1.17.3 Where excess-flow check valves are used, the closing flow shall be greater than the maximum system design flow rate and less than the flow rating of the piping system that results from a complete line failure between the excess-flow valve and the equipment downstream of the excess-flow check valve.

10.3.1.17.4 Gas piping from an outdoor compressor or storage system into a building shall be provided with an automatic emergency shutoff valve located outside the building.

10.3.1.17.5 An emergency manual shutdown device shall be provided at the dispensing area and also at a location remote from the dispensing area.

10.3.1.17.5.1 This device, when activated, shall shut off the power supply and gas supply from the hydrogen source to the dispenser.

10.3.1.17.5.2 When GH_2 is being produced from the conversion of LH_2, the emergency shutdown system also shall shut off the liquid supply and power to the LH_2 transfer equipment necessary for the conversion process.

10.3.1.17.5.3 Emergency shutdown devices shall be distinctly marked for easy recognition with a permanently affixed legible sign.

10.3.1.17.6 Control circuits shall be arranged so that, when an emergency shutdown device is activated or electric power is cut off, systems that shut down shall remain down until manually activated or reset after a safe condition is restored.

10.3.1.17.7 The emergency shutdown system shall include an automatic emergency shutoff valve at the hydrogen storage and supply system.

10.3.1.17.7.1 When supplying an indoor dispenser, a redundant automatic emergency shutoff shall be installed where the hydrogen piping enters the building.

(A) This valve shall be located outside.

(B) This valve shall shut when the dispensing area gas detection system actuates.

10.3.1.17.7.2 The automatic emergency shutdown valve(s) shall close when an emergency shutdown is activated.

10.3.1.17.7.3 This valve shall be fail closed.

10.3.1.18* Fire Protection. A portable fire extinguisher having a rating of not less than 20-B:C shall be provided at the dispensing area in approved locations not more than 50 ft (15.2 m) away from the dispensing area. Fire extinguishers shall be inspected and maintained according to NFPA 10.

10.3.1.18.1 Dispensing equipment shall be provided with hydrogen gas detection, leak detection, and flame detection at the fueling area.

10.3.1.18.1.1 The detection systems shall be maintained and calibrated in accordance with Chapter 6.

10.3.1.18.1.2 The station owner or operator shall maintain a record of detector maintenance and calibration in good condition and accessible to the inspector.

10.3.1.18.1.3 Activation of the detection systems shall automatically stop dispensing and activate the automatic emergency shutoff valve. Reactivation of the dispenser requires a manual restart following the provisions of this chapter.

10.3.1.18.1.4 Dispenser enclosure shall be designed to prevent the accumulation of flammable gas within the enclosure.

10.3.1.19 Canopies Used to Support Gaseous Hydrogen Systems. Canopies that are used to shelter dispensing operations where flammable compressed gases are located on the roof of the canopy shall be in accordance with the following:

(1) The canopy shall meet or exceed Type I construction requirements of the adopted building code.
(2) Operations located under canopies shall be limited to refueling only.
(3) The canopy shall be constructed in a manner that prevents the accumulation of hydrogen gas.

10.3.2 Dispensing to the Public.

10.3.2.1 General.

10.3.2.1.1 GH_2 compression, hydrogen generation equipment, storage, and dispensing shall be located and conducted outdoors or indoors in compliance with this section.

10.3.2.1.1.1 Compression, gas processing, dispensing equipment, and storage containers connected for use shall be permitted to be located inside of buildings reserved exclusively for these purposes or in rooms within or attached to buildings used for other purposes in accordance with 10.3.2.2.

10.3.2.1.1.2 Dispensing equipment is to be installed on foundations with anchoring systems designed to meet the requirements of the adopted building code for the appropriate seismic and wind conditions.

10.3.2.2 Indoor Public Fueling. (Reserved)

10.3.2.2.1 Indoor Public Full Service Fueling. (Reserved)

10.3.2.2.2 Indoor Public Attended Self Service Fueling. (Reserved)

10.3.2.2.3 Indoor Public Unattended Self Service Fueling. (Reserved)

10.3.2.3 Outdoor Public Fueling.

10.3.2.3.1 General.

10.3.2.3.1.1 A facility in which GH_2 compression, gas processing, hydrogen generation equipment, storage, and dispensing equipment are sheltered by an enclosure that is constructed as weather protection in accordance with Section 6.6 with a roof designed for ventilation and dispersal of escaped gas shall be considered to be located outdoors.

10.3.2.3.1.2 Aboveground installations shall include systems installed overhead on appropriately engineered structures.

10.3.2.3.1.3* The vehicle fueling pad shall be of concrete or a material having a resistivity not exceeding 1 megaohm as determined by an approved method unless the vehicle is grounded by other means, such as a grounding cable.

10.3.2.3.1.4 The outdoor installation of hydrogen dispensers shall meet the separation distances shown in Table 10.3.2.3.1.4.

10.3.2.3.1.5 The point of transfer shall be permitted to be located at a lesser distance from buildings or walls constructed of concrete or masonry materials or of other material having a fire resistance rating of at least 2 hours, but at least 10 ft (3.0 m) from any building openings.

10.3.2.3.1.6 Dispensing points shall be permitted to be located at a lesser distance from buildings or walls constructed of materials having a fire resistance rating of not less than 2 hours, but at least 10 ft (3.0 m) from building openings.

Table 10.3.2.3.1.4 Separation Distances for Outdoor Gaseous Hydrogen Dispensing Systems

System Component	Exposure	Required Separation ft	Required Separation m
Dispensing equipment	Nearest important building or line of adjoining property that can be built upon or from any source of ignition	10	3.0
Dispensing equipment	Nearest public street or public sidewalk	10	3.0
Dispensing equipment	Nearest rail of any railroad main track	10	3.0
Point of transfer	Any important building other than buildings of Type I or Type II construction with exterior walls having a fire resistance rating of not less than not less than 2 hours	10	3.0
Point of transfer	Buildings of Type I or II construction with exterior walls having a fire resistance rating of not less than 2 hours or walls constructed of concrete or masonry, or of other material having a fire resistance rating of not less than 2 hours	No limit	No limit
Point of transfer	Storage containers	3	1.0

10.3.2.3.2 Outdoor Public Full Service Fueling.

10.3.2.3.3 Outdoor Public Attended Self Service Fueling. (Reserved)

10.3.2.3.4 Outdoor Public Unattended Self Service Fueling. (Reserved)

10.3.3 Dispensing to Nonpublic Users.

10.3.3.1 General. (Reserved)

10.3.3.2 Indoor Nonpublic Fueling.

10.3.3.2.1 General. Indoor dispensing to nonpublic users shall meet the provisions of 10.3.3.2.

10.3.3.2.1.1 Vehicle Fueling Appliances in Nonresidential Occupancies.

(A) Vehicle fueling appliances (VFAs) shall not exceed a gas flow of 36 scf/min (1.0 SCM/min).

(B) VFAs shall be listed.

(C) The installation of VFAs shall be in accordance with the manufacturer's instructions and the listing.

(D) VFAs shall be permitted to be used to fill stationary containers at vehicle fueling locations.

(E) The method of connecting the VFA to such storage shall be in accordance with the manufacturer's instructions and the listing.

(F) The provisions of 10.3.3.2.1.1(B) shall apply to the VFA where connected to stationary containers at vehicle fueling locations.

(G) Where installed indoors in public assembly and educational occupancies, a VFA shall be located in a portion of the occupancy where NFPA *101* or the local adopted building code permits the installation of hazardous equipment.

(1) Where the VFA is located outdoors, the dispensing point shall be permitted to be located indoors without the need for a separate room.

(H) VFAs shall not be installed within 10 ft (3.0 m) of any flammable gas or liquid storage.

(1) Storage in the vehicle fuel supply container.

10.3.3.2.1.2 GH_2 compression, hydrogen generation equipment, storage, and dispensing shall be located and conducted outdoors or indoors in compliance with this section.

(A) Compression, gas processing, dispensing equipment, and storage containers connected for use shall be permitted to be located inside of buildings reserved exclusively for these purposes or in rooms within or attached to buildings used for other purposes in accordance with 10.3.2.2.

(B) Dispensing equipment is to be installed on foundations with anchoring systems designed to meet the requirements of the adopted building code for the appropriate seismic and wind conditions. [**52:**9.3.1.2]

10.3.3.2.2 General.

10.3.3.2.2.1 Dispensing. Fuel dispensing indoors shall be in accordance with 10.3.3.2.

10.3.3.2.2.2 Deflagration Venting. When used, deflagration (explosion) venting shall be provided in exterior walls and roofs only.

10.3.3.2.2.3 Vents shall be permitted to consist of any one or any combination of the following:

(1) Walls of light material
(2) Lightly fastened hatch covers
(3) Lightly fastened, outward opening doors in exterior walls
(4) Lightly fastened walls or roofs
(5) Other methods in accordance with NFPA 69

10.3.3.2.2.4 Where applicable, snow loads shall be included in the calculations of the building venting system.

10.3.3.2.2.5 Rooms Within Buildings. Rooms within or attached to other buildings shall be constructed of noncombustible or limited-combustible materials.
Exception: Window glazing shall be permitted to be plastic.

(A) Interior walls or partitions shall be continuous from floor to ceiling, shall be anchored, and shall have a fire resistance rating of at least 2 hours.

(B) At least one wall shall be an exterior wall.

(C) Explosion venting shall be provided in accordance with 10.3.3.2.2.2 and 10.3.3.2.2.3.

(D) Access to the room shall be from outside the primary structure.

(E) If access to the room from outside the primary structure is not possible, access from within the primary structure shall be permitted where such access is made through a vapor-sealing, self-closing fire door having the appropriate rating for the location where installed.

10.3.3.2.2.6 Ventilation.

(A) Indoor locations shall be ventilated utilizing air supply inlets and exhaust outlets arranged to provide uniform air movement to the extent practical.

(B) Inlets shall be uniformly arranged on exterior walls near floor level.

(C) Outlets shall be located in exterior walls at the high point of the room or in the roof.

10.3.3.2.2.7 Room Ventilation.

(A) Ventilation shall be by a continuous mechanical ventilation system or by a mechanical ventilation system activated by a continuously monitoring hydrogen detection system where a gas concentration of not more than one-quarter of the lower flammable limit is present.

(B) In either case in 10.3.3.2.2.6(D)(1), the system shall immediately shut down the fueling system in the event of detection of an alarm condition or failure of the ventilation system, the detection system, or of the controls.

10.3.3.2.2.8 The ventilation rate shall be at least 1 $ft^3/min/ft^2$ (0.3 $m^3/min/m^2$) of room area, but no less than 1 $ft^3/min/12\ ft^3$ (0.03 $m^3/min/0.34\ m^3$) of room volume.

10.3.3.2.2.9 A ventilation system for a room within or attached to another building shall be separate from any ventilation system for the other building.

10.3.3.2.2.10 Where installed, a gas detection system shall be equipped to sound a latched alarm and visually indicate when a maximum of one-quarter of the lower flammable limit is reached.

(A) The gas detection system shall be certified by a qualified engineer with expertise in fire safety and gaseous detection.

10.3.3.2.2.11 The gas detection system shall function during system maintenance operations.

10.3.3.2.2.12 Reactivation of the fueling system shall be by manual restart and shall be conducted by trained personnel.

10.3.3.2.2.13 Buildings and rooms used for compression other than that integral to the bulk storage system, gas processing, and dispensing shall be classified in accordance with Table 10.3.1.15.1 for installations of electrical equipment.

10.3.3.2.2.14 Nonelectrical sources of ignition, other than electrical installations as permitted by Table 10.3.1.15.1, shall not be permitted.

10.3.3.2.2.15 Warning Signs.

(A) Access doors shall have warning signs with the words "WARNING — NO SMOKING — FLAMMABLE GAS." "HYDROGEN HAS NO ODOR."

(B) The wording shall be in plainly legible, bright red letters not less than 1 in. (25 mm) high on a white background.

10.3.3.2.2.16 Construction of Indoor Areas. Walls, ceilings, and floors within 15 feet (4.6 m) of the dispenser shall be constructed as fire barriers having a fire resistance rating not less than 2 hours.

(A) Openings. Opening protectives shall be provided for wall openings in accordance with the requirements of the adopted building code.

(B) Penetrations. Through-penetrations and membrane penetrations of fire resistance rated construction shall be protected in accordance with the requirements of the adopted building code.

(C) Roof-Ceiling Assemblies. The fire-resistive protection of a roof-ceiling assembly required by 10.3.3.2.2.16 shall not be required where every part of the roof-ceiling assembly is 20 ft (6.1 m) or more above any floor immediately below.

(D) Floors. Floors in dispensing areas constructed of noncombustible or limited-combustible materials shall not be required to comply with 10.3.3.2.2.16.

10.3.3.2.3* Indoor Nonpublic Fast-Fill Fueling.

10.3.3.2.3.1 Fast-fill fueling indoors shall be permitted where storage, gas processing, and compression equipment is located outdoors complying with 10.3.2.3.1.1 through 10.3.2.3.1.6.

10.3.3.2.3.2 Ventilation.

(A) Ventilation shall be in accordance with 10.3.3.2.2.6.

(B) The ventilation system of 10.3.3.2.2.6 shall not be required in industrial and storage occupancies when the room or area in which dispensing occurs is in accordance with the following:

(1) The minimum volume of the room in which a dispenser is installed shall be not less than 180,000 ft^3 (5000 m^3), and the maximum quantity of fuel to be dispensed per fueling event shall be limited to 9.2 lb (4.2 kg).
(2) The dispenser shall be equipped with an automatic shutoff control to shut down the source of fuel when the maximum fuel quantity per dispensing event is reached or when the vehicle has been fueled to capacity, whichever is less.
    (a) The shutoff control shall be tested at installation and annually thereafter.
    (b) Failure of the controller shall shut down the dispensing system.
(3) When multiple dispensers are installed in a room, the minimum room volume shall be incrementally increased for each additional dispenser.
(4) The height of the ceiling of the room where dispensing occurs shall be not less than 25 ft (8 m).
(5) The maximum refueling rate shall be limited to not more than 2.2 lb/min (1 kg/min), and the flow limiting device shall be installed outdoors.
(6) All potential leak points between the dispenser cabinet and the refueling nozzle shall be monitored by the dispenser in accordance with 10.3.1.11.4 and 10.3.1.11.5. Activation of the monitoring system shall shut down the dispensing system.
(7) The fueling hose shall be limited to a maximum length of 25 ft (7.6 m) and shall be protected from mechanical damage, from abrasion, and from being driven over by a vehicle.
    (a) Transfer systems shall be capable of depressurizing the nozzle through the dispenser vent line to facilitate disconnection.
(8) The dispensing area shall be inspected annually and certified in accordance with 10.1.1.1.

10.3.3.2.3.3 The electrical area classification for the dispenser shall be Class 1 Division 2 within 15 ft (4.6 m) of the point of transfer during filling.

(A) The classified area shall extend outwards from the point of dispensing in the shape of a cylinder with a radius of 15 ft (4.6 m) that extends from the floor to the ceiling.

(B) The electrical area classification shall not apply to vehicles.

10.3.3.2.3.4 Fire Detection System. The dispensing room or area shall be equipped with a fire detection system.

(A) Actuation of the fire detection system shall shut down the gas flow from the dispenser and stop the flow of gas into the piping system located in the room where dispensing occurs.

(B) Actuation of the fire detection system shall sound a local fire alarm signal to alert building occupants of a fire in the dispensing area and shall provide a visual indication in the dispensing area of an alarm condition.

(C) The fire detection system shall be maintained in an operational condition when the dispenser is either operating or being maintained.

(1) An interlock shall be provided so that the dispenser will not operate if the fire alarm is not operational.

10.3.3.2.3.5 Fire Alarm System. The dispensing area shall be equipped with a protected premises (local) fire alarm system in accordance with *NFPA 72*.

(A) Manual Fire Alarm Boxes. A manual fire alarm box shall be located not less than 20 ft (6.1 m) and not more than 100 ft (30.5 m) from the dispensing station.

(1) An additional manual fire alarm box shall be located at the nearest exit from the dispensing area.
(2) Activation of the fire alarm box shall sound a local fire alarm signal to alert building occupants of a fire in the dispensing area and shall shut down the dispenser, stop the flow of gas into the room, and start or continue to run the ventilation system.

10.3.3.2.3.6 Emergency Shutdown Device (ESD). A manual emergency shutdown device (ESD) shall be located in the dispensing area not less than 20 ft (6.1 m) and not more than 100 ft (30.5 m) in the path of egress from the dispensing area.

(A) An additional shutdown shall be installed on the dispenser.

(B) Actuation of the ESD shall shut down the dispenser, stop the flow of gas into the room, and start or continue to run the ventilation system.

10.3.3.2.3.7 Dispensing Equipment. Gas dispensing equipment shall be listed or approved for indoor use.

(A) Automatic Shutoff Valve. Hydrogen gas piping used to transport GH_2 between the bulk hydrogen compressed gas storage system and a dispenser at a fast-fill station shall have a valve that closes when one of the following occurs:

(1) The power supply to the dispenser is shut off.
(2) Any emergency shutdown device at the refueling station is activated.

(B) Manual Shutoff Valve. A fast-closing, "quarter turn" manual shutoff valve shall be provided at a fast-fill station upstream of the breakaway device specified in 10.3.3.3.4.3(H)(1), where it is readily accessible to the person dispensing hydrogen, unless one of the following occurs:

(1) The self-closing valve referred to in 10.3.3.2.3.7(A) is located immediately upstream of the dispenser.
(2) The dispenser is equipped with a self-closing valve that closes each time the control arm is turned to the OFF position or when the ESD is activated.

(C) Shutdown. Actuation or failure of the following systems shall automatically shut down the gas flow from the dispenser, stop the flow of gas to the room, and start or continue to run the mechanical ventilation system when mechanical ventilation systems are required:

(1) Gas detection system
(2) Fire alarm system
(3) Fire detection system
(4) Emergency shutdown system (ESD)
(5) Sensors or controls used to prevent overtemperature or overpressurization of the on-board fuel container
(6) Required ventilation systems
(7) Dispenser leak monitoring system

(D) Reactivation. Reactivation of the dispenser and gas flow into the room after system shutdown required by 10.3.3.2.3.7(A) or 10.3.3.2.3.7(C) shall be by manual restart and shall be conducted by trained personnel.

(E) Gas Detection System. The dispenser enclosure or housing shall be equipped with a gas detection system that shall actuate when a maximum of 25 percent of the lower flammable limit (LFL) is detected (1 percent H_2 in air).

(1) Actuation of the gas detection system shall shut down the dispenser, stop the flow of gas into the room, and start or continue to run the ventilation system when mechanical ventilation systems are required.
(2) Actuation of the gas detection system shall sound a local alarm and provide visual indication when a maximum of 25 percent of the lower flammable limit (LFL) is detected (1 percent H_2 in air).
(3) The gas detection system shall remain functional during maintenance operations on the ventilation system.

(F) Electrical. Electrical equipment on dispensers shall be in accordance with 10.3.3.2.2.13.

(G) Temperature Limits. Dispensing systems shall be provided with a means to prevent the on-board fuel system from exceeding prescribed temperature limits during fueling operations.

(H) Pressure Limits. Dispensing systems shall be provided with a means to prevent the on-board fuel system from exceeding prescribed pressure limits during fueling operations.

(I) Ignition Source Control. The owner/operator shall not allow hot work/ open flames within 15 ft (4.6 m) of the refueling location unless the dispenser is shut down, depressurized, and purged with an inert gas.

(J) Defueling. If GH_2 is to be removed from the vehicle storage system, GH_2 shall be discharged into a closed transfer system or vented outdoors through a vent pipe system installed and constructed in accordance with CGA G-5.5, *Hydrogen Vent Systems*.

10.3.3.2.4 Indoor Nonpublic Slow Fill Fueling. (Reserved)

10.3.3.2.5 Indoor Nonpublic Residential Fueling. (Reserved)

10.3.3.3 Outdoor Nonpublic Fueling.

10.3.3.3.1 General. Outdoor, nonpublic fueling installations shall meet the requirements of 10.3.2.3.1.

10.3.3.3.2 Outdoor Nonpublic Fast-Fill Fueling. (Reserved)

10.3.3.3.3 Outdoor Nonpublic Slow-Fill Fueling. (Reserved)

10.3.3.3.4 Outdoor Nonpublic Residential Fueling (RFF-GH_2).

10.3.3.3.4.1 Application. This section applies to the design, construction, installation, and operation of an RFF-GH_2.

10.3.3.3.4.2 The RFF-GH_2 shall store GH_2 outdoors.

10.3.3.3.4.3 System Component Qualifications. System components not part of a listed vehicle fueling appliance shall comply with the appropriate provisions of Section 10.3.

(A) Vehicle Fueling Appliances. Vehicle fueling appliances shall be listed.

(1) VFAs shall be installed, operated, and maintained in accordance with the manufacturer's instructions and the listing.

(B) General Safety Requirements. All equipment related to RFF-GH_2 installation shall be protected to minimize the possibilities of physical damage and vandalism.

(1) The use of an enclosure for the compressor package, similar to that of a central air conditioner, shall be permitted to satisfy the requirement of 10.3.3.3.4.3(B).
(2) All equipment related to RFF-GH_2 installation shall be designed for the pressure, temperature, and service of the system.
(3) Vehicles shall be considered as unclassified electrically with respect to *NFPA 70*, Article 500.
(4) Vehicles containing fuel-fired equipment, such as recreational vehicles, shall be considered a source of ignition unless this equipment is shut off completely before entering an area in which ignition sources shall not be permitted.
(5) Unless specifically permitted in the recommendations of the manufacturers, multiple RFF-GH_2s shall not be manifolded together on the discharge side.
(6) Where more than one RFF-GH_2 is located in a common area, spacing between the RFF-GH_2s shall not be less than 3 ft (1 m) unless permitted by the installation instructions of the manufacturers.

(C) Installation.

(1) **General.** The RFF-GH_2 shall be installed outdoors and shall be installed, operated, and maintained in accordance with the manufacturer's instructions.
(2) **Markings.** The RFF-GH_2 shall have a nameplate marked with minimum and maximum gas inlet pressures and flow rates, gas outlet maximum pressure, and electrical requirements.

(D) Piping and Hose. The use of hose in an installation shall be restricted to the following:

(1) A fueling hose that is limited to a maximum length of 25 ft (7.6 m) and is protected from mechanical damage from abrasion and from being driven over by a vehicle.

(2) A maximum of 3 ft (1 m) in length where used to prevent abrasion damage resulting from vibration on the inlet, outlet, or both.
(3) Transfer systems shall be capable of depressurizing the nozzle to facilitate disconnection.
(4) Bleed connections shall lead to a safe point of discharge.

(E) Installation of pressure relief valves shall have pressure relief device vents or vent lines to convey escaping gas to the outdoors and then upward to a safe area to prevent impinging on buildings, other equipment, or areas open to the public, such as sidewalks.

(F) Testing. All piping and tubing shall be tested after assembly according to 10.3.1.10.

(1) Integral piping and tubing provided as part of a listed VFA shall not be required to be tested according to 10.3.1.10.

(G) Installation of Emergency Shutdown Equipment. An RFF-GH_2 shall be equipped with emergency manual shut down of the fuel supply and electrical supply prior to the RFF-GH_2 device.

(1) The emergency manual shutdown actuator shall be at least 5 ft (1.52 m) from the RFF-GH_2 and in view of the RFF-GH_2.

(H) Breakaway Protection. Breakaway protection shall be provided in a manner so that, in the event of a pull away, GH_2 ceases to flow.

(1) A breakaway device shall be installed at every dispensing point.
(2) The breakaway device in 10.3.3.3.4.3(H)(1) shall be arranged to separate using a force not greater than 150 lb (68 kg) when applied in a horizontal direction.

(I) Operation. An RFF-GH_2 shall be operated in accordance with the instructions of the manufacturer.

(1) A fuel supply container shall not be charged in excess of its maximum allowable service pressure at normal temperature.
(2) DOT and TC containers shall be charged in accordance with DOT and TC regulations.
(3) Where GH_2 is being transferred to a motor vehicle, the engine shall be turned off.

(J) Maintenance and Inspection. All RFF-GH_2 equipment shall be inspected and maintained in accordance with the instructions of the manufacturer.

(1) After installation, all hose shall be examined visually as part of this inspection.
(2) Hose that is kinked or worn shall be replaced.
(3) All safety relief valves shall be maintained in operating condition in accordance with the recommendations of the manufacturer.

10.3.3.3.5 Outdoor Nonpublic Refueling from Transport Vehicles.

10.3.3.3.5.1 Mobile refueling vehicles, temporary trailers (with or without tractors), and other means of providing vehicle refueling or onsite storage shall be subject to the same requirements as a permanent refueling or storage installation, with the exception of vessel requirements.

10.3.3.3.5.2 The dispensing of GH_2 in the open from a transport vehicle to a motor vehicle located at a separate fleet fueling area in connection with commercial, industrial, governmental, or manufacturing establishments and intended for fueling vehicles used in connection with their businesses shall be permitted if all of the requirements of 10.3.3.3.5.2(A) through 10.3.3.3.5.2(K) have been met.

(A) The AHJ shall be notified before commencing operations, and permitting sought if required, under 10.3.3.3.5.

(B) The transport vehicle shall comply with U.S. DOT requirements for the transportation of GH_2.

(C) Nighttime deliveries shall only be made in an area considered to be adequately lighted.

(D) Smoking materials, including matches, lighters, and other sources of ignition, including torches, shall not be used within 20 ft (6.1 m) of the dispensing of GH_2 in the open from a transport vehicle to a motor vehicle.

(E) Each area where dispensing of GH_2 in the open from a transport vehicle to a motor vehicle shall be provided with one or more listed fire extinguishers that have a minimum capability of 40-B:C.

(1) The fire extinguishers shall be within the dispensing operation.
(2) Fire extinguishers shall be inspected and maintained under NFPA 10.

(F) Transport vehicle brakes shall be set and chock blocks shall be in place.

(G) Persons performing dispensing operations shall be qualified to deliver and dispense GH_2 fuels.

(H) Operators of transport vehicles used for mobile fueling operations shall have access on site or be in possession of an emergency communications device to notify the authorities in the event of an emergency.

(I) The transport vehicles shall be positioned with respect to vehicles being fueled to prevent traffic from driving over the delivery hose and between the transport vehicle and motor vehicle being fueled.

(J) The dispensing hose shall be properly placed on an approved reel or in an approved compartment before moving the transport vehicle.

(K) Additional requirements. The transfer area shall meet the requirements of 10.3.1.16.3.

10.4 Storage.

10.4.1 General. The storage of GH_2 in bulk and nonbulk gas installations shall be in accordance with the applicable requirements of Chapters 6 and 7.

10.4.2 Indoor Storage.

10.4.2.1* Storage in Buildings. Bulk hydrogen compressed gas systems shall be in accordance with the applicable requirements of Chapters 6 and 7.

10.4.2.1.1 GH_2 stored in vehicle-mounted fuel supply containers.

10.4.3 Outdoor Storage. (Reserved)

10.4.4 Vaults for Aboveground Containers. (Reserved)

10.4.5 Underground Storage Systems. (Reserved)

Chapter 11 LH_2 Fueling Facilities

11.1 Scope. This chapter applies to the design, siting, construction, installation, and operation of containers, pressure vessels, pumps, vaporization equipment, and associated equipment used for the storage or dispensing of LH_2 as an engine fuel for vehicles of all types.

11.1.1 Application. This chapter shall apply to the storage, use, and handling of LH_2 in connection with self-propelled vehicles powered by hydrogen.

11.1.1.1 The storage, use, and handling of LH_2 in connection with self-propelled vehicles powered by hydrogen shall also comply with the requirements of Chapters 1 through 4 and the applicable requirements of Chapters 5 through 8.

11.1.1.2 Chapters 4 and 6 through 8 contain fundamental requirements that shall apply to all hydrogen systems.

11.1.1.2.1 The use-specific requirements of this chapter for the storage, use, and handling of LH_2 shall apply.

11.1.1.2.2 Where there is a conflict between a fundamental requirement and a use-specific requirement, the use-specific requirement shall apply.

11.1.1.3 The requirements of Chapter 11 shall be applicable to LH_2 systems only. When LH_2 is converted to GH_2, those portions of the system utilized for GH_2 shall be in accordance with Chapter 10.

11.2 General.

11.2.1 Hazard Analysis. All hydrogen refueling station sites shall have a complete HAZOP or process safety analysis prior to dispensing fuel.

11.2.1.1 The hazard analysis shall be updated when changes to the process affect operating limits or design specifications that were included as the basis for the original hazard analysis.

11.2.2 Security. LH_2 dispensers shall be designed to secure all equipment from tampering.

11.2.3 Operating Instructions. Operating instructions identifying the location and operation of emergency controls shall be posted conspicuously in the facility area.

11.2.4 Lighting. LH_2 dispensing areas transferring LH_2 during the night shall have permanent lighting at points of transfer and operation.

11.2.4.1 The lighting shall be designed to provide illumination of the dispensing apparatus and dispensing area, such that all controls including emergency shutdown devices are visible to the operator.

11.2.5 Personnel Protection. LH_2 refueling sites utilizing or dispensing LH_2 shall provide personnel protection barriers such as walls, cabinets, vacuum-jacketed pipe, and similar barriers to protect the fueling operator and the vehicle being fueled from contact with a release of LH_2. All facility piping other than the refueling line to the vehicle shall be behind the barrier, to deflect any LH_2 that is released due to an equipment malfunction.

11.2.6 Sources of Ignition. Smoking materials, including matches and lighters, shall not be used within [25 ft (7.6 m)] of areas used for fueling, servicing fuel systems of internal combustion engines, or receiving or dispensing of [LH_2]. The motors of all equipment being fueled shall be shut off during the fueling operation except for emergency generators, pumps, [pagers], and so forth, where continuing operation is essential. [**30A:**9.2.5.1]

11.2.7 Fire Extinguishers. Each motor fuel dispensing facility or repair garage shall be provided with fire extinguishers installed, inspected, and maintained as required by NFPA 10. Extinguishers for outside motor fuel dispensing areas shall be provided according to the extra (high) hazard requirements for Class B hazards, except that the maximum travel distance to a 80 B:C extinguisher shall be permitted to be 100 ft (30.48 m). [**30A:**9.2.5.2]

11.2.8 Piping, Tubing, and Fittings.

11.2.8.1 Pipe, tubing, and fittings shall be designed for hydrogen service and for maximum pressures and minimum and maximum temperatures.

11.2.8.1.1 Pipe, tubing, fittings, gaskets, and packing material shall be compatible with the fuel under service conditions.

11.2.8.1.2 Pipe, valves, and fittings fabricated from cast iron or carbon steel shall not be used.

11.2.8.2 Pipe, tubing, fittings, and other components shall be designed with a minimum safety factor of 3.

11.2.8.3 Hydrogen gas piping shall be fabricated and tested in accordance with ANSI/ASME B31.3, *Process Piping*.

11.2.8.4 Piping components such as strainers, snubbers, and expansion joints shall be permanently marked by the manufacturer to indicate the service ratings.

11.2.8.5 Installation of Piping and Hoses on Dispensing Systems.

11.2.8.5.1 Piping and hose shall be protected from the effects of expansion, contraction, jarring, vibration, and settling.

11.2.8.5.2 Manifolds connecting fuel containers shall be fabricated to minimize vibration and shall be installed in a protected location or shielded to prevent damage from unsecured objects.

11.2.8.5.3 Joints or connections shall be located in an accessible location.

11.2.8.5.4 The number of joints shall be minimized and placed in a location considering hazards to personnel safety.

11.2.8.5.5 Hydrogen shall be vented in accordance with Section 6.16.

11.2.9 Piping Systems and Components. Piping shall be in accordance with 8.1.4.

11.2.10 Pressure Relief Devices — Vaporizers. The discharge from pressure relief devices serving the vaporizer system shall be connected to a vent pipe system.

11.2.11 Instrumentation.

11.2.11.1* Emergency Shutdown Device (ESD). All ESDs shall be of a type requiring that they be manually reset.

11.2.11.2* Pressure Gauges. Pressure monitoring systems or indicating devices shall be capable of reading at least 1.2 times the system maximum allowable working pressure (MAWP).

11.2.12 Electrical Equipment.

11.2.12.1 Electrical equipment and wiring shall be as specified by and shall be installed in accordance with *NFPA 70* and shall meet the requirements of Class I, Group B, Division or Zone as specified in Table 11.2.12.1.

Table 11.2.12.1 LH_2 Fueling Facility Electrical Area Classification

Part	Location	Class I, Group B Division or Zone[a]	Extent of Classified Area[b]
A	Pits, trenches, or sumps located in or adjacent to Division 1 or 2 areas	1	Entire pit, trench, or sump
B	Discharge from relief valves, drains	1	Within 5 ft (1.5 m) from point of discharge
		2	Beyond 5 ft (1.5 m) but within 25 ft (7.6 m) in all directions from point of discharge
C	Vehicle/cargo transfer area		
	Outdoors in open air at or above grade	1	Within 3 ft (1 m) of connection
	Points where connections to the hydrogen system are regularly made and disconnected[c]	2	Between 3 ft (1 m) and 25 ft (7.6 m) of connection

[a]See Article 500, "Hazardous (Classified) Locations," in *NFPA 70* for definitions of classes, groups, and divisions.
[b]The classified area not to extend beyond an unpierced wall, roof, or solid vaportight partition.
[c]Indoor fueling with LH_2 is not permitted. See 11.3.2.
[d]Ventilation is considered adequate when provided in accordance with the provisions of this code.

11.2.12.1.1 Electrical equipment on internal combustion engines installed in accordance with NFPA 37.

11.2.12.2 Static protection shall be required when LH_2 cargo transport vehicles are unloaded, except where cargo transport vehicles or marine equipment are loaded or unloaded by conductive hose, flexible metallic tubing, or pipe connections through or from tight (top or bottom) outlets where both halves of metallic couplings are in contact.

11.2.12.3 Each interface between a flammable fluid system and an electrical conduit or wiring system, including process instrumentation connections, integral valve operators, foundation heating coils, canned pumps, and blowers, shall be sealed or isolated to prevent the passage of flammable fluids or gases to another portion of the electrical installation.

11.2.12.4 Each seal, barrier, or other means used to comply with 11.2.12.5 shall be designed to prevent the passage of flammable fluids or gases through the conduit, stranded conductors, and cables.

11.2.12.5 A primary seal shall be provided between the flammable fluid system and the electrical conduit wiring system. If the failure of the primary seal would allow the passage of flammable fluids to another portion of the conduit or wiring system, an additional approved seal, barrier, or other means shall be provided to prevent the passage of the flammable fluid beyond the additional device or means in the event that the primary seal fails.

11.2.12.6 Each primary seal shall be designed to withstand the maximum allowable service conditions to which it is expected to be exposed.

11.2.12.7 Each additional seal or barrier and interconnecting enclosure shall meet the pressure and temperature requirements of the condition to which it could be exposed in the event of failure of the primary seal, unless other approved means are provided to accomplish this purpose.

11.2.12.8 Unless specifically designed and approved for the purpose, the seals specified in 11.2.12.5 through 11.2.12.9 are not intended to replace the conduit seals required by 501.15(A) through 501.15(D) of *NFPA 70*.

11.2.12.9 Where primary seals are installed, drains, vents, or other devices shall be provided for monitoring purposes to detect flammable fluids and leakage.

11.2.13 LH_2 to GH_2 Systems. In addition to the emergency shutdown systems described in Section 11.3 the emergency shutdown system also shall shut off the liquid supply and power to the LH_2 transfer equipment necessary for producing GH_2 from LH_2.

11.2.14 Maintenance.

11.2.14.1 Maintenance shall be performed based on the OEM component manufacturer's recommendations and not less than every 6 months. Maintenance records shall be made available upon demand.

11.2.14.1.1 The refueling site shall have a written maintenance program or process safety analysis program in place. A written record of the required maintenance shall be maintained by the operator.

11.2.14.1.2 Records of required maintenance shall be provided to the authority having jurisdiction upon request.

11.2.14.1.3 Fueling facilities shall be free within 25 ft (7.6 m) from rubbish, debris, weeds, and other material that present a fire hazard.

11.2.14.1.4 Grass areas on the LH_2 fueling facility grounds shall be maintained in a manner that does not present a fire hazard.

11.2.14.2 A preventive maintenance program shall be in place and shall include a schedule of written procedures for test and inspection of facility systems and equipment.

11.2.14.3 Each component in service, including its support system, shall be maintained in a condition that is compatible with its operation or safety purpose by repair, replacement, or other means.

11.2.14.4 If a safety device is taken out of service for maintenance, the component being served by the device shall be taken out of service unless the same safety function is provided by an alternative means.

11.2.14.5 If the inadvertent operation of a component taken out of service could cause a hazardous condition, the system shall be shut down until the component is replaced.

11.2.14.5.1 All maintenance and servicing shall be done in accordance with 29 CFR 1910 for energy control.

11.2.14.6 Safety, gas detection, and fire protection equipment shall be tested or inspected at intervals not to exceed 6 months.

11.2.14.7 Maintenance activities on fire control equipment shall be scheduled so that a minimum of equipment is taken out of service at any one time and fire prevention safety is not compromised.

11.2.14.8 Hose Assemblies.

11.2.14.8.1 Hoses, nozzles, and breakaways shall be examined according to the manufacturers' recommendations or at least monthly and shall be maintained in accordance with the manufacturers' instructions.

11.2.14.8.2 Hose shall be tested for leaks per manufacturer's requirements, and any unsafe leakage or surface cracks shall be reason for rejection and replacement.

11.2.14.8.3 Testing shall be carried out using an inert gas as the test medium.

(A) Where this is not possible, the hose assembly shall be completely isolated from the system and tested with the flammable gas normally within the system, or with air and then purged with an inert gas.

(B) In the case of hydrogen, testing shall be carried out with helium or a helium inert gas blend (10 percent by volume [helium] or greater) as the test gas or, if this is not possible, with hydrogen using precautions.

11.2.14.8.4 Hose Protection. When not in use, hose shall be secured to protect it from damage.

11.2.14.8.5 Hose Assemblies. Listed hose assemblies shall be used to dispense fuel. Hose length at automotive motor fuel dispensing facilities shall not exceed 18 ft (5.5 m). [**30A:**12.2.4]

11.3 Dispensing.

11.3.1 General.

11.3.1.1 System Component Qualifications. The following systems and system components shall be listed or approved:

(1) Pressure relief devices, including pressure relief valves
(2) Pressure gauges
(3) Pressure regulators
(4) Valves
(5) Hose and hose connections
(6) Vehicle fueling connections (nozzle)
(7) Electrical equipment used with LH_2 systems
(8) Gas detection equipment and alarms
(9) Hydrogen dispensers
(10) Pressure switches
(11) Flow meters

11.3.1.2 Fail-Safe Design. LH_2 fueling facilities shall be designed so that, in the event of a power or equipment failure, the system shall go into a fail-safe condition.

11.3.1.3 Design and Construction of Containers, Cylinders, and Tanks.

11.3.1.3.1 Containers, cylinders, and tanks shall be fabricated of materials compatible with hydrogen service.

11.3.1.3.2 Containers, cylinders, and tanks shall be designed for LH_2 service and shall be permanently marked LH_2 by the manufacturer.

11.3.1.3.3* Containers, cylinders, and tanks manufactured prior to the effective date of this code shall be permitted to be used in LH_2 service if designated for LH_2 service by the container manufacturer or if approved by the AHJ.

11.3.1.3.4 ASME Containers, Cylinders, and Tanks.

11.3.1.3.4.1 Welding or brazing for the repair or alteration of an ASME pressure vessel shall comply with the documents under which the pressure vessel was fabricated.

(A) Other welding or brazing shall be permitted only on saddle plates, lugs, or brackets attached to the pressure vessel by the pressure vessel manufacturer.

(B) The exchange or interchange of pressure vessel appurtenances intended for the same purpose shall not be considered a repair or alteration.

11.3.1.4 Dispensing Device Protection. The dispensing device shall be protected from vehicle collision damage.

11.3.1.5 Pressure Relief Devices.

11.3.1.5.1 Pressure relief valves for LH_2 service shall not be fitted with lifting devices.

11.3.1.5.1.1 The adjustment, if external, shall be provided with a means for sealing the adjustment to prevent tampering.

11.3.1.5.1.2 If at any time it is necessary to break such a seal, the valve shall be removed from service until it has been reset and sealed.

11.3.1.5.1.3 Adjustments shall be made only by the manufacturer or other companies having competent personnel and facilities for the repair, adjustment, and testing of such valves.

11.3.1.5.1.4 The organization making such adjustment shall attach a permanent tag with the setting, capacity, and date.

11.3.1.5.1.5 Pressure relief valves protecting ASME pressure vessels shall be repaired, adjusted, and tested in accordance with the ASME *Boiler and Pressure Vessel Code*.

11.3.1.5.2 Installation of Pressure Relief Devices on Dispensing Systems.

11.3.1.5.2.1 Pressure relief devices shall be in accordance with 7.1.5.5.

11.3.1.5.2.2 Pressure relief devices shall be so arranged that they discharge in accordance with Section 6.16 and 7.1.5.5.5.

11.3.1.5.2.3 An overpressure protection device, other than a rupture disc, shall be installed in the fueling transfer system to prevent overpressure in the vehicle.

11.3.1.5.2.4 The set pressure of the overpressure protection device for the dispensing system shall not exceed 140 percent of the service pressure of the fueling nozzle it supplies.

11.3.1.5.3 Pressure relief valves shall be installed where liquid or cold gas can be trapped between shutoff valves in the piping system and shall be in accordance with 8.1.3.1.5.2. [**55:**8.14.6.2]

11.3.1.5.4* The discharge from pressure relief devices serving the fueling system shall be connected to a vent system in accordance with Section 6.16.

11.3.1.6 Hose and Hose Connections.

11.3.1.6.1 Hose shall be constructed of or lined with materials that are resistant to corrosion and exposure to LH_2.

11.3.1.6.2 Hose, metallic hose, flexible metal hose, tubing, and their connections shall be designed or selected for the most severe pressures and temperatures expected under normal operating conditions with a burst pressure of at least three times the MAWP.

11.3.1.6.3 Prior to use, hose assemblies shall be tested by the component OEM or its designated representative at a pressure at least twice the maximum allowable pressure.

11.3.1.6.4 Hose and metallic hose shall be distinctly marked by the manufacturer, either by the manufacturer's permanently attached tag or by distinct markings indicating the manufacturer's name or trademark, applicable service identifier, design pressure, and flow direction.

11.3.1.6.5 The use of hose in an installation shall be limited to the following:

(1) Vehicle fueling hose
(2) Inlet connection to compression or pumping equipment
(3) Section of hose not exceeding 36 in. (910 mm) in length in a pipeline to provide flexibility where necessary.

11.3.1.6.5.1 Each section shall be so installed that it is protected against mechanical damage and is visible for inspection.

11.3.1.6.5.2 The individual component and manufacturer's identification shall be retained in each section and throughout the system.

11.3.1.6.5.3 The hose shall be approved or listed for hydrogen service.

11.3.1.7 Valves.

11.3.1.7.1 Valves, valve packing, and gaskets shall be designed or selected for the fuel over the full range of pressures and temperatures to which they can be subjected under any operating conditions.

11.3.1.7.1.1 Shutoff-valves shall have a rated service pressure not less than the rated service pressure of the entire system and shall be designed with a minimum safety factor of 3.

11.3.1.7.1.2 Leakage shall not occur when tested to at least one-and-a-half of the rated service pressure, using an inert gas as the test medium.

11.3.1.7.2 Valves of a design that allows the valve stem to be removed without removal of the complete valve bonnet or without disassembly of the valve body shall not be used.

11.3.1.7.3 The manufacturer shall stamp or otherwise permanently mark the valve body to indicate the service ratings.

11.3.1.7.3.1 Container valves incorporating integral pressure relief devices complying with Section 8.1.4 shall not require additional marking.

11.3.1.8 Emergency Shutdown System. An emergency shutdown system (ESD) shall be provided that includes a shut-off valve, which shall be provided within 10 ft (3.1 m) of the dispenser, for stopping liquid supply and shutting down transfer equipment. An actuator for the valve, distinctly marked for easy recognition with a permanently affixed, legible sign, shall be provided with a shutdown control point located near the dispenser and another shutdown control point located at a safe, remote location.

11.3.1.9 Maximum Delivery Pressure. The maximum delivery pressure at the vehicle tank inlet shall not exceed the maximum allowable pressure of the vehicle fuel tanks.

11.3.1.10 System Testing.

11.3.1.10.1 Piping, tubing and hose, and hose assemblies shall be leak tested after assembly to prove them free from leaks at a pressure equal to at least the normal service pressure of that portion of the system.

11.3.1.10.2 This leak test shall be in addition to the ANSI/ASME B31.3, *Process Piping*, testing required by 11.2.8.3.

11.3.1.10.3 The assembly shall be leak tested using hydrogen or helium.

11.3.1.10.4 Where hydrogen is to be used as the leak test media, the system shall first be purged with an inert gas to ensure that all oxygen is removed.

11.3.1.10.5 Pressure relief valves shall be tested at least every 3 years.

11.3.1.10.6 At fueling stations, gas used for calibration and testing shall be vented to a vent pipe in accordance with Section 6.16.

11.3.1.11 Shutoff Valve and Breakaway Device. Hose and arms shall be equipped with a shut-off valve at the fuel end and a breakaway device to minimize release of liquid and vapor in the event that a vehicle pulls away while the hose remains connected. Such a device shall be installed and maintained in accordance with the manufacturer's instructions.

11.3.1.12 Emergency Shutoff Valve. Where a hose or arm of nominal 3 in. (76 mm) diameter or larger is used for liquid transfer or where one of nominal 4 in. (100 mm) diameter or larger is used for vapor transfer, an emergency shutoff valve shall be installed in the piping of the transfer system within 10 ft (3.0 m) from the nearest end of the hose or arm.

11.3.1.12.1 Where the flow is away from the hose, a check valve shall be permitted to be used as the shut-off valve.

11.3.1.12.2 Where either a liquid or vapor line has two or more legs, an emergency shut-off valve shall be installed either in each leg or in the feed line before the legs.

11.3.1.13 Bleed or Vent Connections. Bleed or vent connections shall be provided so that loading arms and hose can be drained and depressurized prior to disconnection if necessary. These bleed or vent connections shall lead to a safe point of discharge.

11.3.1.14 Fueling Connections. A fueling connector and mating vehicle receptacle shall be used for reliable, safe, and secure transfer of LH_2 or gas vapor to or from the vehicle with minimal leakage.

11.3.1.14.1 The fueling connector either shall be equipped with an interlock device that prevents release while the line is open or shall have self-closing ends that automatically close upon disconnection.

11.3.1.15 Transfer of LH_2. The transfer of LH_2 into vehicular onboard fuel supply containers shall be performed in accordance with the manufacturer's instructions. The dispenser manufacturer's instructions shall be posted at the dispensing device.

11.3.1.16 Signs.

11.3.1.16.1 A warning sign with the words "STOP MOTOR, NO SMOKING, NO CELL PHONES, FLAMMABLE GAS" shall be posted at dispensing station and compressor or pumping areas.

11.3.1.16.1.1 If the hydrogen is not odorized, the wording "HYDROGEN GAS DOES NOT HAVE A DISTINCTIVE ODOR" shall be added to the warning sign.

11.3.1.16.1.2 The location of signs shall be determined by local conditions.

11.3.1.16.1.3 The lettering on the sign shall be large enough to be visible and legible from each point of transfer.

11.3.1.17 Dispenser Installations Beneath Canopies. Where [LH_2] dispensers are installed beneath a canopy or enclosure, either the canopy or enclosure shall be designed to prevent accumulation or entrapment of ignitable vapors or all electrical equipment installed beneath the canopy or enclosure shall be suitable for Class I, Division 2 hazardous (classified) locations. [**30A:**12.4]

11.3.1.18 Dispenser Connections. A means shall be provided that connects to the dispenser supply piping and that prevents flow in the event that the dispenser is displaced from its mounting. [**30A:**12.2.2]

11.3.1.19 Dispensing Devices. Dispensing devices for LH_2 shall be listed. [**30A:**12.2.3]

11.3.2 Dispensing to the Public. Indoor LH_2 fueling shall not be permitted.

11.3.2.1 Outdoors. A facility in which LH_2 pumping, gas processing, hydrogen generation equipment, storage, and dispensing equipment are sheltered by an enclosure that is constructed as weather protection in accordance with Section 6.6 with a roof designed for ventilation and dispersal of escaped gas shall be considered to be located outdoors.

11.3.3 Outdoor Public Fueling.

11.3.3.1 General.

11.3.3.1.1 Dispensing devices including points of transfer from dispensers installed at outdoor motor fuel dispensing stations shall be located as follows:

(1) Not less than 25 ft (7.6 m) from the nearest important building not associated with the LH_2 facility
(2) Not less than 25 ft (7.6 m) from the line of adjoining property that can be built upon
(3) Not less than 25 ft (7.6 m) from fixed sources of ignition
(4) Such that all parts of the vehicle being served will be on the premises of the service station
(5) Such that the nozzle, when the hose is fully extended, will not reach within 10 ft (3 m) of building openings, as adopted in 10.3.3.2.2.4

11.3.3.1.1.1 Points of transfer shall include the maximum length of the refueling hose serving the dispenser.

11.3.3.1.2 Dispensing devices shall be mounted on a concrete island or shall otherwise be protected against collision damage by means acceptable to the authority having jurisdiction. Dispensing devices shall be securely bolted in place. [-] Dispensing devices shall also be located in a position where they cannot be struck by a vehicle that is out of control descending a ramp or other slope. Dispensing devices shall be installed in accordance with the manufacturers' instructions. [**30A:**6.3.4]

11.3.3.1.3 Motor vehicle traffic patterns at motor fuel dispensing facilities shall be designed to inhibit movement of vehicles that are not being fueled from passing through the dispensing area. [**30A:**6.3.7]

11.3.3.1.4 Fire Detection. Dispensing equipment shall be provided with gas detectors, leak detection, and flame detectors such that fire and gas can be detected at any point on the equipment.

11.3.3.1.4.1 These detectors shall be maintained and calibrated in accordance with the manufacturer's instructions on at least an annual basis or earlier if required by the manufacturer.

11.3.3.1.4.2 The station owner or operator shall maintain a record of detector maintenance and calibration in good condition and accessible to the inspector.

11.3.3.1.4.3 A sticker at least 6 in.^{2} (39 cm^2) shall be affixed on the dispenser indicating the date of the next scheduled maintenance and calibration.

11.3.3.1.5 A vehicle fueling pad shall be provided in the area where vehicles are to be refueled.

11.3.3.1.5.1 The pad shall be constructed with a length and width to accommodate the types of vehicles to be fueled and to provide a surface under the fueling hose.

11.3.3.1.5.2 The vehicle fueling pad shall be of concrete construction.

(A) Combustible materials including asphalt shall not be used for the construction of or surfacing of the fueling pad. *(See 8.3.2.3.1.5.)*

11.3.3.2 Outdoor Public Full Service Attended Fueling.

11.3.3.2.1 Operating Requirements. Each motor fuel dispensing facility shall have an attendant or supervisor on duty whenever the facility is open for business. The attendant or supervisor shall dispense liquids into fuel tanks or into containers, except as covered in 11.3.3.3 and 11.3.3.4. [**30A:**9.3]

11.3.3.3 Outdoor Public Attended Self Service Fueling.

11.3.3.3.1 There shall be at least one attendant on duty while the self-service facility is open for business. The attendant's primary function shall be to supervise, observe, and control the dispensing of fuels including the dispensing of hydrogen while said hydrogen is actually being dispensed. [**30A:**9.4.2]

11.3.3.3.2 The responsibility of the attendant shall be as follows: [**30A:**9.4.3]

(1) Control sources of ignition [**30A:**9.4.3(3)]
(2) Immediately activate emergency controls and notify the fire department of any fire or other emergency [**30A:**9.4.3(4)]

11.3.3.3.3 The attendant or supervisor on duty shall be mentally and physically capable of performing the functions and assuming the responsibility prescribed in 11.3.3.3. [**30A:**9.4.3.1]

11.3.3.3.4 Operating instructions shall be conspicuously posted in the dispensing area. [**30A:**9.4.4]

11.3.3.3.5 Emergency controls as specified in [*NFPA 70*] shall be installed at a location acceptable to the authority having jurisdiction, but controls shall not be more than 100 ft (30 m) from dispensers. [**70:**514.11(B)]

11.3.3.4 Outdoor Public Unattended Self Service Fueling.

11.3.3.4.1 Unattended self-service facilities shall be permitted, where approved by the authority having jurisdiction. [**30A:**9.5.1]

11.3.3.4.2 At unattended self-serve motor fuel dispensing facilities, coin- and currency-type devices shall only be permitted with the approval of the authority having jurisdiction. [**30A:**6.3.8]

11.3.3.4.3 Operating instructions shall be conspicuously posted in the dispensing area. The instructions shall include location of emergency controls and a requirement that the user stay outside of his/her vehicle and in view of the fueling nozzle during dispensing. [**30A:**9.5.2]

11.3.3.4.4 In addition to the warning signs specified in 11.3.1.16.1, emergency instructions shall be conspicuously posted in the dispenser area. The instructions shall incorporate the following or equivalent wording: [**30A:**9.5.3]

Emergency Instructions

In case of fire or spill

(1) Use emergency stop button.

(2) Report accident by calling (*specify local fire number*) on the phone. Report location.

[**30A:**9.5.3]

11.3.3.4.5 A telephone or other approved, clearly identified means to notify the fire department shall be provided on the site in a location approved by the authority having jurisdiction. [**30A:**9.5.5]

11.3.3.4.6* Additional fire protection shall be provided where required by the authority having jurisdiction. [**30A:**9.5.6]

11.3.3.4.7* Emergency controls as specified in [*NFPA 70*] shall be installed at a location acceptable to the authority having jurisdiction, but the control shall be more than 20 ft (6 m) but less than 100 ft (30 m) from the dispensers. Additional emergency controls shall be installed on each group of dispensers or the outdoor equipment used to control the dispensers. Emergency controls shall shut off all power to all dispensing equipment at the station. Controls shall be manually reset only in a manner approved by the authority having jurisdiction. [**70:**514.11(C)]

11.3.4 Outdoor Nonpublic Fueling.

11.3.4.1 General. (Reserved)

11.3.4.2 Outdoor Nonpublic Full Service Fueling. (Reserved)

11.3.4.3 Outdoor Nonpublic Attended Self-Service Fueling. (Reserved)

11.3.4.4 Outdoor Nonpublic Unattended Self-Service Fueling. (Reserved)

11.3.4.5 Outdoor Nonpublic Residential Fueling. (Reserved)

11.3.4.6 Refueling from Transport Vehicles. Mobile refueling vehicles, temporary trailers (with or without tractors), and other means of providing vehicle refueling or onsite storage shall be subject to the same requirements as a permanent refueling or storage installation.

11.3.4.6.1 The dispensing of LH_2 in the open from a transport vehicle to a motor vehicle located at a separate fleet fueling area in connection with commercial, industrial, governmental, or manufacturing establishments and intended for fueling vehicles used in connection with their businesses shall be permitted if all of the requirements of 11.3.4.6.1 through 11.3.4.6.9 have been met.

11.3.4.6.2 The AHJ shall be notified before commencing operations, and permitting sought if required, under 11.3.4.6.1.

11.3.4.6.3 The transport vehicle shall comply with U.S. DOT requirements for the transportation of LH_2.

11.3.4.6.4 Smoking materials, including matches, lighters, and other sources of ignition, including torches, shall not be used within 25 ft (7.6 m) of the dispensing of LH_2 in the open from a transport vehicle to a motor vehicle.

11.3.4.6.5 Each area where dispensing of LH_2 in the open from a transport vehicle to a motor vehicle shall be provided with one or more listed fire extinguishers that have a minimum capability of 40-B:C.

11.3.4.6.5.1 The fire extinguishers shall be within the dispensing operation.

11.3.4.6.5.2 Fire extinguishers shall be inspected and maintained under NFPA 10.

11.3.4.6.6 Transport vehicle brakes shall be set, and chock blocks shall be in place.

11.3.4.6.7 Persons performing dispensing operations shall be qualified to deliver and dispense LH_2 fuels. Operators of transport vehicles used for mobile fueling operations shall have access on site or be in possession of an emergency communications device to notify the authorities in the event of an emergency.

11.3.4.6.8 The transport vehicles shall be positioned with respect to vehicles being fueled to prevent traffic from driving over the delivery hose and between the transport vehicle and the motor vehicle being fueled. The dispensing hose shall be properly placed on an approved reel or in an approved compartment before the transport vehicle is moved.

11.3.4.6.9 The transfer area shall meet the requirements of 10.3.1.16.3.

11.3.4.7 Refueling from Vehicle Mounted Tank at Commercial and Industrial Facilities. Dispensing from vehicle-mounted tanks located at commercial and industrial facilities used in connection with their business shall be permitted where the following conditions are met:

(1) An inspection of the premises and operations has been made and approval granted by the authority having jurisdiction. All dispensing of LH_2, including mobile refueling, into vehicle onboard fuel systems shall comply with the requirements of a permanent LH_2 refueling installation at the point of dispensing fuel.
(2) The vehicle-mounted container shall comply with the requirements of DOT.
(3) The dispensing hose shall not exceed 50 ft (15 m) in length.
(4) Nighttime deliveries shall be made only in lighted areas.
(5) Mobile refueling units shall meet the site requirements of a permanent refueling station at the point of dispensing and if left on site.

11.4 Storage.

11.4.1 General. The storage of LH_2 in bulk and non-bulk LH_2 installations shall be in accordance with the applicable requirements of Chapters 6 and 8.

11.4.2 Indoor Storage. Indoor storage of LH_2 to be used for vehicle fueling purposes shall not be permitted.

11.4.3 Outdoor Storage.

11.4.3.1 Ullage Space. All cryogenic containers, vessels, and tanks shall provide and maintain ullage space to prevent overfilling of the vessel.

11.4.3.2 Stationary Storage Tanks. Points of transfer shall be located not less than 25 ft (7.6 m) from the nearest important building not associated with the LH_2 facility, from the line of adjoining property that can be built upon, or from fixed sources of ignition. Points of transfer shall also include the maximum length of the off-loading LH_2 bulk supply tanker, and off-loading hoses. *(See also 8.3.4.5.)*

11.4.4 Underground Storage. (Reserved)

Chapter 12 Hydrogen Fuel Cell Power Systems

12.1 Scope. This chapter shall apply to the design, construction, and installation of fuel cell power systems.

12.1.1 Application. The requirements of this chapter shall apply to stationary portable and micro fuel cell power generation systems.

12.1.1.1 The storage, use, and handling of hydrogen in any quantity shall also comply with the requirements of Chapters 1 through 4 and the applicable requirements of Chapters 5 through 8.

12.1.1.2 Chapters 4 and 6 through 8 contain fundamental requirements that shall apply to all hydrogen systems.

12.1.1.2.1 The use-specific requirements of this chapter for hydrogen fuel cell power systems shall apply.

12.1.1.2.2 Where there is a conflict between a fundamental requirement and a use-specific requirement, the use-specific requirement shall apply.

12.2* General.

12.2.1* Listed and Approved Equipment.

12.2.1.1 Listed and approved hydrogen fuel cell equipment shall be installed in accordance with the listing requirements and manufacturers' instructions.

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

12.3 Specific Requirements.

12.3.1 Stationary Fuel Cells.

12.3.1.1 General. [853:4.1]

12.3.1.1.1 Prepackaged, Self-Contained, Fuel Cell Power Systems. [853:4.2]

12.3.1.1.1.1 Prepackaged, self-contained [stationary] fuel cell power systems shall be designed, tested, and listed in accordance with ANSI CSA FC.1, *American National Standard for Fuel Cell Power Systems.* [**853:**4.2.1]

12.3.1.1.1.2 Prepackaged, self-contained [stationary] fuel cell power systems outside the scope of ANSI CSA FC.1, *American National Standard for Fuel Cell Power Systems*, shall meet the provisions of 12.3.1.1.2 [**853:**4.2.2]

12.3.1.1.2 Pre-Engineered Fuel Cell Power Systems. [853:4.3]

12.3.1.1.2.1 Pre-engineered fuel cell power systems and matched modular components shall be designed and tested to meet the intent of ANSI CSA FC.1, *American National Standard for Fuel Cell Power Systems.* [**853:**4.3.1]

12.3.1.1.2.2 Proprietary equipment or materials for which no generally recognized codes or standards exist shall be evaluated based on data from operational experience in the same or comparable service or test records covering the performance of the equipment or materials. [**853:**4.3.2]

12.3.1.1.3 Engineered and Field-Constructed Fuel Cell Power Systems. [853:4.4]

12.3.1.1.3.1 Documentation for engineered and field-constructed fuel cell power systems shall be provided. [**853:**4.4.1]

12.3.1.1.3.2 Documentation shall include a fire risk evaluation prepared by a registered engineer or third party acceptable to the authority having jurisdiction. [**853:**4.4.2]

12.3.1.2 Siting and Installation.

12.3.1.2.1 Siting. Stationary fuel cell power system(s) and associated equipment, components, and controls shall be sited and installed in accordance with NFPA 853.

12.3.2 Portable Fuel Cells.

12.3.2.1 General.

12.3.2.1.1* Prepackaged, self-contained portable fuel cell power systems shall be designed, tested, and listed in accordance with ANSI/CSA FC 3, *American National Standard / CSA American Standard for Portable Fuel Cell Power Systems,* or IEC 6228-1, *Portable Fuel Cell Power Systems, Safety.*

12.3.2.2 Indoor Portable Fuel Cells. (Reserved)

12.3.2.3 Outdoor Portable Fuel Cells. (Reserved)

12.3.3 Micro Fuel Cells Power Systems.

12.3.3.1 General.

12.3.3.1.1 Listed or Approved Systems. Prepackaged, self-contained micro fuel cell power systems shall be listed or approved for the application.

12.3.3.2 Indoor Micro Fuel Cells. (Reserved)

12.3.3.3 Outdoor Micro Fuel Cells. (Reserved)

12.4 Storage.

12.4.1 Requirements for Hydrogen Storage Systems Serving Stationary Fuel Cell Installations.

12.4.1.1 Storage systems serving stationary fuel cell power systems shall be in accordance with NFPA 853.

12.4.2 Requirements for Hydrogen Storage Systems Serving Portable Fuel Cell Power Systems.

12.4.2.1 General.

12.4.2.1.1 Fuel Cell Cartridges.

12.4.2.1.1.1 Listed or Approved Devices. Fuel cell cartridges shall be listed or approved for the application.

12.4.2.1.1.2 Fuel cell cartridge refilling equipment shall be listed or approved for the application, and refill shall be in accordance with the manufacturer's published instructions and the listing.

12.4.2.2 Indoor Storage. (Reserved)

12.4.2.3 Outdoor Storage. (Reserved)

12.4.3 Requirements for Hydrogen Storage Systems Serving Micro Fuel Cell Power Systems.

12.4.3.1 General.

12.4.3.1.1 Fuel Cell Cartridges.

12.4.3.1.1.1 Listed or Approved Devices. Fuel cell cartridges shall be listed or approved for the application.

12.4.3.1.1.2 Fuel cell cartridge refilling equipment shall be listed or approved for the application, and refill shall be in accordance with the manufacturer's published instructions and the listing.

12.4.3.2 Indoor Storage. (Reserved)

12.4.3.3 Outdoor Storage. (Reserved)

Chapter 13 Hydrogen Generation Systems

13.1 Scope. This chapter shall apply to equipment used to generate hydrogen.

13.1.1 Application.

13.1.1.1 This chapter shall apply to permanently installed hydrogen generation systems with rated capacity to generate greater than 1.3 oz/hr (36 g/hr) but less than 220 lb/hr (100 kg/hr).

13.1.1.1.1 Systems that generate hydrogen in excess of the quantity indicated in 13.1.1 shall be constructed, installed, and operated in accordance with nationally recognized standards.

13.1.1.2 The storage, use, and handling of GH_2 or LH_2 shall also comply with the requirements of Chapters 1 through 4 and the applicable requirements of Chapters 5 through 8.

13.1.1.3 Chapters 4 and 6 through 8 contain fundamental requirements that shall apply to all hydrogen systems.

13.1.1.3.1 The use-specific requirements of this chapter for hydrogen generation systems shall apply.

13.1.1.3.2 Where there is a conflict between a fundamental requirement and a use-specific requirement, the use-specific requirement shall apply.

13.2 General.

13.2.1* Listed or Approved Equipment.

13.2.1.1* Listed or approved hydrogen-generating equipment shall be installed in accordance with the listing or approval requirements and manufacturers' instructions.

13.2.2 Interconnection. The installation and interconnection of hydrogen generation equipment shall be in accordance with this chapter.

13.2.2.1* Interconnecting Hydrogen Piping. Hydrogen piping, valves, and fittings from the hydrogen generation equipment to other equipment including hydrogen storage systems shall conform to the appropriate section of ASME B31, *Code for Pressure Piping*.

13.2.3 Integral Fuel Processing Equipment. Fuel processing equipment integral to listed fuel cell power system appliances installed in accordance with NFPA 853 shall not be required to meet the requirements of this chapter.

13.2.4 Siting. Hydrogen generation system(s) shall be installed in accordance with the following:

(1) The system shall be placed on a firm foundation that is capable of supporting the equipment or components as in accordance with ASCE-7.
(2) The system shall be anchored, located, and protected so that the system and equipment will not be adversely affected by freezing temperatures and seismic events.
(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 Article 500 of *NFPA 70* unless listed and approved for such areas.
(5) Vent terminations from hydrogen generation systems shall be in accordance with Section 6.16.
(6) All safety-related controls shall comply with NFPA 79.

13.2.5 Indoor Installations. In addition to the requirements of 13.2.4, indoor hydrogen generation system(s) shall be installed in accordance with the following:

(1) Separation distances of hydrogen generation system equipment with internal volumes exceeding the MAQ defined in 6.4.1.1 from exposures shall be in accordance with the lesser of 7.2.2.2.2 or 7.3.2.3.
(2) Separation distances of hydrogen generation system equipment with internal volumes less than or equal to the MAQ defined in 6.4.1.1 from exposures shall be in accordance with the lesser of 7.2.2.2 or 7.3.2.3.
    (a) A hydrogen generation system and associated hydrogen storage with internal volumes less than or equal to the MAQ defined in 6.4.1.1 shall not be required to have fire-rated separation.

13.2.5.1 Ventilation — Indoor Installations. A hydrogen generation system installed indoors shall be located in a ventilated area in accordance with the provisions of Section 6.17.

13.2.6 Outdoor and Rooftop Installations.

13.2.6.1 Siting — Outdoor and Rooftop Installations. In addition to the requirements of 13.2.4, outdoor hydrogen generation system(s) shall be installed in accordance with the following:

(1) The system shall be anchored, located, and protected so that the system and equipment will not be adversely affected by rain, snow, ice, wind, and lightning.
(2) Separation distances of hydrogen generation system equipment with internal volumes exceeding the MAQ defined in 6.4.1.1 from exposures shall be in accordance with 7.3.2.3.
(3) Separation distances of hydrogen generation system equipment with internal volumes less than or equal to the MAQ defined in 6.4.1.1 from exposures shall be in accordance with the lesser of 7.2.2.3 or 7.3.2.3.
    (a) A hydrogen generation system and associated hydrogen storage with internal volumes less than or equal to the MAQ defined in 6.4.1.1 shall not be required to have fire-rated separation.

13.2.6.2 For outdoor or rooftop installations, a hydrogen generation system and related components shall be designed and constructed for outdoor installation.

13.2.6.2.1 Hydrogen gasifiers shall not be installed on rooftops or in penthouse areas of occupied structures.

13.2.6.2.2 The installation of listed or approved gasifiers shall be allowed provided the listing or approval is specific to rooftop installations.

13.2.6.3 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*.

13.2.6.4 For units installed on rooftops, the roofing material under and within 12 in. (305 mm) horizontally of a hydrogen generation system or component thereof shall be noncombustible or shall have a Class A rating as in accordance with the adopted building code.

13.3 Use.

13.3.1 Electrolyzers.

13.3.1.1 General.

13.3.1.1.1 Siting and Interconnecting. Siting and interconnection of water electrolyzers shall be in accordance with the applicable requirements of Section 13.2 as modified or appended by this section.

13.3.1.1.2* Product Standards. Water electrolyzers shall be listed or approved for their use.

13.3.1.1.3 Hazardous Material Containment. With the exception of gaseous hydrogen, electrolyzers that contain or utilize hazardous materials as defined by the adopted building code shall be designed and installed to contain such materials in accordance with the adopted building code.

13.3.1.2 Ventilation for Indoor Electrolyzers. If mechanical ventilation is required, a control interlock shall be provided to shut down the electrolyzer upon loss of ventilation.

13.3.1.3 If oxygen is released within the electrolyzer room, sufficient ventilation shall be provided to prevent oxygen-enriched atmospheres above 23.5 percent oxygen.

13.3.1.4 Ventilation for indoor electrolyzers shall be in accordance with manufacturer's installation instructions and with one of the following:

(1) In accordance with Section 6.17.
(2) Use of constant ventilation sufficient to maintain an average H2 gas concentration within the room below 25 percent LFL based on the maximum anticipated hydrogen leak as determined by the manufacturer's installation instructions.
(3) Use of a hydrogen detection system, using GH2 detection equipment per Section 6.12, that initiates ventilation per Section 6.17 at a detected level of 10 percent LFL.

13.3.1.5 Indoor Installations of Electrolyzers.

13.3.1.5.1* Residential. Electrolyzers listed or approved for residential occupancies compliant with the GH_2 content limit of 6.4.1.5.1.1 shall be permitted.

13.3.1.6 Outdoor Installations of Electrolyzers. (Reserved)

13.3.2 Catalytic Reforming–Based Hydrogen Generation Systems.

13.3.2.1 General.

13.3.2.1.1 Siting and Interconnecting. Siting and interconnection of catalytic reformer–type hydrogen generation systems shall be in accordance with 13.2.4 through 13.2.6 as modified or appended by this section.

13.3.2.1.1.1 Hydrogen piping, valves, and fittings from the catalytic reforming–based hydrogen generation equipment to hydrogen storage system shall conform to ASME/ANSI B31.12, *Hydrogen Piping and Pipelines*.

13.3.2.1.2 Fire Protection for Catalytic Reforming–Based Hydrogen Generation Systems. The fire protection requirements of NFPA 853 shall apply, in addition to the following:

(1) When a catalytic reformer-based hydrogen generation system is installed indoors, 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.

13.3.2.2 Indoor Installations of Reformers.

13.3.2.2.1 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 13.3.2.2.1.1 through 13.3.2.2.1.6.

13.3.2.2.1.1 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 ASME E119, *Standard Test Methods for Fire Tests of Building Construction and Materials* or UL 263, *Fire Tests of Building Construction and Materials*.

13.3.2.2.1.2 Electrical and piping penetrations and joints associated with the room shall be sealed with approved materials that have a 1-hour fire resistance rating.

13.3.2.2.1.3 Openings between the room and other occupied spaces shall be protected by fire doors and dampers.

13.3.2.2.1.4 Fire doors shall be installed in accordance with NFPA 80 and shall have a minimum fire resistance rating equivalent to that of the barrier.

13.3.2.2.1.5 Fire dampers shall be installed in accordance with NFPA 90A.

13.3.2.2.1.6 Each room shall be provided with egress in accordance with the adopted building code.

13.3.2.2.2 Clearances from combustible construction and other combustible materials shall be in accordance with manufacturer's instructions, NFPA 31, NFPA 54, or NFPA 58.

13.3.2.2.3 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 19.5 percent unless it can be demonstrated by other means that the oxygen level will not drop below 19.5 percent.

13.3.2.2.4 The exhaust system materials shall be compatible with the exhaust gas and any resulting condensate.

13.3.2.2.5 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 7 or meet all of the following requirements:

(1) The catalytic reforming system enclosure plus the connected indoor liquid fuel piping shall contain less than 5 gal (0.019 m^3) 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 catalytic reforming system shall be equipped with an automatic isolation valve at the tank.

13.3.2.2.6 Catalytic reforming systems that store hydrogen shall be installed in accordance with the manufacturer's instructions and Chapter 7.

13.3.2.2.7 Ventilation.

13.3.2.2.7.1 Catalytic reforming–based hydrogen generation systems shall be provided with a source of ventilation, in accordance with this chapter.

13.3.2.2.7.2 If mechanical ventilation is required, a control interlock shall be provided to shut down the unit upon loss of ventilation.

13.3.2.2.7.3 Ventilation Air.

(A) If mechanical ventilation is required, a separate mechanical ventilation system shall be provided for the area where the catalytic reforming–based hydrogen generation system power is located.

(B) If natural ventilation is available, it shall be permitted to provide all required ventilation.

(C) The air inlets shall be designed to prevent foreign matter from entering.

13.3.2.2.8 Combustible Gas Detection.

13.3.2.2.8.1 Where combustible gas detection is used to provide safety from hydrogen hazards per the requirements in 4.2.3.3.2, it shall be installed in accordance with 8.1.5.4 through 8.1.5.8 of NFPA 853, except where the fuel gas system is listed for indoor use and the fuel is odorized.

13.3.2.3 Outdoor and Rooftop Installations of Reformers.

13.3.2.3.1 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

13.3.2.3.2 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 15 m (50 ft) from HVAC air intakes, windows, doors, and other openings into buildings, or in accordance with 7.3.2.3.

(B) Hydrogen generation system ventilation outlets that exhaust flammable gas in concentration exceeding 25 percent of the lower LEL shall not be directed onto walkways or other paths of travel for pedestrians.

(C) Reformer burner exhausts shall be located and installed in accordance with Chapter 12 of NFPA 54.

13.3.2.3.3 Air intakes to a hydrogen generation system shall be located so the plant is not adversely affected by other exhausts, gases, or contaminants.

13.3.2.3.4 Security barriers, fences, landscaping, and other enclosures shall not affect the required process air flow into the hydrogen generation system and its components.

13.3.2.4 Small Catalytic Reforming–Based Hydrogen Generation Systems.

13.3.2.4.1 General. Subsection 13.3.2.4 identifies additional requirements and or modifications to 13.3.2 for small catalytic reforming hydrogen generation systems with hydrogen generation capacity of less than 9 lb/hr (4 kg/hr).

13.3.3 Gasifiers.

13.3.3.1 General.

13.3.3.1.1 Gasifier systems shall comply with the requirements of Chapters 1 through 8 and the modifications identified in Chapter 13.

13.3.3.1.2* Siting and Interconnection of Gasifiers.

13.3.3.1.2.1* Gasification systems contain conditioning equipment to cool and scrub the gas prior to delivery as a fuel; the conditioning equipment shall comply with 13.3.3.1.2.1(A) and 13.3.3.1.2.1(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.

13.3.3.1.2.2 The area classification around the gasification equipment shall be in accordance with Article 500 or 505 of *NFPA 70*.

13.3.3.1.2.3 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

13.3.3.1.2.4 In no case shall this distance (hereinafter referred to as the "gasifier hazard area") be less than the distance specified in 7.1.9.

13.3.3.1.2.5 Air intakes to the gasifier systems shall be located so the equipment is not adversely affected by other exhausts, gases, or contaminants.

13.3.3.1.2.6 Security barriers, fences, landscaping, or other obstacles shall be provided to define the gasifier hazard area and prevent access by unauthorized persons.

13.3.3.1.2.7 Warning Signals.

(A) Warning signals (strobes and rotating lights) shall be provided at all gasifier hazard area access points.

(B) These signals shall be tied to the detection systems outlined in 13.3.3.1.2.10 to warn of hazardous conditions.

13.3.3.1.2.8 The controller for the gasifier process control system shall be located in a safe area, isolated from the gasifier hazard area.

13.3.3.1.2.9 Process Systems for Gasifiers.

(A) Piping, valves, and fittings from the gasifier chamber to the end use or storage system shall conform to ASME/ANSI B31.3, *Process Piping*.

(B) Backflow prevention shall be provided to preclude inducing external atmospheres into the gasifier systems.

(C) Manual Shutoff Valve.

(1) 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.
(2) 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.

(D) Emergency Stop.

(1) 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.
(2) Activation of the emergency stop system shall do the following:
    (a) Isolate the gasifier from all downstream users and storage facilities
    (b) Immediately halt the flow of feedstock
    (c) Depressurize the gasifier chamber and associated gas conditioning equipment.
(3) 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 7.
(4) The emergency stop capability shall be provided by an independent controller from the main process controller.

13.3.3.1.2.10 Hazard Detection and Fire Protection for Gasifiers.

(A) Flammable gas detection shall be provided in the vicinity of major gasifier components.

(1) For indoor installations, detection shall also be provided in areas where hydrogen could collect in the event of a leak.
(2) 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.

(B)* Toxic Gas Detection.

(1) 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.
(2) This detection capability shall include detection of carbon monoxide as a minimum.

(C)* Thermal Detectors.

(1) Thermal detectors shall be provided throughout the gasifier area to detect fires and activate the fire suppression system and initiate a gasifier shutdown.
(2) The detection system shall comply with *NFPA 72*.
(3) 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.

(D) Detection Devices and Visual Warning System.

(1) Detection devices shall be tied to visual warning devices.
(2) Activation of emergency stop for detected hazards other than fire shall be as recommended by the manufacturer or as required by local regulatory requirements.

(E)* 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.

13.3.3.2 Indoor Installations of Gasifiers.

13.3.3.2.1* Buildings for gasifier equipment shall be highly ventilated and include pressure relief panels to prevent overpressure from deflagrations.

13.3.3.2.2 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.

13.3.3.2.3 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

13.3.3.2.4 Gasifiers that occupy a portion of a building shall be separated from other occupancies in accordance with 7.1.9.

13.3.3.3 Outdoor Installations of Gasifiers. 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

13.4 Storage.

13.4.1 Requirements for Hydrogen Storage Systems Serving Electrolyzer Installations. The requirements of this section addressing hydrogen storage systems serving electrolyzer installations are supplemental to those specified by Section 13.2 and 13.3.1.

13.4.1.1 In residential applications, the electrolyzer installation shall be in accordance with the equipment listing and the manufacturer's instructions.

13.4.1.2 Hydrogen piping, valves, and fittings from the electrolyzer to the hydrogen storage system shall be in accordance with ASME B31.12, *Hydrogen Piping and Pipelines*.

Chapter 14 Combustion Applications

14.1 Scope. This chapter shall apply to equipment that uses hydrogen as a fuel source for combustion fuel to provide heat used for the processing of materials and related equipment.

14.1.1* Applicability. The requirements of this chapter shall apply to the use of GH_2 as part of a manufacturing process using thermal spraying or as a fuel in heating applications. This chapter shall apply to new installations and to alterations or extensions to existing equipment. The storage, use, and handling of GH_2 in any quantity shall also comply with the requirements of Chapters 1 through 4 and the applicable requirements of Chapters 5 through 8.

14.1.1.1 The requirements of Chapters 4 and 6 through 8 contain fundamental requirements applicable to all hydrogen systems. Use-specific requirements for hydrogen or hydrogen mixtures used as a fuel for thermal spray equipment and for heating applications are found in this chapter. Where there is a conflict between a fundamental requirement and a use-specific requirement, the use-specific requirement shall be applicable.

14.2 General. [Reserved]

14.3 Use.

14.3.1 Thermal Spraying Equipment.

14.3.1.1 General. Thermal spraying equipment shall meet the requirements of 14.3.1.

14.3.1.2* Indoor Installations of Thermal Spraying Equipment.

14.3.1.2.1* Thermal spray equipment shall be installed, inspected, and maintained in accordance with the manufacturer's instructions to minimize the potential for leaks of the gas delivery system.

14.3.1.2.2* The area in which the thermal spray equipment is installed shall be classified in accordance with *NFPA 70*, Article 500.

14.3.1.2.2.1 Electrical equipment comply with the requirements of *NFPA 70* for the electrical classification of the area in which it is installed.

14.3.1.2.3 The area containing the thermal spray equipment shall be ventilated to prevent flammable gas buildup from potential system leaks.

14.3.1.2.3.1 Mechanical exhaust ventilation systems required by Section 6.17 or for operation of the equipment shall be interlocked with the thermal spraying equipment to prevent the flow of gases without the ventilation system operating.

14.3.1.2.4* The ceiling of rooms in which thermal spray equipment is installed shall be constructed in a manner to prevent the accumulation of hydrogen gas.

14.3.1.2.5 Venting systems discharging hydrogen to the atmosphere shall be piped to a designated point outside the building in accordance with Section 6.16.

14.3.1.2.6* A hydrogen gas detection system shall be installed in the room or area where thermal spray equipment utilizing hydrogen gas is installed.

14.3.1.2.6.1 Activation of the gas detection system shall result in the following:

(1) The thermal spraying system shall be prevented from starting if hydrogen is detected at a concentration exceeding 25 percent LFL.
(2) The thermal spray system shall be shut down upon detection of hydrogen during operation at a concentration exceeding 25 percent LFL.

14.3.1.2.7 Automatic emergency shutoff valves shall be provided on the piping used to supply hydrogen gas to the thermal spraying equipment. Activation of the valves shall shut off the flow of hydrogen in the event of the following:

(1) Loss of ventilation systems required by 14.3.1.2.3.1
(2) Detection of hydrogen at a concentration exceeding 25 percent LFL
(3) Activation of emergency stop functions provided with the manufacturer's equipment

14.3.1.3 Outdoor Installations of Thermal Spray Equipment. (Reserved)

14.4 Storage.

14.4.1 Requirements for Hydrogen Storage Systems Serving Thermal Spray Equipment.

14.4.1.1 General. Hydrogen storage systems attendant to thermal spraying facilities shall be in accordance with the applicable requirements of Chapters 6 through 8.

14.4.1.1.1 Active gas generation devices used as a source of hydrogen supply, including but not limited to electrolyzers or reformers, shall also be in accordance with the applicable provisions of Chapter 13.

14.4.1.2 Indoor Storage. (Reserved)

14.4.1.3 Outdoor Storage. (Reserved)

14.4.2 Requirements for Hydrogen Storage Systems Serving Heating Applications. (Reserved)

Chapter 15 Special Atmosphere Applications

15.1 Scope. This chapter shall apply to equipment that uses hydrogen as an atmosphere for use in the following applications:

(1) Furnaces regulated by NFPA 86 using hydrogen in special atmosphere applications
(2) Hydrogen used as a heat exchange medium for hydrogen cooled electrical generators

15.1.1 The storage, use, and handling of GH_2 in any quantity shall also comply with the requirements of Chapters 1 through 4 and the requirements of Chapters 6 through 8, as applicable.

15.1.2 In addition to the requirements of this code, furnaces using hydrogen in the form of a special atmosphere shall be in accordance with NFPA 86.

15.1.3 Where there is a conflict between a fundamental requirement and a use-specific requirement, the use-specific requirement shall apply.

15.2 General. (Reserved)

15.3 Use.

15.3.1 Furnaces.

15.3.1.1 General.

15.3.1.1.1* Subsection 15.3.1 shall apply to the production and use of special atmospheres either by blending (or mixing) pure hydrogen gas with other gases, such as nitrogen or the use of pure hydrogen as the sole constituent of the special atmospheres in furnaces.

15.3.1.1.1.1 Subsection 15.3.1 shall apply to special atmospheres containing hydrogen used in Class C or Class D furnaces.

15.3.1.1.1.2 All furnace installations shall also comply with the requirements of NFPA 86.

15.3.1.1.2 Before new equipment is installed or existing equipment is remodeled, complete plans, sequence of operations, and specifications shall be submitted for approval to the authority having jurisdiction. [**86:**4.1.1]

15.3.1.1.2.1* Plans shall be drawn that show all essential details with regard to location, construction, ventilation, piping, and electrical safety equipment. A list of all combustion, control, and safety equipment giving manufacturer and type number shall be included. [**86:**4.1.1.1]

15.3.1.1.2.2* Wiring diagrams and sequence of operations for all safety controls shall be provided. [**86:**4.1.1.2]

15.3.1.1.2.3 Any deviation from this code shall require approval from the authority having jurisdiction. [**86:**4.1.2]

15.3.1.1.3 Venting.

15.3.1.1.3.1 Unwanted, normal operating, and emergency releases of fluids (gases or liquids) from special [hydrogen] atmosphere generators, storage tanks, gas cylinders, and flow control units shall be disposed of to an approved location. [**86:**13.5.1.3]

15.3.1.1.3.2 Venting of unwanted flammable [hydrogen] atmosphere gas shall be done by controlled venting to an approved location outside the building or by completely burning the atmosphere gas and venting the products of combustion to an approved location. [**86:**13.5.1.4]

15.3.1.1.3.3 Nonflammable and nontoxic fluids shall be vented to an approved location outside the building at a rate that does not pose a hazard of asphyxiation. [**86:**13.5.1.5]

15.3.1.1.4 Flow Control of Special [Hydrogen] Atmospheres. [86:13.5.7]

15.3.1.1.4.1* Processes and equipment for controlling flows of special [hydrogen] atmospheres shall be designed, installed, and operated to maintain a positive pressure within connected furnaces. [**86:**13.5.7.1]

15.3.1.1.4.2 The flow rates used shall restore positive internal pressure without infiltration of air during atmosphere contractions when furnace chamber doors close or workloads are quenched. [**86:**13.5.7.2]

15.3.1.1.4.3* Where the atmosphere is flammable, its flow rate shall be sufficient to provide stable burn-off flames at vent ports. [**86:**13.5.7.3]

15.3.1.1.4.4 Means shall be provided for metering and controlling the flow rates of all fluids that the special [hydrogen] atmosphere for a furnace comprises. [**86:**13.5.7.4]

(A) Devices with visible flow indicators shall be used to meter the flows of carrier gases, carrier gas component fluids, inert purge gases, enrichment gases, or air. [**86:**13.5.7.4 (A)]

(B) The installation of flow control equipment shall meet the following criteria: [**86:**13.5.7.4 (C)]

(1) It shall be installed at the furnace, at the generator, or in a separate flow control unit. [**86:**13.5.7.4 (C)(1)]
(2) It shall be accessible and located in an illuminated area so that its operation can be monitored. [**86:**13.5.7.4 (C)(2)]

15.3.1.1.5* Special Processing Hydrogen Atmosphere Gas Mixing Systems. Where [hydrogen atmospheres are prepared using] gas mixing systems that incorporate a surge tank mixing scheme that cycles between upper and lower set pressure limits, the following shall apply:

(1)*Pipes feeding [hydrogen] atmosphere mixing systems shall contain manual isolation valves.
(2) The effluents from the relief devices used to protect a [hydrogen] atmosphere mixing system shall be piped to an approved location.
(3)*Piping and components shall be in accordance with ASME B31.1, appropriate volume.
(4) The use of liquids shall not be permitted in [hydrogen] atmosphere mixing systems.
(5) Means shall be provided for metering and controlling the flow rates of all gases.
(6) Flow control of the blended atmosphere gas shall be in compliance with each furnace's applicable special [hydrogen] atmosphere flow requirements and protective equipment.
(7) Atmosphere gas mixers that create nonflammable or indeterminate gas mixtures shall be provided with the following:
   (a) Gas analyzers or other equipment for continuously monitoring and displaying the flammable gas composition
   (b) Automatic controls to shut off the flammable gas flow when the [hydrogen] concentration rises above the operating limit
(8) If the creation of a gas mixture with a [hydrogen] content that is higher than intended results in the risk of explosions where none existed, controls shall be provided to shut off the [hydrogen] flow automatically when the [-] concentration rises above the operating limit.
(9) When the [hydrogen] concentration in a mixed gas exceeds the established high limit, an alarm shall be actuated to alert personnel in the area.
(10) Restart of [hydrogen] flow after a high concentration limit interruption shall require manual intervention at the site of the gas mixer.
(11) Safety shutoff valves used to admit combustible gases to the gas mixer shall be normally closed and capable of closing against maximum supply pressure.
(12) Atmosphere gas mixers installed outdoors shall be selected for outdoor service or placed in a shelter that provides weather protection.
(13) Where a gas mixer is sited in a shelter, the temperature within shall be maintained in accordance with the manufacturer's recommendations.
[**86:**13.5.6]

15.3.1.1.6 Synthetic Atmosphere Flow Control. Synthetic atmosphere flow control units shall have the additional capabilities specified in 15.3.1.1.6.1 through 15.3.1.1.6.9. [**86:**13.5.8]

15.3.1.1.6.1 An atmosphere flow control unit equipped with an inert purge mode shall have a manually operated switch on the face of the unit that actuates the purge. [**86:**13.5.8.1]

15.3.1.1.6.2 A safety interlock shall be provided for preventing the initial introduction of [any] flammable fluid into a furnace before the furnace temperature has risen to 1400°F (760°C). [**86:**13.5.8.2]

(1) Open circuit failure of the temperature-sensing components shall cause the same response as an operating temperature less than 1400°F (760°C). [**86:**8.17.2]
(2)*The 1400°F (760°C) bypass interlock shall be equipped with temperature indication. [**86:**8.17.3]
(3)*The temperature-sensing components of the 1400°F (760°C) bypass interlock shall be rated for the temperature and the atmosphere to which they are exposed. [**86:**8.17.4]
(4) The temperature-sensing element of the 1400°F (760°C) bypass interlock shall be located so that unsupervised burners are not allowed to operate at temperatures below 1400°F (760°C). [**86:**8.17.5]
(5)*The temperature-sensing element of the [1400°F (760°C)] bypass interlock shall be located where recommended by the [furnace] manufacturer or designer. [**86:**8.16.8]
(6)*The 1400°F (760°C) bypass interlock set point shall not be set below 1400°F (760°C) and shall indicate its set point in units of temperature (degrees Fahrenheit or degrees Celsius) that are consistent with the primary temperature-indicating controller. [**86:**8.17.6]
(7) Visual indication shall be provided to indicate when the 1400°F (760°C) bypass interlock is in the bypass mode. [**86:**8.17.7]
(8)*The operating temperature interlock and its temperature-sensing element shall not be used as the 1400°F (760°C) bypass interlock. [**86:**8.17.8]

15.3.1.1.6.3 Resumption of [hydrogen atmosphere] flow following a power failure shall require manual intervention (reset) by an operator after power is restored. [**86:**13.5.8.5]

15.3.1.1.6.4 Where the flammable fluid flow is interrupted, one of the following shall apply:

(1) The flow control unit shall automatically admit a flow of inert gas that restores positive pressure and shall initiate an audible and visual alarm, unless otherwise permitted by 15.3.1.1.6.4(2).
(2) Manual inert gas purge shall be provided for furnaces where operators are present and able to effect timely shutdown procedures subject to the authority having jurisdiction. [**86:**13.5.8.6]

15.3.1.1.6.5 Means shall be provided to test for leak-free operation of safety shutoff valves for flammable or toxic fluids. [**86:**13.5.8.7]

15.3.1.1.6.6* Safety relief valves to prevent overpressurizing of glass tube flowmeters and all other system components shall be in accordance with ASME B31.1, appropriate volume. [**86:**13.5.8.8]

15.3.1.1.6.7 The effluents from relief valves used to protect control unit components containing flammable or toxic fluids shall be piped to an approved disposal location. [**86:**13.5.8.9]

15.3.1.1.6.8 Alternative valves meeting the following criteria shall be provided for manually shutting off the flow of flammable fluids into a furnace: [**86:**13.5.8.10]

(1) They shall be separate from the atmosphere control unit. [**86:**13.5.8.10(1)]
(2) They shall be accessible to operators. [**86:**13.5.8.10(2)]
(3) They shall be located remotely from the furnace and control unit. [**86:**13.5.8.10(3)]
(4) They shall be listed or approved for the service.

15.3.1.1.6.9* Pipes feeding atmosphere flow control units shall contain isolation valves. [**86:**13.5.8.11]

15.3.1.1.6.10 Low melting point solder shall not be used with piping supplying hydrogen to furnaces or to special [hydrogen] atmosphere blending systems of flow control manifolds.

15.3.1.1.7 Piping Systems for Hydrogen Atmospheres.

15.3.1.1.7.1 Piping shall be sized for the full flow of [hydrogen] atmospheres to all connected furnaces at maximum demand rates. [**86:**13.5.9.1]

15.3.1.1.7.2* Pressure vessels and receivers shall be constructed of materials compatible with the lowest possible temperature of [hydrogen] processing atmospheres, or controls shall be provided to stop the flow of gas when the minimum temperature is reached. [**86:**13.5.9.2]

(A) A low temperature shutoff device used as prescribed in 15.3.1.1.7.2 shall not be installed so that closure of the device can interrupt the main flow of inert safety purge gas to connected furnaces containing indeterminate special processing atmospheres. [**86:**13.5.9.2(A)]

(B) If closure of a low temperature shutoff device creates any other hazard, an alarm shall be provided to alert furnace operators or other affected persons of this condition. [**86:**13.5.9.2(B)]

(C) The user shall consult with the industrial gas supplier to select the low temperature shutoff device, its placement, and a shutoff set point temperature. [**86:**13.5.9.2(C)]

15.3.1.1.8 Inspection, Testing, and Maintenance.

15.3.1.1.8.1 All safety interlocks shall be tested for function at least annually. [**86:**7.4.4]

15.3.1.1.8.2* The set point of temperature, pressure, or flow devices used as safety interlocks shall be verified at least annually. [**86:**7.4.5]

15.3.1.1.8.3 Safety device testing shall be documented at least annually. [**86:**7.4.6]

15.3.1.1.8.4 Whenever any safety interlock is replaced, it shall be tested for function. [**86:**7.4.16]

15.3.1.1.8.5 Whenever any temperature, pressure, or flow device used as a safety interlock is replaced, the set point setting shall be verified. [**86:**7.4.17]

15.3.1.1.9 Fire Protection.

15.3.1.1.9.1* General. A study shall be conducted to determine the need for fixed or portable fire protection systems for ovens, furnaces, or related equipment. [**86:**9.1]

(A) The determination of the need for fire protection systems shall be based on a review of the fire hazards associated with the equipment. [**86:**9.1.1]

(B) Where determined to be necessary, fixed or portable fire protection systems shall be provided. [**86:**9.1.2]

15.3.1.1.10* Special Atmospheres and Furnaces.

15.3.1.1.10.1 Indeterminate Atmospheres. Indeterminate atmospheres shall be treated as flammable atmospheres with the following considerations:

(1) Where one special atmosphere is replaced with another special atmosphere (e.g., flammable [hydrogen] replaced with nonflammable) that can cause the atmosphere to become indeterminate at some stage, burn-in or burn-out procedures shall not be used.
(2) In the case of any indeterminate atmosphere, inert gas purge procedures alone shall be used for introduction and removal of special processing atmospheres. [**86:**13.5.10.1]

15.3.1.1.10.2 Automatic Cycling. Automatic cycling of a furnace (e.g., quenching, load transfer from a heated zone to a cold vestibule) shall not be permitted where the special atmosphere has become indeterminate during the replacement of a flammable [hydrogen] atmosphere with a nonflammable or an inert atmosphere (or vice versa) until the special atmosphere in all furnace chambers has been verified as either flammable, nonflammable, or inert. [**86:**13.5.10.2]

15.3.1.1.10.3* Furnace Type. The type of furnace shall be determined in accordance with Table 15.3.1.1.10.3. [**86:**13.5.10.3]

15.3.1.1.11 Design Requirements for the Introduction, Use, and Removal of Flammable and Indeterminate Special Atmospheres from Furnaces. [86:13.5.11.1]

15.3.1.1.11.1 General.

(A) Flammable and indeterminate atmosphere gases shall be introduced, used, and removed from furnaces without creating an uncontrolled fire, deflagration, or explosion. [**86:**13.5.11.1(A)]

(B)* Special atmosphere furnaces that use flammable [hydrogen] or indeterminate special atmospheres shall be designed and maintained to minimize the unintended infiltration of air into the furnace. [**86:**13.5.11.1(B)]

(C)* Operating instructions for introducing, using, and removing flammable special [hydrogen] atmosphere gases shall comply with Chapter 15 and Section 7.3 of NFPA 86. [**86:**13.5.11.1(C)]

(D)* Where present, the liquid level in manometers or bubbler bottles on vent lines shall be checked and maintained at the required operating range as necessary. [**86:**13.5.11.1(D)]

(E)* Discharge from effluent vents of furnaces using special [hydrogen] atmospheres shall be piped or captured by hoods and discharged to an approved location. [**86:**13.5.11.1(E)]

Table 15.3.1.1.10.3 Types of Furnaces

<table>
<tr><th>Furnace Type</th><th>Feature</th><th>Operating Temperature</th><th>Example</th></tr>
<tr><td>Type I</td><td rowspan="2">The chamber(s) <1400°F are separated by doors from those operating at > 1400°F</td><td>One or more zones always >1400°F</td><td>Pusher tray (cold chambers at each end, inner and outer doors with and without integral quench)</td></tr>
<tr><td>Type II</td><td>Can be <1400°F after introduction of a cold load</td><td>Batch integral quench (1 or more cold chambers, integral quench)</td></tr>
<tr><td>Type III</td><td>Both inlet and outlet ends of furnace are open and no external doors or covers</td><td rowspan="3">At least one zone >1400°F and have no inner doors separating zones > and <1400°F</td><td>Belt (both ends open)</td></tr>
<tr><td>Type IV</td><td>Only one end of the furnace is open and there are no external doors or covers</td><td>Belt (with integral quench, entry end open)</td></tr>
<tr><td>Type V</td><td>Outer doors or covers are provided</td><td>Box (exterior door)</td></tr>
<tr><td>Type VI</td><td></td><td>>1400°F before introduction and removal of special [hydrogen] atmosphere gas</td><td></td></tr>
<tr><td>Type VII</td><td></td><td>Never >1400°F</td><td></td></tr>
<tr><td>Type VIII</td><td>A heating cover furnace with an inner cover</td><td rowspan="2">A heating cover and inner cover are separated from a base that supports the work being processed</td><td>Bell (with or without retort)</td></tr>
<tr><td>Type IX</td><td>A heating cover furnace without an inner cover or with a nonsealed inner cover</td><td>Car tip-up</td></tr>
</table>

For SI units, 1400°F = 760°C.
[**86:** Table 13.5.10.3]

(F)* Process control air or burnout air shall be supplied from an air blower. [**86:**13.5.11.1(F)]

15.3.1.1.11.2 Burn-Off Pilots and Other Ignition Sources. [86:13.5.11.2] This section applies to burn-off pilots and other ignition sources provided for the purpose of igniting flammable special [hydrogen] atmosphere gases at effluent stacks, open ends, or doors when a flammable atmosphere is present in the furnace. [**86:**13.5.11.2]

(A) A burn-off pilot, glow plug, flame screen, or other source of ignition shall be provided and located at the gas–air interface and sized to reliably ignite the flammable special [hydrogen] atmosphere gas that is released at effluents, open ends or doors. [**86:**13.5.11.2(A)]

(B)* Burn-off pilots that are exposed to inert purge gas or special [hydrogen] atmosphere gas under either normal or emergency conditions shall be of a type that will remain in service to ignite flammable effluent gases. [**86:**13.5.11.2(B)]

(C)* Burn-off pilots igniting effluent from vent pipes shall not require flame supervision. [**86:**13.5.11.2(C)]

(D) Where burn-off pilots are the primary ignition source for effluent from open furnace ends, at least one burn-off pilot shall have flame supervision at each open end. [**86:**13.5.11.2(D)]

(E)* Where one or more burn-off pilots are the primary ignition source at a door, at least one burn-off pilot shall have flame supervision interlocked to prevent automatic door opening in the event of flame failure. [**86:**13.5.11.2(E)]

(F) Burn-off pilots that have flame supervision shall accomplish the following:

(1) Provide an audible and visual alarm to alert the operator to the failure
(2) Not shut off the burn-off pilot gas in the event of flame failure
[**86:**13.5.11.2(F)]

(G)* Burn-off pilot gas shall not shut off in the event of power failure. [**86:**13.5.11.2(G)]

(H)* Burn-off pilots shall be located and sized to reliably ignite the effluent stream. [**86:**13.5.11.2(H)]

(I) Each burn-off pilot shall be equipped with an individual manual shutoff valve. [**86:**13.5.11.2(I)]

(J)* Burn-off pilots gas supply source shall be located downstream of the equipment main manual isolation valve and upstream of any other shutoff devices that can close automatically, including safety shutoff valves. [**86:**13.5.11.2(J)]

15.3.1.1.11.3* Flame Curtains. Where a flame curtain is used, the following features shall be provided and in service:

(1) One or more flame curtain pilots shall be positioned to reliably ignite the flame curtain.
(2) At least one flame curtain pilot at a flame curtain shall have flame supervision interlocked to prevent the opening of a closed door served and interlocked to prevent operation of the flame curtain at the door served.
(3) At least one safety shutoff valve upstream of all flame curtains on a furnace shall be interlocked to close upon the following conditions:
    (a) Low fuel gas pressure on the flame curtain fuel gas supply
    (b) High fuel gas pressure on the flame curtain fuel gas supply where a high gas pressure issue would create a safety concern
(4) An automatic control valve shall be provided ahead of each flame curtain arranged to open when the door served is not closed.
(5) When the safety shutoff valve in item 15.3.1.1.11.3(3) is closed, any doors served by that safety shutoff valve shall be interlocked so they cannot open.
(6)*A manual means of overriding the door interlock in 15.3.1.1.11.3(5)shall be provided.
[**86:**13.5.11.3]

15.3.1.1.11.4 Flammable Special Atmosphere Introduction. Flammable special [hydrogen] atmospheres shall be introduced into a furnace using one of the following methods:

(1) Purge-in
(2) Burn-in
[**86:**13.5.11.4]

15.3.1.1.11.5 Flammable Special Atmosphere Removal. Flammable special [hydrogen] atmospheres shall be removed from a furnace using one of the following methods:

(1) Purge-out
(2) Burn-out
[**86:**13.5.11.5]

15.3.1.1.11.6 Purge-in Requirements.

(A) Written purge-in instructions shall be provided for each furnace. [**86:**13.5.11.6.1]

(1)*Purge effectiveness shall not be compromised during the purge process. [**86:**13.5.11.6.1(A)]
(2) Furnace doors and covers shall be positioned in accordance with the operating instructions before purge-in begins. The inner and outer covers of Type VIII and Type IX furnaces shall not be placed in position onto the furnace base unless the workload and base are at least 50°F (28°C) below the auto-ignition temperature of any flammable gas mixture that can be present in the cover. [**86:**13.5.11.6.1(B)]

(B) Purge-in shall reduce the oxygen content of the furnace to less than 1 percent by displacement with an inert gas or before introduction of the flammable special [hydrogen] atmosphere gas. [**86:**13.5.11.6.2]

(C) Positive Furnace Pressure.

(1) A positive furnace pressure shall be maintained during the purge-in process and continue through the transition from the inert gas purge to the introduction of special [hydrogen] atmosphere gas. [**86:**13.5.11.6.3(A)]
(2) Positive pressure for Type VIII or Type IX heating-cover (retort) type furnaces shall be indicated by a bubbler, vent manometer, or similar device. [**86:**13.5.11.6.3(B)]

(D)* During the inert gas purge, flammable special [hydrogen] atmosphere safety shutoff valves shall remain closed. [**86:**13.5.11.6.4]

(E) Purging of the furnace shall continue until the purge has been verified as complete using one of the following methods:

(1) Time-flow purge method in accordance with Section 13.5.12 of NFPA 86
(2) Two consecutive analyses of all chambers indicating that the oxygen content is less than 1 percent
[**86:**13.5.11.6.5]

(F) Furnaces shall not be required to be at any specific temperature when the inert gas is displaced by the flammable special [hydrogen] atmosphere gases. [**86:**13.5.11.6.6]

(G)* Active sources of ignition shall be provided at interfaces between air and flammable or indeterminate special [hydrogen] atmosphere gases at furnace openings and doors. Effluent vents terminating inside a building shall also be provided with an active source of ignition. [**86:**13.5.11.6.7]

(H)* All furnace and vestibule volumes that will contain a flammable special [hydrogen] atmosphere gas shall be purged with inert gas prior to the special [hydrogen] atmosphere gas being admitted. [**86:**13.5.11.6.8]

(I) During the inert gas purge, all flame curtain fuel gas valves shall be closed. [**86:**13.5.11.6.9]

(J) During the inert gas purge, all circulating and recirculating fans shall be operating as required by the operating instructions. [**86:**13.5.11.6.10]

(K) Flammable special [hydrogen] atmosphere gases shall not be introduced unless the following conditions exist:

(1) Burn-off pilots at open ends, doors, and effluent lines are ignited.
(2) All manual valves to flame curtains (where provided) are open.
(3) All automatic valves to flame curtain are in service.
(4)*All required quench fluid levels are at the correct level.
(5) Purging of the furnace has been completed as defined by 15.3.1.1.11.6(E)
(6) Operation of flame curtains (where provided) is verified. [**86:**13.5.11.6.11]

(L)* After the introduction of the flammable special [hydrogen] atmosphere, the purge-in atmosphere introduction process is considered complete when flame appears at furnace doors, open ends, or effluent lines in accordance with the specific design features and operating instructions for the furnace. [**86:**13.5.11.6.12]

15.3.1.1.11.7 Burn-in Requirements.

(A) Written burn-in instructions shall be provided for each furnace. [**86:**13.5.11.7.1]

(1)*Burn-in effectiveness shall not be compromised by taking any action that deviates from the written operating instructions for burn-in. [**86:**13.5.11.7.1(A)]
(2) The position of inner and outer furnace doors and the placement of manual torches shall be as directed in the operating instructions during each stage of the burn-in procedure. [**86:**13.5.11.7.1(B)]

(B)* Burn-in shall reduce the oxygen content of the furnace by consuming the oxygen in the air through combustion with a flammable atmosphere gas that will reliably ignite at the gas–air interfaces. [**86:**13.5.11.7.2]

(C)* To begin the burn-in process, the flammable special [hydrogen] atmosphere gas shall be introduced at a location in the furnace that is at or above 1400°F (760°C). [**86:**13.5.11.7.3]

(D)* Where a stable flame front propagating through a chamber under 1400°F (760°C) cannot be maintained, the burn-in process shall not be used. [**86:**13.5.11.7.4]

(E)* For zones under 1400°F (760°C), stable flames of burning gas shall be maintained in the zones as the special [hydrogen] atmosphere gas is burned-in. [**86:**13.5.11.7.5]

(F)* For a Type II furnace (batch integral quench furnace) with heating chamber fan, the fan shall not be operating during burn-in while the inner heating chamber door is open. [**86:**13.5.11.7.6]

(G)* For Types I through VII furnaces, recirculating fans in cooling zones shall be turned off during burn-in. [**86:**13.5.11.7.7]

(H) Special Requirements for Type VIII and IX Furnaces.

(1) Circulating base fans, where provided, shall be turned on. [**86:**13.5.11.7.8(A)]
(2)*The cover shall be sealed to the furnace base before flammable or indeterminate special [hydrogen] atmospheres are introduced. [**86:**13.5.11.7.8(B)]
(3)*Where a furnace uses an oil seal between a cover and a base, means shall be provided so that furnace pressure is maintained below the static head pressure of the seal oil. [**86:**13.5.11.7.8(C)]

(I) For Type VIII furnaces, atmosphere introduction shall be by purge-in, and atmosphere removal shall be by purge-out; burn-in and burn-out procedures shall not be used. [**86:**13.5.11.7.9]

(J)* After the introduction of the flammable special [hydrogen] atmosphere, the burn-in atmosphere introduction process shall be considered complete when flame appears at the furnace doors, open ends, or effluent lines, where present, in accordance with the specific design features and operating instructions for the furnace. [**86:**13.5.11.7.10]

15.3.1.1.11.8 Purge-Out Requirements.

(A) Written purge-out instructions shall be provided for each furnace. [**86:**13.5.11.8.1]

(1)*Purge effectiveness shall not be compromised during the purge process. [**86:**13.5.11.8.1(A)]
(2) Furnace doors and covers shall be positioned in accordance with the manufacturer's instructions before purge-out begins. [**86:**13.5.11.8.1(B)]

(B) Positive Furnace Pressure.

(1) A positive furnace pressure shall be maintained at all times during purge-out, including the transition from the special [hydrogen] atmosphere gas operation to the inert gas purge. [**86:**13.5.11.8.2(A)]
(2) For Types VIII and IX furnaces, an indication of positive furnace pressure shall be provided by an indicating manometer or similar device. [**86:**13.5.11.8.2(B)]

(C)* Once the inert purge gas flow has been established for purge-out, the flow of all flammable special [hydrogen] atmosphere gases shall be stopped. [**86:**13.5.11.8.3]

(D)* Purging shall include all of the furnace volume that contains a flammable or indeterminate special [hydrogen] atmosphere gas. [**86:**13.5.11.8.4]

(E)* Purge-out shall be considered complete when all chambers that would create a hazard are below 50 percent of LFL and shall be determined by one of the following two methods:

(1) Time-flow purge method in accordance with Section 13.5.12 of NFPA 86 as it applies to the purge-out process
(2) Two consecutive analyses of all chambers indicating that the flammable level within the furnace is below 50 percent of LFL
[**86:**13.5.11.8.5]

(F) When purge-out is complete, the following shall be permitted to be turned off:

(1) Burn-off pilots
(2) Circulation and recirculation fans required for purge-out
(3) Inert purge gas supply to the furnace
(4) Flame curtains
[**86:**13.5.11.8.6]

15.3.1.1.11.9 Burn-Out Requirements.

(A) Written burn-out instructions shall be provided for each furnace. [**86:**13.5.11.9.1]

(1)*Burn-out effectiveness shall not be compromised by taking any action that deviates from the written operating instructions for burn-out. [**86:**13.5.11.9.1(A)]
(2)*Inner and outer furnace doors, where provided, shall be placed in the appropriate position as directed in the operating instructions during each stage of the burn-out procedure. [**86:**13.5.11.9.1(B)]

(B)* Through the controlled admission of air to a furnace, burn-out shall reduce the flammable content within all heating chambers and vestibules through combustion with the oxygen in the air. [**86:**13.5.11.9.2]

(C)* To initiate the burn-out process, one of the following conditions shall be met:

(1) Air is introduced into the furnace at a point that is at or above 1400°F (760°C).
(2) Where air is introduced into a furnace at a point below 1400°F (760°C), the following shall apply:
   (a)*The furnace is under positive pressure.
   (b) A source of ignition is provided at the interface between the flammable atmosphere and the point of air introduction.
   [**86:**13.5.11.9.3]

(D) Burn-out shall include turning off all special [hydrogen] atmosphere gases and admitting air in a sequence outlined in the written burn-out instructions. [**86:**13.5.11.9.4]

(E) Burnout air shall be admitted by any of the following arrangements:

(1) Through furnace doors
(2) Through independent piping and furnace gas inlets
(3) Through sections of piping and furnace inlets that are common to both flammable special [hydrogen] atmosphere and burnout air when the systems are designed to prevent the flow of air and flammable special [hydrogen] atmosphere at the same time
[**86:**13.5.11.9.5]

(F)* During burn-out, recirculating fans shall be turned off in furnace zones under 1400°F (760°C) and in zones at or above 1400°F (760°C) that can cause turbulence in zones under 1400°F (760°C). [**86:**13.5.11.9.6]

(G) Burn-out shall be considered complete when one of the following conditions is satisfied:

(1) For furnaces that do not contain soot, all visible flame in the furnace and at all effluents are observed to be extinguished.
(2) For furnaces that contain soot that cannot re-form a flammable atmosphere gas, all visible flames in the furnace and at all effluents are observed to be extinguished.
(3) For furnaces that contain soot that re-form flammable atmosphere gas, all visible flames in the furnace and at effluents are observed to be extinguished after burn-out procedures are performed that include the introduction of additional air to effect the burn-out of the re-formed flammable atmosphere gas.
[**86:**13.5.11.9.7]

(H) When burn-out is complete, the following shall be permitted to be turned off:

(1) Burn-off pilots
(2) Circulation and recirculation fans required for burn-out
(3) Flame curtains
[**86:**13.5.11.9.8]

15.3.1.1.11.10* Special Atmosphere Equipment Piping System. [86:13.5.11.10]

(A) General. The special [hydrogen] atmosphere equipment piping system shall be that piping starting at the equipment manual isolation valve that includes the components for the delivery of special [hydrogen] atmosphere fluids to a furnace. [**86:**13.5.11.10.1]

(B) Manual Shutoff Valves and Equipment Isolation.

(1)*An equipment isolation manual shutoff valve shall be provided for each special [hydrogen] atmosphere fluid, shall be located upstream of all devices on the special [hydrogen] atmosphere equipment piping, and shall be lockable. [**86:**13.5.11.10.2.1]
   (a) Where fuel gas is used as a special [hydrogen] atmosphere gas, a separate manual shutoff valve shall be provided for the special [hydrogen] atmosphere feed. This valve shall not be required to be lockable where the fuel gas main isolation manual shutoff valve is lockable. [**86:**13.5.11.10.2.1(A)]
   (b) Equipment isolation manual shutoff valves for each special [hydrogen] atmosphere fluid shall be accessible from the normal operator working level without the use of ladders or portable equipment. [**86:**13.5.11.10.2.1(B)]
(2) The position of any manual shutoff valve that can interrupt the supply of inert gas to an automatic inert purge gas line shall be electrically supervised and cause a visual and audible alarm to alert the operator whenever this valve is not in the open position and the automatic inert purge is required to be in service. [**86:**13.5.11.10.2.2]
(3) A bypass manual shutoff valve shall be provided to bypass each normally open emergency inert gas purge valve, and be arranged as follows:
   (a) Be accessible to the operator for use in accordance with written operating instructions
   (b) Have a port area equal to or larger than the bypassed normally open emergency inert gas purge valve
   [**86:**13.5.11.10.2.3]
(4) Each manual shutoff valve shall have a tag that identifies the valve and the special [hydrogen] atmosphere it controls. [**86:**13.5.11.10.2.4]
(5) The operating instructions required by Section 7.3.3 of NFPA 86 shall reference the valve tag identifications required by 15.3.1.1.11.10(B). [**86:**13.5.11.10.2.5]
(6) Each manual shutoff valve (equipment isolation valve) shall be in accordance with the following: [**86:**13.5.11.10.2.6]
   (a) They shall be provided for each piece of equipment.

(b) They shall have permanently affixed visual indication of the valve position.
(c) They shall be quarter-turn valves with stops.
(d) Wrenches or handles shall remain affixed to valves and shall be oriented with respect to the valve port to indicate the following:
i. An open valve when the handle is parallel to the pipe
ii. A closed valve when the handle is perpendicular to the pipe
(e) They shall be readily accessible.
(f) Valves with removable wrenches shall not allow the wrench handle to be installed perpendicular to the fuel gas line when the valve is open.
(g) They shall be able to be operated from full open to full close and return without the use of tools.

(7) Manual valves that are not used for shutoff shall not be required to comply with 15.3.1.1.11.10(B) other than 15.3.1.1.11.10(B)(4). [**86:**13.5.11.10.2.7]

(C) Regulators.

(1) Regulators shall be provided on each special [hydrogen] atmosphere gas line where the gas supply pressure exceeds the operating or design parameters of equipment piping and components in the equipment piping. [**86:**13.5.11.10.3(A)]
(2)*Regulator atmospheric vents shall be vented to an approved location. [**86:**13.5.11.10.3(B]
(3) Regulator vents shall not be manifolded with the following:
(a) Vents from other furnaces
(b) Vents downstream of the safety shutoff valves
(c) Relief valve vents
[**86:**13.5.11.10.3(C)]
(4)*Where a regulator vent is manifolded with other vents, the area of the vent manifold shall equal or exceed the sum of the individual vent line areas of each vent line served from its point of connection. [**86:**13.5.11.10.3(D)]
(5) The regulator vent termination shall be designed to prevent the entry of water and insects without restricting the flow capacity of the vent. [**86:**13.5.11.10.3(E)]

(D) Relief Valves.

(1)*Relief valves shall be provided downstream of any regulator where a regulator failure could expose downstream piping, components, or furnace to pressures exceeding their maximum design pressure. [**86:**13.5.11.10.4(A)]
(2)*Relief valve(s) or other means of controlling pressure shall be provided for each liquid special atmosphere piping system where there is a potential to overpressurize the liquid special atmosphere piping. This specifically includes each section of liquid-filled special atmosphere piping that can be isolated by valves. [**86:**13.5.11.10.4(B)]
(3)*Relief valves shall be piped to an approved location. [**86:**13.5.11.10.4(C)]
(4) Relief valve piping shall not be manifolded with either of the following:
(a) Vents from other furnaces
(b) Vents from regulators
[**86:**13.5.11.10.4(D)]
(5) Relief valve piping shall not be manifolded with other relief valve piping where either of the following could occur: [**86:**13.5.11.10.4(E)]
(a) Mixing of liquids and gases [**86:**13.5.11]
(b) Mixing of fluids (liquids or gases) that could result in corrosion to relief valves or relief valve piping [**86:**13.5.11]

(E) Filters.

(1) A filter shall be provided upstream of each liquid flow sensor. [**86:**13.5.11.10.5(A)]
(2) A filter shall have a particle size rating that will not allow particles of a size that can foul liquid flow sensors or liquid flowmeters to pass the filter. [**86:**13.5.11.10.5(B)]

(F) Flowmeters. One flowmeter shall be provided on each special [hydrogen] atmosphere equipment supply line. [**86:**13.5.11.10.6]

(G) Pressure Gauges. Pressure gauges shall be provided at points in the special [hydrogen] atmosphere equipment piping where the operator must be provided visual pressure information to verify the furnace is being maintained within safe operating limits. These points shall be determined as part of the furnace design. [**86:**13.5.11.10.7]

(H)* Atmosphere Inlets. Atmosphere inlets shall not be located in such a way that atmosphere flow will directly impinge on temperature control or over temperature control thermocouples. [**86:**13.5.11.10.8]

15.3.1.1.12 Special Atmosphere Safety Equipment. Paragraphs 15.3.1.1.12.1 through 15.3.1.1.12.17 shall apply to the safety equipment and its application to the furnace special [hydrogen] atmosphere system. [**86:**13.5.11.11]

15.3.1.1.12.1 All safety devices, with the exception of flow sensors, shall be one of the following:

(1) Listed for the service intended
(2) Approved where listed devices are not available
(3) Programmable controllers applied in accordance with Section 8.4 of NFPA 86
[**86:**13.5.11.11.1]

15.3.1.1.12.2 Electric relays and safety shutoff valves shall not be used as substitutes for electrical disconnects and manual shutoff valves. [**86:**13.5.11.11.2]

15.3.1.1.12.3 Regularly scheduled inspection, testing, and maintenance of all safety devices shall be performed. *(See 15.3.1.1.8.)* [**86:**13.5.11.11.3]

15.3.1.1.12.4 Safety devices shall be installed, used, and maintained in accordance with this standard and manufacturers' instructions. [**86:**13.5.11.11.4]

15.3.1.1.12.5 Where a device is used with a flammable special [hydrogen] atmosphere gas and the device manufacturer's instructions require conduit seals or a cable type that will not permit transfer of gas, the required seals or cable type shall be installed. [**86:**13.5.11.11.5]

15.3.1.1.12.6 Safety devices shall be located or guarded to protect them from physical damage. [**86:**13.5.11.11.6]

15.3.1.1.12.7 Safety devices shall not be bypassed electrically or mechanically. [**86:**13.5.11.11.7]

(A) The requirement in 15.3.1.1.12.7 shall not prohibit safety device testing and maintenance in accordance with Chapter 7. Where a system includes a built-in test mechanism that bypasses any safety device, it shall be interlocked to prevent operation of the system while the device is in test mode, unless listed for that purpose. [**86:**13.5.11.11.7(A)]

(B) The requirement in 15.3.1.1.12.7 shall not prohibit a time delay applied to the action of pressure proving or flow proving, where the following conditions exist:

(1) There is an operational need demonstrated for the time delay.
(2) The use of a time delay is approved.
(3) The time delay feature is not adjustable beyond 5 seconds.
(4) A single time delay does not serve more than one pressure-proving or flow-proving safety device.
(5) The time from an abnormal pressure or flow condition until the holding medium is removed from the safety shutoff valves does not exceed 5 seconds.
[**86:**13.5.11.11.7(B)]

15.3.1.1.12.8* A manual emergency means shall be provided for the removal of the furnace special [hydrogen] atmosphere using the method, either purge-out or burn-out, that is the basis of the furnace design. [**86:**13.5.11.11.8]

15.3.1.1.12.9 The activation of any carrier gas or furnace pressure safety interlock required in 15.3.1.1.12 shall initiate the appropriate action to bring the furnace to a safe state. The action shall be manual or automatic in accordance with the furnace design and operating instructions. [**86:**13.5.11.11.9]

15.3.1.1.12.10 Removal of Flammable Special Atmospheres. [86:13.5.11.11.10]

(A)* Removal of flammable special [hydrogen] atmospheres by burn-out, purge-out, or emergency purge-out shall be initiated under the following conditions:

(1) Normal furnace atmosphere burn-out initiated
(2) Normal furnace atmosphere purge-out initiated
(3) Low flow of carrier gas(es) that will not maintain a positive pressure in chambers below 1400°F (760°C) and positive pressure not restored by the automatic transfer to another source of gas
(4) A furnace temperature below which any liquid carrier gas used will not reliably dissociate
(5) Automatic emergency inert gas purge initiated
(6) Manual operator emergency inert gas purge initiated
[**86:**13.5.11.11.10(A)]

(B) When removal of flammable special [hydrogen] atmospheres is initiated in response to the conditions listed in 15.3.1.1.12.10(A)(3) through 15.3.1.1.12.10(A)(6), one of the following shall occur based upon chamber temperature:

(1) For chambers below 1400°F (760°C), one of the following actions shall occur, and the selected action shall be implemented as part of the furnace design:
   (a) Automatically burned-out where burn-out is an acceptable option
   (b) Purged-out by normal means where burn-out is not an acceptable option
   (c) Automatically purged-out by emergency inert gas purge
   (d) Manual burn-out or purge-out by manual emergency inert gas purge where furnace design allows the time needed for manual action
(2) For chambers at or above 1400°F (760°C), the chamber shall be manually or automatically burned-out or purged-out.
[**86:**13.5.11.11.10(B)]

15.3.1.1.12.11 Flammable Special Atmosphere Safety Shutoff Valves — General. [86:13.5.11.11.11]

(A) One safety shutoff valve shall be provided in the supply line of each flammable special [hydrogen] atmosphere gas or liquid. [**86:**13.5.11.11.11(A)]

(B)* Exothermic generated special [hydrogen] atmosphere gas supplies used for both purging and process shall not require safety shutoff valves. [**86:**13.5.11.11.11(B)]

(C) Safety shutoff valve components shall be of materials selected for compatibility with the gas or liquid handled and for ambient conditions. [**86:**13.5.11.11.11(C)]

(D) Means for testing all gas safety shutoff valves for valve seat leakage shall be installed. [**86:**13.5.11.11.11(D)]

(E)* A test of seat leakage of gas safety shutoff valves shall be completed at least annually. [**86:**13.5.11.11.11(E)]

15.3.1.1.12.12 Flammable Special Atmosphere Safety Shutoff Valves. [86:13.5.11.11.12]

(A) For furnaces using burn-in procedures for introducing flammable special [hydrogen] atmosphere carrier gases, it shall be permissible to admit flammable special [hydrogen] atmosphere carrier gas when the following conditions exist:

(1) The furnace temperature exceeds 1400°F (760°C) at the point where the flammable special [hydrogen] atmosphere carrier gas is introduced.
(2) If the furnace is designed to operate with an automatic inert gas purge, the presence of the required inert gas pressure shall be verified manually or automatically.
(3) Operator action opens the valve.
[**86:**13.5.11.11.12(A)]

(B) For furnaces using purge-in procedures for introducing flammable special [hydrogen] atmosphere carrier gases, it shall be permissible to admit flammable special [hydrogen] atmosphere carrier gas when one following conditions exist:

(1) The inert gas purge is complete.
(2) If the furnace is designed to operate with an automatic inert gas purge, the presence of the required inert gas pressure shall be verified manually or automatically.
(3) Operator action opens the valve.
[**86:**13.5.11.11.12(B)]

(C) For furnaces using burn-in or purge-in procedures for introducing flammable special [hydrogen] atmosphere gases that are not carrier gases, the safety shutoff valves for the non-carrier gases shall open only when the carrier gas flow has been established. [**86:**13.5.11.11.12(C)]

(D)* Safety shutoff valves shall automatically close upon occurrence of the following conditions:

(1) Normal furnace atmosphere burn-out initiated
(2) Normal furnace atmosphere purge-out initiated
(3) Low flow of carrier gas(es) that will not maintain a positive pressure in chambers below 1400°F (760°C) and positive pressure not restored by the automatic transfer to another source of gas
(4) A furnace temperature below which any liquid carrier gas used will not reliably dissociate
(5) Automatic emergency inert gas purge initiated
(6) Manual operator emergency inert gas purge initiated
(7) Power failure
(8) Liquid carrier gas excess flow
[**86:**13.5.11.11.12(D)]

15.3.1.1.12.13 Emergency Inert Gas Purge. [86:13.5.11.11.13]

(A) Where a furnace is designed for purge-out, the inert purge gas equipment pipe shall be controlled by a normally open purge control valve. [**86:**13.5.11.11.13(A)]

(B) Where a furnace is equipped with an emergency inert gas purge, the emergency inert gas purge shall be initiated upon any of the following conditions:

(1) Low flow of carrier gas(es) that will not maintain a positive pressure in chambers below 1400°F (760°C) and positive pressure not restored by the automatic transfer to another source of gas
(2) A furnace temperature below which sufficient dissociation of liquids intended for use as a carrier gas will not occur at levels required to maintain positive furnace pressure
(3) Manual operator emergency inert gas purge initiated
(4) Power failure
[**86:**13.5.11.11.13(B)]

15.3.1.1.12.14 Special Atmosphere Flow Interlocks. [86:13.5.11.11.14]

(A) Minimum carrier gas flow(s) required by this standard shall be proved by either:

(1) A flow switch for each special atmosphere that is considered a carrier gas
(2) Furnace pressure switch(es)
[**86:**13.5.11.11.14(A)]

(B) If minimum carrier gas flow is not proven, the following shall be applied:

(1) Actions listed in 15.3.1.1.12.12(C) shall be initiated.
(2) Visual and audible alarms shall alert the operator of loss of minimum carrier gas flow.
[**86:**13.5.11.11.14(B)]

(C) Inert purge gas equipment piping shall be equipped with:

(1) A pressure switch that will audibly and visually alert the operator of a low purge pressure condition.
(2) A flow switch that will audibly and visually alert the operator of a low purge flow condition.
[**86:**13.5.11.11.14(C)]

15.3.1.1.12.15* Furnace vestibules shall be equipped with means for explosion relief. [**86:**13.5.11.11.15]

15.3.1.1.12.16* The flow of noncarrier special atmosphere gases that are nonflammable shall not be permitted until minimum carrier gas flow has been proven. [**86:**13.5.11.11.16]

15.3.1.1.12.17 Operating Precautions for Heating Cover–Type Furnaces. The rate of separating a heating cover from or rejoining a heating cover to the inner cover shall not exceed a rate that causes rapid expansion or contraction of the atmosphere gas inside the inner cover. [**86:**13.5.11.11.17]

15.3.1.1.13* Burner Management System Logic. [86:8.3]

15.3.1.1.13.1 Safety interlocks shall meet one or more of the following criteria:

(1) Be hardwired without relays in series and ahead of the controlled device
(2) Be connected to an input of a programmable controller logic system complying with Section 8.4 of NFPA 86
(3) Be connected to a relay that represents a single safety interlock that is configured to initiate safety shutdown in the event of power loss
(4) Be connected to a listed safety relay that represents one or more safety interlocks and initiates safety shutdown upon power loss
[**86:**8.3.1.3]

15.3.1.1.13.2* Electrical power for safety control circuits shall be dc or single-phase ac, 250 volt maximum, one-side grounded, with all breaking contacts in the ungrounded, fuse-protected, or circuit breaker–protected line. [**86:**8.3.1.4]

15.3.1.1.14 Programmable logic controller systems shall be in accordance with Section 8.4 of NFPA 86.

15.3.1.1.15* Inert Gas for Furnace Purge. NFPA 86 identifies several specific situations where inert gas purge is required; NFPA 86 shall be referenced to identify the appropriate requirements.

15.3.1.1.15.1 Where inert purge gas is required by NFPA 86, the following shall apply:

(1) It shall be available at all times and be sufficient for five volume changes of all connected atmosphere furnaces.
(2) If the inert gas has a flammable gas component, it shall be analyzed on a continuous basis to verify that the oxygen content is less than 1 percent and the combined combustible gas concentration remains less than 25 percent of the LFL.
[**86:**13.5.5.1(D)]

15.3.1.1.16 Where inert gases are used as safety purge media, the minimum volume stored shall be the amount required to purge all connected special [hydrogen] atmosphere furnaces with at least five furnace volume changes wherever the flammable atmospheres are being used. [**86:**13.5.5.1(F)]

15.3.1.1.17 Purge Gas Inventory.

15.3.1.1.17.1 Tanks containing purge media shall be provided with a low-level audible and visual alarm that meets the following criteria:

(1) The alarm is situated in the area normally occupied by furnace operators.
(2) The low-level alarm set point is established to provide time for an orderly shutdown of the affected furnace(s).
(3) The minimum contents of a tank containing a purge medium at the low-level alarm set point is sufficient to purge all connected atmosphere furnaces with at least five volume changes.
[**86:**13.5.5.2]

15.3.1.2 Special Atmospheres in Class D Furnaces.

15.3.1.2.1 Safety Controls and Equipment. The requirements of 15.3.1.2 shall apply to any vacuum chamber or vacuum furnace in which [hydrogen] gas is used at a pressure of 50 percent or more of its lower flammable limit (LFL) in air. [**86:**14.5.3.1]

15.3.1.2.1.1 A minimum supply of inert purge gas equal to five times the total vacuum system volume shall be available during operation with flammable atmospheres. [**86:**14.5.3.1.1]

15.3.1.2.1.2 The purge gas supply shall be connected to the vacuum chamber through a normally open valve. [**86:**14.5.3.1.2]

(A) A pressure sensor shall monitor the purge gas line pressure and shall stop the supply of flammable gas if the pressure becomes too low to allow purging in accordance with 15.3.1.2.1.9.1. [**86:**14.5.3.1.2(A)]

(B) Any manual inert purge gas shutoff valves shall be proved open through the use of a position monitoring switch and interlocked to prevent the introduction of flammable gas. [**86:**14.5.3.1.2(B)]

15.3.1.2.1.3 Flammable Gas Supply. [86:14.5.3.1.3]

(A) The flammable gas supply shall be connected to the vacuum chamber through a normally closed automatic safety shutoff valve. [**86:**14.5.3.1.3(A)]

(B) Vacuum furnaces that rely on a partial vacuum to hold the door closed shall have the flammable gas supply connected to the vacuum chamber through two normally closed automatic safety shutoff valves. [**86:**14.5.3.1.3(B)]

(C) A manual shutoff valve shall be provided in all flammable atmosphere supply pipe(s). [**86:**14.5.3.1.3(C)]

15.3.1.2.1.4 The flammable gas supply system shall be interlocked with the vacuum system to prevent the introduction of any flammable atmosphere until the furnace has been evacuated to a level of 1×10^{-1} torr (13.3 Pa) or less. [**86:**14.5.3.1.4]

15.3.1.2.1.5 High and low pressure switches shall be installed on the flammable gas line and shall be interlocked to shut off the supply of gas when its pressure deviates from the design operating range. [**86:**14.5.3.1.5]

15.3.1.2.1.6* In the case of a multiple chamber-type or continuous-type vacuum furnace, the following criteria shall apply:

(1) Each chamber shall be regarded as a separate system.
(2) Interlocks shall be provided that prevent the valves from opening between adjacent interconnecting chambers once a flammable atmosphere has been introduced into any of them.
[**86:**14.5.3.1.6]

15.3.1.2.1.7 The vacuum pumping system shall be interlocked with the supply gas system so that mechanical pumps continue to operate while flammable gas is in the vacuum chamber, to prevent the backflow of air through nonoperating pumps. [**86:**14.5.3.1.7]

15.3.1.2.1.8 The following shall be piped to a source of inert gas:

(1) Mechanical pump gas ballast valves
(2) Vacuum air release valves on roughing or forelines
[**86:**14.5.3.1.8]

15.3.1.2.1.9 Manual air release valves shall not be permitted. [**86:**14.5.3.1.9]

15.3.1.2.1.10 Vacuum furnaces that rely on a partial vacuum to hold the door closed shall incorporate a pressure switch, independent of the chamber pressure control device, to terminate flammable gas addition before the backfill pressure rises to a point where door clamping is lost. [**86:**14.5.3.1.10]

15.3.1.2.1.11 Vacuum furnaces that are backfilled with flammable gases to pressures greater than that required to hold the door closed shall incorporate clamps and seals to ensure the door is tightly and positively sealed. [**86:**14.5.3.1.11]

15.3.1.2.1.12* Sight glasses, where provided, shall be valved off before operation with flammable gases, except for sight glasses used solely for pyrometers. [**86:**14.5.3.1.12]

15.3.1.2.2 Flammable Gases. [86:14.5.3.2]

15.3.1.2.2.1 During processing, flammable gases shall be exhausted from vacuum furnaces by pumping them through the vacuum pumps or by venting in continuous flow to the atmosphere. [**86:**14.5.3.2.1]

15.3.1.2.2.2 If the flammable gas is exhausted through a vacuum pump, the system shall be designed to prevent air backflow if the pump stops. [**86:**14.5.3.2.2]

15.3.1.2.2.3 Venting of the vacuum pump shall be in accordance with 14.2.7 of NFPA 86, and one of the following actions shall be taken during flammable gas operation:

(1) The pump discharge shall be diluted with inert gas to lower the combustible level of the mixture below the LFL.
(2) The pump discharge shall be passed through a burner.
[**86:**14.5.3.2.3]

15.3.1.2.2.4 If the flammable gas is vented to the atmosphere directly without passing through the vacuum pumps, the vent line shall be provided with a means of preventing air from entering the furnace chamber. [**86:**14.5.3.2.4]

15.3.1.2.2.5 If the flammable gas is vented to the atmosphere through a burner, the vent line shall be provided with a means of preventing air from entering the furnace chamber, and the following criteria also shall apply:

(1) The existence of the burner ignition source shall be monitored independently.
(2) Interlocks shall be provided to shut off the flammable gas supply and initiate inert gas purge if the flame is not sensed.
[**86:**14.5.3.2.5]

15.3.1.2.2.6 Where flammable gas is used to maintain chamber pressure above atmospheric pressure, the following criteria shall be met:

(1) A pressure switch shall be interlocked to close the flammable gas supply if the chamber pressure exceeds the maximum operating pressure.
(2) The pressure switch shall be independent of the chamber pressure control device.
[**86:**14.5.3.2.6]

15.3.1.2.2.7 Where flammable gas is used to maintain chamber pressure above atmospheric pressure, the following criteria shall be met:

(1) A pressure switch shall be interlocked to close the flammable gas supply and initiate purge if the chamber pressure drops below the minimum operating pressure.
(2) The pressure switch shall be independent of the chamber pressure control device.
[**86:**14.5.3.2.7]

15.3.1.2.2.8 Where flammable gas is exhausted through a vent (not through the pump), the vent valve shall not open until a pressure above atmosphere is attained in the chamber. [**86:**14.5.3.2.8]

15.3.1.2.3 Removal of Flammable Gas — Purging. [86:14.5.3.3]

15.3.1.2.3.1 When purge is initiated, the flammable gas valve(s) shall be closed. [**86:**14.5.3.3 (A)]

15.3.1.2.3.2 Purging shall be complete when any of the following criteria is satisfied: [**86:**14.5.3.3 (B)]

(1) Two consecutive analyses of the vent gas from the furnace indicate that less than 50 percent of the LFL has been reached. [**86:**14.5.3.3(B)(1)]
(2) Five furnace volume changes with inert gas have occurred. [**86:** 14.5.3.3(B)(2)]
(3) The furnace is pumped down to a minimum vacuum level of 1×10^{-1} torr (13.3 Pa) prior to inert gas backfill. [**86:**14.5.3.3(B)(3)]

15.3.1.2.4* Emergency Shutdown Procedure. In the event of an electrical power failure or flammable gas failure, the system shall be purged in accordance with 15.3.1.2.3. [**86:**14.5.3.4]

15.3.2* Hydrogen Cooled Generators.

15.3.2.1 General.

15.3.2.1.1 Subsection 15.3.2 shall apply to electric power-generating equipment that employs a hydrogen atmosphere to provide cooling of the equipment or power-generation efficiency gains or both.

15.3.2.1.1.1 The storage and delivery piping systems and equipment for hydrogen-cooled generators shall comply with the applicable requirements of Chapters 1 through 4 and 6 through 8 and the modifications identified herein.

15.3.2.1.1.2 If the hydrogen supply is an active gas-generation device, such as an electrolyzer or a reformer, the applicable provisions of Chapter 13 shall apply.

15.3.2.1.2 Monitoring of Hydrogen Atmosphere.

15.3.2.1.2.1 The internal atmosphere of the generator shall be monitored to ensure maintenance of hydrogen purity at 85 percent or better.

15.3.2.1.2.2 Warnings of low purity shall be provided to the operator(s).

15.3.2.1.3 Ignition Sources.

15.3.2.1.3.1* The area classification around hydrogen-cooled generators shall, as a minimum, be in accordance with ANSI/IEEE C2, *National Electrical Safety Code*.

15.3.2.1.3.2 Installations in which the generator is coupled to the exhaust end of a gas turbine, or in which the high-pressure section of a steam turbine results in the generator being in the proximity of hot surfaces that might exceed 1000°F (538°C), shall require risk mitigations for potentially hazardous areas associated with the generator intersecting such hot surfaces.

15.3.2.1.3.3 As a function of necessary design, generators might contain electrical ignition sources in close proximity (i.e., field excitation brushes, shaft grounding brushes, and various high-current electrical devices necessary for control of the generator output.

15.3.2.1.3.4 The presence of potential ignition sources shall be considered when providing risk mitigation.

15.3.2.1.4 Seal Oil Systems.

15.3.2.1.4.1 Where seal oil systems are used, the oil pressure shall be monitored to detect system failure.

(A) Where automatic shutdown capability exists, system failure shall automatically shut the unit down.

(B) If there is no automatic shutdown capability, an operator alarm shall be provided to enable timely operator action to shut the unit down.

15.3.2.1.4.2 The seal oil system shall include a secondary system capable of providing full seal oil pressure for the time required to reduce the speed to the manufacturer's recommended RPM to purge the generator of hydrogen.

15.3.2.1.4.3 Where an automatic purge capability is available, loss of seal oil pressure shall initiate the automatic purge of the generator hydrogen once the unit RPM has been reduced to the manufacturer's recommended purge speed.

15.3.2.1.4.4 Warnings of loss of seal oil pressure shall be provided to the operator(s).

15.3.2.2 Indoor Installations.

15.3.2.2.1* Buildings that enclose hydrogen-cooled generator installations shall be ventilated to avoid flammable gas buildup from potential system leaks.

15.3.2.2.2 The building ceiling shall avoid features that could trap hydrogen gas, such as solid beams that form a tight fit with the roof deck.

15.3.2.2.3 The building designer shall consider the use of redundant fans and hydrogen detection systems in the design of the ventilation system.

15.3.2.2.4* All hydrogen system vents shall be routed to an appropriate area outside the building and meet the requirements of Chapters 5 through 8, as applicable.

15.3.2.3 Outdoor Installations.

15.3.2.3.1 The potentially hazardous area surrounding a hydrogen-cooled generator and associated equipment shall not intersect with heating, ventilating, and air-conditioning (HVAC) air intakes and windows, doors, and other openings into occupied spaces (e.g., control rooms and break rooms).

15.3.2.3.2* All hydrogen system vents shall be routed to an appropriate point above other equipment and buildings and meet the requirements of Chapters 5 through 8 as applicable.

15.4 Storage.

15.4.1 Requirements for Hydrogen Storage Systems Serving Furnace Installations.

15.4.1.1* General. The storage of GH_2 or LH_2 serving furnace installations shall be in accordance with Chapters 6 through 8, as applicable.

15.4.1.2 Indoor Storage. (Reserved)

15.4.1.3 Outdoor Storage. (Reserved)

15.4.2 Requirements for Hydrogen Storage Systems Serving Hydrogen-Cooled Generators.

15.4.2.1 General. The storage of GH_2 or LH_2 serving hydrogen-cooled generators shall be in accordance with Chapters 6 through 8, as applicable.

15.4.2.2 Indoor Storage. (Reserved)

15.4.2.3 Outdoor Storage. (Reserved)

Chapter 16 Laboratory Operations

16.1 Scope. The requirements of this chapter shall apply to the storage, use, and handling of GH_2 and LH_2 in laboratories, laboratory buildings, laboratory units, or laboratory work areas as defined by Chapter 3.

16.1.1 Application.

16.1.1.1 The requirements of this chapter shall apply to the storage, use, handling, or dispensing of GH_2 in laboratory buildings, laboratory units, and laboratory work areas, whether located above or below grade, when the amount of GH_2 exceeds 75 scf (2.2 standard m^3) or the amount of LH_2 exceeds 1 gal (3.8 L).

16.1.1.2 The storage, use, and handling of GH_2 in any quantity shall also comply with the requirements of Chapters 1 through 4 and the requirements of Chapters 5 through 8, as applicable.

16.1.1.3 Chapters 4 and 6 through 8 contain fundamental requirements that shall apply to all hydrogen systems.

16.1.1.4 The use-specific requirements of this chapter for hydrogen in laboratory operations shall apply.

16.1.1.5 Where there is a conflict between a fundamental requirement and a use-specific requirement, the use-specific requirement shall apply.

16.1.2 This chapter shall not apply to the following:

(1) Laboratory units that contain less than 75 scf (2.2 standard m^3) of GH_2 or 1 gal (3.8 L) of LH_2
(2)*Laboratories that are pilot plants
(3) Laboratories that are primarily manufacturing plants
(4) Incidental testing facilities

16.2 General.

16.2.1 Means of Access to an Exit.

16.2.1.1* A second means of access to an exit shall be provided from a laboratory work area if any of the following situations exist: [**45:**5.4.1]

(1) A laboratory work area contains an explosion hazard located so that an incident would block escape from or access to the laboratory work area. [**45:**5.4.1(1)]
(2) A hood in a laboratory work area is located adjacent to the primary means of exit access. [**45:**5.4.1(4)]
(3) A compressed gas cylinder larger than lecture bottle size [approximately 2 in. × 13 in. (5 cm × 33 cm)] is located such that it could prevent safe egress in the event of accidental release of cylinder contents. [**45:**5.4.1(5)]
(4) A cryogenic container is located such that it could prevent safe egress in the event of accidental release of container contents. [**45:**5.4.1(6)]

16.2.1.2 Emergency lighting facilities shall be provided for any laboratory work area requiring a second means of access to an exit, in accordance with 16.2.1.1. [**45:**5.4.4]

16.2.1.3 Emergency lighting in laboratory work areas and exits shall be installed in accordance with Section 7.9, Emergency Lighting, of NFPA *101.* [**45:**5.4.5]

16.2.2 Electrical Installation. All electrical installations, including wiring and appurtenances, apparatus, lighting, signal systems, alarm systems, remote control systems, or parts thereof, shall comply with *NFPA 70*. [**45:**5.6]

16.2.2.1* Laboratory work areas, laboratory units, and chemical fume hood interiors shall be considered as unclassified electrically with respect to Article 500 of *NFPA 70*, unless operations are determined to cause a hazardous atmosphere. [**45:**5.6.2]

16.2.3 Fire Protection.

16.2.3.1 Automatic Fire Extinguishing Systems.

16.2.3.1.1 Automatic Sprinkler Systems.

16.2.3.1.1.1 A fire protection system shall be provided for laboratories in accordance with Chapter 6.

16.2.3.1.1.2* Fire sprinklers in laboratory units shall be the quick-response (QR) sprinkler type installed in accordance with NFPA 13. [**45:**6.1.1.2]

16.2.3.1.1.3 Automatic sprinkler systems shall be regularly inspected, tested, and maintained in accordance with NFPA 25. [**45:**6.1.1.3]

16.2.3.2 Fire Alarm Systems.

16.2.3.2.1 A fire alarm system shall be provided for laboratories in accordance with Chapter 6.

16.2.3.2.2 The fire alarm system, where provided, shall be designed so that all personnel endangered by the fire condition or a contingent condition shall be alerted. [**45:**6.4.3]

16.2.3.2.3 The fire alarm system shall alert local emergency responders or the public fire department. [**45:**6.4.4]

16.2.3.3 Standpipe and Hose Systems.

16.2.3.3.1* In all laboratory buildings that are two or more stories above or below the grade level (level of exit discharge), Class I wet pipe standpipe systems shall be installed in accordance with NFPA 14. [**45:**6.2.1]

16.2.3.3.2* Standpipe systems shall be regularly inspected, tested, and maintained in accordance with NFPA 25. [**45:**6.2 2]

16.2.3.4 Portable Fire Extinguishers.

16.2.3.4.1 Portable fire extinguishers shall be installed, located, and maintained in accordance with NFPA 10. [**45:**6.3.1]

16.2.4 Explosion Hazard Protection.

16.2.4.1 A laboratory work area shall be considered to contain an explosion hazard if an explosion involving hydrogen could result in significant damage to a facility or serious injuries to personnel within that laboratory work area.

16.2.5 Fire Prevention.

16.2.5.1 Fire Prevention Procedures.

16.2.5.1.1 Fire prevention procedures shall be established for all new and existing laboratories. [**45:**6.5.1.1]

16.2.5.1.2 Fire prevention procedures shall include, but not be limited to, the following:

(1) Handling and storage of [GH_2 and LH_2]
(2) Open flame and spark-producing equipment work permit system
(3) Arrangements and use of portable electric cords
(4) Smoking area controls

[**45:**6.5.1.2]

16.2.5.2* Maintenance Procedures. Maintenance procedures shall be established for all new and established laboratories. [**45:**6.5.2]

16.2.5.3* Emergency Plans.

16.2.5.3.1 Plans for laboratory emergencies shall be established for all new and existing laboratories. The emergency action plan shall include the following procedures in the event of a chemical emergency, fire, or explosion:

(1) Procedures for sounding the alarm
(2) Procedures for notifying and coordinating with the fire department, governmental agencies, or other emergency responders or contacts, as required
(3) Procedures for evacuating and accounting for personnel, as applicable
(4) Procedures for establishing requirements for rescue and medical duties for those requiring or performing these duties
(5)*Procedures and schedules for conducting drills
(6) Procedures for shutting down and isolating equipment under emergency conditions to include the assignment of personnel responsible for maintaining critical functions or for shutdown of process operations
(7) Appointment and training of personnel to carry out assigned duties, including steps to be taken at the time of initial assignment, as responsibilities or response actions change, and at the time anticipated duties change
(8) Alternative measures for occupant safety, when applicable
(9) Aisles designated as necessary for movement of personnel and emergency response
(10) Maintenance of fire protection equipment
(11) Safe procedures for startup to be taken following the abatement of an emergency
[**400:**7.2.3.2]

16.2.5.3.2* Procedures for extinguishing clothing fires shall be established for all new and existing laboratories. [**45:**6.5.3.2]

16.2.5.3.3 All laboratory users, including, but not limited to, instructors and students, shall be trained prior to laboratory use and at least annually thereafter on the emergency plan. [**45:**6.5.3.3]

16.3 Use.

16.3.1 General.

16.3.1.1 Instructional Laboratories. Experiments and tests conducted in educational and instructional laboratory units shall be under the direct supervision of an instructor.

16.3.1.2 Cylinders in Use.

16.3.1.2.1 Cylinders, when in use, shall be connected to gas delivery systems designed by a qualified person. [**45:**10.1.6.1]

16.3.1.2.2 Cylinders shall be attached to an instrument for use by means of a regulator. [**45:**10.1.6.2]

16.3.1.2.3 A compressed gas cylinder shall be considered to be "in use" if it is in compliance with one of the following:

(1) Connected through a regulator to deliver gas to a laboratory operation
(2) Connected to a manifold being used to deliver gas to a laboratory operation
(3) A single cylinder secured alongside the cylinder described in 16.3.1.2.3(1) as the reserve cylinder for the cylinder described in 16.3.1.2.3(1).
[**45:**10.1.6.3]

16.3.1.2.4 Cylinders not "in use" shall not be stored in the laboratory unit. [**45:**10.1.6.4]

16.3.2 Indoor Use.

16.3.2.1 Laboratory Ventilating Systems and Hood Requirements.

16.3.2.1.1* General.

16.3.2.1.1.1 This chapter shall apply to laboratory exhaust systems, including chemical fume hoods, local ventilated enclosures, fume arms, special local exhaust devices, and other systems for exhausting air from laboratory work areas in which [GH_2 or LH_2] are released. [**45:**7.1.1]

16.3.2.1.1.2 This chapter shall apply to laboratory air supply systems and shall provide requirements for identification, inspection, and maintenance of laboratory ventilation systems and hoods. [**45:**7.1.2]

16.3.2.1.2 Basic Requirements.

16.3.2.1.2.1* Laboratory ventilation systems shall be designed to ensure that fire hazards and risks are minimized. [**45:**7.2.1]

16.3.2.1.2.2* Laboratory units and laboratory hoods in which [GH_2 or LH_2] are present shall be continuously ventilated under normal operating conditions. [**45:**7.2.2]

16.3.2.1.2.3* Chemical fume hoods shall not be relied upon to provide explosion (blast) protection unless specifically designed to do so. *(See also G.6.4 and G.6.5 for further information on explosion-resistant hoods and shields.)* [**45:**7.2.3]

16.3.2.1.2.4 Exhaust and supply systems shall be designed to prevent a pressure differential that would impede egress or ingress when either system fails or during a fire or emergency scenario. This design includes reduced operational modes or shutdown of either the supply or exhaust ventilation systems. [**45:**7.2.5]

16.3.2.1.2.5 The release of [GH_2] into the laboratory shall be controlled by enclosure(s) or captured to prevent any flammable concentrations of vapors from reaching any source of ignition. [**45:**7.2.6]

16.3.2.1.3 Supply Systems.

16.3.2.1.3.1 Laboratory ventilation systems shall be designed to ensure that [GH_2] originating from the laboratory shall not be recirculated. [**45:**7.3.1]

16.3.2.1.3.2* The location and configuration of fresh air intakes shall be chosen so as to avoid drawing in [GH_2] or products of combustion coming either from the laboratory building itself or from other structures and devices. [**45:**7.3.2]

16.3.2.1.3.3 The air pressure in the laboratory work areas shall be negative with respect to corridors and non-laboratory areas of the laboratory unit except in the following instances:

(1) Where operations such as those requiring clean rooms preclude a negative pressure relative to surrounding areas, alternate means shall be provided to prevent escape of the atmosphere in the laboratory work area or unit to the surrounding spaces.
(2) The desired static pressure level with respect to corridors and non-laboratory areas shall be permitted to undergo momentary variations as the ventilation system components respond to door openings, changes in chemical fume hood sash positions, and other activities that can for a short term affect the static pressure level and its negative relationship.

(3) Laboratory work areas located within a designated electrically classified hazardous area with a positive air pressure system as described in NFPA 496, Chapter 7, Pressurized Control Rooms, shall be permitted to be positive with respect to adjacent corridors. [**45:**7.3.3]

16.3.2.1.3.4* The location of air supply diffusion devices shall be chosen so as to avoid air currents that would adversely affect the performance of chemical fume hoods, exhaust systems, and fire detection or extinguishing systems. *(See 16.2.3.1, 16.2.3.2, and 16.3.2.1.8.1.)* [**45:**7.3.4]

16.3.2.1.4 Exhaust Air Discharge.

16.3.2.1.4.1* Air exhausted from chemical fume hoods and other special local exhaust systems shall not be recirculated. *(See also 16.3.2.1.3.1.)* [**45:**7.4.1]

16.3.2.1.4.2* Energy Conservation Devices.

(A) If energy conservation devices are used, they shall be designed in accordance with 16.3.2.1.3.1 through 16.3.2.1.3.3. [**45:**7.4.2.1]

(B) Energy conservation devices shall only be used in a laboratory ventilation system when evaluated and approved by a qualified person. These systems must meet, or exceed, the criteria established by Section 5.4.7 and Section 5.4.7.1 of ANSI/AIHA Z9.5, 2012, *Laboratory Ventilation.* Systems that recirculate within their respective laboratory area, such as fan coil units for sensible heat loads, are exempt from these requirements. [**45:**7.4.2.2]

(C) Energy conservation devices shall be designed and installed in a manner that safely facilitates anticipated service and maintenance requirements and does not adversely impact the proper operation of the exhaust system. [**45:**7.4.2.3]

16.3.2.1.4.3 Air exhausted from laboratory work areas shall not pass unducted through other areas. [**45:**7.4.3]

16.3.2.1.4.4* Air from laboratory units and laboratory work areas in which [GH_2] is present shall be continuously discharged through duct systems maintained at a negative pressure relative to the pressure of normally occupied areas of the building. [**45:**7.4.4]

16.3.2.1.4.5 Positive pressure portions of the lab hood exhaust systems (e.g., fans, coils, flexible connections, and ductwork) located within the laboratory building shall be sealed airtight or located in a continuously mechanically ventilated room. [**45:**7.4.5]

16.3.2.1.4.6 Chemical fume hood face velocities and exhaust volumes shall be sufficient to contain [GH_2] generated within the hood and exhaust them outside of the laboratory building. [**45:**7.4.6]

16.3.2.1.4.7* The hood shall provide containment of the possible hazards and protection for personnel at all times when [GH_2 is] present in the hood. [**45:**7.4.7]

16.3.2.1.4.8 Special local exhaust systems, such as snorkels or "elephant trunks," shall have sufficient capture velocities to entrain the [GH_2] being released. [**45:**7.4.8]

16.3.2.1.4.9* Canopy hoods, laminar flow cabinets, and ductless enclosures shall not be used in lieu of chemical fume hoods. [**45:**7.4.9]

16.3.2.1.4.10 Laminar flow cabinets shall not be used in lieu of chemical fume hoods. [**45:**7.4.11]

16.3.2.1.4.11* Air exhausted from chemical fume hoods and special exhaust systems shall be discharged above the roof at a location, height, and velocity sufficient to prevent re-entry of chemicals and to prevent exposures to personnel. [**45:**7.4.12]

16.3.2.1.5 Duct Construction for Hoods and Local Exhaust Systems.

16.3.2.1.5.1 Ducts from chemical fume hoods and from local exhaust systems shall be constructed entirely of noncombustible materials except in the following cases:

(1) Flexible ducts of combustible construction shall be permitted to be used for special local exhaust systems within a laboratory work area. *(See 16.3.2.1.5.2.)*
(2) Combustible ducts shall be permitted to be used if enclosed in a shaft of noncombustible or limited-combustible construction where they pass through non-laboratory areas or through laboratory units other than the one they serve. *(See 16.3.2.1.5.2.)*
(3) Combustible ducts shall be permitted to be used if all areas through which they pass are protected with an approved automatic fire extinguishing system, as described in 16.2.3. *(See 16.3.2.1.5.2.)* [**45:**7.5.1]

16.3.2.1.5.2 Combustible ducts or duct linings shall have a flame spread index of 25 or less when tested in accordance with ASTM E84 *Standard Test Method for Surface Burning Characteristics of Building Materials,* or ANSI/UL 723, *Standard for Test for Surface Burning Characteristics of Building Materials.* Test specimens shall be of the minimum thickness used in the construction of the duct or duct lining. [**45:**7.5.2]

16.3.2.1.5.3 Ducts shall be of adequate strength and rigidity to meet the conditions of service and installation requirements and shall be protected against mechanical damage. [**45:**7.5.5]

16.3.2.1.5.4 Materials used for vibration isolation connectors shall comply with 16.3.2.1.5.2. [**45:**7.5.6]

16.3.2.1.5.5 Controls and dampers, where required for balancing or control of the exhaust system, shall be of a type that, in event of failure, will fail open to ensure continuous draft. *(See 16.3.2.1.9.3 through 16.3.2.1.9.5.)* [**45:**7.5.8]

16.3.2.1.5.6 Hand holes, where installed for damper, sprinkler, or fusible link inspection or resetting and for residue clean-out purposes, shall be equipped with tight-fitting covers provided with substantial fasteners. [**45:**7.5.9]

16.3.2.1.5.7 Manifolding of Chemical Fume Hood and Ducts.

(A) Exhaust ducts from each laboratory unit shall be separately ducted to a point outside the building, to a mechanical room, or to a shaft. [**45:**7.5.10.1]

(B) Connection to a common chemical fume hood exhaust duct system shall be permitted to occur within a building only in any of the following locations:

(1) A mechanical room, not connected to a shaft, shall be protected in accordance with Table 5.1.1 of NFPA 45.
(2) A shaft or a mechanical room connected to a shaft, shall be protected in accordance with the chapter for protection of vertical openings of NFPA *101*
(3) A point outside the building [**45:**7.5.10.2]

(C) Exhaust ducts from chemical fume hoods and other exhaust systems within the same laboratory unit shall be permitted to be combined within that laboratory unit. *(See 16.3.2.1.4.1.)* [**45:**7.5.10.3]

16.3.2.1.6 Exhausters (Fans), Controls, Velocities, and Discharge.

16.3.2.1.6.1 Fans shall be selected to meet requirements for fire, explosion, and corrosion. [**45:**7.7.1]

16.3.2.1.6.2 Fans conveying both corrosive and flammable or combustible materials shall be permitted to be lined with or constructed of corrosion-resistant materials having a flame spread index of 25 or less when tested in accordance with ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials,* or ANSI/UL 723, *Standard for Test for Surface Burning Characteristics of Building Materials.* [**45:**7.7.2]

16.3.2.1.6.3 Fans shall be located and arranged so as to afford ready access for repairs, cleaning, inspection, and maintenance. [**45:**7.7.3]

16.3.2.1.6.4* Where [GH_2 is] passed through the fans, the rotating element shall be of nonferrous or spark-resistant construction; alternatively, the casing shall be constructed of or lined with such material. [**45:**7.7.4]

(A) Nonferrous or spark-resistant materials shall have a flame spread index of 25 or less when tested in accordance with ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials,* or ANSI/UL 723, *Standard for Test for Surface Burning Characteristics of Building Materials.* [**45:**7.7.4.2]

16.3.2.1.6.5 Motors and their controls shall be located outside the location where [GH_2 is] generated or conveyed, unless specifically approved for that location and use. [**45:**7.7.5]

16.3.2.1.6.6* Fans shall be marked with an arrow or other means to indicate direction of rotation and with the location of chemical fume hoods and exhaust systems served. [**45:**7.7.6]

16.3.2.1.7 Chemical Fume Hood Construction. *(See also 16.3.2.1.2.2)* [**45:**7.8]

16.3.2.1.7.1 Chemical Fume Hood Interiors.

(A)* Materials of construction used for the interiors of new chemical fume hoods or for the modification of the interiors of existing chemical fume hoods shall have a flame spread index of 25 or less when tested in accordance with ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials,* or ANSI/UL 723, *Standard for Test for Surface Burning Characteristics of Building Materials,* unless the interior of the hood is provided with automatic fire protection in accordance with 16.3.2.1.9.2. [**45:**7.8.1.1]

(B)* Baffles shall be constructed so that they are unable to be adjusted to materially restrict the volume of air exhausted through the chemical fume hood. [**45:**7.8.1.3]

(C)* Chemical fume hoods shall be provided with a means of preventing overflow of a spill of 0.5 gal (2 L) of liquid. [**45:**7.8.1.4]

16.3.2.1.7.2* Chemical Fume Hood Sash Glazing. The sash, if provided, shall be glazed with material that will provide protection to the operator against the hazards associated with the use of the hood. *(See also Annex G.)* [**45:**7.8.2]

16.3.2.1.7.3* Chemical Fume Hood Sash Closure.

(A) Chemical fume hood sashes shall be kept closed whenever possible. [**45:**7.8.3.1]

(B) When a fume hood is unattended, its sash shall remain fully closed. [**45:**7.8.3.2]

16.3.2.1.7.4* Electrical Devices.

(A) In installations where services and controls are within the hood, additional electrical disconnects shall be located within 50 ft (15 m) of the hood and shall be accessible and clearly marked. [**45:**7.8.4.1]

(B) If electrical receptacles are located external to the hood, no additional electrical disconnect shall be required. [**45:**7.8.4.2]

16.3.2.1.7.5 Other Hood Services.

(A) For new installations or modifications of existing installations, controls for chemical fume hood services (gas, air, water, etc.) shall be located external to the hood and within easy reach. [**45:**7.8.5.1]

(B) In existing installations where service controls are within the hood, additional shutoffs shall be located within 50 ft (15 m) of the hood and shall be accessible and clearly marked. [**45:**7.8.5.2]

16.3.2.1.7.6 Auxiliary Air. For auxiliary air hoods, auxiliary air shall be introduced exterior to the hood face in such a manner that the airflow does not compromise the protection provided by the hood and so that an imbalance of auxiliary air to exhaust air will not pressurize the hood interior. [**45:**7.8.6]

16.3.2.1.7.7 Hood Proper Function Alarm.

(A)* A measuring device for indicating that the hood airflow remains within safe design limits shall be provided on each chemical fume hood. [**45:**7.8.7]

(B)* The measuring device for hood airflow shall be a permanently installed device and shall provide continuous indication to the hood user of adequate airflow and alert inadequate hood airflow by a combination of an audible and visual alarm. Where an audible alarm could compromise the safety of the user or the research, alternative means of alarm shall be considered. [**45:**7.8.7.1]

16.3.2.1.8 Chemical Fume Hood Location.

16.3.2.1.8.1* Chemical fume hoods shall be located in areas of minimum air turbulence. [**45:**7.9.1]

16.3.2.1.8.2 Chemical fume hoods shall not be located adjacent to a single means of access to an exit or to high-traffic areas. [**45:**7.9.2]

16.3.2.1.8.3* Work stations not directly related to the chemical fume hood activity shall not be located directly in front of chemical fume hood openings. [**45:**7.9.3]

16.3.2.1.9 Chemical Fume Hood Fire Protection.

16.3.2.1.9.1* Automatic fire protection systems shall not be required in chemical fume hoods or exhaust systems except in the following cases: [**45:**7.10.1]

(1) If a hazard assessment shows that an automatic extinguishing system is required for the chemical fume hood, then the applicable automatic fire protection system standard shall be followed. [**45:**7.10.1(2)]

16.3.2.1.9.2 Automatic fire protection systems, where provided, shall comply with the following standards, as applicable:

(1) NFPA 11, *Standard for Low-, Medium-, and High-Expansion Foam*
(2) NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems*
(3) NFPA 12A, *Standard on Halon 1301 Fire Extinguishing Systems*
(4) NFPA 13, *Standard for the Installation of Sprinkler Systems*
(5) NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*
(6) NFPA 17, *Standard for Dry Chemical Extinguishing Systems*
(7) NFPA 17A, *Standard for Wet Chemical Extinguishing Systems*
(8) NFPA 69, *Standard on Explosion Prevention Systems*
(9) NFPA 750, *Standard on Water Mist Fire Protection Systems*
(10)*NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems* [**45:**7.10.2]

(A) The fire extinguishing system shall be suitable to extinguish fires within the chemical fume hood under the anticipated conditions of use. [**45:**7.10.2.1]

16.3.2.1.9.3* The design and installation of ducts from chemical fume hoods shall be in accordance with NFPA 91, except that specific requirements in NFPA 45 shall take precedence. [**45:**7.10.3]

(A)* Automatic fire dampers shall not be used in laboratory exhaust systems connected to chemical fume hoods. Any exhaust duct conveying fume hood exhaust through a fire rating shall provide an alternative means of protection equal to or greater that the rating through which the duct passes by one of the following:

(1) Wrapped or encased with listed or approved materials having a fire-resistance rating equal to the fire rating after exiting the originating fire compartment for a minimum distance of 3.05 m (10 ft) beyond the opening.
(2) Constructed of materials and supports having a minimum fire resistance rating equal to the fire barrier [**45:**7.10.3.1]

(B) When a branch duct from a fume hood and/or lab exhaust connects to a common riser located in a shaft enclosure that must travel upward, then the connection shall be made utilizing a separate upturned steel subduct of at least 22 gauge and a length of at least 0.56 m (22 in.) prior to joining the riser manifold from each separate branch duct entering the shaft entrance. [**45:**7.10.3.1.1]

16.3.2.1.9.4 Fire detection and alarm systems shall not be interlocked to automatically shut down chemical fume hood exhaust fans. [**45:**7.10.4]

16.3.2.1.9.5 Proper door operation for egress shall be maintained when the supply system shuts down and the lab exhaust system operates, creating a pressure differential. [**45:**7.10.5]

16.3.2.1.9.6 Chemical fume hoods equipped with control systems that vary the hood exhaust airflow as the sash opening varies and/or in conjunction with whether the laboratory room is in use (occupied or unoccupied) shall be equipped with a user-accessible means to attain maximum exhaust hood airflow regardless of sash position when necessary or desirable to ensure containment and removal of a potential hazard within the hood. [**45:**7.10.6]

16.3.2.1.9.7* Chemical fume hoods shall be installed in a manner that prevents fire or smoke from a fire in the chemical fume hood from spreading into the voids above the ceiling. [**45:**7.10.7]

16.3.2.1.10 Identification of Chemical Fume Hood Systems.

16.3.2.1.10.1* Special-use chemical fume hoods and special-use local exhaust systems shall be identified to indicate their intended use. [**45:**7.13.1]

16.3.2.1.10.2 A sign containing the following information from the last inspection shall be affixed to each hood, or a properly maintained log of all hoods providing the following information shall be maintained:

(1) Inspection interval
(2) Last inspection date
(3) Average face velocity
(4) Location of fan that serves hood
(5) Inspector's name [**45:**7.13.2]

16.3.2.1.11 Inspection, Testing, and Maintenance.

16.3.2.1.11.1* When installed or modified and at least annually thereafter, chemical fume hoods, chemical fume hood exhaust systems, and laboratory special exhaust systems shall be inspected and tested as applicable, as follows:

(1) Visual inspection of the physical condition of the hood interior, sash, and ductwork
(2) Measuring device for hood airflow
(3) Low airflow and loss-of-airflow alarms at each alarm location
(4) Face velocity
(5) Verification of inward airflow over the entire hood face
(6) Changes in work area conditions that might affect hood performance [**45:**7.14.1]

16.3.2.1.11.2 Deficiencies in hood performance shall result in immediate suspension of all activities in the hood until the deficiencies can be corrected. [**45:**7.14.2]

16.3.2.1.11.3 Chemical fume hood face velocity profile or hood exhaust air quantity shall be checked after any adjustment to the ventilation system balance. [**45:**7.14.3]

16.3.2.1.11.4 Detectors and Alarms. Air system flow detectors, if installed, shall be inspected and tested annually. [**45:**7.13.4.1]

16.3.2.1.11.5 Fans and Motors.

(A)* Air supply and exhaust fans, motors, and components shall be inspected at least annually. [**45:**7.14.5.1]

(B) Where airflow detectors are not provided or airflow-rate tests are not made, fan belts shall be inspected quarterly; double sheaves and belts shall be permitted to be inspected semiannually. [**45:**7.14.5.2]

(C) Frayed or broken belts shall be replaced promptly. [**45:**7.14.5.3]

16.3.2.2 Laboratory Operations and Apparatus.

16.3.2.2.1 Operations. This chapter shall apply to new and existing laboratories [**45:**11.1]

16.3.2.2.1.1* Hazards of Chemicals and Chemical Reactions.

(A) Before laboratory tests or chemical reactions are begun, evaluations shall be made for hazards that can be encountered or generated during the course of the work. [**45:**11.2.1.1]

(B) Evaluations shall include the hazards associated with the properties and the reactivity of the materials used and any intermediate and end products that can be formed, hazards associated with the operation of the equipment at the operating conditions, and hazards associated with the proposed reactions — for example, oxidation and polymerization. *[See also 16.3.2.2.1.1(D).]* [**45:**11.2.1.2]

(C) Regular reviews of laboratory operations and procedures shall be conducted with special attention given to any change in materials, operations, or personnel. [**45:**11.2.1.3]

(D)* Where reactions are being performed to synthesize materials, the hazard characteristics of which have not yet been determined by test, precautions shall be employed to control the highest possible hazard based on a known hazard of similar material. [**45:**11.2.1.4]

(E) Where use of a new material might present a severe explosion potential, initial experiments or tests shall be conducted in an enclosure that is designed to protect people and property from potential explosion damage. *(See 16.2.4.)* [**45:**11.2.1.5]

(F) Unattended or automatic laboratory operations involving hazardous chemicals shall be provided with regular surveillance for abnormal conditions. [**45:**11.2.1.6]

(1) Unattended operations shall be provided with override control and automatic shutdown to prevent system failure that can result in fire or explosion. [**45:**11.2.2.4]
(2) Electrically heated constant temperature baths shall be equipped with over-temperature shutoff switches in addition to normal temperature controls, if overheating could result in a fire or an explosion. [**45:**11.3.4.1]

16.3.2.2.1.2 Other Operations.

(A) Other laboratory operations, such as reactions at temperatures and pressures either above or below ambient conditions, shall be conducted in a manner that minimizes hazards. [**45:**11.2.8.1]

(B) Shielding shall be used whenever there is a reasonable probability of explosion or vigorous chemical reaction and associated hazards during charging, sampling, venting, and discharge of products. *(See 16.2.4 and 16.3.2.2.2.3.)* [**45:**11.2.8.2]

(C) Glass apparatus containing gas or vapors under vacuum or above ambient pressure shall be shielded, wrapped with tape, or otherwise protected from shattering (such as engineering controls or by apparatus design) during use. [**45:**11.2.8.3]

(D)* Quantities of reactants shall be limited and procedures shall be developed to control or isolate vigorous or exothermic reactions. [**45:**11.2.8.4]

(E) [GH_2] evolved during drying operations shall be condensed, trapped, or vented to avoid ignition. [**45:**11.2.8.5]

16.3.2.2.2 Apparatus.

16.3.2.2.2.1 General.

(A) Apparatus shall be installed in compliance with applicable requirements of NFPA standards, including *NFPA 70*. [**45:**11.13.1.1]

(B) Operating controls shall be accessible under normal and emergency conditions. [**45:**11.13.1.2]

16.3.2.2.2.2 Heating Equipment.

(A) All unattended electrical heating equipment shall be equipped with a manual reset over-temperature shutoff switch, in addition to normal temperature controls, if overheating could result in a fire or explosion. [**45:**11.3.3.1]

(B) Heating equipment with circulation fans or water cooling shall be equipped with an interlock arranged to disconnect current to the heating elements if the fan fails or the water supply is interrupted. [**45:**11.3.3.2]

(C) Burners, induction heaters, ovens, furnaces, and other heat-producing equipment shall be located a safe distance from areas where temperature-sensitive and flammable materials and [GH_2] are handled. [**45:**11.3.3.3]

(D) Oven and furnace installations shall comply with NFPA 86. [**45:**11.3.3.4]

16.3.2.2.2.3 Pressure Equipment.

(A)* Equipment used at pressures above 15 psi (103 kPa gauge) shall be designed and constructed by qualified individuals for use at the expected temperature, pressure, and other operating conditions affecting safety. [**45:**11.3.5.1]

(B) Pressure equipment shall be fitted with a pressure relief device, such as a rupture disc or a relief valve. The pressure relief device shall be vented to a safe location. [**45:**11.3.5.2]

(C) Equipment operated at pressures above 15 psi (103 kPa gauge), such as autoclaves, steam sterilizers, reactors, and calorimeters, shall be operated and maintained according to manufacturers' instructions, the design limitations of the equipment, and applicable codes and regulations. [**45:**11.3.5.3]

(1) Such equipment shall be inspected on a regular basis. [**45:**11.3.5.3.1]
(2) Any significant change in the condition of the equipment, such as corrosion, cracks, distortion, scale formation, or general chemical attack, or any weakening of the closure, or any inability of the equipment to maintain pressure, shall be documented and removed from service immediately and shall not be returned to service until approved by a qualified person. [**45:**11.3.5.3.2]

(D) Any pressure equipment that has been found to be degraded shall be derated or discarded, whichever is appropriate. [**45:**11.3.5.4]

16.3.2.2.2.4 Analytical Instruments.

(A) Analytical instruments, such as infrared, ultraviolet, atomic absorption, x-ray, mass spectrometers, chromatographs, and thermal analyzers, shall be installed in accordance with the manufacturers' instructions and applicable standards and codes. [**45:**11.3.6.1]

(B)* Analytical instruments shall be operated in accordance with manufacturers' instructions or approved recommended operating procedures. [**45:**11.3.6.2]

16.3.2.3 Hazard Identification. This chapter shall apply to new and existing laboratories [**45:**13.1]

16.3.2.3.1* Exhaust Systems. Exhaust systems used for the removal of hazardous materials shall be identified to warn personnel of the possible hazards. [**45:**13.3]

16.3.2.3.2 Identification Systems. Graphic systems used to identify hazards shall comply with ANSI Z535.1, *Safety Color Code*; ANSI Z535.2, *Environmental and Facility Safety Signs*;

ANSI Z535.3, *Criteria for Safety Symbols*; and ANSI Z535.4, *Product Safety Signs and Labels*; or other approved graphic systems. [**45:**13.5]

16.3.3 Outdoor Dispensing. (Reserved)

16.4 Storage.

16.4.1 General.

16.4.1.1 GH_2 and LH_2 in Cylinders.

16.4.1.1.1 Cylinders shall be handled only by trained personnel. *(See Annex H.)*

16.4.1.1.2 Cylinder Safety.

16.4.1.1.2.1 Cylinders shall be secured in accordance with 7.1.7.4.

16.4.1.1.2.2 Cylinders in the laboratory shall be equipped with a pressure regulator designed for the specific gas and marked for its maximum cylinder pressure. [**45:**10.1.5.2]

(A) The regulator system shall be equipped with two gauges, either on the regulator or remote from the regulator, installed so as to show both the cylinder pressure and the outlet pressure. [**45:**10.1.5.2.1]

(B) Where the source cylinder is outside of the laboratory, a station regulator and gauge shall be installed at the point of use to show outlet pressure. [**45:**10.1.5.2.2]

(C) Cylinders shall have a manual shutoff valve. A quick connect shall not be used in place of a shutoff valve. [**45:**10.1.5.3]

16.4.1.2 Storage and Piping Systems.

16.4.1.2.1* The method of storage and piping systems for compressed and liquefied gases shall comply with Chapters 4, 6, 7, and 8.

16.4.1.2.2* Each point of use shall have an accessible manual shutoff valve. [**45:**10.2.3]

16.4.1.2.2.1 The manual shutoff valve at the point of use shall be located away from the potential hazards and be located within 6 ft (1.8 m) of the point of use. [**45:**10.2.3.1]

16.4.1.2.2.2 Where the cylinder valve is located within immediate reach, a separate point-of-use shutoff valve shall not be required. [**45:**10.2.3.2]

16.4.1.2.2.3 Line regulators that have their source away from the point of use shall have a manual shutoff valve. [**45:**10.2.3.3]

16.4.1.2.2.4 An emergency gas shutoff device in an accessible location at the exit shall be provided in addition to the manual point-of-use valve in each educational and instructional laboratory space that has a piped gas-dispensing valve. [**45:**10.2.3.4]

16.4.1.2.3 Each and every portion of a piping system shall have uninterruptible pressure relief. [**45:**10.2.4]

16.4.1.2.3.1 Any part of the system that can be isolated from the rest of the system shall have adequate pressure relief. [**45:**10.2.4.1]

16.4.1.2.3.2 Piping shall be designed for a pressure greater than the maximum system pressure that can be developed under abnormal conditions. [**45:**10.2.4.2]

16.4.1.2.3.3 A pressure relief system shall be designed to provide a discharge rate sufficient to avoid further pressure increase and shall vent to a safe location. [**45:**10.2.4.3]

16.4.1.2.4* Permanent piping shall be identified at the supply point and at each discharge point with the name of the material being transported. [**45:**10.2.5]

16.4.1.2.5* Piping systems, including regulators, shall not be used for gases other than those for which they are designed and identified unless a thorough review of the design specifications, materials of construction, and service compatibility is made and other appropriate modifications have been made. [**45:**10.2.6]

16.4.1.3 LH_2.

16.4.1.3.1 All system components used for cryogenic fluids shall be selected and designed for such service. [**45:**10.4.1]

16.4.1.3.1.1 Design pressure for vessels and piping shall be not less than 150 percent of maximum pressure relief. [**45:**10.4.1.1]

16.4.1.3.1.2* Systems or apparatus handling a cryogenic fluid that can cause freezing or liquefaction of the surrounding atmosphere shall be designed to prevent contact of the condensed air with organic materials. [**45:**10.4.1.2]

16.4.1.3.2 Pressure relief of vessels and piping handling cryogenic fluids shall comply with the applicable requirements of 16.4.1.2. [**45:**10.4.2]

16.4.1.3.3 The space in which cryogenic systems are located shall be ventilated commensurate with the properties of [LH_2]. [**45:**10.4.3]

16.4.2 Indoor Storage. Cylinders [-] that are not necessary for current laboratory requirements shall be stored outside the laboratory unit in accordance with Chapters 7 and 9. [**45:**10.1.2]

16.4.3 Outdoor Storage.

16.4.3.1 [GH_2] cylinders installed or stored outside of laboratory buildings shall be installed and operated in accordance with Chapters 1 through 7. [**45:**10.3.1]

16.4.3.2 Compressed gas delivery systems shall be designed in accordance with Chapters 1 through 7. [**45:**10.3.2]

Chapter 17 Parking Garages

17.1 Scope. This chapter shall apply to open and enclosed parking garages used to store self-propelled vehicles powered by GH_2 or LH_2. This chapter shall also apply to storage of self-propelled vehicles powered by GH_2 or LH_2 within the residential garages of one- and two-family dwellings.

17.1.1 Application. This chapter shall apply to buildings and parking structures that store self-propelled vehicles powered by GH_2 or LH_2. This chapter does not apply to dispensing of GH_2 or LH_2 or to storage or use of GH_2 or LH_2 in parking garages.

17.1.2 Storage or use of GH_2 or LH_2 other than within the fuel and propulsion systems of vehicles being stored shall not be allowed unless specifically approved by the AHJ.

17.2* Parking Garages.

17.2.1 The storage of self-propelled vehicles powered by GH_2 or LH_2 in parking garages or residential garages associated with one- or two-family dwellings shall be subject to the same requirements applicable to vehicles powered by traditional fuels.

Chapter 18 Repair Garage

18.1 Scope This chapter shall apply to buildings and structures used for service and repair operations in connection with self-propelled vehicles (including, but not limited to, passenger automobiles, buses, trucks and tractors) in which GH_2 or LH_2 is used.

18.2 Applicability. This chapter shall apply to service and repair operations in connection with self-propelled vehicles powered by GH_2 or LH_2. The storage, use, and handling of GH_2 or LH_2 in any quantity shall comply with the requirements of Chapters 1 through 4 and the applicable requirements of Chapters 5 through 8. Dispensing of GH_2 or LH_2 shall comply with Chapters 10 and 11.

18.2.1 Major repair facilities that also repair flammable and combustible liquid vehicles shall also meet the requirements of NFPA 30A.

18.2.2 In major repair garages where CNG-fueled vehicles, LNG-fueled vehicles, or LP-Gas–fueled vehicles are also repaired all applicable requirements of NFPA 52 or NFPA 58, whichever is applicable, shall be met.

18.3 General.

18.3.1 Motor Vehicle Repair Areas. Repairing of motor vehicles shall be restricted to areas specifically provided for such purposes. [**30A:**9.7.1]

18.3.1.1 The discharge or defueling of hydrogen from fuel supply containers shall be required for the purpose of fuel storage system modification or repair or when welding or open flame activities occur within 18 in. (0.45 m) of the vehicle fuel supply container. Defueling shall be in accordance with Section 18.7.

18.3.1.2 Other than for those repairs listed in 18.3.1.1, repairs that would be required to be performed in a major repair garage shall be permitted to be performed in a minor repair garage if the vehicle is defueled in accordance with Section 18.7 to less than 200 scf (5.7 Nm^3) and the fuel supply container is sealed.

18.3.2 Automatic Sprinkler Systems. Automatic sprinkler systems shall be provided in accordance with the building code and the fire code adopted by the AHJ.

> Subsection 18.3.3 was revised by a tentative interim amendment (TIA). See page 1.

18.3.3 Gas Detection System. Major repair garages shall be provided with an approved hydrogen gas detection system such that gas can be detected where vehicle hydrogen fuel storage systems are serviced or indoor defueling occurs.

18.3.3.1 The detection system shall be maintained and calibrated in accordance with the manufacturer's instructions on at least an annual basis, or more often, if required by the manufacturer.

18.3.3.2 The repair garage operator shall maintain a record of detection system maintenance and calibration in good condition and accessible to an inspector.

18.3.3.3 The hydrogen detection system shall be designed to activate when the level of hydrogen exceeds 25 percent of the lower flammable limit.

18.3.3.4 Location. System shall provide coverage of the fuel cell vehicle service area. The hydrogen detection system shall have sensors in the following locations:

(1) At inlets to exhaust systems
(2) At high points in service bays with natural ventilation near vents
(3) At the inlets to mechanical ventilation systems; where hydrogen vehicle fuel systems are serviced or defueled.

18.3.3.5 Activation of hydrogen detection system shall result in all of the following:

(1) Initiation of distinct audible and visual alarm signals in the repair garage
(2) Deactivation of heating systems located in the repair garage
(3) Activation of the exhaust system, unless the exhaust system is in continuous operation

18.3.3.6 Failure of the hydrogen detection system shall result in the deactivation of the heating system and activation of the exhaust system and shall cause a trouble signal to sound in an approved location.

18.3.3.7 The circuits of the detection system required by 18.3.3.6 shall be monitored for integrity in accordance with, *NFPA 72.*

18.4 Exhaust System. In major repair garages, or where indoor defueling occurs exhaust duct openings shall be located so that they effectively remove hydrogen accumulation at ceiling level from all parts of the room.

18.4.1 The exhaust system should be designed per the mechanical code adopted by the AHJ.

18.5 Heat-Producing Appliances.

18.5.1 Heat-producing appliances shall be installed to meet the requirements of NFPA 31, NFPA 54, NFPA 82, NFPA 90A, and NFPA 211, as applicable, except as hereinafter specifically provided. [**30A:**7.6.9]

18.5.2 Heat-producing appliances shall be of an approved type. Solid- fuel stoves, improvised furnaces, salamanders, or space heaters shall not be permitted in major repair garages or where indoor refueling occurs.

18.5.3 Heat-producing appliances in major repair garages shall be permitted to be installed in a special room that is separated from the repair area by walls that are constructed to prevent the transmission of hydrogen, that have a fire resistance rating of at least 1 hour, and that have no openings in the walls that lead to a classified area. Specific small openings through the wall, such as for piping and electrical conduit, shall be permitted, provided the gaps and voids are filled with a fire-resistant material to resist transmission of hydrogen. All air for combustion purposes shall be taken from outside the building.

18.5.4 Heat-producing appliances using gas or oil fuel shall be permitted to be installed in a major repair garage provided the combustion chamber is at least 18 in. (455 mm) below the ceiling.

18.5.5 In major repairs garages, open-flame heaters or heating equipment with exposed surfaces having a temperature in excess of 750°F (399°C) shall not be permitted in areas subject to ignitible concentrations of gas.

18.5.6 Electrical heat-producing appliances shall meet the requirements of Chapter 6.

18.6 Welding and Open-Flame Operations.

18.6.1 Operations involving open flame or electric arcs, including fusion gas and electric welding, shall be restricted to areas specifically provided for such purposes. Cutting and welding and related fire prevention precautions shall be in accordance with the requirements of NFPA 51B. [**30A:**9.7.2.1]

18.6.2 Electric arc welding generators or transformers shall conform to *NFPA 70*. Gas fusion welding apparatus and storage of compressed gas cylinders shall be in accordance with the provisions of NFPA 51. [**30A:**9.7.2.2]

18.6.3 The grounded side of an electric welding circuit shall be attached to the part being welded. [**30A:**9.7.2.3]

18.6.4 Gas fusion welding equipment shall be periodically inspected for worn or injured hoses and defective or damaged valves, gauges, and reducing devices. [**30A:**9.7.2.5]

18.7 Defueling Systems.

18.7.1 Methods of Discharge. The discharge of hydrogen from motor vehicle fuel storage tanks shall be accomplished through an approved method of atmospheric venting in accordance with 18.7.1 through 18.7.6.

18.7.2 Defueling Equipment Required at Vehicle Maintenance and Repair Facilities. Major repair garages shall have equipment to defuel vehicle fuel supply containers. Equipment used for defueling shall be listed and labeled for the intended use.

18.7.3 Manufacturer Equipment Required. Equipment supplied by the vehicle manufacturer shall be used to connect the vehicle fuel supply containers to be defueled to the defueling system.

18.7.4 Isolated Use. The defueling shall not be connected to another venting system used for any other purpose.

18.7.5 Defueling systems shall discharge to a safe location in accordance with the requirements of CGA-G-5.5, *Hydrogen Vent Systems*.

18.7.6 Grounding and Bonding. The defueling system shall include a method of grounding and bonding and operator instructions to facilitate safe use. The defueling nozzle of the vehicle storage tank system shall be bonded with the defueling system prior to the commencement of discharge or defueling operations.

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.1.3 Although the requirements established in NFPA 2 focus on gaseous and liquefied hydrogen, the provisions can be applied to deuterium, hydrogen's stable isotope. Hydrogen's unstable isotopes or other forms might have other controls that might be applicable. For example, the isotope tritium is radioactive, and while the flammable character of the material might have similarities, the radioactive nature of the material requires the application of other controls. NFPA 801 provides requirements for fire protection in facilities using radioactive materials. The material is used in extremely small quantities as an energy source in some exit signs. When used in other commercial applications, this material might be subject to other controls imposed by the Department of Defense or the Nuclear Regulatory Commission.

A.1.7.1 Use of NFPA documents for regulatory purposes should be accomplished through adoption by reference. The phrase "adoption by reference" means the citing of title, edition, and publishing information only. Any deletions, additions, and changes desired by the adopting authority should be noted separately in the adopting instrument.

A.2.3.5 Applicable equivalent regulations apply in the country of use. [**55:** A.2.3.6]

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.3.3.6.6 Use Area. Piping systems are used to transport gas (and liquids) from a point of storage to the actual point of use where the gas is deployed. Piping alone does not create a condition of "use" where the material is being consumed or otherwise released from a closed pipe system. On the other hand, piping that connects to "process equipment," which is acting to raise or lower the energy in the system, or that either consumes or releases the material must be viewed as "active," and as a result the material is viewed as being "placed into action" at the point of delivery or connection to the process equipment. [**55,** 2016]

A.3.3.22.1 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. [**55,** 2016]

A.3.3.32 Chemical. For fire hazard ratings of many chemicals, see the NFPA's *Fire Protection Guide to Hazardous Materials*, which contains the following NFPA documents:

(1) NFPA 49
(2) NFPA 325

A.3.3.37 Class C Furnace. This type of furnace uses any type of heating system and includes a special atmosphere supply system(s). Also included in the Class C classification are integral quench furnaces and molten salt bath furnaces. [**86,** 2015]

A.3.3.48.2 Explosion Control. NFPA 68 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 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 [adopted] 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 can require approval by the AHJ. [**55,** 2016]

A.3.3.57 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 scf to 1.76 scf (43 L to 50 L) or a water capacity of 95 lb to 110 lb (43 kg to 50 kg). [**55,** 2016]

A.3.3.58 Defueling. Defueling of the vehicle storage system can be used for some vehicle maintenance procedures. Defueling systems can also be used at fueling stations to allow for the safe discharge of hydrogen from vehicle fuel tank test systems during dispenser calibration, certification, and periodic validation procedures. The dispensers at a fueling station are typically commissioned, validated, certified, and periodically tested by conducting test fills of H2 vehicle storage tanks. After a test fill, the test tank system can be vented safely using a vent system installed at the fueling station.

A.3.3.61 Distributed Integrated Controls (DIC). The DIC is made up of a collection of modules, each with its own function, interconnected to process data for a specific operation or function. Also referred to as distributed control system (DCS). [**853,** 2015]

A.3.3.70.1 Fire Risk Evaluation. The evaluation results in a list of required fire protection elements to be provided based on acceptable means for separation or control of common or special hazards (e.g., temperature and pressure), the control or elimination of ignition sources, the detection and suppression of fires, and the safeguarding of life. [**853,** 2015]

A.3.3.75 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. [**55,** 2016]

A.3.3.79.2.4 Motor Fuel Dispensing Facility Located Inside a Building. The motor fuel dispensing facility can be either enclosed or partially enclosed by the building walls, floors, ceilings, or partitions or can be open to the outside. The motor fuel dispensing area is that area required for dispensing of fuels to motor vehicles. Dispensing of fuel at manufacturing, assembly, and testing operations is not included within this definition. [**30A,** 2015]

A.3.3.80 Fail-Safe. Periodic testing of fail-safe systems should be conducted to ensure that the system performs as intended.

A.3.3.99 Full Trycock. The full trycock valve provides a physical indication of the filling status of a liquid tank, and it is typically used as a redundant means to that of other liquid level indicators. A full trycock line is used to connect the inner vessel vapor space near the top of a cryogenic fluid tank with an internal dip tube located at a point equivalent to the net liquid capacity of the tank. The vapor space in the inner vessel above the full try-cock level is considered the tank ullage. The tank is determined to be full when liquid is emitted from the full trycock valve when the valve is opened.

A.3.3.101.1 Major Repair Garage. The propulsion system on a hydrogen fuel cell vehicle includes the high voltage (>12 volts) battery, the high voltage electrical system, and the high voltage electric motor(s) used to propel the vehicle.

A.3.3.101.2 Minor Repair Garage. Work on the components of a hydrogen fuel cell vehicle that are similar or identical to conventional liquid fueled vehicles (gasoline or diesel fuel) such as wheel, tires, brakes, shock absorbers, and so forth, does not present any unique fire hazard; therefore, no additional fire safety requirements beyond those in place for conventional liquid vehicles are warranted.

A.3.3.102.1 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.
[**55,** 2016]

A.3.3.102.3 Flammable Gas. The definition of flammable gas is applicable to all flammable cryogens, as the vapors released when the cryogen vaporizes are ignitable when mixed in the proper proportions with air.

A.3.3.102.6 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. Radon is inert under the definition provided, but because it is radioactive, it is not considered inert for the purposes of NFPA 55. [**55,** 2016]

A.3.3.102.8 Other Gas. A gas classified as an "other gas" might be a nonflammable gas or an inert gas. [**55,** 2016]

A.3.3.102.12 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

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 [**55,** 2016]

A.3.3.111 Handling. Within the definition, the term *handling* is intended to address containers being transported from one location to another. The term *transportation* is not used in order that problems related to off-site transportation or modes of transportation regulated by the Department of Transportation are not intermingled with the code, creating confusion. Unloading of bulk cargo from a vehicle into stationary storage vessels is regulated by the Department of Transportation. The unloading of bulk GH_2 or LH_2 from independent transport vehicles into a storage system involves a transient function. Transport vehicles are regulated as a portion of the bulk system when they are connected and in the unloading process. Requirements for unloading have been organized under the requirements for "handling" in order to avoid confusing the unloading function with "use." It is not the intent to view materials transported by a pipeline or piping system as a "handling function," as such uses are other than transient in nature.

A.3.3.112 Hazard Rating. The criteria for hazard rating are as defined in NFPA 704. [**55,** 2016]

A.3.3.115.1 Canopy Hood. This is not a chemical fume hood and generally is not effective for exhausting toxic or flammable materials. [**45,** 2015]

A.3.3.115.2 Chemical Fume Hood. For further information on descriptions of types of chemical fume hoods and exhaust ventilation devices, see ANSI/AIHA Z9.5, *Laboratory Ventilation*. The following are types of chemical fume hoods:

(1) *Conventional hood*. A square-post hood without an airfoil directional vane across the bottom of the hood face, and in most cases without provision for a bypass. As the sash is lowered in hoods without an air bypass, the face velocity increases rapidly. The square-post design and absence of a deflector vane have been known to create turbulence at the hood face. The turbulence at the hood face can bring fumes from the hood interior out to the hood face, where they are easily drawn out into the room by the air turbulence caused by a person working at the hood, persons passing the hood, or minor room cross drafts. If hoods are not equipped with a bypass, face velocities could become objectionably high as the sash is closed, and with the sash completely closed, airflow can be insufficient to carry vapors away.
(2) *Bypass air hood*. A hood having a bypass protected by a grille that serves to maintain a relatively constant volume of airflow regardless of sash position. Current design recommends a streamlined entry profile with a deflector vane across the bottom of the hood to direct the airflow across the work surface.
(3) *Auxiliary air hood*. A bypass air hood with the addition of an auxiliary air bonnet to provide a direct source of makeup air in addition to the makeup air from the laboratory work area.

(4) Special purpose hoods are as follows:
   (a) *Radioisotope hoods.* Designed primarily for use with radiochemicals
   (b) *Perchloric acid hoods.* Designed primarily for use with perchloric acid
   (c) *Walk-in hoods.* Designed primarily for extra headroom to accommodate tall equipment
   [**45,** 2015]

A.3.3.117 Hydrogen Equipment Enclosure (HEE). Hydrogen equipment enclosures can include repurposed "shipping" or "ISO" containers as defined in Section 3.3.8 of NFPA 307: A reusable, intermodal boxlike structure of rigid construction fitted with devices to permit lifting and handling particularly transfer from one mode of transportation to another mode of transportation.

Hydrogen equipment located in enclosures larger than the largest standard intermodal container (presently 56 ft long x 8 ft wide x 9.5 ft high) typically are subject to the requirements for indoor installations.

Hydrogen equipment enclosures include those used for equipment that process or store hydrogen. Enclosures can be for weather protection, aesthetic treatment, security, or to prevent external damage. Exterior enclosure walls are not typically intended to carry a fire resistance rating. Enclosures can be enterable but are not intended to be occupied. Hydrogen equipment in enclosures in laboratories are covered by Section 6.19.

A.3.3.122 Indoor Installation. An indoor installation can be a separate building, room, or area within a building. [**853,** 2015]

A.3.3.128 ISO Module. The characteristic internal water volume of individual tubular cylinders is 43 scf (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. [**55,** 2016]

A.3.3.133 Laboratory Work Area. This work area can be enclosed. [**45,** 2015]

A.3.3.136 LH_2. Hydrogen in a liquid state is a flammable cryogenic fluid, regardless of the pressure.

A.3.3.138.1 Ceiling Limit. The ceiling limits utilized are to be those published in 29 CFR 1910.1000. [**55,** 2016]

A.3.3.138.2.1 Permissible Exposure Limit (PEL). The maximum permitted time-weighted average exposures to be utilized are those published in 29 CFR 1910.1000. [**55,** 2016]

A.3.3.138.2.2 Short-Term Exposure Limit (STEL). STEL limits are published in 29 CFR 1910.1000. [**55,** 2016]

A.3.3.141.1 Combustible Liquid. Combustible liquids shall be classified in accordance with the following:

(1) Class II Liquid — Any liquid that has a flash point at or above 100°F (37.8°C) and below 140°F (60°C)
(2) Class III Liquid — Any liquid that has a flash point at or above 140°F (60°C)
   (a) Class IIIA Liquid — Any liquid that has a flash point at or above 140°F (60°C), but below 200°F (93°C)
   (b) Class IIIB Liquid — Any liquid that has a flash point at or above 200°F (93°C)

[**30:** 2015]

A.3.3.141.2 Flammable Liquid (Class I). Materials that boil at a temperature of less than 68°F (20°C) are compressed gases. [**55,** 2016]

Users are cautioned that the use of the definitions found in NFPA 30 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. [**55,** 2016]

A.3.3.143.1 Hazardous Material. Hazardous wastes might or might not be classified as hazardous materials. Management and disposal of hazardous waste is regulated by the EPA under the Resource Conservation and Recovery Act (RCRA). EPA requires wastes identified as hazardous to be handled, stored, treated, and disposed of according to the stipulations of the RCRA hazardous waste program in 40 CFR 260 to 265 and 40 CFR 266 to 299.

Not all of the hazardous materials categories are placed into the high hazard category, and some of these materials have been recognized as being of low or ordinary hazards, depending on their nature in a fire. Inert compressed gases and inert cryogenic fluids, Class IIIB combustible liquids, Class 1 unstable (reactive) materials, Class 1 water-reactive materials, Class 1 oxidizing solids and liquids, and Class IV and Class V organic peroxides are high hazard materials, which, in some cases, do not have an established maximum allowable quantity per control area (MAQ) and, therefore, are not required to comply with the requirements for hazardous occupancies within the context of the adopted building codes.

A.3.3.147 Maximum Operating Pressure. The maximum operating pressure should not exceed the allowable working pressure, and it is usually kept at a suitable level below the setting of pressure-limiting/relieving devices to prevent their frequent functioning. [**52,** 2013]

A.3.3.155 Mobile [Refueling]. The mobile refueler can also contain a compressor for pressurizing the gas to be dispensed and a dispenser, which is the interface between the supply vehicle and the vehicle to be fueled.

A.3.3.161 Nonbulk Hydrogen Compressed Gas. Nonbulk GH_2 includes individual cylinders, containers, or tanks of compressed hydrogen gas typically found in storage with the valves shut and protective caps in place. A nonbulk GH_2 system can include interconnected cylinders, containers, or tanks that have been manifolded or connected for use providing the aggregate volume of individual systems does not exceed 5000 scf (141.6 Nm^3).

A.3.3.178 Parking Structure. A parking structure is permitted to be enclosed or open, use ramps, and use mechanical control push-button-type elevators to transfer vehicles from one floor to another. Motor vehicles are permitted to be parked by the driver or an attendant or are permitted to be parked mechanically by automatic facilities. Where automated-type parking is provided, the operator of those facilities is permitted either to remain at the entry level or to travel to another level. Motor fuel is permitted to be dispensed, and motor vehicles are permitted to be serviced in a parking structure in accordance with NFPA 30A. [**88A,** 2015]

A.3.3.189.1 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). [**55,** 2016]

A.3.3.189.4 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.3.3.194.1 Cathodic Protection. This protection renders a metallic container or piping system or component negatively charged with respect to its surrounding environment. [**55,** 2016]

A.3.3.195 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 and *NFPA 5000* 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. [**55,** 2016]

A.3.3.196 Purge [Special Atmosphere Applications]. The term *high oxygen-bearing atmosphere* is a relative term. In the case of furnaces the concern is that the oxygen is reduced to a point where a flammable mixture can be formed. A concentration less that from 1 percent to 3 percent oxygen might be acceptable. In other cases, any oxygen may be detrimental. Therefore the term *high* is subjective, depending on the use. See NFPA 69, Annex C, for additional information on limiting oxygen concentration.

A.3.3.207 Safety Device. Safety devices are redundant controls, supplementing controls utilized in the normal operation of a furnace system. Safety devices act automatically, either alone or in conjunction with operating controls, when conditions stray outside of design operating ranges and endanger equipment or personnel. [**86,** 2015]

A.3.3.211 Self-Service Motor Fuel Dispensing Facility. Self-service motor fuel dispensing facilities can also include, where provided, facilities for the sale of other retail products.

A.3.3.227.2 Bulk Hydrogen Compressed Gas System. The bulk system terminates at the source valve [commonly referred to as] 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 3,000 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.3.3.227.2(a) through Figure A.3.3.227.2(f). [**55,** 2016]

A.3.3.227.3 Bulk Liquefied Hydrogen (LH_2) System. The bulk system terminates at the source valve [commonly referred to as] 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. [**55,** 2016]

A bulk liquefied hydrogen gas system can include a liquid source where the liquid is vaporized and subsequently compressed 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. [**55,** 2016]

A.3.3.227.4 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.

Bulk oxygen systems can be used to supply gas in either its compressed gaseous or liquefied form. Systems that may be used to supply both gaseous and liquid forms are referred to as hybrid systems. The following bulk oxygen systems are typical of those in use:

(1) When the primary supply of the gas as stored is from a compressed gaseous source that is used in the compressed and gaseous form, the bulk oxygen system is said to be a bulk compressed oxygen gas system.

(2) When the primary supply of the gas as stored is in a liquid form and the system is designed to transfer only liquid, the system is said to be a bulk liquefied oxygen system.

(3) When the primary supply of the gas as stored is in a liquid form and the system is designed to transfer or store the gas in a compressed gaseous form, with or without a feature that may also allow the subsequent transfer and use of liquid, the bulk oxygen system is said to be a hybrid bulk oxygen system. For the purpose of the application of the code, a hybrid system is viewed as a bulk liquefied oxygen system.
[**55,** 2016]

A.3.3.227.7 Engineered and Field-Constructed Fuel Cell Power System. The power system is engineered and designed for the assembly of various components from various sources and is installed on site. *(See Figure A.3.3.227.9 for a schematic of a typical fuel cell power system.)* [**853,** 2015]

A.3.3.227.9 Fuel Cell Power System. The system is composed of all or some of the systems shown in Figure A.3.3.227.9. [**853,** 2010]

A.3.3.227.11 Gaseous Hydrogen (GH_2) System. The gaseous hydrogen system terminates at the point where hydrogen at service pressure first enters the distribution piping.

A.3.3.227.16 Liquefied Hydrogen (LH_2) 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.

A.3.3.227.19 Non-Bulk Flammable Gas System. Non-bulk systems can have more than 5000 scf (141.6 Nm^3) as long as the volume of any individual container or connected system is less than 5000 scf (141.6 Nm^3). Table 7.2.2.3.2 shows exposure distances for non-bulk flammable gases with total storage up to 200,000 scf (5664 Nm^3). [**55,** 2016]

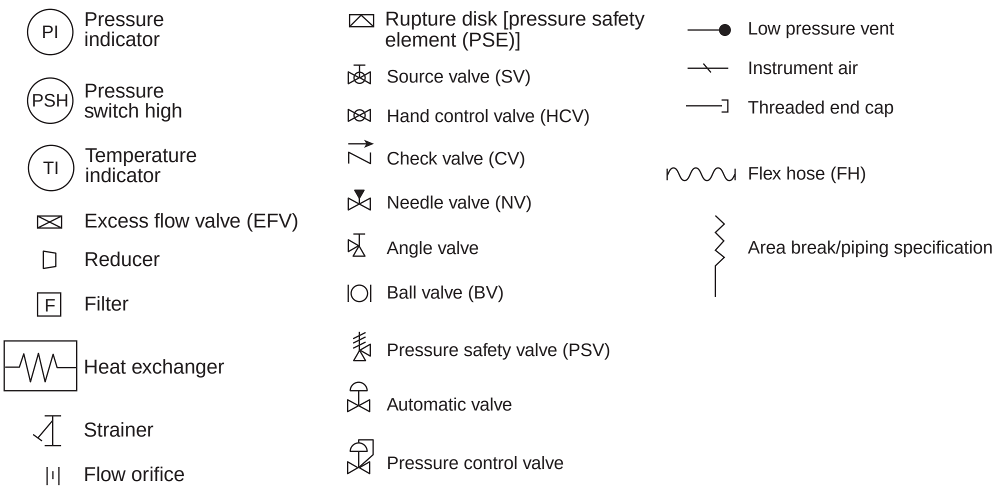


FIGURE A.3.3.227.2(a) Symbol Legend for Figure A.3.3.263.10.2.1(b) through Figure A.3.3.263.10.2.1(f). [55: Figure 3.3.93.2(a)]

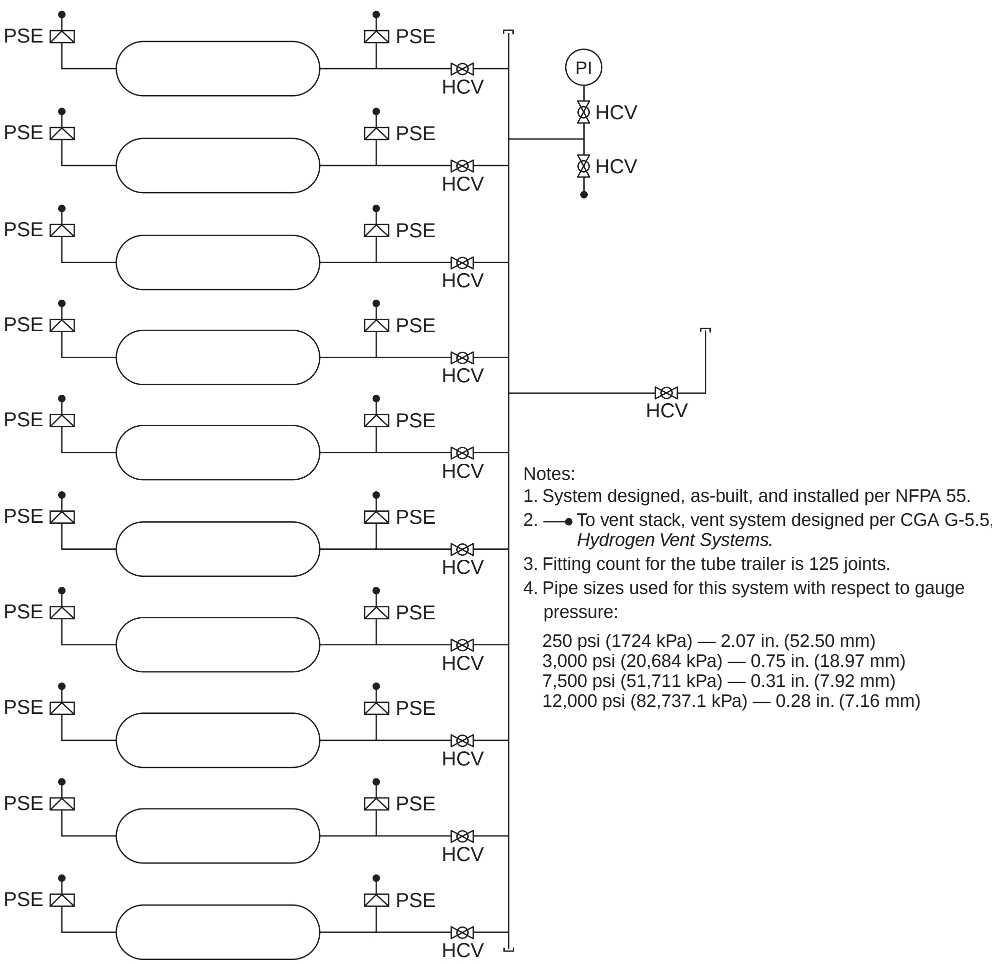


FIGURE A.3.3.227.2(b) Typical Tube Trailer. [55: Figure A.3.3.93.2(b)]

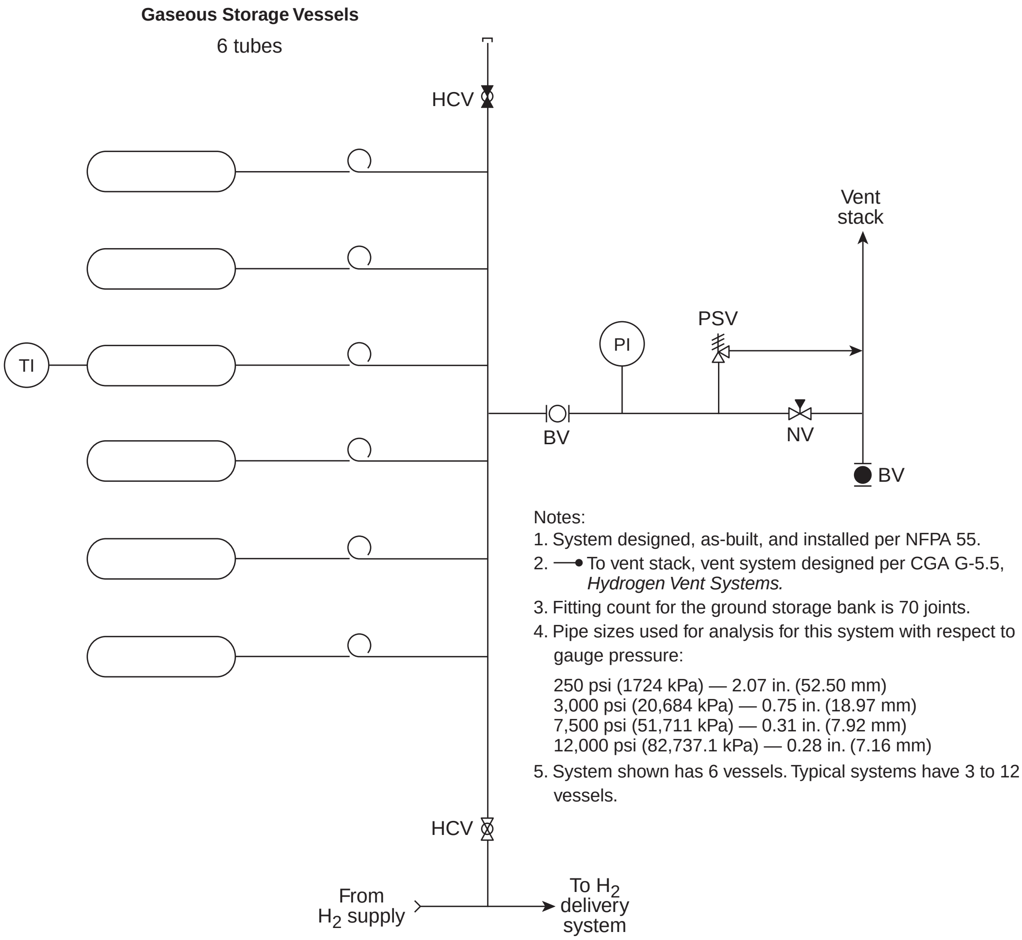


FIGURE A.3.3.227.2(c) Typical Bulk Compressed Gaseous Storage System. [55: Figure A.3.3.93.2(c)]

A.3.3.227.20 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. [**55,** 2016]

A.3.3.227.21 Pre-Engineered and Matched Modular Components Fuel Cell Power System. The modules are matched to be installed in the field. [**853,** 2015]

A.3.3.228.3 Stationary Tank. A stationary tank does not include a cylinder having less than 1000 lb (453.5 kg) water capacity. [**55,** 2016]

A.3.3.230 Thermal Spraying. Thermal spray can consist of any of the following operations:

(1) *Plasma Thermal Spray.* Process gases and feedstock are electrically heated by passing through an electric arc to produce a plasma plume.
(2) *Combustion Spray.* A fuel gas is combusted with an oxidizer to produce a combustion flame with the feedstock entrained within the flame.
(3) *High-Velocity Oxy-Fuel (HVOF).* A fuel gas is combusted with an oxidizer at high pressures and flows to produce a high-velocity combustion flame, with the feedstock entrained within the flame.

A.3.3.234 Tube Trailer. The characteristic internal water volume of individual tubular cylinders ranges from 43 scf to 93 scf (1218 L to 2632 L) or a water capacity of 2686 lb to 5803 lb (1218 kg to 2632 kg). [**55,** 2016]

A.3.3.235.1 Laboratory Unit. A laboratory unit can include offices, lavatories, and other incidental contiguous rooms maintained for or used by laboratory personnel, and corridors within the unit. It can contain one or more separate laboratory work areas. It can be an entire building. [**45,** 2015]

A.3.3.235.2 Mobile Supply Unit. Examples include ISO modules, tube trailers, and cylinder packs. [**55,** 2016]

A.3.3.239 Vacuum Jacket. Construction of this type is normally used for tanks that contain cryogenic fluids. The outer vessel is called a jacket, as it is formed around the inner vessel. The inner vessel is used to contain the substance under pressure, and the annular space between the inner and outer vessel is used as a form of insulation to reduce the transfer of ambient heat to the inner vessel. The space between the inner vessel and outer vessel is maintained gastight in order to avoid condensation as well as heat transfer. Any residual atmosphere that might be retained in the annular space between the vessels is evacuated by the use of vacuum pumps before the vessel is placed in

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)

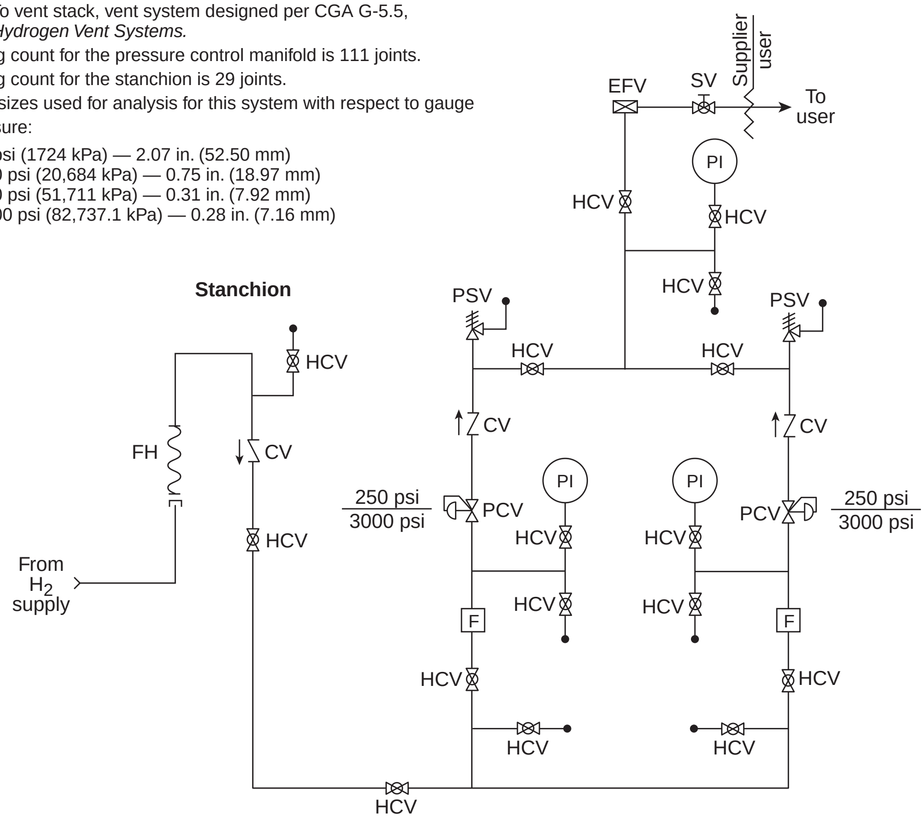


FIGURE A.3.3.227.2(d) Typical Tube Trailer Discharge Stanchion and Pressure Control Manifold. [55: Figure A.3.3.93.2(d)]

service. The annular space might also contain insulating material that serves to increase the insulating properties of the construction.

A.3.3.241.2.1 Safety Shutoff Valve. The valve can be opened either manually or automatically, but only after the solenoid coil or other holding mechanism is energized. [**86,** 2015]

A.3.3.241.3 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. [**55,** 2016]

A.3.3.242 Vaporizer. The outside source of heat can include, but is not limited to, ambient air, steam, thermal fluids (such as water or oil), or other sources that are capable of adding heat to the system.

A.3.4.7 Exposure Fire. An exposure fire usually refers to a fire that starts outside a building, such as a wildlands fire or vehicle fire, and that, consequently, exposes the building to a fire. [***101,*** 2015]

A.3.4.8 Fire Model. Due to the complex nature of the principles involved, models are often packaged as computer software. Any relevant input data, assumptions, and limitations needed to properly implement the model will be attached to the fire models. [***101,*** 2015]

A.3.4.9 Fire Scenario. A fire scenario defines the conditions under which a proposed design is expected to meet the fire safety goals. Factors typically include fuel characteristics, ignition sources, ventilation, building characteristics, and occupant locations and characteristics. The term *fire scenario* includes more than the characteristics of the fire itself but excludes design specifications and any characteristics that do not vary from one fire to another; the latter are called assumptions. The term *fire scenario* is used here to mean only those specifications required to calculate the fire's development and effects, but, in other contexts, the term might be used to mean both the initial specifications and the subsequent development and effects (i.e., a complete description of fire from conditions prior to ignition to conditions following extinguishment). [***101,*** 2015]

A.3.4.14 Performance Criteria. Performance criteria are stated in engineering terms. Engineering terms include temperatures, radiant heat flux, and levels of exposure to fire products. Performance criteria provide threshold values used to evaluate a proposed design. [***101,*** 2015]

A.3.4.15 Proposed Design. The design team might develop a number of trial designs that will be evaluated to determine whether they meet the performance criteria. One of the trial designs will be selected from those that meet the performance criteria for submission to the authority having jurisdiction as the proposed design. [***101,*** 2015]

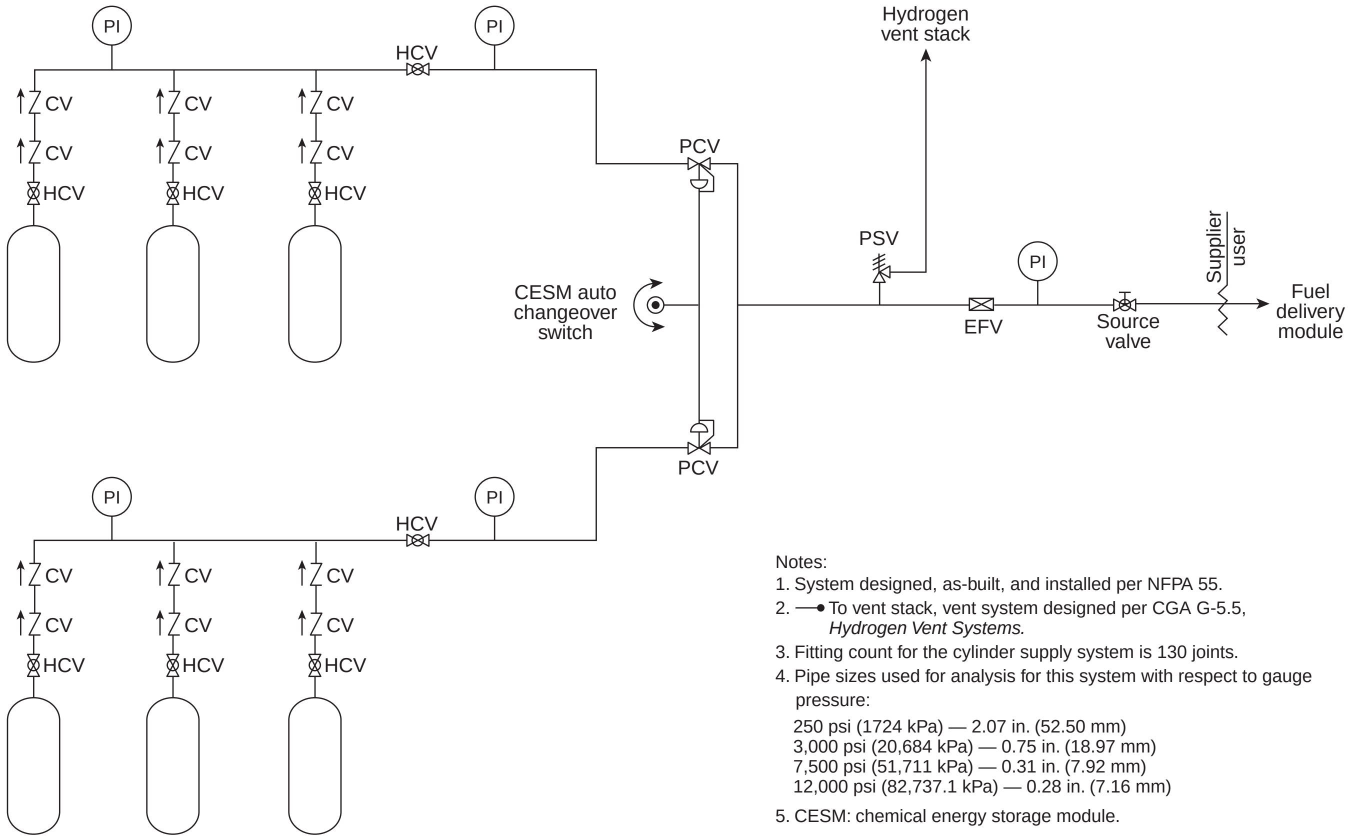


FIGURE A.3.3.227.2(e) Typical Chemical Energy Storage Module (CESM). [55: Figure A.3.3.93.2(e)]

The proposed design is not necessarily limited to fire protection systems and building features. It also includes any component of the proposed design that is installed, established, or maintained for the purpose of life safety, without which the proposed design could fail to achieve specified performance criteria. Therefore, the proposed design often includes emergency procedures and organizational structures that are needed to meet the performance criteria specified for the proposed design. [***101,*** 2015]

A.3.4.20.1 Design Specification. Design specifications include both hardware and human factors, such as the conditions produced by maintenance and training. For purposes of performance-based design, the design specifications of interest are those that affect the ability of the building to meet the stated goals and objectives. [**5000,** 2015]

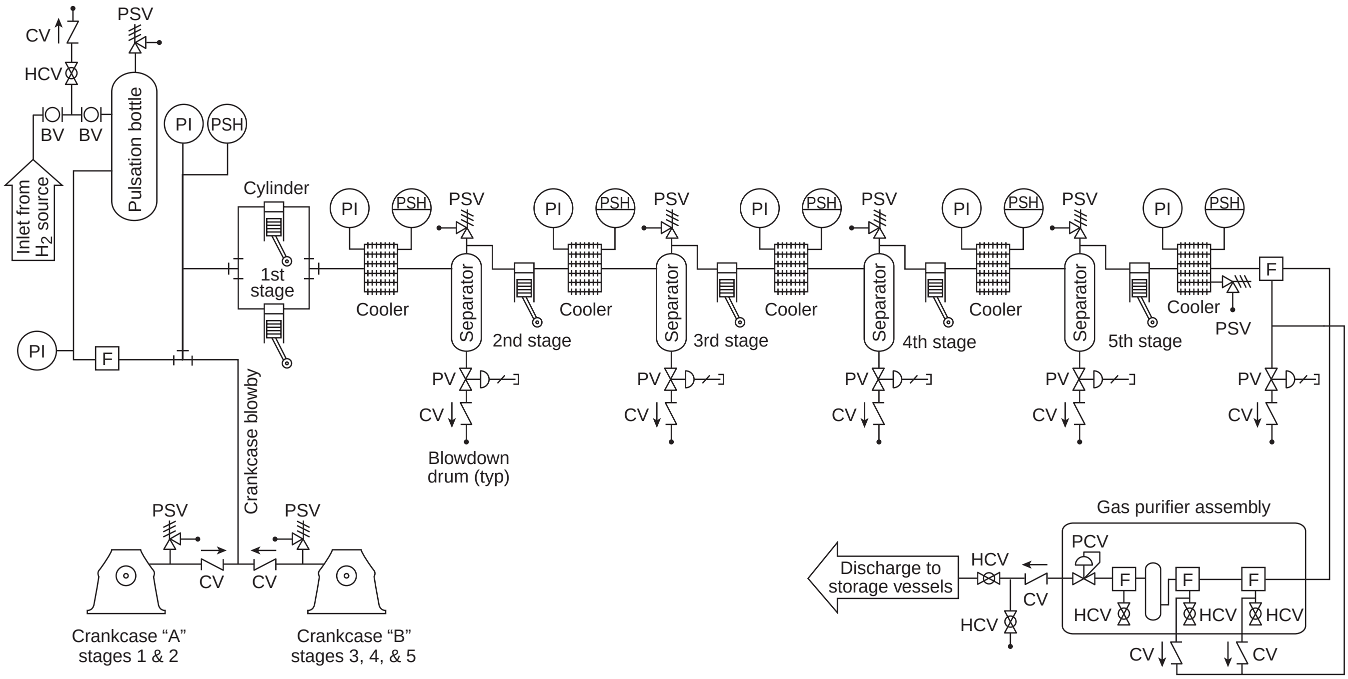
A.4.1.2 Zoning codes in some jurisdictions will determine whether a proposed use is permitted. In some jurisdictions, the installation of bulk hydrogen systems might not be permitted in densely populated areas or in other than industrial zones. Local zoning regulations will dictate requirements, and users are responsible for determining the limitations of zoning regulations on a case by case basis.

A.4.1.3 Permits for construction of facilities, whether indoors or outdoors, will vary based on jurisdictional requirements. Not all jurisdictions require permits. Some jurisdictions might require permits for hydrogen, others might require permits for the operation of certain equipment. The local fire prevention code or adopted building code might require permits, depending on the operation or the facility to be constructed. Users are responsible for determining whether permits are required and for meeting the requirements on a case by case basis.

A.4.2 The overall goals of this Code are presented in 4.2.1. These overall goals are treated in greater depth in 4.2.3 through 4.2.5. In each of these subsections, an overall goal for the subsection is defined, specific goals relating to the overall goal are presented next, and the objectives that relate to the specific goal follow. This format is intended to enhance the usability of the Code.

A.4.2.1 These highest level goals are intentionally general in nature. Each includes a broad spectrum of topics as shown in 4.2.3. The property protection goal is not just a goal unto itself, as it is also achieved in part as a result of designing to achieve the other stated goals. A reasonable level of safety is further defined by subsequent language in the Code. The facility/property owner or an insurance representative might also have other goals, which might necessitate more stringent objectives as well as more demanding criteria. [**1:** A.4.1.1]

A.4.2.2 The objectives apply regardless of which option a user of the Code selects for a design — the performance-based option or the prescriptive-based option. The objectives are stated in more specific terms than the goals and tend to be more quantitative. The goals and objectives, taken together, form the broad, general targets at which a performance-based design can take aim. Specific criteria for design follow in Chapter 5. [**1:** A.4.1.2]

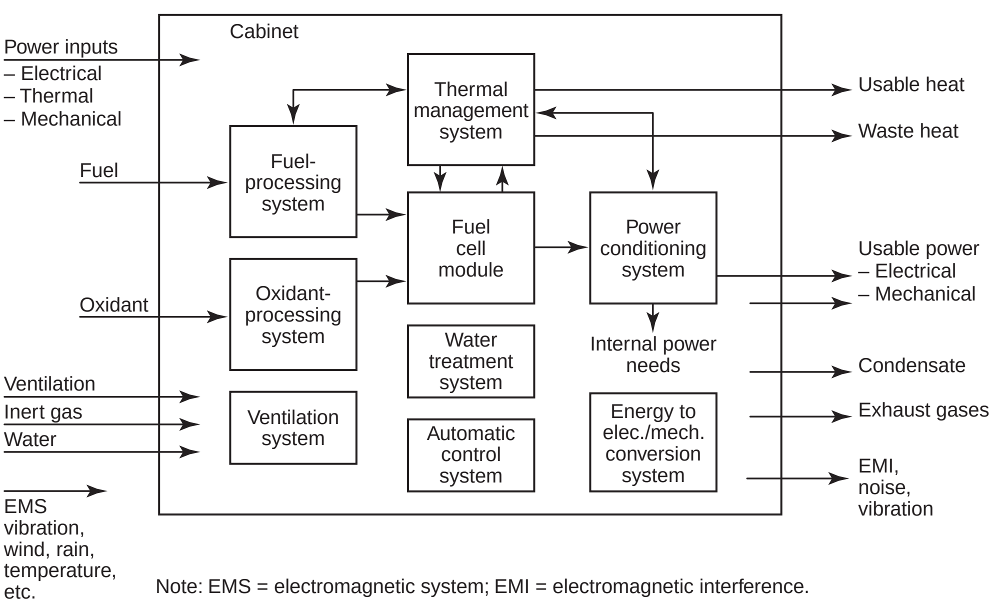


Notes:

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.3.3.227.2(f) Typical Compressor Module. [55: Figure A.3.3.93.2(f)]



Note: EMS = electromagnetic system; EMI = electromagnetic interference.

FIGURE A.3.3.227.9 Typical Fuel Cell Power System. [853: Figure B.1]

A.4.2.3 The concept of providing for safety applies not only to safety during a fire, explosion, or hazardous materials incident, but also during the normal use of a building or facility. A reasonable level of safety should be provided for occupants in and individuals near the facility or building in question. The resultant design in addition to providing for occupant's safety also promotes the public welfare. Public welfare is also provided as a result of the mission continuity provisions of this Code. [**1:** A.4.1.3]

A.4.2.3.1.1 The phrase *reasonably safe* from fire is defined by subsequent language in this Code, primarily in the objectives. [**1:** A.4.1.3.1.1]

A.4.2.3.1.2.2 In many cases, the provisions of the Code to provide safety for occupants satisfies this goal for protection of emergency responders. [**1:** A.4.1.3.1.2.2]

A.4.2.3.1.2.5 This provision addresses the fire safety objectives of operations addressed elsewhere in the Code, such as hot work, tar kettle operation, and so forth, that are not directly related to building construction and use. [**1:** A.4.1.3.1.2.5]

A.4.2.3.2.1 The phrase *reasonably safe during normal use* is defined by subsequent language in this Code, primarily in the objectives. Certain requirements, such as heights of guards and stair dimensions, are provided to ensure that the occupants are safe during nonemergency use of the buildings. Failure to address these features could result in falls or other injuries to occupants in their normal day-to-day activities in the building. [**1:**4.1.3.2.1]

A.4.2.3.3 The focus of NFPA 2 is on hydrogen. However, this should not detract from the overall safety goal of reducing the hazards from exposure to or mishap with other hazardous materials. For example, hydrogen can be generated from natural gas or ammonia. One cannot disregard the hazards of these materials and focus solely on the hazards of hydrogen. It is not intended that NFPA 2 be used as the sole means to regulate the broad category of hazardous materials. For additional information on hazardous materials refer to the adopted fire prevention code or other referenced codes and standards. See Section 2.2 and Annex M for additional information.

A.4.2.3.3.2.2 For item 3, the phrase *external force* refers to the application of factors such as heat, water, shock, or other phenomenon onto hazardous materials that are sensitive to such factors and could react vigorously to produce unsafe conditions. [**1:** A.4.1.3.3.2.2]

A.4.2.4.2.1 Ignition occurs when combustible materials come into contact with a source of heat of sufficient temperature and power for a requisite time in an atmosphere where oxygen is present. Combustible material does not necessarily ignite immediately upon contact with a source of heat. [**1:** A.4.1.4.2.1]

A.4.2.4.2.2 Examples of specific conditions to avoid include, but are not limited to, flashover, fire spread beyond the item or room of fire origin, overheating of equipment, and overpressure of exterior walls. [**1:** A.4.1.4.2.2]

A.4.2.5.1 This goal is applicable to certain buildings and facilities that have been deemed to be necessary to the continued welfare of a community. Depending on the nature of the critical mission provided by the building, various stakeholders, including community leaders, AHJs, and owners will identify the mission critical buildings. Mission critical areas should be identified and appropriately protected. The objectives for property protection and mission continuity are sometimes difficult to differentiate. Achieving the objectives for property protection could, to a certain extent, accomplish the objectives for mission continuity. [**1:** A.4.1.5.1]

A.4.2.5.2 Examples of buildings and facilities that provide a public welfare role for a community could include hospitals, police and fire stations, evacuation centers, schools, water and sewerage facilities, and electrical generating plants. Also included are buildings and facilities with significant impact on the economic viability of the community. This objective is intended to ensure that such buildings and facilities are capable of providing essential services following a disaster since the community's well-being depends on such service being available. [**1:** A.4.1.5.2]

A.4.3.1 Additional assumptions that need to be identified for a performance-based design are addressed in Chapter 5. [**1:** A.4.2.1]

A.4.3.2 It is not assumed that a design scenario will be considered that simulates the hazards produced when unauthorized releases of hazardous materials occur simultaneously at different locations within a facility, unless it is reasonable to expect that a single incident, such as a fork lift accident or pipe failure, could be expected to create such a condition. However, when hazardous materials are in close proximity to one another, such as on a shelf or in adjacent storage cabinets, it could be reasonable to apply a design scenario where multiple releases of the hazardous materials occur simultaneously from these close proximity areas. In this case, it is not unreasonable to expect the shelf to collapse or a forklift to damage adjacent hazardous materials containers. [**1:** A.4.2.2]

A.4.3.3 It is not assumed that a design scenario will be considered that simulates the hazards produced when a fire, explosion, or external force that creates a dangerous condition occurs at the same time that hazardous materials have been subject to an unauthorized release. This does not preclude considering a scenario where a fire or explosion occurs and impinges on hazardous materials that are in their normal storage, use, or handling conditions. [**1:** A.4.2.3]

The phrase *external force that creates a dangerous condition* refers to the application of factors such as heat, water, shock, or other phenomenon onto hazardous materials that are sensitive to such factors and could react vigorously to produce unsafe conditions. [**1:** A.4.2.3]

A.4.8 Out-of-service systems should not be abandoned in place. Systems that remain out of service should be maintained in a useable 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 as the system is removed. [**55:** A.4.4]

A.4.10.1 GH_2 and LH_2 releases do not currently require the issuance of environmental permits. The release of GH_2 and LH_2 creates potential safety concerns that are addressed by this code but are not likely to negatively impact the environment.

A.4.10.3 The discharges recorded as unauthorized are those that are prohibited by 4.10.1 or that are catastrophic or that occur beyond the design of the system. This is not intended to include releases that are part of the design of the system, such as normal venting and operations.

A.4.11 The hazard potential of a facility is not dependent on any single factor. Physical size, number of employees, and the quantity and the nature of the hazardous materials are important considerations. The level of training can vary with the complexity of the facility under consideration. [**400:** A.6.1.4]

A.4.11.4 Emergency responders can include on-site personnel that have been designated and trained to respond to emergencies, persons from the public sector such as fire department personnel, or persons from the private sector that can be contracted or otherwise engaged to perform emergency response duties. *(See Annex I in NFPA 400 for additional information.)* [**400:** A.6.1.4.4]

A.4.11.4.1 OSHA describes an Incident Command System as a standardized on-scene incident management concept designed specifically to allow responders to adopt an integrated organizational structure equal to the complexity and demands of any single incident or multiple incidents without being hindered by jurisdictional boundaries. [**400:** A.6.1.4.4.1]

A.4.11.4.2 Responses to releases of hazardous materials where there is no potential safety or health hazard such as fire, explosion, or chemical exposure are not considered emergency responses as defined within the context of this code. [**400:** A.6.1.4.4.2]

A.4.11.4.3 Emergency response training will vary depending on the level of emergency response required and by the requirements of the governmental agency. [**400:** A.6.1.4.4.3]

A.4.13.2.1(4) Such locations could include vaults and other systems located underground.

A.4.14.1.1(1) The term *tank* is used in a generic way. All pressure vessels should be included in this requirement.

A.4.15 The term *materials* used throughout this section applies to building construction materials and not to hazardous materials, compressed gases, or cryogenic fluids. [**55:** A.4.12]

A.4.15.1 The provisions of 4.15.1 do not require inherently noncombustible materials to be tested in order to be classified as noncombustible materials. [***101:*** A.4.6.13]

A.4.15.1(1) Examples of such materials include steel, concrete, masonry, and glass. [***101:*** A.4.6.13.1(1)]

A.4.15.2 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 are considered combustible. *(See NFPA 259 and NFPA 220).* [***101:*** A.4.6.14]

A.5.1 The performance option of this code establishes acceptable levels of risk for facilities (i.e., buildings and other structures and the operations therewith associated) as addressed in Section 1.3. (Note that "facility" and "building" can be used interchangeably with facility being the more general term.) While the performance option of this code does contain goals, objectives, and performance criteria necessary to provide for an acceptable level of risk, it does not describe how to meet these goals, objectives, and performance criteria. Design and engineering are needed to meet the provisions of Chapter 5. For fire protection designs, the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* provides a framework for these assessments. [**1:** A.5.1]

Pre-construction design requirements address those issues, which have to be considered before the certificate of occupancy is issued for a facility. [**1:** A.5.1]

A.5.1.3 Qualifications should include experience, education, and credentials that demonstrate knowledgeable and responsible use of applicable models and methods. [**1:** A.5.1.3]

A.5.1.4 The *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* outlines a process for using a performance-based approach in the design and assessment of building fire safety design and identifies parameters that should be considered in the analysis of a performance-based design. As can be seen this process requires the involvement of all stakeholders who have a share or interest in the successful completion of the project. The steps that are recommended by the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* for this process are shown in Figure A.5.1.4. [**1:** A.5.1.4]

The guide specifically addresses building fire safety performance-based design. It might not be directly applicable to performance-based designs involving other systems and operations covered within this code, such as hot work operations or hazardous materials storage. However, the various steps for defining, developing, evaluating, and documenting the performance-based design should still provide a useful framework for the overall design process. [**1:** A.5.1.4]

The steps in the performance-based design process are as follows: [**1:** A.5.1.4]

(1) *Step 1: Defining Project Scope.* The first step in a performance-based design is to define the scope of the project. Defining the scope consists of identifying and documenting the following: [**1:** A.5.1.4(1)]
   (a) Constraints on the design and project schedule [**1:** A.5.1.4(1)(a)]
   (b) The stakeholders associated with project [**1:** A.5.1.4(1)(b)]
   (c) The proposed building construction and features desired by the owner or tenant [**1:** A.5.1.4(1)(c)]
   (d) Occupant and building characteristics [**1:** A.5.1.4(1)(d)]
   (e) The intended use and occupancy of the building [**1:** A.5.1.4(1)(e)]
   (f) Applicable codes and regulations [**1:** A.5.1.4(1)(f)]
   An understanding of these items is needed to ensure that a performance-based design meets the stakeholders' needs. [**1:** A.5.1.4]
(2) *Step 2: Identifying Goals.* Once the scope of the project is defined, the next step in the performance-based design process is to identify and document the fire safety goals of various stakeholders. Fire safety goals could include levels of protection for people and property, or they could provide for continuity of operations, historical preservation, and environmental protection. Goals could be unique for different projects, based on the stakeholders needs and desires. The stakeholders should discuss which goals are the most important for the project. In order to avoid problems later in the design process, all stakeholders should be aware of and agree to the goals prior to proceeding with the performance-based design process (*see Step 7*). [**1:** A.5.1.4(2)]
(3) *Step 3: Defining Stakeholder and Design Objectives.* The third step in the design process is to develop objectives. The objectives are essentially the design goals that are further refined into tangible values that can be quantified in engineering terms. Objectives could include mitigating the consequences of a fire expressed in terms of dollar values, loss of life, or other impact on property opera-

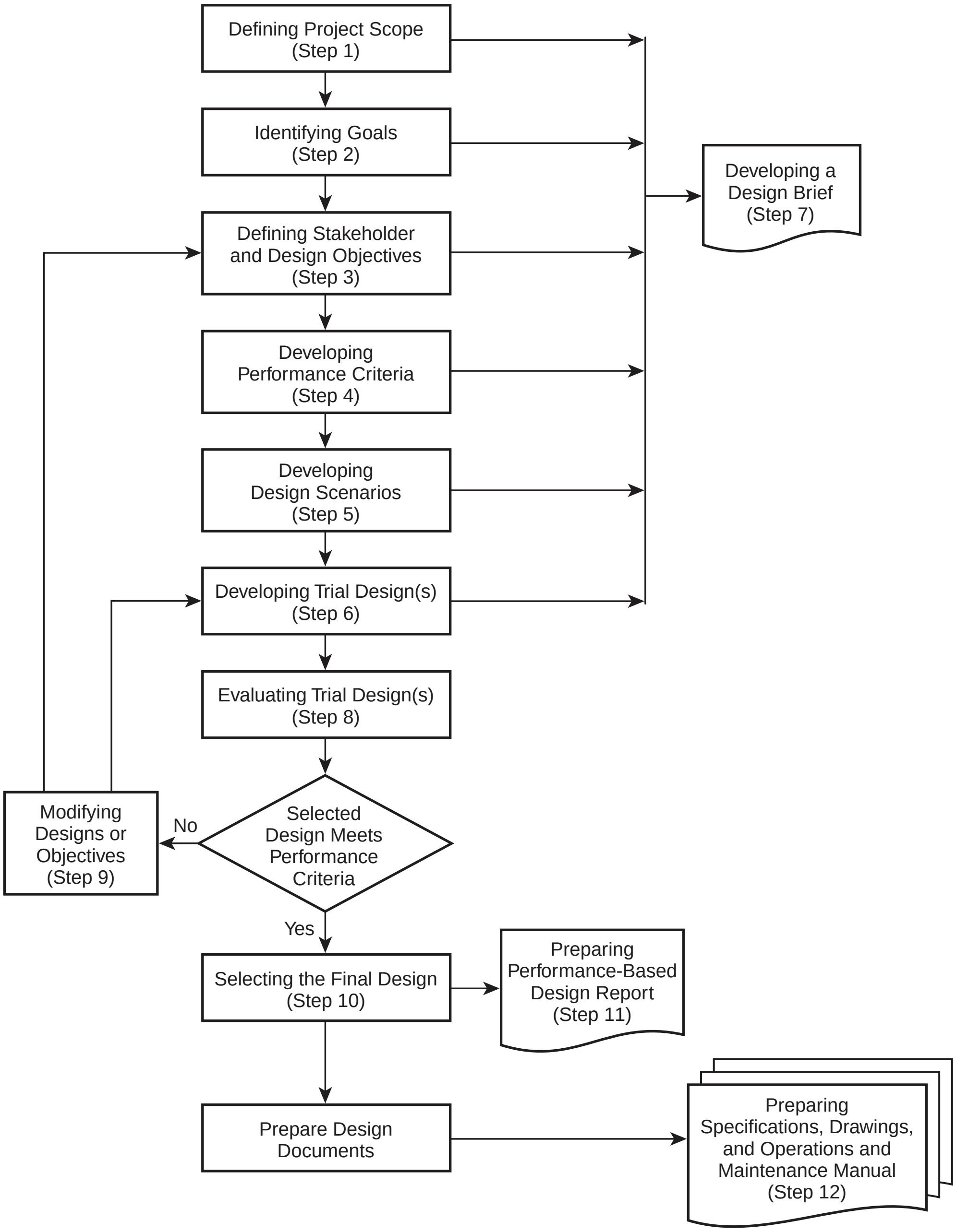


FIGURE A.5.1.4 Steps in the Performance-Based Analysis and the Conceptual Design Procedure for Fire Protection Design. [1: Figure A.5.1.4]

tions, or maximum allowable conditions, such as extent of fire spread, temperature, spread of combustion products, and so forth. [**1:** A.5.1.4(3)]

(4) *Step 4: Developing Performance Criteria.* The fourth step in the design process is the development of performance criteria to be met by the design. These criteria are a further refinement of the design objectives and are numerical values to which the expected performance of the trial designs can be compared. Performance criteria could include threshold values for temperatures of materials, gas temperatures, carboxyhemoglobin (COHb) levels, smoke obscuration, and thermal exposure levels. [**1:** A.5.1.4(4)]

(5) *Step 5: Developing Design Scenarios.* Once the performance criteria have been established, the engineer will develop and analyze design alternatives to meet performance criteria. The first part of this process is the identification of possible scenarios and design scenarios. Fire scenarios are descriptions of possible fire events, and consist of fire characteristics, building characteristics (including facility operations), and occupant characteristics. The fire scenarios identified will subsequently be filtered (i.e., combined or eliminated) into a subset of design fire scenarios against which trial designs will be evaluated. Hazardous materials scenarios can be treated similarly. [**1:** A.5.1.4(5)]

(6) *Step 6: Developing Trial Design(s).* Once the project scope, performance criteria, and design scenarios are established, the engineer develops preliminary designs, referred to as trial designs, intended to meet the project requirements. The trial design(s) include proposed fire protection systems, construction features, and operation that are provided in order for a design to meet the performance criteria when evaluated using the design fire scenarios. The evaluation method should also be determined at this point. The evaluation methods used should be appropriate for the situation and agreeable to the stakeholders. [**1:** A.5.1.4(6)]

(7) *Step 7: Developing a Fire Protection Engineering Design Brief.* At this point in the process a fire protection engineering design brief should be prepared and provided to all stakeholders for their review and concurrence. This brief should document the project scope, goals, objectives, trial designs, performance criteria, design fire scenarios, and analysis methods. Documenting and agreeing upon these factors at this point in the design process will help avoid possible misunderstandings later. [**1:** A.5.1.4(7)]

(8) *Step 8: Evaluating Trial Designs.* Each trial design is then evaluated using each design scenario. The evaluation results will indicate whether the trial design will meet the performance criteria. Only trial design(s) that meet the performance criteria can be considered as final design proposals. Yet, the performance criteria can be revised with the stakeholders' approval. The criteria cannot be arbitrarily changed to ensure that a trial design meets a criterion, but can be changed based on additional analysis and the consideration of additional data. [**1:** A.5.1.4(8)]

(9) *Step 9: Modifying Designs or Objectives.* If none of the trial designs evaluated comply with the previously agreed upon performance criteria, it could be necessary to either develop and evaluate new trial designs, or revisit the objectives and performance criteria previously agreed upon by the stakeholders to determine if stakeholder objectives and performance criteria should be modified. [**1:** A.5.1.4(9)]

(10) *Step 10: Selecting the Final Design.* Once an acceptable trial design is identified using the evaluation, it can be considered for the final project design. If multiple trial designs are evaluated, further analysis will be needed to select a final design. The selection of an acceptable trial design for the final design could be based on a variety of factors, such as financial considerations, timeliness of installation, system and material availability, ease of installation, maintenance and use, and other factors. [**1:** A.5.1.4(10)]

(11) *Step 11: Preparing Performance-Based Design Report.* Once the final design is identified, design documents need to be prepared. Proper documentation will ensure that all stakeholders understand what is necessary for the design implementation, maintenance, and continuity of the fire protection design. The documentation should include the fire protection engineering design brief, a performance design report, detailed specifications and drawings, and a facility operations and maintenance manual. [**1:** A.5.1.4(11)]

(12) *Step 12: Preparing Specifications, Drawings, and Operations and Maintenance Manual.* The specifications and drawings portion of the performance-based design report convey to building and system designers and installing contractors how to implement the performance design. Specifications and drawings could include required sprinkler densities, hydraulic characteristics and spacing requirements, the fire detection and alarm system components and programming, special construction requirements including means of egress and location of fire-resistive walls, compartmentation, and the coordination of interactive systems. The detailed specifications are the implementation document of the performance-based design report. The detailed drawings will graphically represent the results of the performance design. The Operations and Maintenance (O&M) Manual clearly states the requirement of the facility operator to ensure that the components of the performance design are in place and operating properly. The O&M Manual describes the commissioning requirements and the interaction of the different systems' interfaces. All subsystems are identified, and inspection and testing regimes and schedules are created. [**1:** A.5.1.4(12)]

The O&M Manual also gives instruction to the facility operator on restrictions placed on facility operations. These limitations are based on the engineering assumptions made during the design and analysis. These limiting factors could include critical fire load, sprinkler design requirements, building use and occupancy, and reliability and maintenance of systems. The O&M Manual can be used to communicate to tenants and occupants these limits and their responsibilities as a tenant. It could also be used as a guide for renovations and changes. It also can be used to document agreements between stakeholders. [**1:** A.5.1.4]

A.5.1.5 A third-party reviewer is a person or group of persons chosen by the AHJ to review proposed performance-based designs. Qualifications of the third-party reviewer should include experience, education, and credentials that demonstrate knowledgeable and responsible use of applicable models and methods. [**1:** A.5.1.5]

A.5.1.8 See Step 12 of A.5.1.4 for a description of these documents. [**1:** A.5.1.8]

A.5.1.9 Information that could be needed by the fire service arriving at the scene of a fire in a performance-based designed facility includes, but is not limited to, the following: [**1:** A.5.1.9]

(1) Safe shutdown procedures of equipment and processes [**1:** A.5.1.9(1)]
(2) Facility personnel responsible for assisting the fire service [**1:** A.5.1.9(2)]
(3) Operating procedures required to maintain the effectiveness of the performance-based designed fire protection system: when it is and is not appropriate to alter, shut down, or turn off a design feature; assumptions that have to be maintained if a fire occurs; suggested fire-fighting tactics that relate to the specific nature of the performance-based design. [**1:** A.5.1.9(3)]

The design specifications and O&M Manual documentation described in 5.1.8 should provide a guide for the facility owner and tenants to follow in order to maintain the required level of safety anticipated by the original design. It should also provide a guide for the AHJ to use in conducting ongoing inspections of the facility. [**1:** A.5.1.9]

A.5.1.10 Continued compliance with the goals and objectives of the code involves many factors. The building construction, including openings, interior finish, and fire- and smoke-resistive construction, and the building and fire protection systems need to retain at least the same level of performance as is provided for by the original design parameters. The use and occupancy should not change to the degree that assumptions made about the occupant characteristics, combustibility of furnishings, and existence of trained personnel are no longer valid. In addition, actions provided by other personnel, such as emergency responders, should not be diminished below the documented assumed levels. Also, actions needed to maintain reliability of systems at the anticipated level need to meet the initial design criteria. [**1:** A.5.1.10]

Subsection 5.1.10 deals with issues that arise after the facility has been constructed and a certificate of occupancy has been issued. Therefore, any changes to the facility or the operations conducted therein, up to and including the demolition of the facility that affect the assumptions of the original design are considered as part of the management of change. [**1:** A.5.1.10]

The following is a process for evaluating performance-based facilities: [**1:** A.5.1.10]

(1) Review of original design analysis and documentation as follows: [**1:** A.5.1.10(1)]
    (a) Assumptions [**1:** A.5.1.10(1)(a)]
    (b) Input parameter values [**1:** A.5.1.10(1)(b)]
    (c) Predictions and/or results of other calculations [**1:** A.5.1.10(1)(c)]
(2) Review of design analysis and documentation for any subsequent renovations, additions, modifications, and so forth, as in Step 1 of A.5.1.4 [**1:** A.5.1.10(2)]
(3) Review of the facility's operations and maintenance manual, including any and all revisions to it [**1:** A.5.1.10(3)]
(4) On-site inspection, involving the following: [**1:** A.5.1.10(4)]
    (a) Consideration of "prescriptive" issues (e.g., blocked egress paths, poor maintenance of systems) [**1:** A.5.1.10(4)(a)]
    (b) Comparison of assumptions to specific, pertinent on-site conditions [**1:** A.5.1.10(4)(b)]
    (c) Comparison of input parameter values to pertinent on-site conditions [**1:** A.5.1.10(4)(c)]
    (d) Review of maintenance and testing documentation to ensure adherence to the schedules detailed in the facility's O&M Manual [**1:** A.5.1.10(4)(d)]
(5) Reconciliation of discrepancies as follows: [**1:** A.5.1.10(5)]
    (a) Develop a list of discrepancies [**1:** A.5.1.10(5)(a)]
    (b) Consultation with the facility owner and/or their representative [**1:** A.5.1.10(5)(b)]
    (c) Preparation of a schedule that reconciles the discrepancies [**1:** A.5.1.10(5)(c)]

A.5.1.11 Private fire inspection services can be used to meet this provision provided that they are qualified to assess the impact of changes on the performance-based design and assumptions. [**1:** A.5.1.11]

A.5.2.2 The performance criteria in 5.2.2 define an acceptable level of performance that should be agreed upon by the stakeholders, including the owner and the AHJ. The acceptable level of performance can vary widely between different facilities based on a number of factors, including the existence of potential ignition sources, potential fuel loads present, reactivity and quantity of hazardous materials present, the nature of the operations conducted at the facility, and the characteristics and number of personnel likely to be present at the facility. [**1:** A.5.2.2]

A.5.2.2.1 Many of the performance criteria related to safety from fire can also be found in the annex of NFPA *101*. [**1:** A.5.2.2.1]

A.5.2.2.2 It is anticipated that the design provides protection for occupants who are not intimate with the initial unintentional detonation or deflagration of explosive materials, and individuals immediately adjacent to the property. It is recognized that employees should be trained and knowledgeable in the hazards of the materials present in the workplace. It is recognized that some of these individuals could experience psychological and physical injuries, such as hearing problems, on either a short- or long-term basis. However, the intent is that they do not experience thermal burns or loss of life or limb as a direct result of the explosion. [**1:** A.5.2.2.2]

It is not the intent of the code to provide protection against explosions caused by acts of terrorism. This would involve the introduction of an unknown quantity of explosives in an unknown location within or adjacent to a building. Where protection is needed against such acts of terrorism, the appropriate military and law enforcement agencies should be consulted. [**1:** A.5.2.2.2]

A.5.2.2.3 Given the nature and variety of hazardous materials, more than one performance criterion for a specific facility could need to be developed. Criteria have to be developed for each hazardous material and possibly for different personnel; for example, higher levels of exposure can be tolerated by personnel that are in some way protected than those personnel having no protection. Development of performance criteria for hazardous materials should be developed by the facility owner and the facility's safety personnel in conjunction with the AHJ and the emergency response personnel expected to respond to an incident. [**1:** A.5.2.2.3]

It is anticipated that the design provides protection for occupants inside or immediately adjacent to the facility who are not intimate with the initial unauthorized release of hazardous materials, or the initial unintentional reaction of hazardous materials. However, it is assumed that these individuals depart from the area of the incident in a time frame reasonable for their circumstances, based on their observation of the event, or some other form of notification. [**1:** A.5.2.2.3]

It is also anticipated that employees and emergency response personnel are trained and aware of the hazardous materials present in the facility, and the potential consequences of their involvement in the incident, and take appropriate measures to ensure their own safety during search and rescue operations. [**1:** A.5.2.2.3]

It is not the intent of the code to provide protection against acts of terrorism involving the introduction of hazardous materials into a facility. This involves the introduction of an unknown quantity of materials in an unknown location within or adjacent to a building. Where protection is needed against such acts of terrorism, the appropriate military and law enforcement agencies should be consulted. [**1:** A.5.2.2.3]

A.5.2.2.4 Each facility designed using a performance-based approach most likely has different levels of acceptable and unacceptable property damage. This reflects the unique aspects of the performance-based designed facility and the reasons for pursuing a performance-based design. Therefore, the definition of an acceptable and an unacceptable level of property damage results from discussions between the facility's owner, manager and engineer, the designer, (possibly) the insurance underwriter and field engineer, and the AHJ. There could be cases where a property damage criterion is not needed. [**1:** A.5.2.2.4]

Note that the structural integrity performance criteria for property damage most likely differs from the structural integrity performance criteria for life safety. This reflects the difference in the associated objectives: a life safety criterion probably is more restrictive than one for property damage. [**1:** A.5.2.2.4]

A.5.2.2.5 Each facility designed using a performance-based approach most likely has a different level of acceptable and unacceptable interruption of the facility's mission. This reflects the unique aspects of the performance-based designed facility and the reasons for pursuing a performance-based design. Therefore, the definition of an acceptable and an unacceptable interruption of the facility's mission results from discussions between the facility's owner, manager and engineer, the designer, (possibly) the insurance underwriter and field engineer, and the AHJ. There could be cases where a mission continuity criterion is not needed. [**1:** A.5.2.2.5]

A.5.4 Many events can occur during the life of a facility; some have a higher probability of occurrence than others. Some events, though not typical, could have a devastating effect on the facility. A reasonable design should be able to achieve the goals, objectives, and performance criteria of this Code for any typical or common design scenario and for some of the non-typical, potentially devastating scenarios, up to some level commensurate with society's expectations as reflected in this Code. [**1:** A.5.4]

The challenge in selecting design scenarios is finding a manageable number that are sufficiently diverse and representative so that, if the design is reasonably safe for those scenarios, it should then be reasonably safe for all scenarios, except for those specifically excluded as being unrealistically severe or sufficiently infrequent to be fair tests of the design. [**1:** A.5.4]

A.5.4.1.2 The *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* identifies methods for evaluating fire scenarios. [**1:** A.5.4.1.2]

A.5.4.1.3 It is desirable to consider a wide variety of different design scenarios to evaluate the complete capabilities of the building or structure. Design scenarios should not be limited to a single or a couple of worst-case events. [**1:** A.5.4.1.3]

A.5.4.2 Building construction including requirements for life safety affecting the egress system should be in accordance with the adopted building code. In the absence of requirements established by the adopted building code, considerations regarding design scenarios affecting matters of construction and/or egress related to fire can include the following:

Fire Design Scenario 1. Fire Design Scenario 1 involves an occupancy-specific design scenario representative of a typical fire for the occupancy. [**1:**5.4.2.1]

This design scenario should explicitly account for the following: [**1:**5.4.2.1.1]

(1) Occupant activities [**1:**5.4.2.1.1(1)]
(2) Number and location [**1:**5.4.2.1.1(2)]
(3) Room size [**1:**5.4.2.1.1(3)]
(4) Furnishings and contents [**1:**5.4.2.1.1(4)]
(5) Fuel properties and ignition sources [**1:**5.4.2.1.1(5)]
(6) Ventilation conditions [**1:**5.4.2.1.1(6)]

The first item ignited and its location [should] be explicitly defined. [**1:**5.4.2.1.2]

An example of such a scenario for a health care occupancy involves a patient room with two occupied beds with a fire initially involving one bed and the room door open. This is a cursory example in that much of the explicitly required information indicated in A.5.4.2 can be determined from the information provided in the example. Note that it is usually necessary to consider more than one scenario to capture the features and conditions typical of an occupancy. [**1:** A.5.4.2.1]

Fire Design Scenario 2. Fire Design Scenario 2 involves an ultrafast-developing fire in the primary means of egress with interior doors open at the start of the fire. This design scenario [should] address the concern regarding a reduction in the number of available means of egress. [**1:**5.4.2.2]

Examples of such scenarios are a fire involving ignition of gasoline as an accelerant in a means of egress, clothing racks in corridors, renovation materials, or other fuel configurations that can cause an ultrafast fire. The means of egress chosen is the doorway with the largest egress capacity among doorways normally used in the ordinary operation of the building. The baseline occupant characteristics for the property are assumed. At ignition, doors are assumed to be open throughout the building. [**1:** A.5.4.2.2]

Fire Design Scenario 3. Fire Design Scenario 3 involves a fire that starts in a normally unoccupied room that can potentially endanger a large number of occupants in a large room or other area. This design scenario [should] address the concern regarding a fire starting in a normally unoccupied room and migrating into the space that can, potentially, hold the greatest number of occupants in the building. [**1:**5.4.2.3]

An example of such a scenario is a fire in a storage room adjacent to the largest occupiable room in the building. The contents of the room of fire origin are specified to provide the largest fuel load and the most rapid growth in fire severity consistent with the normal use of the room. The adjacent occupiable room is assumed to be filled to capacity with occupants. Occupants are assumed to be somewhat impaired in whatever form is most consistent with the intended use of the building. At ignition, doors from both rooms are assumed to be open. Depending on the design, doorways connect the two rooms or they connect via a common hallway or corridor. [**1:** A.5.4.2.3]

For purposes of this scenario, an occupiable room is a room that could contain people (i.e., a location within a building where people are typically found). [**1:** A.5.4.2.3]

Fire Design Scenario 4. Fire Design Scenario 4 involves a fire that originates in a concealed wall or ceiling space adjacent to a large occupied room. This design scenario [should] address the concern regarding a fire originating in a concealed space that does not have either a detection system or suppression system and then spreading into the room within the building that can, potentially, hold the greatest number of occupants. [**1:**5.4.2.4]

An example of such a scenario is a fire originating in a concealed wall or ceiling space adjacent to a large, occupied function room. Ignition involves concealed combustibles, including wire or cable insulation and thermal or acoustical insulation. The adjacent function room is assumed to be occupied to capacity. The baseline occupant characteristics for the property are assumed. At ignition, doors are assumed to be open throughout the building. [**1:** A.5.4.2.4]

Fire Design Scenario 5. Fire Design Scenario 5 involves a slow-developing fire, shielded from fire protection systems, in close proximity to a high occupancy area. This design scenario [should] address the concern regarding a relatively small ignition source causing a significant fire. [**1:**5.4.2.5]

An example of such a scenario is a cigarette fire in a trash can. The trash can is close enough to room contents to ignite more substantial fuel sources but is not close enough to any occupant to create an intimate-with-ignition situation. If the intended use of the property involves the potential for some occupants to be incapable of movement at any time, then the room of origin is chosen as the type of room likely to have such occupants, filled to capacity with occupants in that condition. If the intended use of the property does not involve the potential for some occupants to be incapable of movement, then the room of origin is chosen to be an assembly or function area characteristic of the use of the property, and the trash can is placed so that it is shielded by furniture from suppression systems. At ignition, doors are assumed to be open throughout the building. [**1:** A.5.4.2.5]

Fire Design Scenario 6. Fire Design Scenario 6 involves the most severe fire resulting from the largest possible fuel load characteristic of the normal operation of the building. This design scenario [should] address the concern regarding a rapidly developing fire with occupants present. [**1:**5.4.2.6]

An example of such a scenario is a fire originating in the largest fuel load of combustibles possible in normal operation in a function or assembly room or in a process/manufacturing area, characteristic of the normal operation of the property. The configuration, type, and geometry of the combustibles are chosen so as to produce the most rapid and severe fire growth or smoke generation consistent with the normal operation of the property. The baseline occupant characteristics for the property are assumed. At ignition, doors are assumed to be closed throughout the building. [**1:** A.5.4.2.6]

This scenario includes everything from a big couch fire in a small dwelling to a rack storage fire in combustible liquids stock in a big box retail store. [**1:** A.5.4.2.6]

Fire Design Scenario 7. Fire Design Scenario 7 involves an outside exposure fire. This design scenario [should] address the concern regarding a fire starting at a location remote from the area of concern and either spreading into the area, blocking escape from the area, or developing untenable conditions within the area. [**1:**5.4.2.7]

An example of such a scenario is an exposure fire. The initiating fire is the closest and most severe fire possible consistent with the placement and type of adjacent properties and the placement of plants and combustible adornments on the property. The baseline occupant characteristics of the property are assumed. [**1:** A.5.4.2.7]

This category includes wildland/urban interface fires and exterior wood shingle problems, where applicable. [**1:** A.5.4.2.7]

Fire Design Scenario 8. Fire Design Scenario 8 involves a fire originating in ordinary combustibles in a room or area with each passive or active fire protection system or feature independently rendered ineffective. This set of design scenarios [should] address concerns regarding each fire protection system or fire protection feature, considered individually, being unreliable or becoming unavailable. This scenario shall not be required to be applied to fire protection systems or features for which both the level of reliability and the design performance in the absence of the system are acceptable to the AHJ. [**1:**5.4.2.8]

This scenario addresses a set of conditions with a typical fire originating in the building with any one passive or active fire protection system or feature being ineffective. Examples include unprotected openings between floors or between fire walls or fire barrier walls, rated fire doors that fail to close automatically or are blocked open, sprinkler system water supply that is shut off, fire alarm system that's nonoperative, smoke management system that is not operational, or automatic smoke dampers that are blocked open. This scenario should represent a reasonable challenge to the other building features provided by the design and presumed to be available. [**1:** A.5.4.2.8]

The exemption from Fire Design Scenario 8 is applied to each active or passive fire protection system individually and requires two different types of information to be developed by analysis and approved by the AHJ. System reliability is to be analyzed and accepted. Design performance in the absence of the system is also to be analyzed and accepted, but acceptable performance does not require fully meeting the stated goals and objectives. It might not be possible to meet fully the goals and objectives if a key system is unavailable, and yet no system is totally reliable. The AHJ determines which level of performance, possibly short of the stated goals and objectives, is acceptable, given the very low probability (that is, the system's unreliability probability) that the system will not be available. [**1:** A.5.4.2.8]

A.5.4.4 Design hazardous materials scenarios should explicitly account for the following: [**1:** A.5.4.4]

(1) Occupant activities, training, and knowledge [**1:** A.5.4.4(1)]
(2) Number and location of occupants [**1:** A.5.4.4(2)]
(3) Discharge location and surroundings [**1:** A.5.4.4(3)]
(4) Hazardous materials' properties [**1:** A.5.4.4(4)]
(5) Ventilation, inerting, and dilution systems and conditions [**1:** A.5.4.4(5)]
(6) Normal and emergency operating procedures [**1:** A.5.4.4(6)]
(7) Safe shutdown and other hazard mitigating systems and procedures [**1:** A.5.4.4(7)]
(8) Weather conditions affecting the hazard [**1:** A.5.4.4(8)]
(9) Potential exposure to off-site personnel [**1:** A.5.4.4(9)]

Design hazardous materials scenarios should be evaluated as many times as necessary by varying the factors previously indicated. Design hazardous materials scenarios could need to be established for each different type of hazardous material stored or used at the facility. [**1:** A.5.4.4]

A.5.4.4.4.2 This provision should be applied to each protection system individually and requires two different types of information to be developed by analysis and approved by the AHJ. System reliability is to be analyzed and accepted. Design performance in the absence of the system is also to be analyzed and accepted, but acceptable performance does not require fully meeting the stated goals and objectives. It might not be possible to meet fully the goals and objectives if a key system is unavailable, and yet no system is totally reliable. The AHJ determines which level of performance, possibly short of stated goals and objectives, is acceptable, given the very low probability (that is, the systems' unreliability probability) that the system will be unavailable. [**1:** A.5.4.4.4.2]

A.5.4.5.1 An example of such a scenario would involve a fire or earthquake effectively blocking the principal entrance/exit but not immediately endangering the occupants. The full occupant load of the assembly space has to exit using secondary means. [**1:** A.5.4.5.1]

A.5.6 The assessment of precision required in 5.7.2 requires a sensitivity and uncertainty analysis, which can be translated into safety factors. [**1:** A.5.6]

Sensitivity Analysis. The first run a model user makes should be labeled as the base case, using the nominal values of the various input parameters. However, the model user should not rely on a single run as the basis for any performance-based fire safety system design. Ideally, each variable or parameter that the model user made to develop the nominal input data should have multiple runs associated with it, as should combinations of key variables and parameters. Thus, a sensitivity analysis should be conducted that provides the model user with data that indicates how the effects of a real fire could vary and how the response of the proposed fire safety design could also vary. [**1:** A.5.6]

The interpretation of a model's predictions can be a difficult exercise if the model user does not have knowledge of fire dynamics or human behavior. [**1:** A.5.6]

Reasonableness Check. The model user should first try to determine whether the predictions actually make sense, that is, they don't upset intuition or preconceived expectations. Most likely, if the results don't pass this test, an input error has been committed. [**1:** A.5.6]

Sometimes the predictions appear to be reasonable but are, in fact, incorrect. For example, a model can predict higher temperatures farther from the fire than close to it. The values themselves could be reasonable, for example, they are not hotter than the fire, but they don't "flow" down the energy as expected. [**1:** A.5.6]

A margin of safety can be developed using the results of the sensitivity analysis in conjunction with the performance criteria to provide the possible range of time during which a condition is estimated to occur. [**1:** A.5.6]

Safety factors and margin of safety are two concepts used to quantify the amount of uncertainty in engineering analyses. Safety factors are used to provide a margin of safety and represent, or address, the gap in knowledge between the theoretically perfect model, that is, reality and the engineering models that can only partially represent reality. [**1:** A.5.6]

Safety factors can be applied to either the predicted level of a physical condition or to the time at which the condition is predicted to occur. Thus, a physical or a temporal safety factor, or both, can be applied to any predicted condition. A predicted condition (that is, a parameter's value) and the time at which it occurs are best represented as distributions. Ideally, a computer fire model predicts the expected or nominal value of the distribution. Safety factors are intended to represent the spread of these distributions. [**1:** A.5.6]

Given the uncertainty associated with data acquisition and reduction, and the limitations of computer modeling, any condition predicted by a computer model can be thought of as an expected or nominal value within a broader range. For example, an upper layer temperature of 1110°F (600°C) is predicted at a given time. If the modeled scenario is then tested (that is, full-scale experiment based on the computer model's input data), the actual temperature at that given time could be 1185°F or 1085°F (640°C or 585°C). Therefore, the temperature should be reported as 1110°F + 75°F, –25°F (600°C + 40°C, –15°C) or as a range of 1085°F to 1184°F (585°C to 640°C). [**1:** A.5.6]

Ideally, predictions are reported as a nominal value, a percentage, or an absolute value. As an example, an upper layer temperature prediction could be reported as 1112°F (600°C), 86°F (30°C) or 1112°F (600°C), 5 percent. In this case, the physical safety factor is 0.05 (that is, the amount by which the nominal value should be degraded and enhanced). Given the state-of-the-art of computer fire modeling, this is a very low safety factor. Physical safety factors tend to be on the order of tens of percent. A safety factor of 50 percent is not unheard of. [**1:** A.5.6]

Part of the problem in establishing safety factors is that it is tk;2difficult to state the percentage or range that is appropriate. These values can be obtained when the computer model predictions are compared to test data. However, using computer fire models in a design mode does not facilitate this since (1) the room being analyzed has not been built yet and (2) test scenarios do not necessarily depict the intended design. [**1:** A.5.6]

A sensitivity analysis should be performed based on the assumptions that affect the condition of interest. A base case that uses all nominal values for input parameters should be developed. The input parameters should be varied over reasonable ranges, and the variation in predicted output should be noted. This output variation can then become the basis for physical safety factors. [**1:** A.5.6]

The temporal safety factor addresses the issue of when a condition is predicted and is a function of the rate at which processes are expected to occur. If a condition is predicted to occur 2 minutes after the start of the fire, then this can be used as a nominal value. A process similar to that described for physical safety factors can also be employed to develop temporal safety factors. In this case, however, the rates (for example, of heat release and toxic product generation) will be varied instead of absolute values (for example, material properties). [**1:** A.5.6]

The margin of safety can be thought of as a reflection of societal values and can be imposed by the AHJ for that purpose. Since the time for which a condition is predicted is most likely the focus of the AHJ (for example, the model predicts occupants have 5 minutes to safely evacuate), the margin of safety is characterized by temporal aspects and tacitly applied to the physical margin of safety. [**1:** A.5.6]

Escaping the harmful effects of fire (or mitigating them) is, effectively, a race against time. When assessing fire safety system designs based on computer model predictions, the choice of an acceptable time is important. When an AHJ is faced with the predicted time of untenability, a decision needs to be made regarding whether sufficient time is available to ensure the safety of facility occupants. The AHJ is assessing the margin of safety. Is there sufficient time to get everyone out safely? If the AHJ feels that the predicted egress time is too close to the time of untenability, then the AHJ can impose an additional time that the designer has to incorporate into the system design. In other words, the AHJ can impose a greater margin of safety than that originally proposed by the designer. [**1:** A.5.6]

A.5.7.1 The *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* describes the documentation that should be provided for a performance-based design. [**1:** A.5.7.1]

Proper documentation of a performance design is critical to the design acceptance and construction. Proper documentation also ensures that all parties involved understand what is necessary for the design implementation, maintenance, and continuity of the fire protection design. If attention to details is maintained in the documentation, then there should be little dispute during approval, construction, start-up, and use. [**1:** A.5.7.1]

Poor documentation could result in rejection of an otherwise good design, poor implementation of the design, inadequate system maintenance and reliability, and an incomplete record for future changes or for testing the design forensically. [**1:** A.5.7.1]

A.5.7.2 The sources, methodologies, and data used in performance-based designs should be based on technical references that are widely accepted and used by the appropriate professions and professional groups. This acceptance is often based on documents that are developed, reviewed, and validated under one of the following processes: [**1:** A.5.7.2]

(1) Standards developed under an open consensus process conducted by recognized professional societies, codes or standards organizations, or governmental bodies [**1:** A.5.7.2(1)]
(2) Technical references that are subject to a peer review process and published in widely recognized peer-reviewed journals, conference reports, or other publications [**1:** A.5.7.2(2)]
(3) Resource publications such as the *SFPE Handbook of Fire Protection Engineering*, which are widely recognized technical sources of information [**1:** A.5.7.2(3)]

The following factors are helpful in determining the acceptability of the individual method or source: [**1:** A.5.7.2]

(1) Extent of general acceptance in the relevant professional community. Indications of this acceptance include peer-reviewed publication, widespread citation in the technical literature, and adoption by or within a consensus document. [**1:** A.5.7.2(1)]
(2) Extent of documentation of the method, including the analytical method itself, assumptions, scope, limitations, data sources, and data reduction methods. [**1:** A.5.7.2(2)]
(3) Extent of validation and analysis of uncertainties. This includes comparison of the overall method with experimental data to estimate error rates as well as analysis of the uncertainties of input data, uncertainties and limitations in the analytical method, and uncertainties in the associated performance criteria. [**1:** A.5.7.2(3)]
(4) Extent to which the method is based on sound scientific principles. [**1:** A.5.7.2(4)]
(5) Extent to which the proposed application is within the stated scope and limitations of the supporting information, including the range of applicability for which there is documented validation. Factors such as spatial dimensions, occupant characteristics, and ambient conditions can limit valid applications. [**1:** A.5.7.2(5)]

In many cases, a method is built from and includes numerous component analyses. These component analyses should be evaluated using the same factors that are applied to the overall method as outlined in items (1) through (5). [**1:** A.5.7.2]

A method to address a specific fire safety issue, within documented limitations or validation regimes, might not exist. In such a case, sources and calculation methods can be used outside of their limitations, provided that the design team recognizes the limitations and addresses the resulting implications. [**1:** A.5.7.2]

The technical references and methodologies to be used in a performance-based design should be closely evaluated by the design team and the AHJ, and possibly by a third-party reviewer. The strength of the technical justification should be judged using criteria in items (1) through (5). This justification can be strengthened by the presence of data obtained from fire testing. [**1:** A.5.7.2]

A.5.7.11 Documentation for modeling should conform to ASTM E1472, *Standard Guide for Documenting Computer Software for Fire Models*, although most, if not all, models were originally developed before this standard was promulgated. [**1:** A.5.7.11]

A.6.4.1.5.1 Occupancies including industrial and storage occupancies are defined by the building code adopted by the jurisdiction. *Occupancy* is a term used to define the activity or purpose of a building or space within a building where activity occurs. In general, occupancies are separated into various categories depending on the use. Some of the categories, depending on the adopted building code, can include but are not limited to the following: assembly, business, educational, factory (or industrial), hazardous, institutional, mercantile, residential, storage, etc. Construction features as well as engineering controls are influenced by the occupancy. The greater the hazard, the more restrictive the controls to be applied within the context of construction features and engineering controls integral to the use of the building. Limitations are placed on building heights, areas, construction types, and construction features, including building or area exits and the egress system in general, depending on the risk based on a predefined set of conditions imposed by the occupancy category. Industrial occupancies are typically involved with manufacturing of a product and involve factories and workshops used to manufacture or process a wide array of materials. A storage occupancy is one in which manufactured goods are stored. Activity in these areas is limited to the storage of goods or materials. The quantity of hazardous materials in occupancies other than those classified as hazardous is limited. When the need for quantity of various hazardous materials including hydrogen increases, the occupancy of the area can revert to that of a "hazardous occupancy," or the excess quantities might have to be isolated from the factory floor by either placing them into a room that is isolated by fire-resistive construction, or by transferring the materials outside of the building or to a separate building where they can be piped to a point of use.

A.6.7 Electrical and electronic equipment and wiring for use in hazardous locations as defined in Article 500 of *NFPA 70* 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. [**55:** A.6.7]

A.6.8 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 [can] 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 [can] also establish requirements for employee alarm systems. [**55:** A.6.8]

A.6.9 Annex K contains additional nonmandatory guidance relative to prevention and mitigation of hydrogen explosions.

A.6.9.3 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. [**55:** A.6.10]

A.6.12 See Annex L for guidance on hydrogen gas detectors.

A.6.12.2.1.1 Many manufacturers recommend at least quarterly testing or calibration, but more frequent testing during the initial operating period. The installation of the detector in extreme or harsh environments can also warrant more frequent testing.

A.6.13 *NFPA 70* and NFPA 497 should be used for guidance in determining the appropriateness of various lighting fixtures.

A.6.16 The termination point for piped vent systems serving cylinders, containers, tanks, and gas systems used for the purpose of operational or emergency venting [should] 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. [**55:**6.15]

A.6.17 The ventilation systems should be designed to ensure that fire hazards and risks are minimized. Designers should consider the use of the *ACGIH Industrial Ventilation Manual* in the design of local exhaust systems.

A.6.17.2.1.4.3 When LH_2 systems are employed, the density of the liquid when released should be considered. For a transient time period, the vapors might be heavier than air.

A.6.20 Figure A.6.20 shows three possible locations of the source valve. [**55:** A.6.19]

A.6.21.1.1(3) The replacement of parts in a system to repair leaks, the addition of gaskets, and similar routine maintenance is not intended to establish the need for cleaning of the entire piping system. Conversely, when a piping system is extended, or when the system needs to be rendered safe for maintenance purposes, purging the system [out of service] before disassembly will likely be required as will internal cleaning if new piping or materials of construction are introduced. [**55:** A.7.1.18.1.1(c)]

A.6.21.1.1(4) Cleaning and purging of [hydrogen] systems can be conducted as individual functions, i.e., just cleaning or just purging, or in combination as required to satisfy the requirements of the procedures. [**55:** A.7.1.18.1.1(d)]

A.6.21.1.3 It is not intended that a new written procedure be required each time the activity occurs within a facility. [**55:** A.7.1.18.1.3]. Guidance on considerations for the written procedure is outlined in Section 4.3 of NFPA 56.

A.6.21.1.3.1 The review of the written procedures should not be performed solely by the same person or persons responsible for developing the procedures. It can be performed by an independent person or group within the company or department or by a third-party consultant. [**55:** A.7.1.18.1.3.1]

A.6.21.1.4.2 *Replacement-in-kind* refers to a situation in which a piece of equipment is replaced with equipment of the same design and service. [**56:** A.4.6.2]

A.6.21.1.5.2 The notification is given to warn personnel that such procedures are about to occur so that they will be out of zones potentially affected by the cleaning or purging procedure. The intended notification is to be commensurate with the operation to be conducted and the timing of the notification should be relevant to the activity conducted so that personnel in the area can respond in a timely manner. Notification could consist of sounding of an audible and/or visible alarm, or it could consist of an announcement over a public address system, private network, radio, or similar and reliable means of electronic transmission.

Verbal notification can be used in operations where the piping system is limited to the area occupied by those that will be conducting the cleaning or purging procedures and related operating personnel. These areas are frequently found in occupancies where the gas used to charge the piping system is supplied from portable containers, as well as those areas where the piping system is primarily located in the occupied work area. [**55:** A.7.1.18.1.5.3]

A.7.1.2 The [GH_2] system equipment referenced is intended to include fuel cell [power system] 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. [**55:** A.10.2.8]

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 hydride 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 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. [**55:** A.10.2.9]

A.7.1.4.1.4 The original equipment manufacturer, for the purpose of this paragraph, should be considered to include a duly authorized and trained representative of the original equipment manufacturer.

A.7.1.7.2 The goal of this requirement is to prevent unauthorized personnel or those unfamiliar with gas storage systems from tampering with the equipment as well as to prevent the inadvertent or unauthorized removal or use of compressed gases from storage areas. Where the compressed gases are located in an area open to the general public, a common practice is to fence and lock the storage or use area, with access restricted to supplier and use personnel. When the storage or use area is located within the user's secure area and is not accessible by the general public, it is not always necessary to fence or otherwise secure the individual gas storage or use areas. Personnel access patterns may still mandate that the system be fenced, as determined by the supplier and the user. [**55:** A.7.1.8.2]

A.7.1.8.1 Storage tubes including ground-mounted tubes and mobile equipment are typically not provided with caps or collars. The condition is normally encountered for bulk systems where the containers used are not conventionally provided with caps or collars as the valves are connected to piping systems or manifolds for the purpose of distributing the gas. The term *similar devices* should not be limited to devices that attach to the container. The intent is to include protection for valves on cylinders, containers, and tanks that are not otherwise equipped against physical damage by barriers, security fencing, spatial arrangement, or other means.

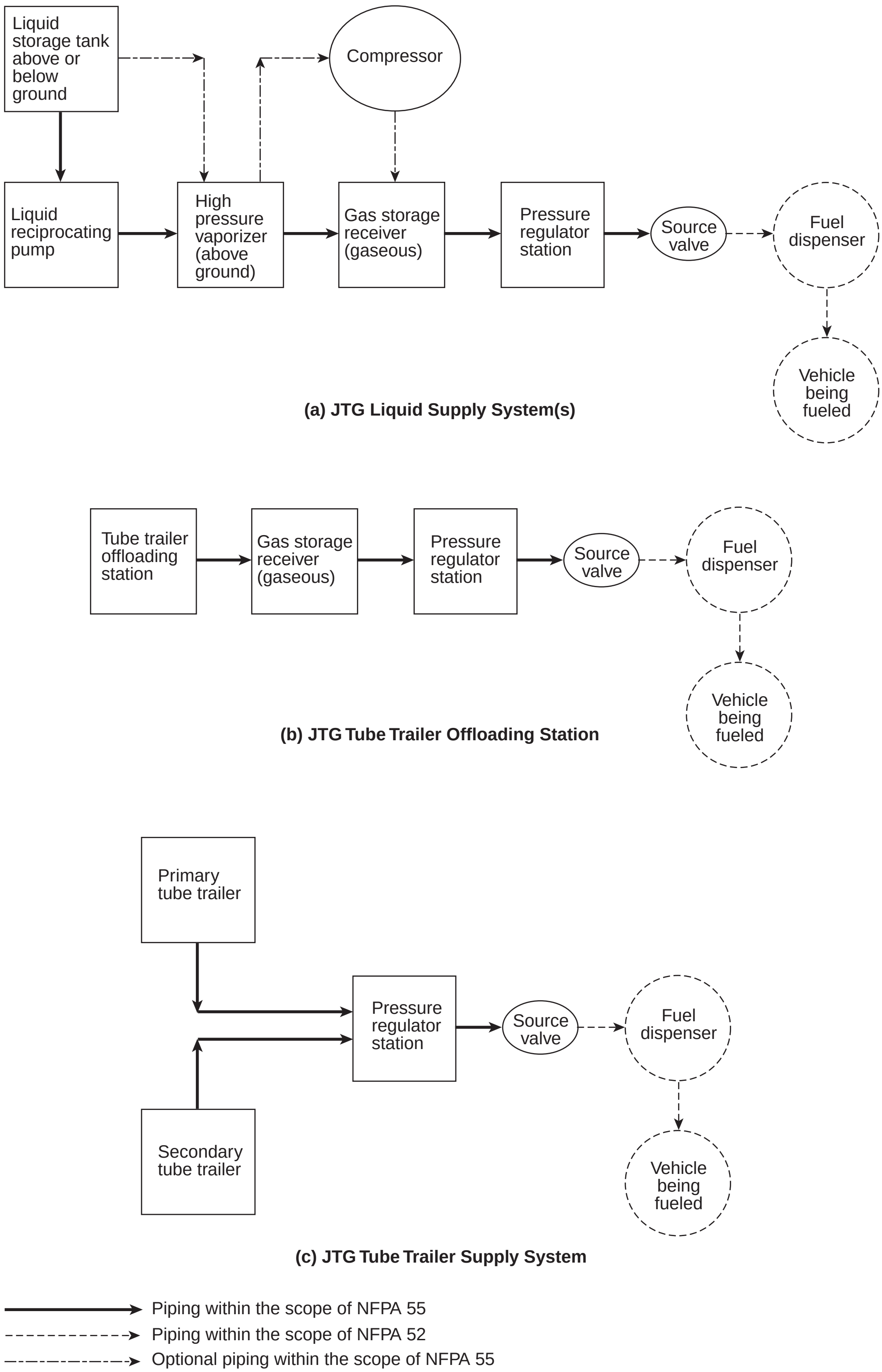


FIGURE A.6.20 Three Examples of Source Valve Locations. [55: A.6.19]

A.7.1.9.1.1 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 does not ordinarily present a hazard and should be allowed. On the other hand, tall dried grass or weeds and vegetation that fringes on the border of an urban-wildland interface might be viewed as a hazard. [**55:** A.7.1.10.3]

A.7.1.9.1.8.1 Electrical devices can include pressure transducers, signal transmitters, shutoff controls, and similar devices. Some of these devices may be nonincendive and suitable for use in hazardous areas. Flammability of gases is not the only concern with respect to electrical circuits, because piping serving systems in use can act as conductors of electrical energy, exposing unrelated portions of the system to electrical hazards if improperly installed. [**55:** A.7.1.10.10.1]

A.7.1.13.1 Compressed gas systems in hydrogen service are subject to leakage; however, leakage has not been defined in quantitative terms. Leak rates for outboard leakage sufficient to support stable flames have been the source of recent study, "Limits for hydrogen leaks that can support stable flames," by Butler et al.[1] The mass flow rate of hydrogen at its quenching limit has been reported to be 3.9 μg/s (0.05 scc/s). Butler, et. al, report that the minimum flow rate necessary for sustaining a hydrogen flame on a leaky 6.3 mm tube compression fitting is 28 μg/s (0.3 scc/s). Leaks below a level sufficient to sustain a hydrogen flame for systems in the open will diffuse into the atmosphere without consequence. In unventilated spaces, bubble leaks as low as 0.1 scc/s (8.6 L/day) can warrant repair depending on the natural or mechanical ventilation available to the space in which the containers are found.

A.7.1.13.3 The gas supplier should be consulted for advice under these circumstances. [**55:** A.7.1.14.3]

A.7.1.15.1 Any reference to listed or approved equipment in the noted sections of the IFGC is within the context of the ANSI/ASME B31.3, *Process Piping*, standard and describes a material or component that conforms to the specifications integral to ANSI/ASME B31.3. [**55:** A.10.2.2]

A.7.1.15.3.1.3 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. [**55:** A.7.1.17.1.2]

A.7.1.23.6 Compliance with 7.1.23.6 is not required for enclosures where operation or maintenance-related work is performed from the exterior of the enclosure.

A.7.1.23.9.2 Consideration should be given to locating automatic emergency shutoff valves prior to where the pipe enters the HEE or compartment, or on each GH_2 storage tank directly after, or connected to, the primary tank manual shutoff valve.

A.7.1.24.1.1 In operations where an automatic emergency shutoff valve is activated by a control system that is operated from a remote station or by remote station software, the software system should be designed to provide a visual indication of the emergency shutdown control system. The visual emergency shutdown function should be able to be identified by trained operators and recognizable to emergency response personnel. [**55:** A.7.3.1.11.1.1]

A.7.2.1.1 Figure A.7.2.1.1 is a schematic showing the separation distances required by 7.2.1.1. [**55:** A.7.1.11.2]

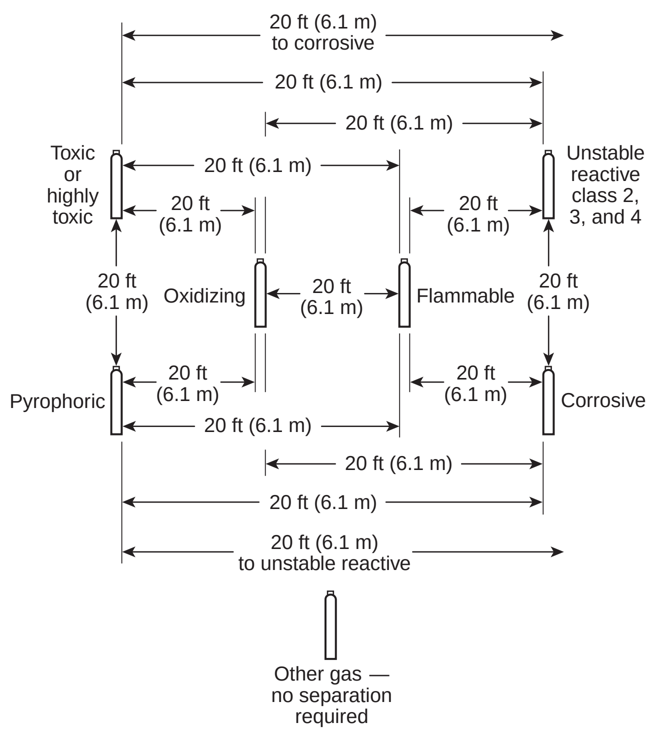


FIGURE A.7.2.1.1 Separation of Gas Cylinders by Hazard. [55:A.7.1.11.2]

A.7.2.2.3.2.1(A) 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 [protective structure]. The [protective structure] serves to protect those portions of the system that are the most vulnerable along with the necessary controls used to operate the system. [**55:** A.7.5.2.1.1]

A.7.3.2.1.2 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. [**55:** A.10.4.5.1.2]

A.7.3.2.2.2.3 For guidance in these construction techniques, see NFPA 68. [**55:** A.10.4.5.2.3]

A.7.3.2.2.3.5 Alternatively, Article 505 details requirements for this equipment and wiring in hazardous locations and uses a zone classification method rather than the division method of Article 500. Class 1, Division 2 locations are equivalent to the Class 1, Zone 2 locations of Article 505.

A.7.3.2.3.1.1 Conversions for distance between inch-pound and SI units of measure cannot be consistently performed using typical mathematical conversion factors. The majority of separation distances shown in the SI table have been determined by the application of a risk-informed approach substantiated by statistical evaluation and modeling based on validated models for both ignited and unignited release of hydrogen gas. Where distance has been determined to allow for access or for correlation with the electrical code, the distances were not established through the use of models. Tabular distances in the inch-pound table have been determined by first converting SI units into inch-pound units and then rounding the distance to the nearest 5 ft for ease of application by code enforcers and users. A similar rounding technique has not been applied in the tabular distances shown in the SI table.

The exposures integral to Table 7.3.2.3.1.1(a), Exposure Group 1(a) Table 7.3.2.3.1.1(b), and Table 7.3.2.3.1.1(c) have been arranged into groups based on similar risks. The thresholds are applicable to the exposures identified in each group, as follows: [**55:** A.10.4.2.2.1]

(1) *Group 1 Exposures.* The distances specified are those required to reduce the radiant heat flux level to 500 Btu/hr / ft^2 (1577 W/m^2) at the property line or the distance to a point in the unignited hydrogen jet where the hydrogen content is reduced to a 4 percent mole fraction (volume fraction) of hydrogen, whichever is greater. In all cases the distance required to achieve a 4 percent mole fraction was the greater distance and used to establish the requirements. [**55:** A.10.4.2.2.1]

(2) *Group 2 Exposures.* The distances specified are those required to reduce the radiant heat flux level to 1500 Btu/hr / ft^2 (4732 W/m^2) for persons exposed a maximum of 3 minutes. [**55:** A.10.4.2.2.1]

(3) *Group 3 Exposures.* The distances specified are those required to reduce the radiant heat flux level to 6340 Btu/hr / ft^2 (20,000 W/m^2) or the visible flame length for combustible materials, or a radiant heat flux level of 8000 Btu/hr / ft^2 (25,237 W/m^2) or the visible flame length for noncombustible equipment. In both cases the visible flame length was used to establish the requirements. [**55:** A.10.4.2.2.1]

Table 7.3.2.3.1.1(a) Exposure Group 1(a). Lot lines (property lines) are those property lines between parcels and should not be construed to be the imaginary property lines that are drawn for the purposes of protecting the exterior walls of multiple buildings placed on the same lot or parcel. Railroad easements that are not accessible to the public other than by rail travel can be used as a means of spatial separation, with the required separation being measured between the hydrogen system and the nearest railroad track. It should be noted that in these cases, the addition or relocation of track may result in an encroachment that will necessitate relocation of the hydrogen system at the system user's expense. [**55:** A.10.4.2.2.1]

Where the property on the other side of a property line is determined to be unbuildable or unoccupiable due to natural features including, but not limited to, waterways, terrain, wetlands, or similar features encroachment by the hydrogen system on the property line can be acceptable with the approval of the authority having jurisdiction. Should the property that is encroached upon become buildable or otherwise occupiable, the hydrogen system location should be reevaluated by the system user and the AHJ notified of the results. [**55:** A.10.4.2.2.1]

Table 7.3.2.3.1.1(a) Exposure Group 2(a). The exposed persons of concern are non-work-related persons or members of the public who are not involved with servicing the system, because these persons typically are neither trained nor knowledgeable in the operation of the system, but are on the premises. By comparison, service personnel or those involved with servicing the system are trained and engaged in activities related to the system operation including, but not limited to, inspecting, monitoring system inventory, delivering product, maintenance, or similar functions. Administrative controls, engineering controls, or construction features are typically used to restrict persons other than service personnel from being within the zone of potential exposure. The permit holder is responsible for managing and administering the controls to restrict access. Examples of such controls could include painted lines or signs or physical barriers such as a fence. [**55:** A.10.4.2.2.1]

A.7.3.2.3.1.1(1)(c) 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 5000 scf (141.6 Nm^3) 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. [**55:** A.10.4.2.2.2.1]

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 5000 scf (141.6 Nm^3) 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 where 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 5000 scf (141.6 Nm^3). 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 piping and instrumentation drawings (P&IDs) shown in Figure A.3.3.227.2(a) through Figure A.3.3.227.2(f) for additional information in this regard. [**55:** A.10.4.2.2.2.1]

The use of Table 7.3.2.3.1.1(c) 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. [**55:** A.10.4.2.2.2.1]

A.7.3.2.3.1.1(1)(d) 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^3) 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^3) of intervening storage at a pressure of 6000 psi (41,369 kPa) or less is considered a 3000 psi (20,684 kPa) system. [**55:** A.10.4.2.2.3]

A.7.3.2.3.1.2 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 7.3.2.3.1.1(a) and Table 7.3.2.3.1.1(b). The lot lines specified in Table 7.3.2.3.1.1(a) are property lines used to separate one lot from another or to separate a property from a street or other public space. [**55:** A.10.4.2.2.4]

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. [**55:** A.10.4.2.2.4]

A.7.3.2.3.1.2(A) As stated by Sandia National Laboratories researchers Houf, Schefer, and Evans in "Evaluation of Barrier Walls 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. Additional analysis by Sandia (LaChance, Phillips, and Houf) in a paper titled "Risk Associated with the Use of Barriers in Hydrogen Refueling Stations" provided insights on 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 [**55:** A.10.4.2.2.4.1]

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 0.72 psi to 0.44 psi (5 kPa to 3 kPa) on the downstream side of the barrier. Although an overpressure can be expected due to latent ignition of a flammable cloud, the overpressure can be expected to be limited to a localized area. Special designs for overpressure in addition to the structural loads imposed by the building code have not been required. [**55:** A.10.4.2.2.4.1]

The function of the fire barrier wall is to protect the exposure from the system and the converse. The code assumes that other factors will enter into locating any material or structure in proximity to the bulk hydrogen compressed gas system. For example, if a property or lot line is involved opposite the hydrogen installation, the proximity of a building to be constructed on the lot line is regulated by the building code based on the type and occupancy of the structure to be constructed. [**55:** A.10.4.2.2.4.1]

A.7.3.2.3.1.2(B) To determine the acceptability of technologies, processes, products, facilities, materials, and uses attending the design, operation or use of such systems, the AHJ is authorized to require the owner or agent to provide, without charge to the jurisdiction, a technical opinion and report. The model fire prevention codes provide the authority for the AHJ to seek technical assistance from independent third parties with expertise in the matter to be reviewed at the submitter's expense. The AHJ is authorized to require design submittals to be prepared by, and bear the stamp of, a registered design professional or professional engineer. [**55:** A.10.4.2.2.4.2]

Active means of control could include a means to detect leakage or fire coupled with automatic system shutdown, such as gas or flame detection. The use of gas or flame detection should consider, but is not limited to, the following: [**55:** A.10.4.2.2.4.2]

(1) *Gas Detection.* To utilize gas detection as a means of control, the gas sensor would be placed at a point between the bulk hydrogen compressed gas system and the exposure. Gas detection systems may be limited in their ability to detect the presence of hydrogen in the open. They are most effective if the sensor is located within an enclosed space such as an equipment enclosure. If used, gas detection systems should be either listed or approved. [**55:** A.10.4.2.2.4.2(1)]
(2) *Flame Detection.* Flame detection systems may include combination UV/IR detection systems and be installed in accordance with the requirements of *NFPA 72*. [**55:** A.10.4.2.2.4.2(2)]

Ultraviolet flame detectors typically use a vacuum photodiode Geiger–Muller tube to detect the ultraviolet radiation that is produced by a flame. The photodiode allows a burst of current to flow for each ultraviolet photon that hits the active area of the tube. When the number of current bursts per unit time reaches a predetermined level, the detector initiates an alarm. [**72:** A.17.8.2]

A single wavelength infrared flame detector uses one of several different photocell types to detect the infrared emissions in a single wavelength band that are produced by a flame. These detectors generally include provisions to minimize alarms from commonly occurring infrared sources such as incandescent lighting or sunlight. An ultraviolet/infrared (UV/IR) flame detector senses ultraviolet radiation with a vacuum photodiode tube and a selected wavelength of infrared radiation with a photocell and uses the combined signal to indicate a fire. These detectors need exposure to both types of radiation before an alarm signal can be initiated. A multiple wavelength infrared (IR/IR) flame detector senses radiation at two or more narrow bands of wavelengths in the infrared spectrum. These detectors electronically compare the emissions between the bands and initiate a signal where the relationship between the two bands indicates a fire. [**72:** A.17.8.2]

A.7.3.2.4.1.1 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.* [**55:** A.10.4.3.1.1.1]

A.7.3.2.4.3 Straight threads alone are not considered to be a seal. [**55:** A.10.4.3.1.4]

A.7.3.2.4.5.6 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. [**55:** A.10.4.3.1.6.6]

A.7.3.2.4.8 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. [**55:** A.10.4.3.1.9]

A.8.1.2 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 of the required regulations for the location in which the vessel is to be installed or used. [**55:** A.8.2]

A.8.1.3.1.5.2 Cold gas can expand to overpressurize a pipe in much the same way as liquid. Cold gas should be considered by designers for portions of the piping system operating at temperatures less than ambient.

A.8.1.4.5.1 Pressure relief valves typically are spring-loaded valves where the relief pressure is set by adjustment of a spring. Valves should be made to be tamper resistant in order 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 requirements of the ASME *Boiler and Pressure Vessel Code* and typically is equipped with a wire and lead seal to resist tampering. [**55:** A.8.2.4.5.1]

A.8.1.6.1.1.2 An example of this identification is 360 degree wraparound tape. [**55:** A.8.4.1.1.2]

A.8.1.7.2 The basis of this requirement is to prevent unauthorized personnel or those unfamiliar with gas storage systems from tampering with the equipment. Where LH_2 is located in an area open to the general public, a common practice is to fence and lock the storage or use area, with access restricted to supplier and user personnel. When the storage or use is located within the user's secure area and is not accessible by the general public, a common practice is to fence and lock the storage or use area, with access restricted to supplier and user personnel. When the storage or use is located within the user's secure area and is not accessible by the general public, it is not always necessary to fence or otherwise secure individual gas storage or use areas. Personnel access patterns may still mandate that the system be fenced, as determined by the supplier and the user. [**55:** A.11.4.1.4]

A.8.2.2.3.8 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 otherwise legally designated. [**55:** A.8.13.2.5]

A.8.2.2.3.9.4(B) 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. [**55:** A.8.13.2.6.4.1]

A.8.3.1.2.1.1 Refer to Figure A.8.3.1.2.1.1 for application of the 18 in. (46 cm) dimension to typical tank supports.

A.8.3.1.2.3 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. [**55:** A.11.2.3]

A.8.3.1.2.3.2 Piping and tubing used for liquid hydrogen and cold gas hydrogen (such as venting form a liquid hydrogen tank or a liquid hydrogen line) typically operates at temperatures below −20°F (−29°C). [**55:** A.11.2.3.2]

A.8.3.1.2.3.8 Like other cryogenic liquids, liquid hydrogen is susceptible to heat leak. Adding heat to the fluid liquid, reduces the net positive suction head (NPSH) to the pump and can reduce the level of sub-cooling or can cause the fluid to flash to vapor. Sub-cooled liquid is the ideal state for pumping liquid hydrogen. As the fluid saturates, the ability to pump decreases. The liquid suction and gas return piping to and from the pump typically is vacuum-jacketed piping. Vacuum-jacketed piping is most commonly used when liquid is to be transferred, because it avoids the potential condensation of air and oxygen enrichment that can occur in piping systems that are insulated with convention materials. In some cases the liquid may be transferred using uninsulated piping systems . Such systems must be designed in a way that condensed air does not present a contact hazard to personnel or otherwise create a potential flammability hazard due to material contact and the presence of oxygen contained in the condensate. [**55:** A.11.2.3.6]

A.8.3.1.2.5.1 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. [**55:** A.11.2.5.1]

A.8.3.1.2.5.2 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. [**55:** A.11.2.5.2]

A.8.3.1.2.8.5 Liquid hydrogen supply systems typically store the liquid, a cryogenic fluid, in storage tanks with maximum allowable working pressures (MAWP) that range from 150 psig to 250 psig. The majority of tanks are limited to 150 psig MAWP. Liquid hydrogen is piped from the tank to a vaporizer that serves as a heat exchanger and to convert the fluid from the liquid to the gaseous state in order to provide a supply of gaseous hydrogen to the user. The gaseous hydrogen supply pressure for such systems is limited to a maximum pressure below that of the storage tank MAWP. [**55:** A.11.2.8.5]

When gaseous or liquid hydrogen is required to be supplied at pressures higher than the storage tank MAWP, either

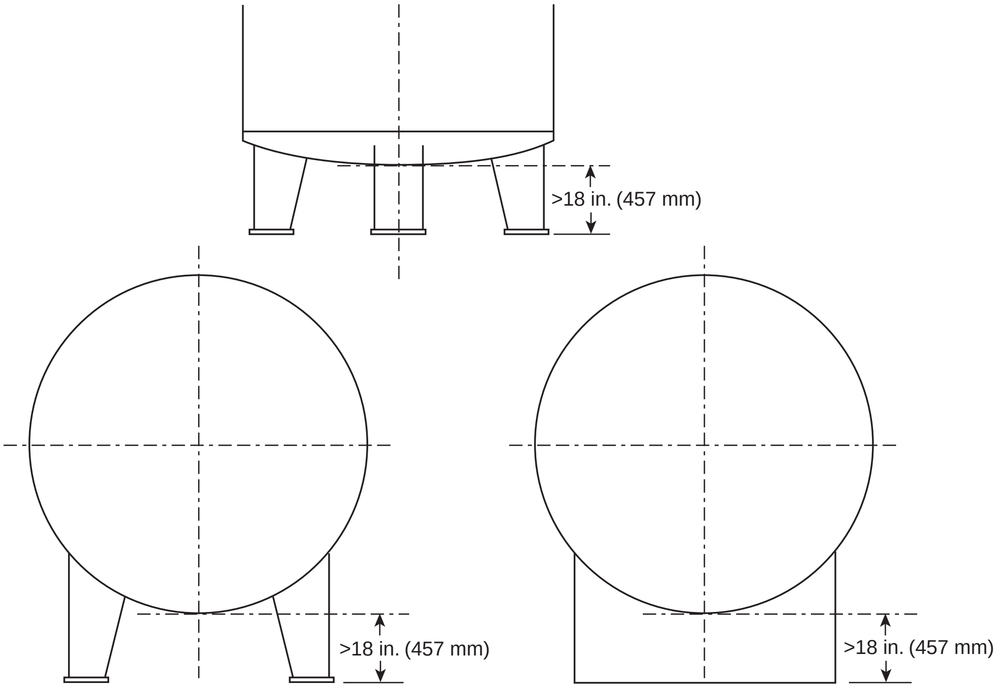


FIGURE A.8.3.1.2.1.1 Dimensions for Typical Tank Supports.

pumps or compressors are added to the system to raise the delivered pressure. Pumps are used for delivering hydrogen in the liquid state, while compressors deliver hydrogen in the gaseous state. Additional details on system arrangement and piping systems can be found in CGA H-5, *Installation Standards for Bulk Hydrogen Supply Systems*. [**55:** A.11.2.8.5]

A.8.3.2.1.2 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. [**55:** A.11.3.1.2]

A.8.3.2.1.4.4(C) Vaporizers or heat exchangers used to vaporize [LH_2] 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 of 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. [**55:** A.8.2.3.3.1]

A.8.3.2.2.2.3 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 have been 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. [**55:** A.11.4.4.3]

A.8.3.2.3.1.3 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. [**55:** A.8.13.2.5]

A.8.3.2.3.1.5(D) The placement of stationary containers is limited with respect to exposure hazards. Table 8.3.2.3.1.6(A) 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. [**55:** A.8.13.2.7.2]

Placement of stationary containers proximate to the wall of the building served is allowable, provided the minimum separation distances for exposure hazards are met. When additional wall encroach on the installation to form a court, the focus of concern shifts away from the exposure hazards associated with personnel due to hazardous atmospheres that can be created due to the lack of free air movement and ventilation. [**55:** A.8.13.2.7.2]

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. [**55:** A.8.13.2.7.2]

A.8.3.2.3.1.5(D)(1) The separation distances shown in Figure A.8.3.2.3.1.5(D)(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 cryogens. 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.8.3.2.3.1.5(D)(1) could be an exterior building wall, and the gas could be hydrogen. Refer to [-] Table 8.3.2.3.1.6(A) for specific details regarding building walls, wall openings, air intakes, and similar conditions. [**55:** A.8.13.2.7.2.1]

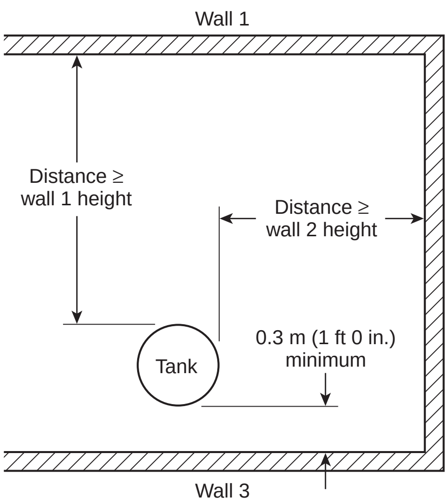


FIGURE A.8.3.2.3.1.5(D)(1) Bulk Cryogenic System Located in a Courtyard. [55:Figure A.8.13.2.7.2.1]

A.8.3.2.3.1.5(E)(1) The basis of this requirement is to prevent unauthorized personnel or those unfamiliar with gas storage systems from tampering with the equipment. Where LH_2 is located in an area open to the general public, a common practice is to fence and lock the storage or use area, with access restricted to supplier and user personnel. When the storage or use is located within the user's secure area and is not accessible by the general public, it is not always necessary to fence or otherwise secure individual gas storage or use areas. Personnel access patterns may still mandate that the system be fenced, as determined by the supplier and the user. [**55:** A.11.4.1.4]

A.8.3.2.3.1.6(A) Table 8.3.2.3.1.6(A) has been split into two tables, with one representing distances to exposure in inch-pound units of measure and the other representing distance to exposure in SI units of measure. At the present time, mathematical rounding of distances in a manner similar to that used in the formulation of Table 7.3.2.3.1.1(a) and Table 7.3.2.3.1.1(b) has not been applied, and the use of conventional conversion factors between the tables remains relevant with Table 8.3.2.3.1.6(A) accordingly.

The Occupational Safety and Health Administration (OSHA) established requirements for hydrogen systems reproduced in Figure A.8.3.2.3.1.6(A) from 29 CFR 1910.103. The tabular distances in Annex I reflect those values published in the July 1, 2006 edition of the CFR. The criteria established in Table I.2(a) and Table I.2(b) are based on the 1969 edition of NFPA 50A, 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. [**55:** A.11.3.2.2]

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. [**55:** A.11.3.2.2]

For an example of clarity, consider row 1, "Building or structure," of Table 8.3.2.3.1.6(A). 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 or the building code. [**55:** A.11.3.2.2]

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 found 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. [**55:** A.11.3.2.2]

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. [**55:** A.11.3.2.2]

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. [**55:** A.11.3.2.2]

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. [**55:** A.11.3.2.2]

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 the installers and the 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. [**55:** A.11.3.2.2]

A.8.3.2.3.1.6(A)(2) See NFPA 259. Separation distances to exposures in Figure A.8.3.2.3.1.6(A) 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 8.3.2.3.1.6(A) facilitates maintenance and enhances ventilation. [**55:** A.11.3.2.2.2]

Table 8.3.2.3.1.6(A) Item 1. Lot lines. Lot lines (property lines) are those property lines between parcels and should not be construed to be the imaginary property lines that are drawn for the purposes of protecting the exterior walls of multiple buildings placed on the same lot or parcel. Railroad easements that are not accessible to the public other than by rail travel can be used as a means of spatial separation with the required separation being measured between the hydrogen system and the nearest railroad track. It should be noted that in these cases, the addition or relocation of track may result in an encroachment that will necessitate relocation of the hydrogen system at the system user's expense. [**55:** A.11.3.2.2.2]

Where the property on the other side of a property line is determined to be unbuildable or unoccupiable due to natural features including, but not limited to, waterways, terrain, wetlands, or similar features encroachment by the hydrogen system on the property line can be acceptable with the approval of the authority having jurisdiction. Should the property that is encroached upon become buildable or otherwise occupiable, the hydrogen system location should be reevaluated by the system user and the AHJ notified of the results. [**55:** A.11.3.2.2.2]

A.8.3.2.3.1.6(A)(2)(b)i. See Figure A.8.3.2.3.1.5(D)(1), which addresses bulk cryogenic systems located in a courtyard. This figure also applies to the case where any or all of the three walls are constructed as fire barrier walls, provided the distances to walls constructed as fire barrier walls for exposure protection is not less than that required by Table 8.3.2.2.1.4. [**55:** A.11.3.2.2.4.1]

A.8.3.2.3.1.6(A)(2)(c) Figure A.8.3.2.3.1.6(A)(2)(c)(a) and Figure A.8.3.2.3.1.6(A)(2)(c)(b) illustrate 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. [**55:** A.11.3.2.2.4.]

A.8.3.2.3.1.7(D)(1) 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. [**55:** A.8.13.2.5]

A.8.3.2.3.1.7(J)(1) Users should notify suppliers where a tank is to be left in place but not refilled for an extended period of time. The supplier can inert the tank or otherwise prepare the tank for ultimate removal.

A.8.3.4.5.10 Liquid tanks, when buried underground, should meet the following provisions:

(1) Liquid hydrogen tanks and associated piping are installed with considerations for physical damage prevention, corrosion protection, and proper layout of piping runs.
(2) Manually operated valves, controls, PRDs, and instrumentation are located above ground, outdoors, and accessible to authorized personnel. Manually operated valves, controls, and instrumentation for filling and routine operations should be readily available to mobile supply equipment at ground level.
(3) Remotely operated emergency shutoff valves can be located below grade to allow for product isolation. These valves should be in a corrosion-resistant area that is accessible from ground level and does not create a confined space.

A.10.2.1.2 A hazard(s) analysis can be performed by a number of methods where the end result can be achieved through the use of more than one method. Several of the more common methods employed by those involved in systems safety today include, but are not limited to, hazard and operability studies (HAZOPs), failure modes effects and criticality analysis (FMECA), preliminary hazards analysis (PHA), fault tree analysis (FTA), and event tree analysis. Standard designs that have been analyzed by recognized methodology need not be studied each and every time such an installation occurs. Rather, site-specific elements that are unique to the installation should be reviewed in concert with the analysis performed on the standard system to ensure that the standard design has not been altered in a way that would negatively affect the hazard analysis.

The reviews conducted frequently involve a series of meetings between members of a multidisciplinary team that methodically "brainstorms" the system design, following a structure provided by study format and the team leader's experience. Members of the team can include engineers as well as other personnel skilled in the application of a systems safety approach.

A.10.3.1.1 Dispensers can be listed and certified to meet the requirements of ANSI/CSA HGV 4.1.

A.10.3.1.3 The amount of gas stored in a container can be estimated by using the information in Table A.4.4 of NFPA 52 referenced to 70°F (21°C). The gas quantity, in standard cubic feet, can be estimated by multiplying the container water capacity scf (m^3) by the stored volume scf/ft^3 (scm/m^3) factor at a given pressure. One scf of hydrogen gas weighs approximately 0.0052 lb (0.0024 kg). See Table A.10.3.1.3(a) and Table A.10.3.1.3(b).

A.10.3.1.4.2.3 The full flow capacity of the dispenser is intended to represent the maximum flow rate of gas possible. This determination could be made by identifying the smallest flow restriction in the dispenser, then assuring the flow capacity of the relief device exceeds that value.

A.10.3.1.7.3 The following are examples of materials and components that should not be used for gaseous GH_2 service:

(1) Grey, ductile, or cast iron
(2) Certain stainless steels
(3) Nickel and its alloys such as Inconel and Monel
(4) Nickel steels such as 2.25, 3.5, and 9 percent Ni

TABLE H-4 - MINIMUM DISTANCE (FEET) FROM LIQUEFIED HYDROGEN SYSTEMS TO EXPOSURE (1)(2)

Type of Exposure	Liquefied hydrogen storage (capacity in gallons)		
	39.63 (150 liters) to 3,500	3,501 to 15,000	15,001 to 30,000
1. Fire-resistive building and fire walls(3)	5	5	5
2. Noncombustible building(3)	25	50	75
3. Other buildings(3)	50	75	100
4. Wall openings, air-compressor intakes, inlets for air-conditioning or ventilating equipment	75	75	75
5. Flammable liquids (above ground and vent or fill openings if below ground) (see 513 and 514)	50	75	100
6. Between stationary liquefied hydrogen containers	5	5	5
7. Flammable gas storage	50	75	100
8. Liquid oxygen storage and other oxidizers (see 513 and 514)	100	100	100
9. Combustible solids	50	75	100
10. Open flames, smoking and welding	50	50	50
11. Concentrations of people	75	75	75

Footnote(1) The distance in Nos. 2, 3, 5, 7, 9, and 12 in Table H-4 may be reduced where protective structures, such as firewalls equal to height of top of the container, to safeguard the liquefied hydrogen storage system, are located between the liquefied hydrogen storage installation and the exposure.

Footnote(2) Where protective structures are provided, ventilation and confinement of product should be considered. The 5-foot distance in Nos. 1 and 6 facilitates maintenance and enhances ventilation.

Footnote(3) Refer to Standard Types of Building Construction, NFPA No. 220-1969 for definitions of various types of construction.

FIGURE A.8.3.2.3.1.6(A) OSHA Table H-4.

A.10.3.1.7.6.5 Mechanical joints can be disassembled and include flanged, threaded, or equivalent joints, including crimped connections. Welded joints do not need to be in an accessible location.

A.10.3.1.7.7 Vent locations should be designed such that if the safety valve is relieving at capacity and ignited, radiated heat felt by an individual who can be present at grade will not exceed 500 Btu/hr/ft^2 (5.68 MJ/hr/m^2). This does not apply to locations where access is restricted to personnel with appropriate protection.

A.10.3.1.10.1 Either the media used for leak testing should be compatible with all equipment according to the manufacturer's instructions or the equipment should be isolated during the test. It is not necessary to pressure test equipment that has already been pressure tested before installation. If a pressure test is required on a system or portion of a system that includes previously tested equipment, either the testing media should be compatible with the previously tested equipment according to the manufacturer's instructions or the equipment should be isolated during the test.

A.10.3.1.10.4 The removal of all oxygen implies the total absence of oxygen. Such removal is not feasible as oxygen is a contaminant even in the commercial hydrogen used as a fuel. Good practice standards advise users to assume that every system contains air before testing any system with hydrogen. The limiting oxygen concentration for oxygen in air (nitrogen as diluents of air) is 3.0 percent or the percentage of oxygen below which flammable mixtures with

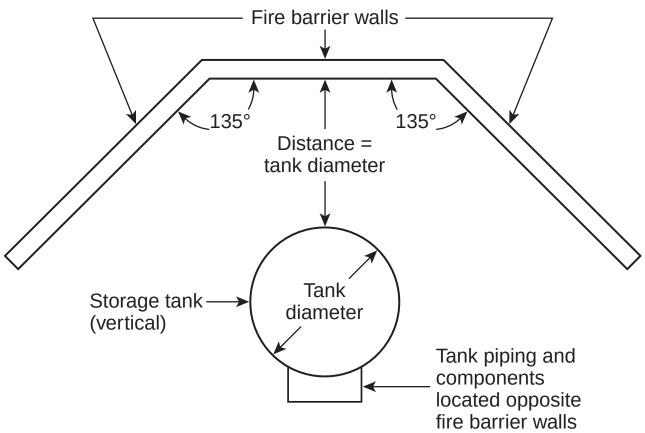


FIGURE A.8.3.2.3.1.6(A)(2)(c)(a) Schematic of Three-Sided Fire Barrier Wall Enclosure for a Vertical Hydrogen Storage System. [55: Figure A.11.3.2.2.4(a)]

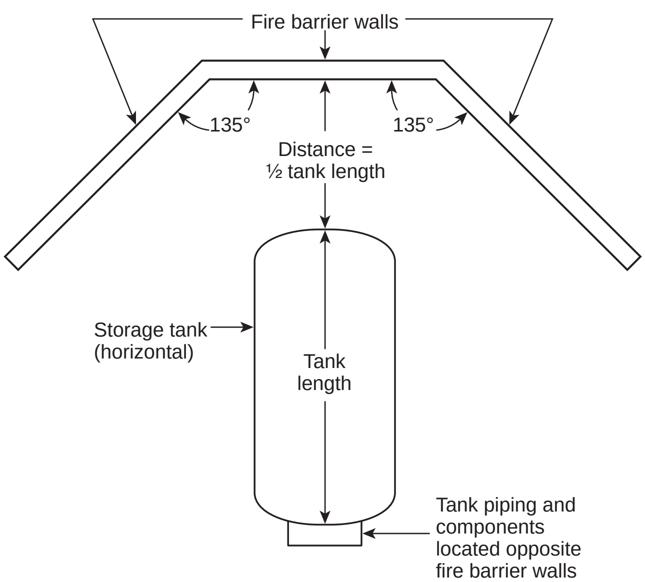


FIGURE A.8.3.2.3.1.6(A)(2)(c)(b) Schematic of Three-Sided Fire Barrier Wall Enclosure for a Horizontal Hydrogen Storage System. [55: Figure A.11.3.2.2.4(b)]

hydrogen does not exist. An oxygen concentration of not more than 1 percent reduces the oxygen concentration to an acceptable level, assuming that the system previously contained atmospheric air.

A.10.3.1.11.4 In addition to the initial integrity check at the beginning of the fueling event, additional integrity checks have been effective at finding leaks that develop during the fueling process. The 2011 edition of NFPA 2 required this integrity check at 3000 psi (20 MPa) increments. Specifying the pressures at which these tests occur will result in greater standardization and consistency of the fueling process. The leak tests should occur within 5 percent of the specified pressure values. For example, the 85 percent fill-point check can occur between 80 percent and 90 percent of the service pressure.

Table A.10.3.1.3(a) Gaseous Hydrogen, Pressure Range 0–6400 psi (0–44 MPa)

Gauge Pressure		
psi	MPa	Stored Volume Ratio
0	0	1
200	1.38	14
400	2.76	28
600	4.14	41
800	5.52	54
1000	6.89	66
1200	8.27	79
1400	9.65	91
1600	11.03	103
1800	12.41	115
2000	13.79	126
2200	15.17	138
2400	16.55	149
2600	17.93	160
2800	19.31	171
3000	20.68	182
3200	22.06	192
3400	23.44	203
3600	24.82	213
3800	26.20	223
4000	27.58	233
4200	28.96	243
4400	30.34	252
4600	31.72	262
4800	33.09	271
5000	34.47	280
5200	35.85	289
5400	37.23	298
5600	38.61	307
5800	39.99	315
6000	41.37	324
6200	42.75	332
6400	44.13	340

A.10.3.1.11.6 As a precaution to keep pressure relief devices in reliable operating condition and to avoid damage, care should be taken in the handling or storage of GH_2 containers.

Care also should be exercised to avoid plugging by paint or other dirt accumulation in pressure relief device channels or other parts that could interfere with the functioning of the device.

A.10.3.1.13.16 The limit of 0.1323 lb (60 g) per second was not intended to include short, transient excursions that occur prior to the start of filling due to opening and closing of valves.

A.10.3.1.16.1 See API RP 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents*.

A.10.3.1.18 The purpose of the extinguisher is not to extinguish a gas fire but other fires in the area. Gas fires should be extinguished by shutting off the source of the gas.

A.10.3.2.3.1.3 Motor vehicles can acquire an electrostatic charge while traveling. The resistance offered by the tires through an uncoated concrete surface is low enough that this charge dissipates to ground very quickly (seconds or less). However, under dry conditions, an asphalt surface can offer

Table A.10.3.1.3(b) Gaseous Hydrogen, Pressure Range 0–14,504 psi (0–100 MPa)

Gauge Pressure		
psi	MPa	Stored Volume Ratio
0	0	1
725	5	49
1,450	10	94
2,176	15	136
2,901	20	176
3,626	25	214
4,351	30	249
5,076	35	283
5,802	40	314
6,527	45	344
7,252	50	372
7,977	55	399
8,702	60	425
9,427	65	449
10,153	70	472
10,878	75	495
11,603	80	516
12,328	85	536
13,053	90	556
13,779	95	575
14,504	100	593

sufficient resistance that the charge will not dissipate in a timely manner. A small number of incidents have occurred in Europe where a nonabsorbent polymer having unusually high resistance was used at service stations to prevent soil contamination from gasoline spills. Therefore, paved surfaces that result in a resistance greater than 1 megohm should not be used. Transfer surface materials meeting the criteria specified will provide for the dissipation of static charge built up on the vehicle before the driver opens the door to initiate refueling. The 1 megohm criterion is cited from the API RP 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents*. Measurement of the resistivity of the vehicle fueling pad can be conducted using BS EN 1081: *Determination of Electrical Resistance — Resilient Floor Coverings*.

A.10.3.3.2.3 A generic dispenser piping and instrumentation diagram with NFPA 2 references is provided to help the user to apply the requirements. See Figure A.10.3.3.2.3.

A.10.4.2.1 NFPA 55 provides regulation for bulk GH_2 storage systems to be located within buildings. Section 10.4 of NFPA 55 provides requirements for detached buildings in 10.4.4 and for hydrogen gas rooms in 10.4.5. Requirements for ventilation, electrical classification, explosion control, and so forth, are provided. The requirements for dispensing and generation systems involving construction features and engineering controls do not supersede requirements for the storage system.

A.11.2.11.1 Although pressure gauges can be used to determine system pressure, pressure transducers are commonly used to monitor pressure and are typically designed to withstand and indicate 20 percent or greater than the maximum system pressure.

A.11.2.11.2 A pressure relief device must be installed on all sections of piping where liquid or cold gas can be trapped between valves.

A.11.3.1.3.3 The temperature of LH_2 is extremely cold. When liquid is transferred, portions of the system are cooled. After transfer occurs and the system warms, the liquid can change to a gaseous state. All portions of the system that are used to transport liquid can also contain cold gas. The trapping of cold gaseous hydrogen represents the same level of concern as that of the liquid when expansion occurs due to warming. Pressure relief devices are used as a means to prevent the rupture of the piping system due to expansion as warming of the system occurs.

A.11.3.1.5.4 The removal of all oxygen implies the total absence of oxygen. Such removal is not feasible as oxygen is a contaminant even in the commercial hydrogen used as a fuel. Good practice standards advise users to assume that every system contains air before testing any system with hydrogen. The limiting oxygen concentration for oxygen in air (nitrogen as diluents of air) is 3.0 percent or the percentage of oxygen below which flammable mixtures with hydrogen does not exist. An oxygen concentration of not more than 1 percent reduces the oxygen concentration to an acceptable level, assuming that the system previously contained atmospheric air.

A.11.3.3.4.6 Additional fire protection considerations can include items such as fixed suppression systems, automatic fire detection, manual fire alarm stations, transmission of alarms to off-site locations, and limiting volume delivered per transaction. [**30A:** A.7.3.5.1]

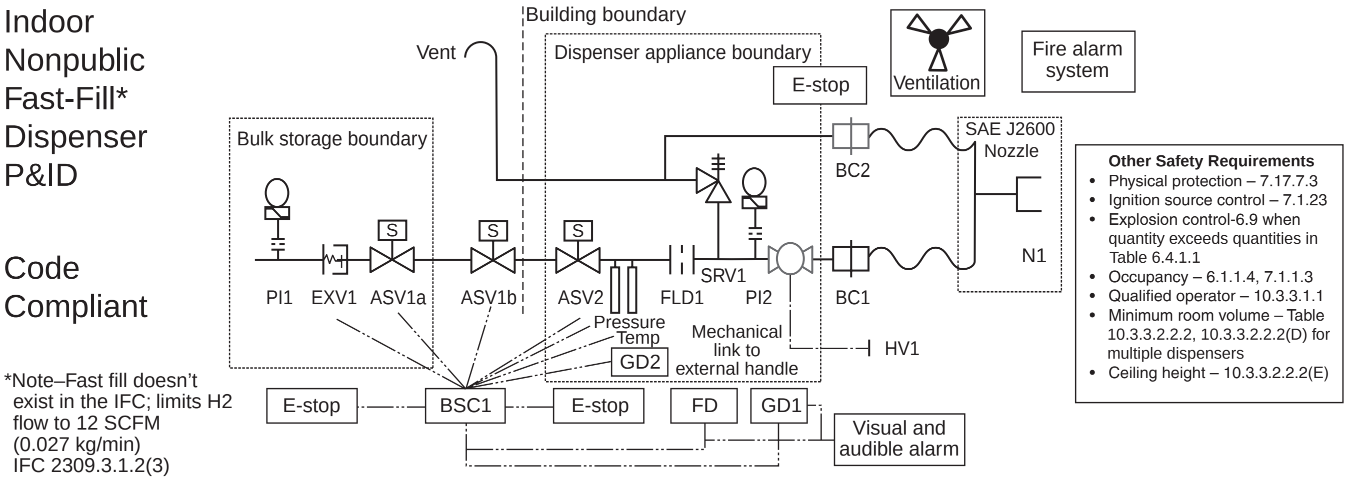
A.11.3.3.4.7 Refer to Articles 510 and 511 with respect to electrical wiring and equipment for other areas as lubritoriums, service rooms, repair rooms, offices, salesrooms, compressor rooms, and similar locations. [**70:**514.2 (Informational Note)]

A.12.2 Fuel cell technology is evolving at a rapid rate, and codes and standards criteria are needed to help acceptance of the new technology. Currently, there is only one standard for testing stationary fuel cell power systems, which is ANSI CSA FC.1, *American National Standard for Fuel Cell Power Systems*. ANSI CSA FC.1 applies to a specific size fuel cell power system that is prepackaged and assembled as one complete unit. The constraints of ANSI CSA FC.1 limit the ability to test and list larger power plants or power systems that use fuels other than natural gas or LP-Gas or that are not prepackaged and self-contained.

NFPA 853 provides additional guidance for acceptance of power system installations that are not within the scope of ANSI CSA FC.1, commensurate with the need to protect life safety and property and the need of the adoption agencies to be able to uniformly evaluate power system installations outside the scope of available equipment standards. [**853:** A.4.1]

A.12.2.1 The equipment referenced is intended to include fuel cell [power system] 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.12.3.2.1.1 ANSI/CSA FC 3, *American National Standard / CSA American Standard for Portable Fuel Cell Power Systems,* applies to ac- and dc-type portable fuel cell power systems, with a rated output voltage not exceeding 600 volts, for commercial, industrial, and residential indoor and outdoor use in nonhazardous locations, in accordance with *NFPA 70*. ANSI CSA FC3 does not apply to



P&ID Tag	Description	Code/Standard Reference
ASV1a	Auto shutoff (solenoid) valve (Source Valve)	6.20 – Source Valve 7.1.21 – Accessible manual or automatic emergency shutoff valve (HGV 4.4/HGV 4.6 Component Standards)
ASV1b	Auto shutoff (solenoid) valve (building isolation)	7.1.21.2...at the point where the system piping enters the building 10.3.1.18.4 – building isolation valve required
ASV2	Auto shutoff (solenoid) valve	7.1.21.2...at the point of use 10.3.3.2.2.7(A) – Automatic shutoff valve
EXV1	Excess Flow Device	7.1.22 Excess flow control – leak detection and emergency shutoff or excess flow control 10.3.1.18.3 – excess flow valve requirements
FD1	Flame detector	10.3.1.19.1 – gas, flame detected at any point on the equipment 10.3.3.2.2.4 – Fire detection system tied to local visual and audible alarm
GD1, GD2	Gas detector	10.3.1.19.1 – gas, flame detected at any point on the equipment 10.3.3.2.2.7(E) – GD2 added, inside of the dispenser housing (a Class 1 Div 1 area) with similar requirements to 10.3.1.19.1 and with additional requirements: activation shuts down dispenser, visual/audible alarm and functions during maintenance
BC1	Breakaway coupling (dispensing hose)	10.3.1.18.6 – breakaway coupling required – NGV 4.4 compliant, breaking force
FLD1	Flow limiting device	10.3.3.2.2.2(F) – max fueling rate 2 kg/min
Fire Alarm	Fire Alarm System	10.3.3.2.2.5 – dispensing area local fire alarm system, pull box between 20 and 100 ft of dispenser, at nearest exit from area, pull boxes shutdown dispenser
BSC1	Building Safety Circuit (Logic Controller)	10.3.1.11.6 – controller performs 5 sec pressure test prior to fueling 10.3.1.11.7 – repeat integrity check at 3000 psi 10.3.1.18.7 – control circuit requirement for manual reset after emergency stop activation 10.3.3.2.1.9 – manual restart after emergency activation 10.3.3.2.2.2(C) automatic shutoff control when max fuel quantity per event or vehicle fueled to capacity 10.3.3.2.2.2(G) – references 10.3.1.11.6 and 10.3.1.11.7 10.3.3.2.2.7(G) – overpressure and over temperature sensing capabilities (assume that this could be communication with vehicle)

P&ID Tag	Description	Code/Standard Reference
PI1/PI2	Dispense delivery pressure indicator (6 in. circular mechanical gauge; 0-10000 psig)	10.3.1.5.3 – indication of storage, dispenser discharge pressure 10.3.1.5.2 – 0.055 in. opening at inlet connection NOTE – a third pressure gauge at compressor discharge is also required (10.3.1.5.3)
SRV1	Safety (Overpressure) relief valve (6000 psig)	10.3.1.4.2.3 – overpressure device shall be installed; 10.3.1.4.2.4 – setting shall not exceed 140 percent of service pressure 10.3.1.10.5 – inspected every 3 years
N1	Nozzle	10.3.14.7 – transfer system capable of depressurization to facilitate disconnection 10.3.1.15.1 – SAE J2600 nozzle required
Vent	Vent Pipe and Vent Pipe Termination	6.16 – CGA5.5, 7.1.17,
Ventilation	Required ventilation for indoor fueling	10.3.3.2.2.2 – in accordance with 10.3.2.2.1.6 10.3.2.2.1.6 – required by clause (A) 10.3.2.2.1.6(D)(1) – continuous or activated by H2 detector
Estop x 3	Manual Emergency Stops	10.3.1.18.5 – local and remote located manual shutdown 10.3.3.2.2.6 – Emergency shutdown device similar to 10.3.1.18.5 with more specified location requirements 10.3.3.2.2.6(A) – 3rd manual shutdown device on the dispenser
H1	Flexible dispensing/vent hose	10.3.1.1 – listed or approved 10.3.1.8 – Hose connections (note – no reference to HGV 4.4.) 10.3.1.11.2 – Hose assemblies 10.3.3.2.2.2(H) – limited to 25 ft; Protected from abrasion or driven over by vehicle
BC2	Breakaway coupling (vent hose)	Not required
HV1	Hand Valve – "quarter turn" manual shut off	10.3.3.2.2.7(B) – not required when ASV2 is located immediately upstream and a control arm or ESD closes the valve

FIGURE A.10.3.3.2.3 Indoor Nonpublic Fast-Fill Dispenser P & ID.

portable fuel cell power systems that are permanently connected (stationary) to either fuel or electric supply, designed to export power to a grid, replacement fuel cell power units for appliances, or fuel cell systems for propulsion. Additional guidance pertaining to portable fuel cell power systems is provided by IEC 62282-5-1, *Portable Fuel Cell Power Systems, Safety.*

A.13.2.1 The equipment referenced is intended to include fuel cell power system 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.13.2.1.1 Where the listing of the hydrogen generator already addresses the requirements in specific sections of Chapter 6 and/or 7, the provisions of those specific sections do not need to be applied. Many of these sections typically are not relevant for small hydrogen generation equipment. For generators in un-occupiable enclosures, the enclosure is typically not considered to be a building.

A.13.2.2.1 Some hydrogen generators (e.g., reformers or gasifiers) can produce a gas mixture that is less than 95 percent hydrogen or above the temperature limits of ASME B31.12, *Hydrogen Piping and Pipelines*. In such cases, another section of ASME B31 might be more appropriate.

A.13.2.4(3) Protection can either be integral to hydrogen generator (locked enclosures, guards, etc.), or the hydrogen generator can be installed in a controlled-access area.

A.13.3.1.1.2 Listing standards for water electrolyzers are available. A commercial electrolyzer product listing standard already in use is ISO 22734-1, *Hydrogen generators using water electrolysis process — Part 1: Industrial and commercial applications.* A companion residential-use electrolysis product listing standard, ISO 22734-2, *Hydrogen generators using water electrolysis process — Part 2: Residential Applications*, is also available. UL and CSA are working to bring forth nationalized versions as UL/CSA 22734-1 and UL/CSA 22734-2. Small electrolyzers have been specifically listed to UL/CSA 61010 for laboratory and other uses.

A.13.3.1.5.1 Listing standards for residential-use electrolyzers, such as ISO 22734-2, allow manufacturers to list electrolyzers for residential applications, such as energy conversion and vehicle fueling. Limiting GH_2 content to 250 scf, GH_2 per 6.4.1.5.1.1 aligns with non-industrial use.

A.13.3.3.1.2 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.13.3.3.1.2.1 This equipment consists of piping, valves, vessels, and instrumentation for monitoring of the process.

A.13.3.3.1.2.10(B) 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 (permissible exposure level) information should be made for other toxic constituents.

A.13.3.3.1.2.10(C) Due to the high temperatures associated with the gasification process, ignition of leaks is very likely, especially in the vicinity of the gasifier vessel proper. Hydrogen burns with 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.13.3.3.1.2.10(E) The application of water deluge fire protection against the gasifier vessel and other very hot components must be done very 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 contains additional recommendations applicable to fire protection of gasifiers.

A.13.3.3.2.1 Pressure relief panels should be designed as outlined in NFPA 68.

A.14.1.1 Examples of the use of hydrogen used as a fuel involving flame, include, but would not be limited to, combustion of the gas in a torch used in welding or heating operations where the gas is used to provide a flame and accompanied by a reducing atmosphere. The melting of quartz or glass frequently involves the use of hydrogen combustion operations.

A.14.3.1.2 Thermal spraying is typically conducted with robotic equipment in isolated chambers or otherwise protected areas to isolate persons from hazards such as noise, intense ultraviolet light, process gases, and vapors. The equipment includes multiple flexible piping or hoses, which pass through the chamber walls to deliver the gas from a control source to the process device or gun. The flexible portions of the fuel delivery system represent potential leak sources.

NFPA 497 provides guidance on the classification of areas.

A.14.3.1.2.1 System preventive maintenance typically includes regular leak checks and the replacement of hoses in accordance with the manufacturer's recommendations. An increase in the frequency might be warranted based on maintenance experience.

A.14.3.1.2.2 NFPA 497 provides guidance on the classification of areas.

A.14.3.1.2.4 Features such as solid beams that form a tight fit with the roof deck should be avoided. The intakes for the ventilation system should be located at high points in the ceiling to prevent the trapping of hydrogen in the thermal spraying area.

A.14.3.1.2.6 The gas detection should be located in the spray area, at the gas controller, and at the gas supply when the source of supply is located indoors.

A.15.3.1.1.1 Special atmospheres can be produced by a number of technologies including ammonia dissociation or endothermic or exothermic gas generation, or by blending nitrogen or another inert gas with a reactive gas or gases, such as hydrogen, methane, ammonia, carbon monoxide, water or other reactive gases. Pure hydrogen can also be used as a special atmosphere.

NFPA 86 categorizes furnaces and ovens used for processing of materials into four classes, including Class A, B, C, and D. The terms furnaces, ovens, and dryers are used interchangeably and apply to heated enclosures used for the processing of materials. The term furnace as used in NFPA 2 is intended to apply to any of the aforementioned equipment individually or collectively. Refer to NFPA 86, paragraph A.1.1 for a detailed description of the various classes of furnaces.

The hazards of Class A furnaces are associated with those generated by the materials being processed. Class A furnaces do not typically use a hydrogen atmosphere. Class B furnaces are those operating at approximately atmospheric pressure that do not contain a flammable atmosphere, nor are flammable volatiles produced or combustible materials heated. There might be blends containing low levels of hydrogen mixed with inert gases in a nonflammable range that can be encountered in use in a Class B furnace. For the purpose of this Chapter, Class B furnaces with atmospheres containing hydrogen in any quantity should be treated as a Class C furnace.

The hazards of Class C furnaces are associated with special atmospheres used in the furnace for the treatment of materials in process. The use of hydrogen is most commonly encountered in furnaces of this type.

Class C ovens and furnaces typically operate at elevated temperatures, often higher than 1400°F (760°C). There are two classes of hazards associated with Class C furnaces. The first is the hazard associated with the physical furnace and its heating system. The second is associated with the atmosphere within the furnace and the equipment to create and control this atmosphere. Furnaces and ovens can be hazardous in and of themselves even without their atmospheres.

In addition, hydrogen is used in Class D furnaces, which are furnaces that operate at pressures ranging from vacuum to several atmospheres.

A.15.3.1.1.2.1 The location of a furnace or oven must be selected carefully so as to not create additional hazards. Furnaces should be located so as to minimize exposure of people to possible injury from fire, explosion, asphyxiation, and hazardous materials and should not obstruct travel to exits.

The location of the furnaces relative to other equipment and to combustible materials is an important consideration. The design of the furnace and oven also requires careful attention. Refer to NFPA 86, Chapter 5 for guidance on specific considerations relative to design features and location of a furnace within a building or structure.

A.15.3.1.1.2.2 Ladder-type schematic diagrams are recommended. [**86:** A.4.1.1.2]

A.15.3.1.1.4.1 The object of this requirement is to prevent infiltration of air that could be detrimental to the work being processed or could result in the creation of flammable gas–air mixtures within the furnace. The flow rates can be varied during the course of a heat treatment cycle. [**86:** A.13.5.7.1]

A.15.3.1.1.4.3 After closure of an outer vestibule door of a batch-type or pusher furnace, a delay usually occurs before burn-off resumes at the vent opening. The duration of the delay depends on the special [hydrogen] atmosphere flow rate, its combustibles content, the vestibule volume, and other factors. [**86:** A.13.5.7.3]

A.15.3.1.1.5 Gas atmosphere mixing systems are used to create special processing atmospheres made up of two or more gases. The majority are built to create binary nitrogen–hydrogen blends, but they also are able to create mixtures of other gases. The blended gas of gas atmosphere mixing systems usually has a constant flammable or indeterminate composition and is supplied on a pressure or demand basis to the special processing atmosphere flow controls situated at one or more furnaces. [**86:** A.13.5.6]

Gas atmosphere mixing systems typically incorporate a surge tank mixing scheme that cycles between set pressure limits. This feature distinguishes them from the flow control systems covered in 15.3.1.1.6. [**86:** A.13.5.6]

A special atmosphere is a gas or a mixture of gases that is introduced into the work chamber of a furnace to replace air and to protect or intentionally modify the surface of a material undergoing thermal processing.

A special atmosphere in a furnace can be inert, nonflammable, flammable, or indeterminate. Atmospheres containing hydrogen are typically not considered to be inert.

If a surge tank blending scheme is used, a separate pipeline can be required to supply inert gas directly to the furnace.

A.15.3.1.1.5(1) Consideration should be given to the inclusion of filters or strainers to improve reliable functioning of pressure regulators, flowmeters, flow monitors, control valves, and other components. [**86:** A.13.5.6(1)]

A.15.3.1.1.5(3) ASME B31.3 is the traditional reference for the piping used in these systems. ASME B31.12 has been published as a hydrogen specific piping standard and may be more appropriate than ASME B31.3.

A.15.3.1.1.6.2(2) Visual indication permits detection of sensor failures, such as thermocouple short circuits, that will not result in the action required by 15.3.1.1.6.2. Operator or maintenance personnel can evaluate the 1400°F (760°C) bypass interlock by observing the temperature indication. It is also acceptable to bring the 1400°F (760°C) bypass interlock thermocouple output into a PLC or another instrument in parallel with the 1400°F (760°C) bypass interlock, providing the accuracy of the 1400°F (760°C) bypass interlock is not diminished. The PLC or other instrument can be used to monitor, trend, and alarm the 1400°F (760°C) bypass interlock thermocouple output by comparing its output with that of an independent temperature measurement, such as from the operating temperature interlock. [**86:** A.8.17.3]

A.15.3.1.1.6.2(3) Temperature-sensing components, such as thermocouple and extension wires, that are not rated for the environment are at greater risk of short circuits. [**86:** A.8.17.4]

A.15.3.1.1.6.2(5) The sensing element should be positioned where the difference between the temperature control sensor and the excess temperature limit sensor is minimized. The temperature-sensing element of the excess temperature limit interlock should be located where it will sense the excess temperature condition that will cause the first damage to the furnace or work as temperatures within the furnace rise above the maximum operating set point most critical to safe operation. [**86:** A.8.16.8]

A.15.3.1.1.6.2(6) The temperature-sensing element of the excess temperature limit interlock can be monitored by other instrumentation, provided that the accuracy of the excess temperature limit interlock temperature reading is not diminished. [**86:** A.8.16.9]

A.15.3.1.1.6.2(8) An auxiliary contact in the excess temperature limit interlock device can be used as a 1400°F (760°C) bypass interlock providing the requirements of 15.3.1.1.6.2(1) are satisfied. [**86:** A.8.17.8]

A.15.3.1.1.6.6 ASME B31.3 is the traditional reference for the piping used in these systems. ASME B31.12 has been published as a hydrogen specific piping standard and may be more appropriate than ASME B31.3.

A.15.3.1.1.6.9 Filters or strainers should be provided to ensure reliable functioning of pressure regulators, flowmeters, flow monitors, control valves, and other components. [**86:** A.13.5.8.11]

A.15.3.1.1.7.2 Special precautions should be taken if aluminum piping is selected for hydrogen service or in the production of special atmospheres because of the low melting point of aluminum. The low melting point of aluminum subjects the piping to potential failure in fire situations. Other materials that are less subject to melting and failure under high temperature conditions should be considered by system designers during the design process.

A.15.3.1.1.8.2 In cases where minimal operating states, such as safety ventilation, must be established to prevent a hazardous condition, it is recommended that the precision of the set point be confirmed. When precision is inadequate, the component should be either recalibrated or replaced. Frequency of this testing and calibration should be established based on the components' mean time between failure (MTBF) data and the component manufacturer's recommendations. [**86:** A.7.4.5]

A.15.3.1.1.9.1 This [code] addresses the protection needs of ovens, furnaces, and related equipment. Fire protection needs external to this equipment are beyond the scope of this code. [**86:** A.9.1]

Fixed fire protection for the equipment can consist of sprinklers, water spray, carbon dioxide, foam, dry chemical, water mist, or steam extinguishing systems. The extent of protection required depends upon the construction and arrangement of the oven, furnace, or related equipment as well as the materials being processed. Fixed protection should extend as far as necessary in the enclosure and ductwork if combustible material is processed or combustible buildup is likely to occur. If the fixtures or racks are combustible or are subject to loading with excess combustible finishing materials, or if an appreciable amount of combustible drippings from finishing materials accumulates in the oven or ductwork, protection should also be provided. [**86:** A.9.1]

Hydrogen and other flammable gas fires are not normally extinguished until the supply of gas has been shut off because of the danger of re-ignition or explosion. Personnel should be cautioned that hydrogen flames are invisible and do not radiate heat. In the event of fire, large quantities of water should be sprayed on adjacent equipment to cool the equipment and prevent its involvement in the fire. Combination fog and solid stream nozzles should be used to allow the widest adaptability in fire control. [**86:** A.9.1]

Small flammable gas fires can be extinguished by dry chemical extinguishers or with carbon dioxide, nitrogen, or steam. Re-ignition can occur if a metal surface adjacent to the flame is not cooled with water or by other means. [**86:** A.9.1]

Dip tanks and drain boards included in oven enclosures should be protected by an automatic fire suppression system if flammable or combustible liquids are involved. NFPA 34 provides guidance for the design of fire suppression systems for dip tanks and drain boards. [**86:** A.9.1]

Refer to NFPA 86, Chapter 6 for guidance on the proper design of a furnace or oven heating system.

Furnaces and ovens can be heated by a variety of techniques, including electrical resistance heating systems or radiant tube combustion systems.

A.15.3.1.1.10 Refer to the definitions for *special atmosphere* in 3.3.217. [**86:** A.13.5.10]

A.15.3.1.1.10.3 Special atmospheres containing hydrogen are typically found in Class C or D furnaces.

A Class C furnace is a furnace that is potentially hazardous because of the special atmosphere that has been added to the furnace for the treatment of materials in the furnace. Class C furnaces are further classified into a variety of types, each of which are comprised of different features and operating principles. Table 15.3.1.1.10.3 illustrates the various Types of Class C furnaces.

A Class D furnace is a furnace that can contain a special atmosphere but that operates under vacuum for all or part of the furnace cycle. Class D furnaces generally are described as either cold-wall furnaces, hot-wall furnaces, or furnaces used for casting or melting of metal at high temperatures up to 5000°F (2760°C). There can be other special types.

Type I furnaces will be used as an example for describing the techniques for furnace operations. Refer to NFPA 86, Chapter 12 for detailed guidance for the introduction and removal of special atmospheres from other Class C furnace types.

A.15.3.1.1.11.1(B) Failure to maintain positive pressure in a furnace can allow air infiltration. Air infiltration can occur at effluents, open ends, or the perimeter of doors. In addition, welds in a furnace shell can break, gasketed joints can fail, and radiant tube heaters can be breached, all of which could introduce additional sources of air infiltration. Furnaces should be designed to minimize sources of air infiltration. In addition, furnace shell joints and radiant tube heaters should be periodically evaluated or tested and repaired as needed. Should positive furnace pressure be lost in furnaces or chambers operating below 1400°F (760°C), air infiltration can lead to a flammable gas–air mixture that can result in an explosion. Loss of positive furnace pressure can be caused by an inadequate flow of carrier gases or loss of furnace heat, and loss of furnace heat will lead to the thermal contraction of the atmosphere volume. [**86:** A.13.5.11.1(B)]

A.15.3.1.1.11.1(C) The character of the flame at furnace open ends and special [hydrogen] atmosphere effluents will be a function of the specific furnace. It is essential for the furnace operator to be trained to recognize the "established character" of these flames. In addition, the operator should be aware of the typical timing for flame to appear at open ends and effluent vents. [**86:** A.13.5.11.1(C)]

A.15.3.1.1.11.1(D) The fluid in a bubbler can be water or oil. Bubblers might be provided to protect a furnace from overpressure or to maintain a minimum positive atmosphere pressure within the furnace. Bubblers also can control pressure within a bell furnace using an oil seal. Overpressure of the retort or work chamber could blow the oil out of the seal ring. It is also possible to have water condensation accumulate in a bubbler bottle that can add to the liquid level and allow an increase in furnace pressure, which could increase furnace pressure to excessive levels and lead to the loss of oil seals. [**86:** A.13.5.11.1(D)]

A.15.3.1.1.11.1(E) Where flammable atmosphere effluent is released unburned to the interior of a building, the accumulation of flammable gases could create a fire or explosion hazard. To avoid this hazard, effluent that will not reliably ignite upon contact with air should be captured by a hood and discharged to a safe outside location. See also A.15.3.1.1.11.10(C)(2), which addresses additional hazards. [**86:** A.13.5.11.1(E)]

A.15.3.1.1.11.1(F) The use of plant air with reducing regulators is prohibited. Plant air lines can become slugged with water passing into the heated furnace resulting in abnormally high furnace pressures. Plant air lines can experience regulator failures resulting in high-pressure air admission into a furnace that contains a flammable atmosphere [**86:** A.13.5.11.1(F)]

A.15.3.1.1.11.2(B) Burn-off pilots using full premix (fuel–gas mixed with all the air needed to support full combustion) and glow plugs are examples of ignition sources meeting the intent of A.15.3.1.1.11.2(B). Full premix burn-off pilots have sufficient air (or, more precisely, sufficient oxygen in air) premixed with the fuel gas to maintain the burn-off pilot if the purge gas or special [hydrogen] atmosphere gas otherwise creates an oxygen-deficient atmosphere that would not support the burning of the burn-off pilot flame. [**86:** A.13.5.11.2(B)]

A.15.3.1.1.11.2(C) Where loss of ignition of vent effluent creates either an environmental or a personal safety concern, the pilot flame should be monitored and an alarm generated to alert the operator to loss of flame. [**86:** A.13.5.11.2(C)]

A.15.3.1.1.11.2(E) The ability to open doors manually in emergency situations is needed. Upon the simultaneous loss of furnace atmosphere and door pilot supervision, there will be a need to purge or manually open doors to burn-out vestibules that use an alternative source of ignition. [**86:** A.13.5.11.2(E)]

A.15.3.1.1.11.2(G) If burn-off pilots were equipped with flame supervision interlocked to turn fuel gas off to the burn-off pilot upon loss of flame, the burn-off pilots would also be turned off in the event of a power failure. The loss of burn-off pilots at special atmosphere effluent points during a power failure is undesirable and would create a serious safety concern with reliably maintaining ignition of effluents. Where flame supervision is provided, it is for an alarm to draw attention to the need to relight the burn-off pilot or it is interlocked to prevent the opening of a furnace door. [**86:** A.13.5.11.2(G)]

A.15.3.1.1.11.2(H) Burn-off pilots should be located where they will contact the effluent stream. For example, for a lighter-than-air effluent flowing from a furnace open end, the effluent most likely will be encountered at the top of the opening [**86:** A.13.5.11.2(H)]

A.15.3.1.1.11.2(J) Burn-off pilots are not to be interrupted by any action other than closing of their individual manual shutoff valve or closing of the main equipment manual shutoff valve. [**86:** A.13.5.11.2(J)]

A.15.3.1.1.11.3 Regarding items (2) and (5), once a door begins to open, it is intended that the door will be permitted to open completely. The interlock is only intended to prevent a closed door from opening. [**86:** A.13.5.11.3]

A.15.3.1.1.11.3(6) The manual override is provided for abnormal conditions to permit the manual removal of special [hydrogen] atmospheres from the furnace. [**86:** A.13.5.11.3(6)]

A.15.3.1.1.11.6(A)(1) Purge effectiveness can be compromised by actions such as operating furnace doors, operating quench elevators, introducing work, and operating fans not included in the purge process. Purge effectiveness can also be compromised by not running fans required to effect the purge. Avoiding such actions can be accomplished by written operating procedures or interlocks. [**86:** A.13.5.11.6.1(A)]

A.15.3.1.1.11.6(D) Verification of flammable special [hydrogen] atmosphere safety shutoff valves being closed can be accomplished by operator observation [**86:** A.13.5.11.6.4]

A.15.3.1.1.11.6(G) Flammable atmosphere–air interfaces occur at doors, open ends, effluents, and other locations where the flammable atmosphere contacts air. Active sources of ignition include door burn-off pilots, flame curtains, manual torches, door effluents above 1400°F (760°C), glow plugs, and hot door parts above 1400°F (760°C). Atmosphere–air interfaces can be avoided by a nitrogen seal.

Where a furnace has open ends or doors, a flame of established character appearing at open ends or atmosphere effluents indicates that the atmosphere introduction has been completed or is being maintained.

Furnaces without open ends or doors, such as bell furnaces and strip processing furnaces with sealed entrance and exit, might not have ignited effluent lines. As such, the operator might not know if or when the flammable atmosphere introduction is complete; however, because the furnace is sealed and positive pressure is maintained, this is not a safety concern. The operator is not using the effluent flame as an indicator for determining when to cycle loads or operate doors.

The character of the flame at furnace open ends and special [hydrogen] atmosphere effluents is a function of the specific furnace. It is essential that the furnace operator be trained to recognize the "established character" of these flames. [**86:** A.13.5.11.6.7]

A.15.3.1.1.11.6(H) The furnace volume includes chambers, zones, covers, and retorts that contain the flammable special [hydrogen] atmosphere within the furnace. Ductwork associated with recirculating fans such as jet coolers are considered part of the furnace volume, as are features such as large door housings or chambers and large pusher chain or mechanism housings that are exposed to the flammable special [hydrogen] atmosphere. [**86:** A.13.5.11.6.8]

A.15.3.1.1.11.6(K)(4) Oil level directly affects the volume of the vestibule. Flammable special [hydrogen] atmosphere introduction should not begin without quench oil being at the appropriate level. Atmosphere introduction should not be interrupted once started. [**86:** A.13.5.11.6.11(4)]

A.15.3.1.1.11.6(L) The character of the flame at furnace open ends and special [hydrogen] atmosphere effluents will be a function of the specific furnace. It is essential that the furnace operator be trained to recognize the "established character" of these flames. In addition, the operator should be aware of the typical timing for flame to appear at open ends and effluent vents.

A.15.3.1.1.11.7(A)(1) Burn-in effectiveness can be compromised by actions that are not included in the burn-in operating instructions. Furnace doors, quench elevators, and fans should not be operated except in accordance with written burn-in operating instructions. Work should not be introduced into a furnace during the burn-in process. Burn-in effectiveness can also be compromised by running or not running fans in accordance with written burn-in instructions. [**86:** A.13.5.11.7.1(A)]

A.15.3.1.1.11.7(B) The burn-in process is anticipated to reduce the oxygen level within the furnace to a point at or below 1 percent as the oxygen in air is consumed by the burn-in process. [**86:** A.13.5.11.7.2]

A.15.3.1.1.11.7(C) Any flammable atmosphere gas introduced into a chamber at or above 1400°F (760°C) will be reliably ignited by auto-ignition. An alternative method of atmosphere gas ignition, beyond just the burning flame front, might be needed where the burning atmosphere gas enters chambers below 1400°F (760°C). [**86:** A.13.5.11.7.3]

A.15.3.1.1.11.7(D) Long cooling tunnels can extinguish the burning atmosphere flame front by cooling the atmosphere gas as it moves along the length of the tunnel [**86:** A.13.5.11.7.4]

A.15.3.1.1.11.7(E) In some furnace designs, such as the Type II furnace (integral quench batch furnace), manual torches might be needed as a means to reliably ignite flammable atmosphere gas as it flows into the cool vestibule chamber from the hot heating chamber. Written burn-in instructions for the specific furnace will outline the specific sequence to follow for burn-in. The following burn-in procedure for a Type II furnace is provided as one example:

(1) Atmosphere gas is introduced into the hot heating chamber and auto-ignites. Ignition is visually verified, and the inner heating chamber door is closed.
(2) A port in the closed inner door allows the atmosphere gas to flow from the heating chamber to the vestibule chamber. A manual torch placed at this port ignites the atmosphere gas.
(3) Once ignition is visually verified at the inner door port, the manual torch is removed and the outer vestibule door is closed, and the vestibule is allowed to burn-in.
(4) Burn-in of the vestibule is visually confirmed once a steady flame appears at the vestibule atmosphere effluent vent. [**86:** A.13.5.11.7.5]

A.15.3.1.1.11.7(F) To avoid adverse effects on the special [hydrogen] atmosphere in the heat zone and vestibule, the heating chamber fan is turned off when the inner door is open. One adverse effect could be the creation of atmosphere flow in the vestibule, that could draw in air around the steel-to-steel contact between the vestibule door and the furnace shell. Also, during initial furnace burn-in, the operator typically will be instructed to visually verify ignition of the special [hydrogen] atmosphere gas as it is introduced to the heating chamber. That requires both the heating chamber door and the vestibule door to be open and the heating chamber fan to be off to allow visual observation. [**86:** A.13.5.11.7.6]

A.15.3.1.1.11.7(G) During burn-in, cooling zone fans are to be turned off to avoid disrupting the flame front burning through the cooling chamber. If a furnace is being heated, the heat zone fans typically need to be kept in service to avoid thermal damage. In a cooling chamber, the only ignition source is the flame front, which is easily disrupted by fan circulation. In a heating chamber above 1400°F (760°C), the entire environment is an ignition source, and fans will not adversely affect the reliability of ignition. [**86:** A.13.5.11.7.7]

A.15.3.1.1.11.7(H)(2) The retort or inner cover of a Type VIII furnace and the cover of a Type IX furnace will be sealed to the base. Sand seals, oil seals, or rubber seals can be used. [**86:** A.13.5.11.7.8(B)]

A.15.3.1.1.11.7(H)(3) The means to maintain furnace pressure below the static head pressure of the seal oil include the use of bubblers or manometers on vent lines. Other means may be possible. Also see A.15.3.1.1.11.1(E). [**86:** A.13.5.11.7.8(C)]

A.15.3.1.1.11.7(J) The character of the flame at furnace open ends and special [hydrogen] atmosphere effluents will be a function of the specific furnace. It is essential that the furnace operator be trained to recognize the "established character" of these flames. In addition, the operator should be aware of the typical timing for flame to appear at open ends and effluent vents.

Furnaces, such as heating-cover types, that have no open ends, doors, or effluent lines will have no features to provide indicators of visible flame. This is an acceptable arrangement and is addressed by the specific furnace design and operating instructions. [**86:** A.13.5.11.7.10]

A.15.3.1.1.11.8(A)(1) Purge effectiveness can be compromised by actions such as operating furnace doors, operating quench elevators, introducing work, and operating fans not included in the purge process. Purge effectiveness can also be compromised by not running the fans required to effect the purge. Avoiding such actions should be addressed by written operating procedures or by interlocks. [**86:** A.13.5.11.8.1(A)]

A.15.3.1.1.11.8(C) Oxidizing special atmosphere gases include air. [**86:** A.13.5.11.8.3]

A.15.3.1.1.11.8(D) The furnace volume includes chambers, zones, covers, and retorts that contain the flammable special [hydrogen] atmosphere within the furnace. Ductwork associated with recirculating fans such as jet coolers is considered part of the furnace volume, as is the space in the furnace steel shell but above the refractory arch if flammable special [hydrogen] atmosphere gas can permeate into that space. Flammable special [hydrogen] atmosphere gases such as hydrogen may migrate into an above-arch space during operation and may require special purging facilities to remove them during the purge-out process. [**86:** A.13.5.11.8.4]

A.15.3.1.1.11.8(E) Chambers include heating chamber, cooling chambers, vestibules, door housings, and other atmosphere containing volumes that would create a hazard if not specifically purged. [**86:** A.13.5.11.8.5]

A.15.3.1.1.11.9(A)(1) Burn-out effectiveness can be compromised by actions that are not included in the burn-out operating instructions. Furnace doors, quench elevators, and fans should not be operated except in accordance with written burn-out operating instructions. Work should not be introduced into a furnace during the burn-out process. Burn-out effectiveness can also be compromised by not running fans required to effect the burn-out. [**86:** A.13.5.11.9.1(A)]

A.15.3.1.1.11.9(A)(2) Typically, where doors are present, the burnout procedure will begin with all inner and outer doors closed. The outermost chamber will be burned-out first. [**86:** A.13.5.11.9.1(B)]

A.15.3.1.1.11.9(B) Burn-out can be accomplished by introducing air by a number of means, including open ends, vents, opening doors, header and feed pipes of burnout manifold systems, process air piping, and so forth. Uncontrolled admission of air can lead to excessive temperatures in some furnaces. Opening doors can create a draft through a furnace that can push ignited atmosphere out other openings, and instructions should be carefully developed to avoid such conditions. The written procedures required in 15.3.1.1.11.9(A) should provide step-by-step instructions for a controlled burn-out.

With hot furnaces that contain soot, it is possible to re-form a flammable atmosphere that may require additional air introduction procedures to effect final burn-out [**86:** A.13.5.11.9.2]

A.15.3.1.1.11.9(C) For Type IX furnaces (cover), visual observation of burn-out is not possible until the cover is removed. Written burn-out procedures will typically include the following actions:

(1) Release the mechanical clamping devices holding the heating cover to the base.
(2) Ignite the manual burn-off pilots or torches and place them in position at the heating cover to the base seal to ignite flammable gases that might be present inside the cover as the seal is broken.
[**86:** A.13.5.11.9.3]

A.15.3.1.1.11.9(C)(2)(a) The requirement for the furnace to be under positive pressure is to eliminate the concern that an indeterminate atmosphere might develop in furnace chambers under 1400°F (760°C). With some furnace burn-out procedures (e.g., opening doors), initiating the burn-out can cause the furnace pressure to immediately fall to atmospheric pressure. This is not an issue once the burn-out procedure has been initiated. [**86:** A.13.5.11.9.3(2)(a)]

A.15.3.1.1.11.9(F) During burn-out, fans are to be turned off to avoid disrupting the flame front burning back through to the special [hydrogen] atmosphere gas source. [**86:** A.13.5.11.9.6]

A.15.3.1.1.11.10 See Figure A.15.3.1.1.11.10.
[**86:** A.13.5.11.10]

A.15.3.1.1.11.10(B)(1) One of the following secondary equipment isolation means should be provided immediately downstream of the equipment isolation manual shutoff valve so that

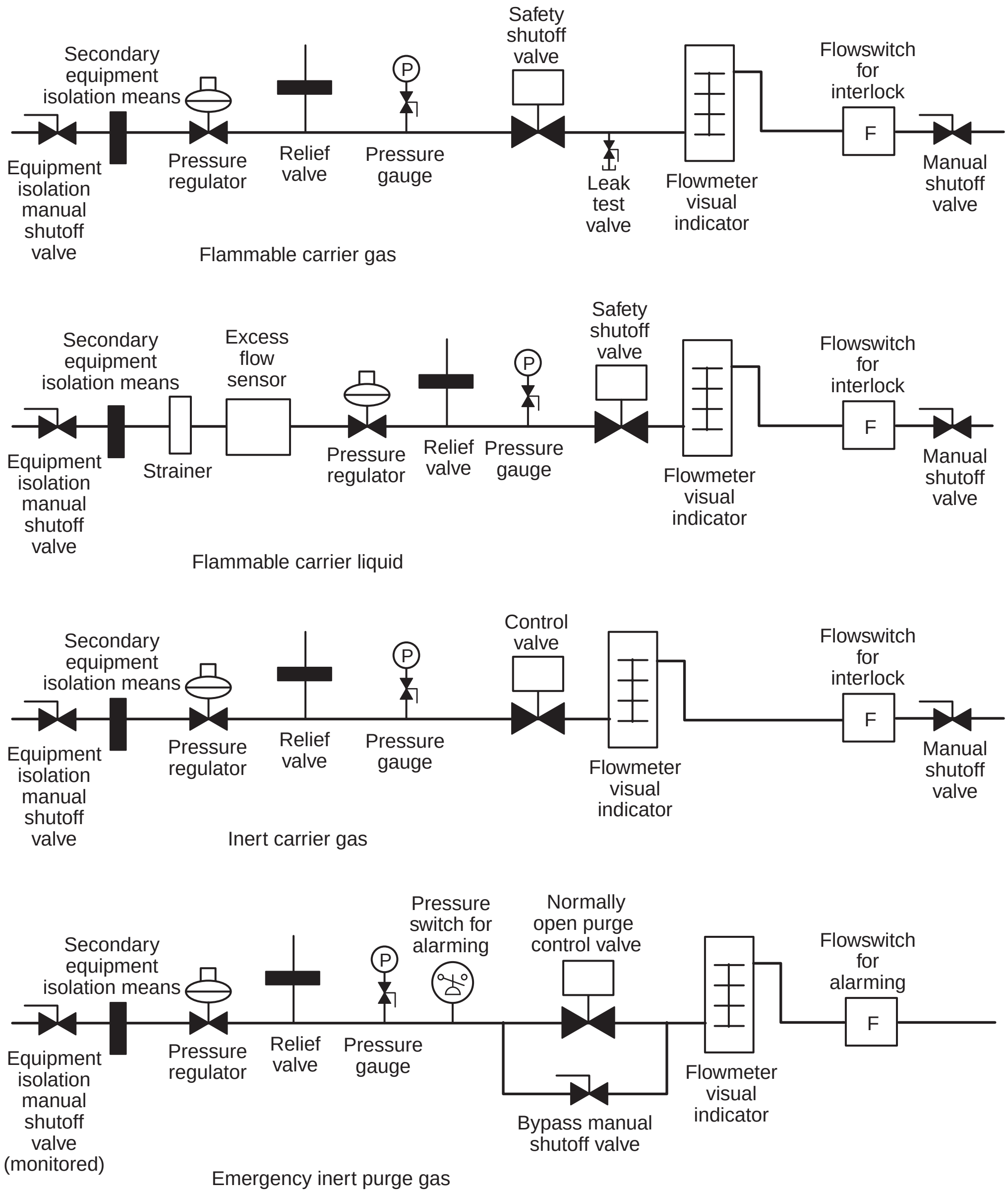


FIGURE A.15.3.1.1.11.10 Examples of Special Atmosphere Equipment Piping.

no leakage of gas passing the equipment isolation manual shutoff valve can enter the downstream special [hydrogen] atmosphere piping:

(1) Removable spool piece
(2) Breakable flanges with loosely inserted blinding plate
(3) Blinding plate secured between flanges
(4) A second valve with venting of the intermediate space between this valve and the special [hydrogen] atmosphere manual isolation valve

Two manual shutoff valves in series without venting of the intermediate space would not be considered equivalent to the above choices. [**86:** A.13.5.11.10.2.1]

A.15.3.1.1.11.10(C)(2) [-] Gases that are asphyxiants, toxic, or corrosive are outside of the scope of this standard. In this regard, other standards should be consulted for appropriate venting. Flammable gases [-] should be vented to a safe location to prevent fire or explosion hazards. When gases are vented, the vent pipe should be located in accordance with the following:

(1) Gas should not impinge on equipment, support, building, windows, or materials because the gas could ignite and create a fire hazard.
(2) Gas should not impinge on personnel at work in the area or in the vicinity of the exit of the vent pipe because the gas could ignite and create a fire hazard.
(3) Gas should not be vented in the vicinity of air intakes, compressor inlets, or other devices that utilize ambient air.

The vent exit should be designed in accordance with the following:

(1) The pipe exit should not be subject to physical damage or foreign matter that could block the exit.
(2) The vent pipe should be sized to minimize the pressure drop associated with length, fitting, and elbows at the maximum vent flow rate.
(3) The vent piping should not have any shutoff valves in the line.

If the gas is to be vented inside the building, the following additional guidance is offered:

(1) If the gas is flammable and lighter than air, the flammable gases should be vented to a location where the gas is diluted below its LFL before coming in contact with sources of ignition and the gas cannot re-enter the work area without extreme dilution.
(2) See also Chapter 4 of NFPA 56, which provides information about the development and implementation of written procedures for the discharge of flammable gases. [**86:** A.13.5.11.10.3(B)] and [**86:** A.6.2.6.3]

A.15.3.1.1.11.10(C)(4) Vent line sizing in accordance with 15.3.1.1.11.10(C)(4) is intended to avoid the operation of individual devices from affecting (cross-impulsing) other manifolded devices under normal operations. Under upset conditions in which a device diaphragm fails, the vent line will direct the release gas to a suitable location, but it would not necessarily avoid adverse control impact upon other manifolded devices. It should be noted that special [hydrogen] atmosphere gases typically operate at low pressure and utilize regulators with large diaphragms that are more sensitive to pressure pulses across interconnected vent lines. [**86:** A.13.5.11.10.3(D)]

A.15.3.1.1.11.10(D)(1) Typically, relief valves would not be provided for generated special [hydrogen] atmosphere gases. Relief valves might not be needed for enriching gas where the fuel gas supply to the furnace is equipped with multiple pressure regulators and where the failure of any one pressure regulator would not introduce excessive pressures to the special [hydrogen] atmosphere system downstream of the failed pressure regulator. Relief valves might be needed for liquid special atmospheres or special [hydrogen] atmosphere gases provided from pressurized storage vessels. [**86:** A.13.5.11.10.4(A)]

A.15.3.1.1.11.10(D)(2) Overpressurization of the liquid special atmosphere piping can occur if liquid is isolated in the piping between closed valves and exposed to an increase in temperature. Closed valves can include manual valves, automatic valves, or safety shutoff valves. Other means of controlling pressure could include an accumulator or an expansion tank. [**86:** A.13.5.11.10.4(B)]

A.15.3.1.1.11.10(D)(3) See A.15.3.1.1.11.10(C)(2). Also, for atmosphere gases supplied in the liquid state, relief valves can be piped back to the liquid storage vessel. [**86:** A.13.5.11.10.4(C)]

A.15.3.1.1.11.10(H) Atmosphere impingement on the temperature control thermocouple can result in overheating of the furnace or erroneous control readings on the over temperature thermocouple. [**86:** A.13.5.11.10.8]

A.15.3.1.1.12.8 The means can be either electrical or mechanical. Mechanical means would include the operation of valves in the special [hydrogen] atmosphere piping. For some applications, additional manual action might be required to bring the process to a safe condition. [**86:** A.13.5.11.11.8]

A.15.3.1.1.12.10(A) The removal of flammable special [hydrogen] atmospheres by burn-out, purge-out, or emergency purge-out can be caused by manual or automatic action. Table A.15.3.1.1.12.10(A) summarizes when the action should be automatic and when it can be automatic or manual.

Part 3 addresses the condition where there is a low flow of carrier gas that will not maintain positive pressure within a chamber that is below 1400°F (760°C). If a chamber is above 1400°F (760°C), the low flow condition might allow furnace pressure to drop and might allow air infiltration; however, while this might lead to process issues, it is not a safety issue requiring the removal of the special [hydrogen] atmosphere. Following operating instructions, the operator can work to restore normal process conditions.

It should be noted that Part 3 does not involve any measurement of the actual furnace pressure. Rather, it is based on comparing the actual carrier gas(es) flow with minimum allowable design flow rates. The actual carrier gas flow is measured with flow sensors. Furnace pressure is subject to fluctuation due to actions such as operating doors and loading or unloading work. The inadvertent shutdown of carrier gases due to a routine furnace pressure fluctuation is considered more of a potential safety hazard than the actual pressure fluctuation itself.

[**86:** A.13.5.11.11.10(A)]

A.15.3.1.1.12.11(B) Where exothermic generated special atmosphere gases are used for purging, the flammable content of the gas is maintained at a limited level that when mixed with air would not exceed 25 percent of LFL and therefore would not need a safety shutoff valve. [**86:** A.13.5.11.11.11(B)]

Table A.15.3.1.1.12.10(A)

Part	Condition	Response
1	Normal furnace atmosphere burn-out initiated	Automatic or manual
2	Normal furnace atmosphere purge-out initiated	Automatic or manual
3	Low flow of carrier gas(es) that will not maintain a positive pressure in chambers below 1400°F (760°C) and positive pressure is not restored by the automatic transfer to another source of gas	Automatic
4	A furnace temperature below which any liquid carrier gas used will not reliably dissociate	Automatic
5	Automatic emergency inert gas purge initiated	Automatic
6	Manual operator emergency inert gas purge initiated	Automatic

A.15.3.1.1.12.11(E) [Refer to NFPA 86 Annex section] A.7.4.9 [which provides a complete discussion of leak test options]. [**86:** A.13.5.11.11.11(E)]

A.15.3.1.1.12.12(D) Normal shutdown of a furnace by burn-out is an example of a practice that causes a furnace chamber to lose positive pressure. However, this loss of positive pressure takes place along with the controlled introduction of air to effect the burn-out of the flammable atmosphere. Safety shut-off valves are to close in response to this action, but there is no safety issue with this intended case of furnace pressure loss.

The unintended interruption of a furnace heating system, unintended loss of furnace temperature, unintended reduction of carrier gas flow, or unintended interruption of power are examples of conditions that can cause furnace chambers to lose positive pressure. These conditions, however, can lead to the uncontrolled infiltration of air into furnace chambers, which could rapidly lead to an unsafe condition (faster than operators might be able to respond) in some of or all the chambers. Chamber temperature will influence whether an unsafe condition can develop.

Where chamber temperature is at or above 1400°F (760°C), the uncontrolled air infiltration could create process quality issues; however, it is not anticipated to create safety issues. This standard has no requirement to initiate the removal of the special [hydrogen] atmosphere in this case. Instead, the operator should follow written operating instructions and work to restore normal process conditions. The written operating instructions could include directions to implement a controlled furnace shutdown if certain specified conditions develop.

Where chamber temperature is below 1400°F (760°C), the uncontrolled air infiltration could create an explosion hazard. Under these conditions, the safety shutoff valves for flammable special [hydrogen] atmospheres will close, and the actions specified in 15.3.1.1.12.12(C)(1) should automatically occur.

Regarding 15.3.1.1.12.12(D)(4), where a carrier gas generated by liquid dissociation is used, furnace temperatures need to be maintained above a temperature that will maintain reliable dissociation of the liquid. In earlier editions of NFPA 86, the minimum temperature was stated as 800°F (427°C). This specific value has been removed from the standard because there is more than one liquid used as a special atmosphere, and each liquid should be evaluated for the minimum temperature that will reliably dissociate that liquid in the furnace. Where a reliable dissociation temperature is not maintained, the special atmosphere liquid might no longer maintain a positive furnace pressure. Once positive furnace pressure is lost, air infiltration will be possible, and a furnace explosion hazard can develop. [**86:** A.13.5.11.11.12(D)]

A.15.3.1.1.12.15 Vestibule explosion relief means usually consist of doors that remain in position under their own weight but are otherwise unrestrained from moving away from the door opening if an overpressure occurs within the furnace. [**86:** A.13.5.11.11.15]

A.15.3.1.1.12.16 Noncarrier special atmosphere gases can be flammable (e.g., enriching gas) or nonflammable (e.g., process air). Their introduction into the furnace should occur only after the carrier gases flow has been established. According to this standard, flammable special [hydrogen] atmosphere gases are equipped with safety shutoff valves. Nonflammable special atmosphere gases typically are equipped with solenoid valves. [**86:** A.13.5.11.11.16]

A.15.3.1.1.13 Furnace controls that meet the performance-based requirements of standards such as ANSI/ISA 84.00.01, *Application of Safety Instrumented Systems for the Process Industries,* can be considered equivalent. The determination of equivalency will involve complete conformance to the safety life cycle, including risk analysis, safety integrity level selection, and safety integrity level verification, which should be submitted to the authority having jurisdiction. [**86:** A.8.3]

A.15.3.1.1.13.2 The control circuit and its non–furnace-mounted or furnace-mounted control and safety components should be housed in a dusttight panel or cabinet, protected by partitions or secondary barriers, or separated by sufficient spacing from electrical controls employed in the higher voltage furnace power system. Related instruments might or might not be installed in the same control cabinet. The door providing access to this control enclosure might include means for mechanical interlock with the main disconnect device required in the furnace power supply circuit.

Temperatures within this control enclosure should be limited to 125°F (52°C) for suitable operation of plastic components, thermal elements, fuses, and various mechanisms that are employed in the control circuit. [**86:** A.8.3.1.4]

A.15.3.1.1.15 The NFPA 86 requirements for inert gas purge are found in Sections 13.5.8, 13.5.10, 13.5.11 and 14.5.3.

A.15.3.1.2.1.6 If a residual amount of air is retained in an external chamber, the inadvertent opening of a valve to an external system in the presence of a flammable atmosphere could create an explosive mixture. [**86:** A.14.5.3.1.6]

A.15.3.1.2.1.12 Cracking of a sight glass, which is not unusual, can admit air into the chamber or allow flammable gas to escape. [**86:** A.14.5.3.1.12]

A.15.3.1.2.4 In case of electric power failure, all the following systems could stop functioning:

(1) Heating system
(2) Flammable atmosphere gas system
(3) Vacuum pumping system

[**86:**14.5.3.4]

A.15.3.2 Large electrical generators have adopted the use of a hydrogen atmosphere within the casing to reduce windage drag, which improves the efficiency of the equipment, and to increase the cooling capability of the generator, thus allowing a higher energy density while minimizing thermal stresses on the machine. Hydrogen cooled generators are supported by a number of subsystems, several of which can also contain hydrogen gas. NFPA 2, Chapters 6 through 8 cover much of the overall system installation, and those provisions should be followed.

Traditionally, hydrogen gas for the generator is supplied either by a cylinder manifold (typically provided by the generator manufacturer) or a tube trailer (tied to the generator hydrogen system by the owner / operator). Such installations consist of piping, valves, and pressure regulation devices that should be installed in accordance with the provisions of Chapters 6 through 8. Recently, the traditional cylinder / tube trailer supply has been replaced on some installations with a local hydrogen generation unit, which lowers the cost of ownership, provides an assured supply of hydrogen, and offers a higher hydrogen purity capability within the generator envelope. Electrolyzer or reformer technology is typically the basis of these on-site hydrogen generation units, and the applicable provisions of Chapter 13 should be applied.

Other systems associated with hydrogen cooled generators include hydrogen purity monitoring, control valves, hydrogen dew point sensors, gas dryers, liquid level detectors, and hydrogen detraining vessels. Active equipment, such as the purity monitoring and dew point equipment, will be purchased commercially and be suitably rated for exposure to hydrogen gas. Other items, such as level detectors and detraining vessels, do not contain ignition sources and require no special consideration other than the potential hazardous area surrounding them. Many of the items will include pressure relief or other venting elements that must be routed to an appropriate safe location as part of the power plant installation.

A.15.3.2.1.3.1 Although electric power generation facilities under the control of an electric utility are specifically excluded under *NFPA 70*, Section 90.2(B)(5), many of the principles outlined in Articles 500 through 506 can be successfully applied to a hydrogen cooled generator to assure the overall safety of the equipment and personnel assigned to the facility.

A.15.3.2.2.1 Hydrogen cooled generator installations can include acoustic walls to meet plant sound pressure level requirements. Although not considered a "building" for the purposes of this section, the effects of the acoustic walls on the ventilation airflow should be accounted for in the building ventilation design.

A.15.3.2.2.4 Given the low ignition energy of hydrogen, the use of flares at the vent termination should be considered. If a flare is not used, the potential extent of hydrogen fires under worst credible conditions (e.g., generator purge) must be considered when establishing the vent termination point in relation to equipment and buildings.

A.15.3.2.3.2 See A.15.3.2.2.4.

A.15.4.1.1 Vaporizers used for safety purging to convert cryogenic liquids to the gas state should be ambient air heat transfer units so that flow from such vaporizers is unaffected by the loss of power.

The use of powered vaporizers is permitted where one of the following conditions is satisfied:

(1) The vaporizer has reserve heating capacity to continue vaporizing at least five furnace volumes at the required purge flow rate immediately following power interruption.
(2) Reserve ambient vaporizers are provided that are piped to the source of supply so that they are unaffected by a freeze-up or flow stoppage of gas from the powered vaporizer. The reserve vaporizers should be capable of evaporating at least five furnace volumes at the required purge flow rate.
(3) Purge gas is available from an alternative source that is capable of supplying five volume changes after interruption of the flow of the atmosphere gas to the furnace.

[**86:** A.13.5.5]

Vaporizers should be rated by the industrial gas supplier or the owner to vaporize at 150 percent of the highest purge gas demand for all connected equipment. Winter temperature extremes for the locale shall be taken into consideration by the agency responsible for rating the vaporizers. [**86:** A.13.5.5]

The industrial gas supplier should be informed of additions to the plant that materially increase the inert gas consumption rate so that vaporizer and storage capacity can be resized for the revised requirements. [**86:** A.13.5.5]

A temperature indicator should be installed in the vaporizer outlet piping for use in evaluating its evaporation performance at any time. [**86:** A.13.5.5]

A device should be installed that prevents the flow rate of gas from exceeding the vaporizer capacity and thereby threatening the integrity of downstream equipment or control devices due to exposure to cryogenic fluids. A break in the downstream pipeline or failure (opening) of the supply pressure regulator could cause excessive flow. Exceeding the capacity of an atmospheric vaporizer leads to a gradual decrease in gas temperature that can be remedied by decreasing the demand on the vaporizer. [**86:** A.13.5.5]

In atmospheric vaporizers, in lieu of the flow-limiting device, a visual and audible alarm should indicate to operators in the vicinity of the furnace that the temperature of the vaporizer outlet gas has fallen below a minimum level, indicating a potential to exceed vaporizer capacity. [**86:** A.13.5.5]

A.16.1.2(2) The hazards of pilot plants are primarily based on the process, the chemistry, and the equipment, not the laboratory environment. [**45:** A.1.1.3(2)]

A.16.2.1.1 A door to an adjoining laboratory work area or laboratory unit is considered to be a second means of access to an exit, provided that the laboratory unit is not of a higher fire hazard classification. [**45:** A.5.4.1]

A.16.2.2.1 A qualified design professional and owner safety officer should review the laboratory conditions through a hazard analysis and/or risk assessment to determine if a hazardous (ignitable) atmosphere could be developed within the laboratory work area, laboratory area, laboratory unit, and/or fume hood. If a hazardous atmosphere could be developed, these areas should be electrically classified per *NFPA 70*, Article 500. [**45:** A.5.6.2]

A.16.2.3.1.1.2 A series of fire tests in typical chemical laboratories was conducted to evaluate quick-response sprinkler technology and the use of quick-response sprinklers in chemical laboratories. Fire test results demonstrated that both standard response and quick-response sprinklers were effective in controlling fires. Additionally, fire test results of the quick-response sprinklers showed lower maximum temperatures at the 5 ft level consistent with what is considered acceptable tenability in the room of fire origin, as discussed in NFPA 13D, and evaluated by ANSI/UL 1626, Residential Sprinklers for Fire Protection Service. Also see NISTIR 89-4200, "Quick Response Sprinklers in Chemical Laboratories: Fire Test Results," sponsored by the National Institutes of Health, Bethesda, MD. [**45:** A.6.1.1.2]

A.16.2.3.3.1 For laboratory buildings where trained personnel are available, Class III standpipe systems can be installed [**45:** A.6.2.1]

A.16.2.3.3.2 For additional information, see NFPA 25.

A.16.2.5.2 Maintenance procedures should include inspection, testing, and maintenance of the following:

(1) Utilities (steam, gas, electrical)
(2) Air supply and exhaust systems
(3) Fire protection equipment
(4) Detectors and alarms
(5) Compressed gas regulators and pressure relief valves
(6) Waste disposal systems
(7) Fire doors
(8) Emergency lighting and exit signs
(9) Electrically operated equipment

[**45:** A.6.5.2]

A.16.2.5.3 An emergency response plan should be prepared and updated. The plan should be available for inspection by the AHJ, upon reasonable notice. The following information should be included in the emergency plan:

(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 marking is provided for each storage area
(4) Location of posted emergency response procedures
(5) Safety data sheets (SDSs) for all hazardous materials stored on site
(6) A list of responsible personnel who are designated and trained to be liaison personnel for the fire department; these individuals should be knowledgeable in the site emergency response procedures and should aid the emergency responders with the following functions:
    (a) Pre-emergency planning
    (b) Identifying where flammable, pyrophoric, oxidizing, and toxic gases are located
    (c) Accessing MSDSs
(7) A list of the types and quantities of compressed and liquefied gases normally at the facility

[**45:** A.6.5.3]

A.16.2.5.3.1(5) Unusual non-fire hazards that emergency response personnel might encounter in responding to a fire in a chemical laboratory might include the following:

(1) Poisons
(2) Corrosives
(3) Irritants
(4) Radioactivity
(5) Nonionizing radiation
(6) Biological hazards

[**45:** A.6.6.3.1(5)]

Laboratory management should train emergency response personnel in detailed emergency response plans that address these special hazards. [**45:** A.6.6.3.1(5)]

Laboratory management should also encourage the public fire department to become familiar with these hazards through in-service inspections, joint emergency plan development, and coordinated emergency response drills. [**45:** A.6.6.3.1(5)]

Emergency telephones are of value when connected directly to an emergency office and when located within the laboratory building so that they can be readily used by laboratory personnel. They are also valuable when available at an exterior location for use by evacuees or passersby. An emergency telephone system should be interconnected with a mass notification system, such as a public address system. [**45:** A.6.6.3.1(5)]

The management of each laboratory work area covered by this standard should be responsible for developing and distributing an evacuation plan for the facility. The plan should be written with accompanying diagrams and distributed to each supervisor and posted in appropriate locations for all employees to read and study. In addition to fires and explosions, the evacuation plan should also consider hazardous incidents such as spills, leaks, or releases of flammable, toxic, or radioactive materials, and acts of nature such as tornadoes, hurricanes, and floods. The evacuation plan should include, but not be limited to, the following:

(1) Conditions under which evacuation will be necessary
(2) Method of alarm transmission
(3) Action to be taken by personnel upon receiving an alarm in addition to evacuation (e.g., turn off flames and other ignition sources)
(4) Primary and secondary routes to horizontal and vertical exits leading either to the exterior of the building or to safe refuge zones within the building, as might be permitted if total evacuation is not necessary and the alarm system is appropriately zoned
(5) Instructions necessary to prevent evacuees from hampering fire-fighting operations or essential duties of emergency personnel (i.e., move away from the building to a predesignated area)
(6) Accountability to determine if everyone has left the facility (Wardens or supervisors should be instructed to check all occupied spaces in their assigned area upon sounding of an alarm to ensure that everyone has heard the alarm and is evacuating. Personnel from particular groups, departments, floors, or areas should be instructed to gather in a predesignated area outside the building or in a safe refuge zone. Special procedures should be established for evacuation of handicapped persons. Wardens or supervisors should be responsible for accounting for all personnel in their areas, including guests and visitors.)
(7) Methods of notifying personnel as to when it is safe to re-enter the facility (Dependence on duly authorized persons, such as wardens, to pass this word will prevent someone from entering the facility prematurely.)

[**45:** A.6.6.3.1(5)]

Laboratory management should conduct fire exit drills at least once a year to test the evacuation procedures by familiarizing personnel with exits, especially emergency exits not normally used, and the safe and efficient use of the exits. For required frequency of fire exit drills in educational occupancies and health care occupancies, see NFPA *101.* (Fire exit drills differ from fire drills in that the latter are held for purposes of fire-fighting practice by the fire brigade or other emergency organizations. Because a conflict exists between evacuation and fire fighting, management should appoint different persons to be responsible for each procedure, as one cannot effectively direct fire-fighting operations and evacuation simultaneously.) [**45:** A.6.6.3.1(5)]

Fire alarm systems, where available, should be used in the conduct of fire exit drills. No one should be excused from participating in a fire exit drill. [**45:** A.6.6.3.1(5)]

A.16.2.5.3.2 Laboratory personnel should be thoroughly indoctrinated in procedures to follow in cases of clothing fires. The most important instruction, one that should be stressed until it becomes second nature to all personnel, is to immediately drop to the floor and roll. All personnel should recognize that, in the case of ignition of another person's clothing, they should immediately knock that person to the floor and roll that person around to smother the flames. Too often a person will panic and run if clothing ignites, resulting in more severe, often fatal, burn injuries. [**45:** A.6.5.3.2]

Fire-retardant or flame-resistant clothing is one option available to help reduce the occurrence of clothing fires. Refer to NFPA 1975 for performance requirements and test methods for fire-resistant clothing. [**45:** A.6.5.3.2]

It should be emphasized that the use of safety showers, fire blankets, or fire extinguishers are of secondary importance. These items should be used only when immediately at hand. It should be recognized that rolling on the floor not only smothers the fire but also helps to keep flames out of the victim's face, reducing inhalation of smoke. [**45:** A.6.5.3.2]

A.16.3.2.1.1 NFPA 90A and NFPA 91 contain additional requirements for general environmental ventilating systems. [**45:** A.7.1]

A.16.3.2.1.2.1 For additional information on laboratory ventilation, see ANSI/AIHA Z9.5, *Laboratory Ventilation.* For information on preventing the spread of smoke by means of utilizing supply and exhaust systems to create airflows and pressure differences between rooms or building areas, see [NFPA 92]. [**45:** A.7.2.1]

A.16.3.2.1.2.2 A minimum ventilation rate for unoccupied laboratories (e.g., nights and weekends) can be as low as four room air changes per hour with proper laboratory operations and storage of chemicals. Occupied laboratories typically operate at rates greater than six air changes per hour, consistent with the conditions of use for the laboratory. Occupied laboratories should determine their supply airflow rates based on cooling requirements, amount of exhaust air required for the hoods, or exhaust devices in the lab, whichever is greatest. Use of only an "air change per hour" criteria is not considered proper design. Adequate ventilation shall be provided to ensure occupant safety and safe operation of exhaust devices inside the laboratory.

Laboratory ventilation operating at lower rates should employ specific measures to monitor for potentially hazardous conditions and increase the ventilation automatically upon detection of any condition within 25 percent of the level of concern. If such a monitoring system is to be used, it should be fail-safe and be of such a nature that it will detect all potential leakage throughout the entire laboratory area. These systems should be reserved for locations where the anticipated contaminants can be measured reliably and activate the control system within a sufficiently rapid time period to provide occupant protection. In the event of a failure of the monitoring system or control components, the ventilation system should return to the designated occupied ventilation rate. Detailed analyses of flow paths, dead pockets, and failure modes under all credible scenarios should be performed to avoid exposure.

It is not the intent of [this code] to require emergency or standby power for laboratory ventilation systems. [**45:** A.7.2.2]

A.16.3.2.1.2.3 Hoods having explosionproof electrical devices are sometimes referred to as *explosionproof hoods.* This term does not imply that they will contain an explosion, only that the electrical equipment will not provide a source of ignition. [**45:** A.7.2.3]

A.16.3.2.1.3.2 Special studies such as air-dispersion modeling might be necessary to determine the location of air intakes for laboratories away from the influence of laboratory exhaust and other local point source emissions. [**45:** A.7.3.2]

A.16.3.2.1.3.4 Room air current velocities in the vicinity of fume hoods should be as low as possible, ideally less than 30 percent of the face velocity of the fume hood. Air supply diffusion devices should be as far away from fume hoods as possible and have low exit velocities. [**45:** A.7.3.4]

A.16.3.2.1.4.1 Ductless chemical fume hoods that pass air from the hood interior through an absorption filter and then discharge the air into the laboratory are only applicable for use with nuisance vapors and dusts that do not present a fire or toxicity hazard. [**45:** A.7.4.1]

A.16.3.2.1.4.2 Consideration should be made of the potential contamination of the fresh air supply by exhaust air containing vapors of flammable or toxic chemicals when using devices for energy conservation purposes.

Where fume hood exhaust is manifolded with general laboratory exhaust, energy recovery devices should be evaluated to ensure they would not recirculate contaminants through an active purge or filtration treatment. Energy recovery systems should be designed with a fail-safe alarm(s) and equipment interlocks to prevent cross contamination or recirculation from occurring, including shutdown of systems if needed.

Enthalpy wheels, in particular, have potential for cross-contamination and should be carefully evaluated for all potential hazards and failure modes.

[**45:** A.7.4.2]

A.16.3.2.1.4.4 Ducts should be sealed to prevent condensation, and so forth, from leaking into occupied areas. [**45:** A.7.4.4]

A.16.3.2.1.4.7 Laboratory fume hood containment can be evaluated using the procedures contained in ASHRAE 110, *Method of Testing Performance of Laboratory Fume Hoods.* Face velocities of 0.4 m/sec to 0.6 m/sec (80 ft/min to 120 ft/min) generally provide containment if the hood location requirements and laboratory ventilation criteria of this standard are met.

Lower flow fume hoods (those with an average face velocity or 0.3 to 0.4 m/sec (60 to 80 ft/min) are often desirable for energy conservation. Lower hood face velocities are effective with hoods designed for lower face velocities. However, many circumstances can lead to inadequate contaminant containment. These include crowding, larger equipment, high thermal loads, internal circulation from equipment and numerous other issues. Hence the owner should carefully consider all potential applications when determining the face velocity to use.

In addition to maintaining proper fume hood face velocity, fume hoods that reduce the exhaust volume as the sash opening is reduced should maintain a minimum exhaust volume to ensure that contaminants are diluted and exhausted from a hood. The chemical fume hood exhaust airflow should not be reduced to less than the flow rate recommended in ANSI/AIHA Z9.5, *Laboratory Ventilation.* [**45:** A.7.4.7]

A.16.3.2.1.4.9 Due to their low capture efficiency, canopy hoods should only be used for exhausting heat and nuisance odors and not for exhausting chemicals. It is not the intent of this standard to prohibit the use of ductless enclosures (often incorrectly called "ductless hoods"). However, the use of such devices requires careful hazard analysis and risk assessment of all potential failure modes (mechanical, breakthrough, contamination, off gassing, etc.), how the owner is able to control uses for which the enclosure will not be adequate, how the user can continuously verify that the adsorption media is working properly, and how the spent media is to be safely removed and replaced, among numerous other concerns. The committee does not believe these enclosures are a suitable replacement for a chemical fume hood except after careful and thorough analysis.

[**45:** A.7.4.9]

A.16.3.2.1.4.11 Exhaust stacks should extend at least 3 m (10 ft) above the highest point on the roof to protect personnel on the roof. Exhaust stacks might need to be much higher to dissipate effluent effectively, and studies might be necessary to determine adequate design. Related information on stack height can be found in Chapter 14, Airflow Around Buildings, of the ASHRAE *Handbook of Fundamentals.* [**45:** A.7.4.11]

A.16.3.2.1.6.4 For informative material regarding spark-resistant fan construction, see Air Movement and Control Association (AMCA) Standards Handbook 99-0401-86, *Classifications for Spark Resistant Construction.* [**45:** A.7.7.4]

A.16.3.2.1.6.6 Exhaust fans should be tested to ensure they do not rotate backward in new installations or after repair on motors. [**45:** A.7.7.6]

A.16.3.2.1.7.1(A) Specifying the flame spread rating alone does not ensure that the liner will provide containment of a small fire. [**45:** A.7.8.1.1]

A.16.3.2.1.7.1(B) Baffles normally should be adjusted for the best operating position for general use. Only where high heat loads or the routine use of large quantities of light or heavy gases occur should compensating adjustment be made. In most cases, however, the low concentrations of heavier-than-air and lighter-than-air vapors take on the characteristics of the large volumes of air going through the hood. It is recommended that the total adjustment not exceed 20 percent of the total airflow. [**45:** A.7.8.1.3]

A.16.3.2.1.7.1(C) The means of containing minor spills might consist of a 6.4 mm (¼ in.) recess in the work surface, use of pans or trays, or creation of a recess by installing a curb across the front of the hood and sealing the joints between the work surface and the sides, back, and curb of the hood. [**45:** A.7.8.1.4]

A.16.3.2.1.7.2 A hood sash greatly enhances the safety provided by a chemical fume hood, and it is recommended that the hood design incorporate this feature. For example, a hood sash can be adjusted to increase the face velocity when working on high hazard material. The sash can be used as a safety shield. It can be closed to contain a fire or runaway reaction, and it can be closed to contain experiments when the hood is left unattended. [**45:** A.7.8.2]

Hoods without sashes or hoods with a side or rear sash in addition to a front sash do not offer the same degree of protection as do hoods with protected single face openings, and, thus, their use is not recommended. A small face opening can be desirable to save exhaust air and energy or to increase the maximum face velocity on existing hoods. [**45:** A.7.8.2]

A.16.3.2.1.7.3 Users should be instructed and periodically reminded not to open sashes rapidly and to allow hood sashes to be open only when needed and only as much as necessary. [**45:** A.7.8.3]

A.16.3.2.1.7.4 Locating services, controls, and electrical fixtures external to the hood minimizes the potential hazards of corrosion and arcing. [**45:** A.7.8.4]

A.16.3.2.1.7.7(A) Where a laboratory exhaust system can be overdrawn (as in a VAV system, for which it is assumed that all hoods are not at full capacity all the time — the so-called diversity factor) the hood alarm provides immediate warning to all users that their hood is no longer working properly. Hence, an indication that the exhaust system capacity has been breached is not required, although it might be desired by the owner. [**45:** A.7.8.7]

A.16.3.2.1.7.7(B) The intent of previous versions of this standard was to provide a local device that alerted users to improper hood performance. However, many commercially common installations showed face velocities that varied slightly, particularly during operation. This has led to frequent "alarms" even when the hoods were still within their design limits. Hence a Go/No Go-type sensor is actually preferred. ANSI/AIHA Z9.5, Laboratory Ventilation, recommends alarming if the average face velocity deviates by 20 percent or more; other sources and industry practice have suggested tighter limits of 10 percent. [**45:** A.7.8.7.1]

A.16.3.2.1.8.1 A person walking past the hood can create sufficient turbulence to disrupt a face velocity of 0.5 m/sec (100 ft/min). In addition, open windows or air impingement from an air diffuser can completely negate or dramatically reduce the face velocity and can also affect negative differential air pressure. [**45:** A.7.9.1]

A.16.3.2.1.8.3 Place low hazard activities (such as desks and microscope benches) away from the chemical fume hood. The term *directly in front of* does not include those areas that are separated by a barrier such as a lab bench or other large structure that would serve as a shield. [**45:** A.7.9.3]

A.16.3.2.1.9.1 A hazard and risk assessment should be conducted for fume hood operations. Circumstances exist where hood fire suppression systems might be appropriate as a standalone protection measure or as part of a more comprehensive strategy to reduce hazards and risks. This assessment should be reviewed when fume hood operations change. See the objectives of the NFPA 45 stated in Section 1.2. [**45:** A.7.10.1]

A.16.3.2.1.9.2(10) For further information, see report entitled "An Investigation of Chemical Fume Hood Fire Protection Using Sprinkler and Water Mist Nozzles" prepared by Factory Mutual Research Corporation. [**45:** A.7.10.2(9)]

A.16.3.2.1.9.3 NFPA 91 *(see 4.2.2)* states that incompatible materials shall not be conveyed in the same system. Section 7.5.10.2 allows exhaust ducts within a laboratory unit to be combined. The apparent inconsistency is due to the focus of both standards. NFPA 45 assumes that in normal routine laboratory operations, the amount of materials released into the exhaust system is small and will be diluted below any levels of concern. [**45:**7.10.3]

A.16.3.2.1.9.3(A) In 2001 at the University of California, a fire resulted in an injury and caused approximately $3.5 million in damage. Based on the investigation, it was concluded that the practice of not having fire dampers on the exhaust duct of the ventilation system at the shaft wall appears to have been beneficial in this fire scenario. The investigation observed that the exhaust system was effective at removing significant quantities of combustion products from the building during the fire, thereby reducing the amount of combustion products spreading to other areas of the building. The shutting down of the supply air by fire dampers did not significantly hinder the exhaust system because fresh air was provided though a broken window. However, if the window had not failed, the team concluded that the exhaust system probably would not have performed as well. [**45:** A.7.10.3.1]

A.16.3.2.1.9.7 Installation of sprinklers in the void area or in the chemical fume hood is an acceptable method to prevent flame spread. [**45:** A.7.10.7]

A.16.3.2.1.10.1 Laboratory hoods in which radioactive materials are handled should be identified with the radiation hazard symbol. For information, see NFPA 801. [**45:** A.7.13.1]

A.16.3.2.1.11.1 The operating characteristics of some chemical fume hood designs, particularly auxiliary air chemical fume hoods, change at intermediate positions of sash height. It is, therefore, important to verify inward airflow over the face of the hood according to 16.3.2.1.11.1(5) at several sash heights from full open to closed. [**45:** A.7.13.1]

A number of test procedures for verifying performance of chemical fume hoods that have been installed in the field have been published. [**45:** A.7.13.1]

A test procedure is given in *Standard on Laboratory Fume Hoods*, by The Scientific Equipment and Furniture Association (SEFA), that uses a velometer and visible fume for checking hood performance. [**45:** A.7.13.1]

A standard has been issued by the American Society of Heating, Refrigerating, and Air Conditioning Engineers entitled ASHRAE 110, *Method of Testing Performance of Laboratory Fume Hoods*. [**45:** A.7.13.1]

The Environmental Protection Agency's *Procedure for Certifying Laboratory Fume Hoods to Meet EPA Standards* contains a test procedure utilizing sulfur hexafluoride as a test gas. [**45:** A.7.13.1]

A.16.3.2.1.11.5(A) The annual inspection of air supply and exhaust fans, motors, and components should ensure that equipment is clean, dry, tight, and friction-free. Bearings should be properly lubricated on a regular basis, according to manufacturers' recommendations. Protective devices should be checked to ensure that settings are correct and that ratings have been tested under simulated overload conditions. Inspections should be made by personnel familiar with the manufacturers' instructions and equipped with proper instruments, gauges, and tools. [**45:** A.7.14.5.1]

A.16.3.2.2.1.1 Reference sources include the following, contained in NFPA's *Fire Protection Guide to Hazardous Materials*:

(1) NFPA 49
(2) NFPA 325
(3) NFPA 491

[**45:** A.11.1.1]

A.16.3.2.2.1.1(D) When a new chemical is produced, it should be subjected to a hazard analysis as appropriate to the reasonably anticipated hazard characteristics of the material. Such tests might include, but are not limited to, differential thermal analysis, accelerating rate calorimetry, drop weight shock sensitivity, autoignition temperature, flash point, thermal stability under containment, heat of combustion, and other appropriate tests. [**45:**11.2.1.4]

A.16.3.2.2.1.2(D) Procedures might include chilling, quenching, cutoff of reactant supply, venting, dumping, and "short-stopping" or inhibiting. [**45:** A.11.2.8.4]

A.16.3.2.2.2.3(A) Pressure vessels require specialized design beyond the scope of normal workshop practice. For design of pressure vessels, see Section VIII, "Rules for Construction of Pressure Vessels," Division 1, ASME *Boiler and Pressure Vessel Code*. [**45:** A.11.3.5.1]

A.16.3.2.2.2.4(B) Hazards to personnel from high voltage, vapors or fumes, radiation, flames, flashbacks, and explosions should be minimized. [**45:** A.11.3.6.2]

A.16.3.2.3.1 The exhaust system should be identified "WARNING — Chemical Laboratory Exhaust" (or "Chemical Fume Hood Exhaust" or other appropriate wording). Exhaust system discharge stacks and discharge vents and exhaust system fans should be marked to identify the laboratories or work areas being served. [**45:**13.3]

A.16.4.1.2.1 For additional information, see the following:

(1) CGA Pamphlet P-1, *Safe Handling of Compressed Gases in Containers*
(2) ASME B31.1, *Power Piping* (including addendum)
(3) ANSI/ASME B31.3, *Process Piping*
(4) National Safety Council Data Sheet 1-688-86, *Cryogenic Fluids in the Laboratory*

[**45:** A.10.2.1]

A.16.4.1.2.2 Additional shutoff valves, located in accessible locations outside of the areas in which the gases are used, are acceptable. [**45:** A.10.2.3]

A.16.4.1.2.4 It is recommended that each intermediate regulator and valve also be identified. The identification should conform to ANSI A13.1, *Scheme for the Identification of Piping Systems*. [**45:** A.10.2.5]

A.16.4.1.2.5 Great care should be taken when converting a piping system from one gas to another. In addition to the requirements of 16.4.1.2.5, thorough cleaning to remove residues might be essential. For example, inert oil-pumped nitrogen will leave a combustible organic residue that is incompatible with oxygen and other oxidizing agents. Similar incompatibilities can occur with other materials. [**45:** A.10.2.6]

A.16.4.1.3.1.2 Air can be condensed when it contacts containers or piping containing cryogenic fluids. When this occurs, the concentration of oxygen in the condensed air increases, thereby increasing the likelihood of ignition of organic material. [**45:** A.10.4.1.2]

A.17.2 The requirements for indoor parking of vehicles are located within the building and fire prevention codes adopted within a jurisdiction.

The fire hazard presented by self-propelled vehicles powered by GH_2 or LH_2 is sufficiently similar to those presented by vehicles fueled by liquid gasoline or diesel fuel that no additional requirements are warranted. Studies and fire tests performed have concluded that the combustible components common to all types of automobiles can cause a vehicle fire to spread from one parked vehicle to an adjacent one but that the presence or release of hydrogen (such as through activation of a thermal pressure relief device) is not a major cause of fire spread.

Annex B Administration

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

The information in Annex B can be used to supplement the administrative requirements of Chapter 1.

B.1 Application.

B.1.1 This code shall apply to both new and existing conditions. [**1:**1.3.1]

B.1.2 Referenced Standards.

B.1.2.1 Details regarding processes, methods, specifications, equipment testing and maintenance, design standards, performance, installation, or other pertinent criteria contained in those codes and standards listed in Chapter 2 of this code shall be considered a part of this code. [**1:**1.3.2.1]

B.1.2.2 Where no applicable codes, standards, or requirements are set forth in this code or contained within other laws, codes, regulations, ordinances, or bylaws adopted by the authority having jurisdiction (AHJ), compliance with applicable codes and standards of NFPA or other nationally recognized standards as are approved shall be deemed as prima facie evidence of compliance with the intent of this code. [**1:**1.3.2.2]

B.1.2.3 Nothing herein shall diminish the authority of the AHJ to determine compliance with codes or standards for those activities or installations within the AHJ's responsibility. [**1:**1.3.2.3]

B.1.3 Conflicts.

B.1.3.1 When a requirement differs between this code and a referenced document, the requirement of this code shall apply. [**1:**1.3.3.1]

B.1.3.2 When a conflict between a general requirement and a specific requirement occurs, the specific requirement shall apply. [**1:**1.3.3.2]

B.1.4 Installations.

B.1.4.1 Buildings permitted for construction after the adoption of this code shall comply with the provisions stated herein for new buildings. [**1:**1.3.6.1]

B.1.4.2 Buildings in existence or permitted for construction prior to the adoption of this code shall comply with the provisions stated herein or referenced for existing buildings. [**1:**1.3.6.2]

B.1.4.3 Repairs, renovations, alterations, and additions to existing hydrogen installations shall conform with NFPA 2 and the adopted building code.

B.1.4.4 Newly introduced equipment, materials, and operations regulated by this code shall comply with the requirements for new construction or processes. [**1:**1.3.6.4]

B.1.4.5 Severability. If any provision of this code or the application thereof to any person or circumstance is held invalid, the remainder of the code and the application of such provision to other persons or circumstances shall not be affected thereby. [**1:**1.3.7]

B.2 Equivalencies, Alternatives, and Modifications.

B.2.1 Equivalencies. Nothing in this code is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety to those prescribed by this code, provided technical documentation is submitted to the AHJ to demonstrate equivalency and the system, method, or device is approved for the intended purpose. [**1:**1.4.1]

B.2.2 Alternatives. The specific requirements of this code shall be permitted to be altered by the AHJ to allow alternative methods that will secure equivalent fire safety, but in no case shall the alternative afford less fire safety than, in the judgment of the AHJ, that which would be provided by compliance with the provisions contained in this code. [**1:**1.4.2]

B.2.3 Modifications. The AHJ is authorized to modify any of the provisions of this code upon application in writing by the owner, a lessee, or a duly authorized representative where there are practical difficulties in the way of carrying out the provisions of the code, provided that the intent of the code shall be complied with, public safety secured, and substantial justice done. [**1:**1.4.3]

B.2.4 Buildings with equivalency, alternatives, or modifications, approved by the AHJ shall be considered as conforming with this code. [**1:**1.4.4]

B.2.5 Each application for an alternative fire protection feature shall be filed with the AHJ and shall be accompanied by such evidence, letters, statements, results of tests, or other supporting information as required to justify the request. The AHJ shall keep a record of actions on such applications, and a signed copy of the AHJ's decision shall be provided for the applicant. [**1:**1.4.5]

B.2.6 Approval. The AHJ shall approve such alternative construction systems, materials, or methods of design when it is substantiated that the standards of this code are at least equaled. If, in the opinion of the AHJ, the standards of this code shall not be equaled by the alternative requested, approval for permanent work shall be refused. Consideration shall be given to test or prototype installations. [**1:**1.4.6]

B.2.7 Tests.

B.2.7.1 Whenever evidence of compliance with the requirements of this code is insufficient or evidence that any material or method of construction does not conform to the requirements of this code, or to substantiate claims for alternative construction systems, materials, or methods of construction, the AHJ shall be permitted to require tests for proof of compliance to be made by an approved agency at the expense of the owner or his/her agent. [**1:**1.4.7.1]

B.2.7.2 Test methods shall be as specified by this code for the material in question. If appropriate test methods are not specified in this code, the AHJ is authorized to accept an applicable test procedure from another recognized source. [**1:**1.4.7.2]

B.2.7.3 Copies of the results of all such tests shall be retained in accordance with Section B.7. [**1:**1.4.7.3]

B.3 Units.

B.3.1 International System of Units. Metric units of measurement in this code are in accordance with the modernized metric system known as the International System of Units (SI). [**1:**1.5.1]

B.3.2 Primary and Equivalent Values. If a value for a measurement as given in this code is followed by an equivalent value in other units, the first stated value shall be regarded as the requirement. A given equivalent value could be approximate. [**1:**1.5.2]

B.4 Enforcement. This code shall be administered and enforced by the AHJ designated by the governing authority. *(See Annex C for sample wording for enabling legislation.)* [**1:**1.6]

B.5 Authority.

B.5.1 Administration. The provisions of this code shall apply without restriction, unless specifically exempted. [**1:**1.7.1]

B.5.2 Minimum Qualifications to Enforce this Code. The AHJ shall establish minimum qualifications for all persons assigned the responsibility of enforcing this code. [**1:**1.7.2]

B.5.3 Interpretations.

B.5.3.1 The AHJ is authorized to render interpretations of this code and to make and enforce rules and supplemental regulations in order to carry out the application and intent of its provisions. [**1:**1.7.3.1]

B.5.3.2 Such interpretations, rules, and regulations shall be in conformance with the intent and purpose of this code and shall be available to the public during normal business hours. [**1:**1.7.3.2]

B.5.4 Enforcement Assistance. Police and other enforcement agencies shall have authority to render necessary assistance in the enforcement of this code when requested to do so by the AHJ. [**1:**1.7.4]

B.5.5 Delegation of Authority. The AHJ shall be permitted to delegate to other qualified individuals such powers as necessary for the administration and enforcement of this code. [**1:**1.7.5]

B.5.6 Inspection.

B.5.6.1 The AHJ shall be authorized to inspect, at all reasonable times, any [hydrogen installation or operation] for dangerous or hazardous conditions or materials as set forth in this code. [**1:**1.7.7.1]

B.5.6.2 The AHJ shall have authority to order any person(s) to remove or remedy such dangerous or hazardous condition or material. Any person(s) failing to comply with such order shall be in violation of this code. [**1:**1.7.7.2]

B.5.6.3 To the full extent permitted by law, any AHJ engaged in fire prevention and inspection work shall be authorized at all reasonable times to enter and examine any building, structure, marine vessel, vehicle, or premises for the purpose of making fire safety inspections [of hydrogen installations and/or operations]. [**1:**1.7.7.3]

B.5.6.4 Before entering, the AHJ shall obtain the consent of the occupant thereof or obtain a court warrant authorizing entry for the purpose of inspection except in those instances where an emergency exists. [**1:**1.7.7.4]

B.5.6.5 As used in B.5.6.4, emergency means circumstances that the AHJ knows, or has reason to believe, exist and that can constitute imminent danger. [**1:**1.7.7.5]

B.5.6.6 Persons authorized to enter and inspect buildings, structures, marine vessels, vehicles, and premises as herein set forth shall be identified by credentials issued by the governing authority. [**1:**1.7.7.6]

B.5.7 Where conditions exist and are deemed hazardous to life and property by the AHJ, the AHJ shall have the authority to summarily abate such hazardous conditions that are in violation of this code. [**1:**1.7.8]

B.5.8 Interference with Enforcement. Persons shall not interfere or cause conditions that would interfere with an AHJ carrying out any duties or functions prescribed by this code. [**1:**1.7.9]

B.5.9 Impersonation. Persons shall not use a badge, uniform, or other credentials to impersonate the AHJ. [**1:**1.7.10]

B.5.10 Investigation.

B.5.10.1 Authority. The AHJ shall have the authority to investigate the cause, origin, and circumstances of any fire, explosion, [or uncontrolled release of hydrogen gas or liquid]. [**1:**1.7.11.1]

B.5.10.2 Evidence. The AHJ shall have the authority to take custody of all physical evidence relating to the cause of the fire, explosion, [or uncontrolled release of hydrogen gas or liquid]. [**1:**1.7.11.2]

B.5.10.3 Limiting Access. The AHJ shall have the authority to limit access to emergencies or other similar situations. [**1:**1.7.11.3]

B.5.10.4 Trade Secret. Information that could be related to trade secrets or processes shall not be made part of the public record except as could be directed by a court of law. [**1:**1.7.11.4]

B.5.11 Plans and Specifications.

B.5.11.1 The AHJ shall have the authority to require plans and specifications to ensure compliance with applicable codes and standards. [**1:**1.7.12.1]

B.5.11.2 Plans shall be submitted to the AHJ prior to construction unless otherwise permitted by B.5.12.4. [**1:**1.7.12.2]

B.5.11.3 The construction documents for each phase shall be complete in themselves, so that review and inspection can properly be made. Preliminary plans of the total building shall be submitted with the construction documents, and with sufficient detail, so that proper evaluation can be made. Areas and items not included in the phase to be permitted shall be shown as not included. [**5000:**1.7.6.3.3.3]

B.5.11.4 The AHJ is authorized to exempt detached one- and two-family dwellings and accessory structures from the submittal of plans. [**1:**1.7.12.4]

B.5.11.5 Plans shall be submitted to the AHJ prior to the change of occupancy of any existing building. [**1:**1.7.12.5]

B.5.11.6 Plans shall be submitted to the AHJ prior to the alteration of the means of egress or fire protection systems of any existing building. [**1:**1.7.12.6]

B.5.11.7 Plans shall be submitted to the AHJ for other conditions as deemed necessary by the AHJ to determine compliance with the applicable codes and standards. [**1:**1.7.12.7]

B.5.11.8 The AHJ shall be authorized to require permits for conditions listed in B.5.11.2, B.5.11.5, and B.5.11.6, unless otherwise permitted by B.5.11.9. [**1:**1.7.12.8]

B.5.11.9 The AHJ is authorized to exempt detached one- and two-family dwellings and accessory structures from the permit requirement of B.5.11.8. [**1:**1.7.12.9]

B.5.11.10 No construction work shall proceed until the AHJ has reviewed the plans for compliance with the applicable codes and standards and the applicable permits have been issued. [**1:**1.7.12.10]

B.5.12 Inspection of Construction and Installation.

B.5.12.1 The AHJ shall be notified by the person performing the work when the installation is ready for a required inspection. [**1:**1.7.13.1]

B.5.12.2 Whenever any installation subject to inspection prior to use is covered or concealed without having first been inspected, the AHJ shall have the authority to require that such work be exposed for inspection. [**1:**1.7.13.2]

B.5.12.3 When any construction or installation work is being performed in violation of the plans and specifications as approved by the AHJ, a written notice shall be issued to the responsible party to stop work on that portion of the work that is in violation. [**1:**1.7.13.3]

B.5.12.4 The notice shall state the nature of the violation, and no work shall be continued on that portion until the violation has been corrected. [**1:**1.7.13.4]

B.5.13 Certificate of Occupancy. If the adopted building code requires a certificate of occupancy, the certificate of occupancy shall not be issued until approved by the AHJ for the adopted fire code enforcement.

B.5.14 Stop Work Order. The AHJ shall have the authority to order an operation, construction, or use stopped when any of the following conditions exists:

(1) Work is being done contrary to provision of this code.
(2) Work is occurring without a permit required by B.5.13.
(3) An imminent danger has been created.

[**1:**1.7.15]

B.5.15 Imminent Dangers and Evacuation.

B.5.15.1 When, in the opinion of the AHJ, an imminent danger exists, the AHJ shall be authorized to order occupants to vacate, or temporarily close for use or occupancy, a building, the right-of-way, sidewalks, streets, or adjacent buildings or nearby areas. [**1:**1.7.16.1]

B.5.15.2 The AHJ shall be authorized to employ the necessary resources to perform the required work in order to mitigate the imminent danger. [**1:**1.7.16.2]

B.5.15.3 Costs incurred by the AHJ in performance of emergency work shall be the responsibility of the property owner or other responsible party creating such imminent danger. [**1:**1.7.16.3]

B.6 Fire Code Board of Appeals.

B.6.1 Establishment of Fire Code Board of Appeals. A Board of Appeals shall be established to rule on matters relating to the fire code and its enforcement. [**1:**1.10.1]

B.6.1.1 Membership.

B.6.1.1.1 The members of the Board of Appeals shall be appointed by the governing body of the jurisdiction. [**1:**1.10.1.1.1]

B.6.1.1.2 The Board of Appeals shall consist of five or seven principal members and one ex officio member representative of the AHJ. Each principal member shall be permitted to have an alternate with similar experience to serve in his or her stead when necessary. [**1:**1.10.1.1.2]

B.6.1.1.3 Members and alternate members shall be appointed based on their education, experience, and knowledge. [**1:**1.10.1.1.3]

B.6.1.1.4 Members and alternates shall be appointed to a 3-year term. [**1:**1.10.1.1.4]

B.6.1.1.5 Members and alternates shall be composed of individuals experienced in the following fields or professions:

(1) Engineering or architectural design
(2) General contracting
(3) Fire protection contracting
(4) Fire department operations or fire code enforcement
(5) Building code enforcement
(6) Legal
(7) General public

[**1:**1.10.1.1.5]

B.6.1.1.5.1 Members and alternates shall not be employees, agents, or officers of the jurisdiction. [**1:**1.10.1.1.5.1]

B.6.1.1.5.2 Members and alternates shall be residents of the jurisdiction. [**1:**1.10.1.1.5.2]

B.6.1.1.5.3 No more than one member shall represent the same field or provision listed in B.6.1.1.5. [**1:**1.10.1.1.5.3]

B.6.1.1.6 The representative of the AHJ shall be an ex officio member and shall be entitled to participate in all discussions. The ex officio member shall not be entitled to a vote. [**1:**1.10.1.1.6]

B.6.1.1.7 No member of the Board of Appeals shall sit in judgment on any case in which the member holds a direct or indirect property or financial interest in the case. [**1:**1.10.1.1.7]

B.6.1.1.8 The board shall select one of its members to serve as chair and one member to serve as vice chair. [**1:**1.10.1.1.8]

B.6.2 Rules and Procedures of the Board of Appeals. The Board of Appeals shall have the authority to establish rules and regulations for conducting its business that are consistent with the provisions of this code. [**1:**1.10.2]

B.6.3 Authority of the Board of Appeals.

B.6.3.1 The Board of Appeals shall provide for the reasonable interpretation of the provisions of this code and issue rulings on appeals of the decisions of the AHJ. [**1:**1.10.3.1]

B.6.3.2 The ruling of the Board of Appeals shall be consistent with the letter of the code or when involving issues of clarity, ensuring that the intent of the code is met with due consideration for public safety and fire fighter safety. [**1:**1.10.3.2]

B.6.3.3 The Board of Appeals shall have the authority to grant alternatives or modifications through procedures outlined in Section B.2 of the code. [**1:**1.10.3.3]

B.6.3.4 The Board of Appeals shall not have the authority to waive the requirements of the code. [**1:**1.10.3.4]

B.6.3.5 The Board of Appeals decisions shall not be precedent setting. [**1:**1.10.3.5]

B.6.4 Means of Appeals.

B.6.4.1 Any person with standing shall be permitted to appeal a decision of the AHJ to the Board of Appeals when it is claimed that any one or more of the following conditions exist:

(1) The true intent of the code has been incorrectly interpreted.
(2) The provisions of the code do not fully apply.
(3) A decision is unreasonable or arbitrary as it applies to alternatives or new materials.

[**1:**1.10.4.1]

B.6.4.2 An appeal shall be submitted to the AHJ in writing within 30 calendar days of notification of violation. The appeal shall outline all of the following:

(1) The code provision(s) from which relief is sought
(2) A statement indicating which provisions of B.6.4.1 apply
(3) Justification as to the applicability of the provision(s) cited in B.6.4.1
(4) A requested remedy
(5) Justification for the requested remedy stating specifically how the code is complied with, public safety is secured, and fire fighter safety is secured

[**1:**1.10.4.2]

B.6.4.3 Documentation supporting an appeal shall be submitted to the AHJ at least 7 calendar days prior to the Board of Appeals hearing. [**1:**1.10.4.3]

B.6.4.3.1 No additional information should be submitted to review by the Board of Appeals without the information submitted to the AHJ for their review prior to the hearing date. Additional information submitted after the filing of the appeal to the Board and AHJ should be made available to the

Board and AHJ in a timeframe that permits adequate review before the hearing date. [**1:** A.1.10.4.3]

B.6.5 Meetings and Records.

B.6.5.1 Meetings of the Board of Appeals shall be held at the call of the chair, at such other times as the board determines, and within 30 calendar days of the filing of a notice of appeal. [**1:**1.10.5.1]

B.6.5.2 All hearings before the Board of Appeals shall be open to the public. [**1:**1.10.5.2]

B.6.5.3 The Board of Appeals shall keep minutes of its proceedings showing the vote of each member on every question or, if the member is absent or fails to vote, these actions shall be recorded. [**1:**1.10.5.3]

B.6.5.4 The Board of Appeals shall keep records of its examinations and other official actions. [**1:**1.10.5.4]

B.6.5.5 Minutes and records of the Board of Appeals shall be public record. [**1:**1.10.5.5]

B.6.5.6 A quorum shall consist of not less than 5 members or alternates. [**1:**1.10.5.6]

B.6.5.7 In varying the application of any provision of this code, or in modifying an order of the AHJ, a two-thirds vote of the quorum shall be required. [**1:**1.10.5.7]

B.6.6 Decisions.

B.6.6.1 Every decision of the Board of Appeals shall be entered in the minutes of the board meeting. [**1:**1.10.6.1]

B.6.6.2 A decision of the Board of Appeals to modify an order of the AHJ shall be in writing and shall specify the manner in which such modification is made, the conditions upon which it is made, the reasons therefore, and justification linked to specific code sections. [**1:**1.10.6.2]

B.6.6.3 Every decision shall be promptly filed in the office of the AHJ and shall be open for public inspection. [**1:**1.10.6.3]

B.6.6.4 A certified copy shall be sent by mail or delivered in person to the appellant, and a copy shall be publicly posted in the office of the AHJ for 2 weeks after filing. [**1:**1.10.6.4]

B.6.6.5 The decision of the Board of Appeals shall be final, subject to such remedy as any aggrieved party might have through legal, equity, or other avenues of appeal or petition. [**1:**1.10.6.5]

B.6.6.6 If a decision of the Board of Appeals reverses or modifies a refusal, order, or disallowance of the AHJ, or varies the application of any provision of this code, the AHJ shall take action immediately in accordance with such decision. [**1:**1.10.6.6]

B.7 Records and Reports.

B.7.1 A record of examinations, approvals, equivalencies, and alternates shall be maintained by the AHJ and shall be available for public inspection during business hours in accordance with applicable laws. [**1:**1.11.1]

B.7.2 The AHJ shall keep a record of all fire prevention inspections, including the date of such inspections and a summary of any violations found to exist, the date of the services of notices, and a record of the final disposition of all violations. [**1:**1.11.2]

B.8 Permits and Approvals.

B.8.1 The AHJ shall be authorized to establish and issue permits, certificates, and approvals pertaining to conditions, operations, or materials hazardous to life or property pursuant to Section B.8. [**1:**1.12.1]

B.8.2 Applications for permits shall be made to the AHJ on forms provided by the jurisdiction and shall include the applicant's answers in full to inquiries set forth on such forms. [**1:**1.12.2]

B.8.2.1 Applications for permits shall be accompanied by such data as required by the AHJ and fees as required by the jurisdiction. [**1:**1.12.2.1]

B.8.2.2 The AHJ shall review all applications submitted and issue permits as required. [**1:**1.12.2.2]

B.8.2.3 If an application for a permit is rejected by the AHJ, the applicant shall be advised of the reasons for such rejection. [**1:**1.12.2.3]

B.8.2.4 Permits for activities requiring evidence of financial responsibility by the jurisdiction shall not be issued unless proof of required financial responsibility is furnished. [**1:**1.12.2.4]

B.8.3 Conditions of Approval.

B.8.3.1 Any conditions of the initial approval by the AHJ of a use, occupancy, permit, or construction shall remain with the use, occupancy, permit, or construction unless modified by the AHJ. [**1:**1.12.3.1]

B.8.3.2 The AHJ shall be permitted to require conditions of approval be memorialized via recording in the public records, as part of the plat, permit, or other method as approved by the AHJ. [**1:**1.12.3.2]

B.8.4 Approvals by Other Authorities Having Jurisdiction.

B.8.4.1 The AHJ shall have the authority to require evidence to show that other regulatory agencies having jurisdiction over the design, construction, alteration, repair, equipment, maintenance, process, and relocation of structures have issued appropriate approvals. [**1:**1.12.4.1]

B.8.4.2 The AHJ shall not be held responsible for enforcement of the regulations of such other regulatory agencies unless specifically mandated to enforce those agencies' regulations. [**1:**1.12.4.2]

B.8.5 Misrepresentation.

B.8.5.1 Any attempt to misrepresent or otherwise deliberately or knowingly design; install; service; maintain; operate; sell; represent for sale; falsify records, reports, or applications; or other related activity in violation of the requirements prescribed by this code shall be a violation of this code. [**1:**1.12.5.1]

B.8.5.2 Such violations shall be cause for immediate suspension or revocation of any related approvals, certificates, or permits issued by this jurisdiction. [**1:**1.12.5.2]

B.8.5.3 Such violations shall be subject to any other criminal or civil penalties as available by the laws of this jurisdiction. [**1:**1.12.5.3]

B.8.6 Permits.

B.8.6.1 A permit shall be predicated upon compliance with the requirements of this code and shall constitute written authority issued by the AHJ to maintain, store, use, or handle materials, or to conduct processes that could produce conditions hazardous to life or property, or to install equipment used in connection with such activities. [**1:**1.12.6.1]

B.8.6.2 Any permit issued under this code shall not take the place of any other approval, certificate, license, or permit required by other regulations or laws of this jurisdiction. [**1:**1.12.6.2]

B.8.6.3 Where additional permits, approvals, certificates, or licenses are required by other agencies, approval shall be obtained from those other agencies. [**1:**1.12.6.3]

B.8.6.4 The AHJ shall have the authority to require an inspection prior to the issuance of a permit. [**1:**1.12.6.4]

B.8.6.5 A permit issued under this code shall continue until revoked or for the period of time designated on the permit. [**1:**1.12.6.5]

B.8.6.6 The permit shall be issued to one person or business only and for the location or purpose described in the permit. [**1:**1.12.6.6]

B.8.6.7 Any change that affects any of the conditions of the permit shall require a new or amended permit. [**1:**1.12.6.7]

B.8.6.8 The AHJ shall have the authority to grant an extension of the permit time period upon presentation by the permittee of a satisfactory reason for failure to start or complete the work or activity authorized by the permit. [**1:**1.12.6.8]

B.8.6.9 A copy of the permit shall be posted or otherwise readily accessible at each place of operation and shall be subject to inspection as specified by the AHJ. [**1:**1.12.6.9]

B.8.6.10 Any activity authorized by any permit issued under this code shall be conducted by the permittee or the permittee's agents or employees in compliance with all requirements of this code applicable thereto and in accordance with the approved plans and specifications. [**1:**1.12.6.10]

B.8.6.11 No permit issued under this code shall be interpreted to justify a violation of any provision of this code or any other applicable law or regulation. [**1:**1.12.6.11]

B.8.6.12 Any addition or alteration of approved plans or specifications shall be approved in advance by the AHJ, as evidenced by the issuance of a new or amended permit. [**1:**1.12.6.12]

B.8.6.13 Permits shall be issued by the AHJ and shall indicate the following:

(1) Operation, activities, or construction for which the permit is issued
(2) Address or location where the operation, activity, or construction is to be conducted
(3) Name, address, and phone number of the permittee
(4) Permit number
(5) Period of validity of the permit
(6) Inspection requirements
(7) Name of the agency authorizing the permit (AHJ)
(8) Date of issuance
(9) Permit conditions as determined by the AHJ

[**1:**1.12.6.13]

B.8.6.14 Any application for, or acceptance of, any permit requested or issued pursuant to this code shall constitute agreement and consent by the person making the application or accepting the permit to allow the AHJ to enter the premises at any reasonable time to conduct such inspections as required by this code. [**1:**1.12.6.14]

B.8.7 Revocation or Suspension of Permits.

B.8.7.1 The AHJ shall be permitted to revoke or suspend a permit or approval issued if any violation of this code is found upon inspection or in case any false statements or misrepresentations have been submitted in the application or plans on which the permit or approval was based. [**1:**1.12.7.1]

B.8.7.2 Revocation or suspension shall be constituted when the permittee is duly notified by the AHJ. [**1:**1.12.7.2]

B.8.7.3 Any person who engages in any business, operation, or occupation, or uses any premises, after the permit issued therefore has been suspended or revoked pursuant to the provisions of this code, and before such suspended permit has been reinstated or a new permit issued, shall be in violation of this code. [**1:**1.12.7.3]

B.8.7.4 Permits shall be required when the amount of GH_2 exceeds 200 ft^3 (5.7 m^3) or LH_2 exceeds 1 gal (3.8 L) inside a building or 60 gal (230 L) outside a building.

B.9 Plan Review.

B.9.1 Where required by the AHJ for new construction, modification, or rehabilitation, construction documents and shop drawings shall be submitted, reviewed, and approved prior to the start of such work as provided in Section B.9. [**1:**1.14.1]

B.9.2 The applicant shall be responsible to ensure that the following conditions are met:

(1) The construction documents include all of the fire protection requirements.
(2) The shop drawings are correct and in compliance with the applicable codes and standards.
(3) The contractor maintains an approved set of construction documents on site.

[**1:**1.14.2]

B.9.3 It shall be the responsibility of the AHJ to promulgate rules that cover the following:

(1) Criteria to meet the requirements of Section B.9
(2) Review of documents and construction documents within established time frames for the purpose of acceptance or providing reasons for nonacceptance

[**1:**1.14.3]

B.9.4 Review and approval by the AHJ shall not relieve the applicant of the responsibility of compliance with this code. [**1:**1.14.4]

B.9.5 When required by the AHJ, revised construction documents or shop drawings shall be prepared and submitted for review and approval to illustrate corrections or modifications necessitated by field conditions or other revisions to approved plans. [**1:**1.14.5]

B.10 Technical Assistance.

B.10.1 The AHJ shall be permitted to require a review by an independent third party with expertise in the matter to be reviewed at the submitter's expense. [**1:**1.15.1]

B.10.2 The independent reviewer shall provide an evaluation and recommend necessary changes of the proposed design, operation, process, or new technology to the AHJ. [**1:**1.15.2]

B.10.3 The AHJ shall be authorized to require design submittals to bear the stamp of a registered design professional. [**1:**1.15.3]

B.10.4 The AHJ shall make the final determination as to whether the provisions of this code have been met. [**1:**1.15.4]

B.11 Notice of Violations and Penalties.

B.11.1 Where Required. Whenever the AHJ determines violations of this code, a written notice shall be issued to confirm such findings. [**1:**1.16.1]

B.11.2 Serving Notice of Violation.

B.11.2.1 Any order or notice of violation issued pursuant to this code shall be served upon the owner, operator, occupant, registered agent, or other person responsible for the condition or violation by one of the following means:

(1) Personal service
(2) Mail to last known address of the owner, operator, or registered agent

[**1:**1.16.2.1]

B.11.2.2 For unattended or abandoned locations, a copy of such order or notice of violation shall be posted on the premises in a conspicuous place at or near the entrance to such premises, and the order or notice shall be disseminated in accordance with one of the following:

(1) Mailed to the last known address of the owner, occupant, or registered agent
(2) Published in a newspaper of general circulation wherein the property in violation is located

[**1:**1.16.2.2]

B.11.2.3 Refusal of an owner, occupant, operator, or other person responsible for the violation to accept the violation notice shall not be cause to invalidate the violation or the notice of violation. When acceptance of a notice of violation is refused, valid notice shall have deemed to have been served under this section provided the methods of service in B.11.2.1 or B.11.2.2 have been followed. [**1:**1.16.2.3]

B.11.3 Destruction or Removal of Notice. The mutilation, destruction, or removal of a posted order or violation notice without authorization by the AHJ shall be a separate violation of this code and punishable by the penalties established by the AHJ. [**1:**1.16.3]

B.11.4 Penalties.

B.11.4.1 Any person who fails to comply with the provisions of this code, fails to carry out an order made pursuant to this code, or violates any condition attached to a permit, approval, or certificate shall be subject to the penalties established by the AHJ. [**1:**1.16.4.1]

B.11.4.2 Where the AHJ establishes a separate penalty schedule, violations of this code shall be subject to a $250.00 penalty. [**1:**1.16.4.2]

B.11.4.3 Failure to comply with the time limits of an order or notice of violation issued by the AHJ shall result in each day that the violation continues being regarded as a separate offense and shall be subject to a separate penalty. [**1:**1.16.4.3]

B.11.4.4 A separate notice of violation shall not be required to be served each day for a violation to be deemed a separate offense. [**1:**1.16.4.4]

B.11.4.5 Abatement. Where a violation creates an imminent danger, the AHJ is authorized to abate such hazard in accordance with B.5.15. [**1:**1.16.5]

Annex C Sample Ordinance Adopting NFPA 2

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

C.1 The following sample ordinance is provided to assist a jurisdiction in the adoption of this *Code* and is not part of this Code.

ORDINANCE NO.__________________

An ordinance of the *[jurisdiction]* adopting the *[year]* edition of NFPA 2, *Hydrogen Technologies Code*, and documents listed in Chapter 2 of that code; prescribing regulations governing conditions hazardous to life and property from fire or explosion; providing for the issuance of permits and collection of fees; repealing Ordinance No.______ of the *[jurisdiction]* and all other ordinances and parts of ordinances in conflict therewith; providing a penalty; providing a severability clause; and providing for publication; and providing an effective date.

BE IT ORDAINED BY THE *[governing body]* OF THE *[jurisdiction]*:

SECTION 1 That the NFPA 2, *Hydrogen Technologies Code*, and documents adopted by Chapter 2, three (3) copies of which are on file and are open to inspection by the public in the office of the *[jurisdiction's keeper of records]* of the *[jurisdiction]*, are hereby adopted and incorporated into this ordinance as fully as if set out at length herein, and from the date on which this ordinance shall take effect, the provisions thereof shall be controlling within the limits of the *[jurisdiction]*. The same are hereby adopted as the code of the *[jurisdiction]* for the purpose of prescribing regulations governing conditions hazardous to life and property from fire or explosion and providing for issuance of permits and collection of fees.

SECTION 2 Any person who shall violate any provision of this code or standard hereby adopted or fail to comply therewith; or who shall violate or fail to comply with any order made thereunder; or who shall build in violation of any detailed statement of specifications or plans submitted and approved thereunder; or failed to operate in accordance with any certificate or permit issued thereunder; and from which no appeal has been taken; or who shall fail to comply with such an order as affirmed or modified by or by a court of competent jurisdiction, within the time fixed herein, shall severally for each and every such violation and noncompliance, respectively, be guilty of a misdemeanor, punishable by a fine of not less than $_________ nor more than $_________ or by imprisonment for not less than_________ days nor more than__________ days or by both such fine and imprisonment. The imposition of one penalty for any violation shall not excuse the violation or permit it to continue; and all such persons shall be required to correct or remedy such violations or defects within a reasonable time; and when not otherwise specified the application of the above penalty shall not be held to prevent the enforced removal of prohibited conditions. Each day that prohibited conditions are maintained shall constitute a separate offense.

SECTION 3 Additions, insertions, and changes — that the *[year]* edition of NFPA 2, *Hydrogen Technologies Code*, is amended and changed in the following respects:

List Amendments

SECTION 4 That ordinance No.____________ of *[jurisdiction]* entitled *[fill in the title of the ordinance or ordinances in effect at the present time]* and all other ordinances or parts of ordinances in conflict herewith are hereby repealed.

SECTION 5 That if any section, subsection, sentence, clause, or phrase of this ordinance is, for any reason, held to be invalid or unconstitutional, such decision shall not affect the validity or constitutionality of the remaining portions of this ordinance. The *[governing body]* hereby declares that it would have passed this ordinance, and each section, subsection, clause, or phrase hereof, irrespective of the fact that any one or more sections, subsections, sentences, clauses, and phrases be declared unconstitutional.

SECTION 6 That the *[jurisdiction's keeper of records]* is hereby ordered and directed to cause this ordinance to be published. [**NOTE:** An additional provision may be required to direct the number of times the ordinance is to be published and to specify that it is to be in a newspaper in general circulation. Posting may also be required.]

SECTION 7 That this ordinance and the rules, regulations, provisions, requirements, orders, and matters established and adopted hereby shall take effect and be in full force and effect *[time period]* from and after the date of its final passage and adoption.

Annex D Physical Properties of Hydrogen

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

D.1 Physical Properties (Informative). 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. [**55:** C.1]

D.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. [**55:** C.1.1]

D.1.2 Hydrogen remains as a gas even at high pressures. It is liquefied when it is cooled to its boiling point of −423°F (−253°C). [**55:** C.1.2]

D.1.3 Hydrogen is nontoxic, but is able to 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. [**55:** C.1.3]

D.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 one fourteenth ($1/14$) as heavy as water. Liquefied hydrogen converted to gaseous hydrogen at standard conditions expands approximately 850 times. [**55:** C.2]

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 extracted from NFPA 55, Annex E.

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 L.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 percent 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:

$$d_{leak} = (0.03)^{1/2} d_{pipe(I.D.)}$$

where d_{leak} is the effective leak diameter and $d_{pipe}(I.D.)$ 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 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 can be used, or alternately the formulas at the bottom of the table can 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 percent 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, and 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.

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.)	
kPa (gauge)	**psig**	**mm**	**in.**
>103 to ≤1724	>15 to ≤250	52.50	2.067
>1724 to ≤20684	>250 to ≤3000	18.97	0.75
>20684 to ≤51711	>3000 to ≤7500	7.92	0.312
>51711 to ≤103421	>7500 to ≤15000	7.16	0.282

Table E.1(b) Hazard Parameters for Separation Distances Tables

Hydrogen unignited jet	Distance to point where concentration has decayed to 4 percent mole fraction hydrogen in air
Hydrogen jet flame	Visible flame length
Hydrogen jet flame	Distance to radiation heat flux level of 1577 W/m^2 (500 $Btu/hr \cdot ft^2$)
Hydrogen jet flame	Distance to radiation heat flux level of 4732 W/m^2 (1500 $Btu/hr \cdot ft^2$) exposure to employees for a maximum of 3 minutes
Hydrogen jet flame	Distance to combustible heat flux level of 20,000 W/m^2 (6340 $Btu/hr \cdot ft^2$)
Hydrogen jet flame	Distance to non-combustible equipment heat flux level of 25,237 W/m^2 (8000 $Btu/hr \cdot ft^2$)

E.2 Description of Engineering Hazard Models: Nomenclature. See Table E.2 for specification of the parameters used in engineering hazard models.

Table E.2 Parameters Used in Hazard Models

b	Coefficient for hydrogen in the Abel-Nobel equation of state (7.691×10^{-3} m^3/kg)
Btu	British thermal unit
C*	Non-dimensional radiant power
CH_4	Methane
C_2H_2	Acetylene
C_2H_4	Ethylene
C_3H_8	Propane
d_{eff}	The effective diameter, m
d_j	Jet exit diameter, m
d*	Jet momentum diameter, m
D_{rad}	Radiation distance, m
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 m/sec^2)
H^2	Molecular hydrogen
hr	Hour
K	The entrainment constant
K^c	The entrainment constant for a round jet
L^{vis}	Visible flame length, m
L*	Non-dimensional flame length
LFL	Lower flammability limit
LFL_{DPF}	Lower flammability limit for a downward propagating flame
LFL_{UPF}	Lower flammability limit for an upward propagating flame
m_{fuel}	Total fuel mass flow rate, kg/sec
$m_{fuel}\Delta H_c$	Total heat released due to chemical reaction, W
p_j	The jet exit pressure, bar
p_{supply}	The pressure in the supply, bar
p_{tank}	The pressure in the tank, bar
$p\infty$	The ambient pressure, bar
$q_{rad}(x,r)$	The radiant heat flux measured at a particular axial location, x, and radial location, r, W/m^2
r	Radial position, m
R_{H2}	Gas constant for hydrogen (4124.18 J/kg/K)
R_u	Universal gas constant (8314.34 J/kmol/K)
R_{max}	The maximum radial position from the flame centerline for the given heat flux level, m
S_{rad}	The total emitted radiative power, W
T_{ad}	Adiabatic flame temperature of hydrogen in air (2390 K)
u_j	Jet exit velocity, m/sec
u_{eff}	The effective velocity at the end of expansion, m/sec
x	Axial position, m
x_o	The virtual origin of the jet, m
$X(R_{max})$	The axial location at which the maximum heat flux level occurs, m
X_{rad}	The radiant fraction or the fraction of the total chemical heat release that is radiated to the surroundings

(continues)

Table E.2 ***Continued***

W_f	Flame width, m
W_{mix}	Mean molecular weight of the products of stoichiometric combustion of hydrogen in air (24.54 kg/kmol)
Z	The compressibility factor $[Z = p/(\rho RT)]$
ΔH_c	Heat of combustion, J/kg
ΔT_f	Peak flame temperature rise due to combustion heat release, K
χ	Pi
ρ_f	Flame density, kg/m^3
ρ_{gas}	The density of the exiting gas evaluated at ambient temperature and pressure, kg/m^3
ρ_j	Jet exit density, kg/m^3
$(\rho_j/\rho\infty)$	Ratio of jet gas density to ambient gas density
$\rho\infty$	Density of the ambient fluid, kg/m^3
$\bar{\eta}$	Volume fraction (mole fraction) along the centerline of the jet
τ_f	Global flame residence time, sec

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 ρ_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 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.

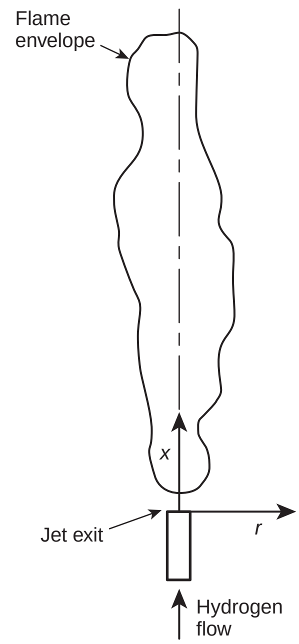


FIGURE E.2 Coordinate System for Turbulent Jet Flame and Unignited Jet.

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 ΔH_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 following form:

$$X_{rad} = S_{rad} / m_{fuel}\Delta H_c \qquad \textbf{[E.2.1a]}$$

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 following form (Sivathanu and Gore, 1993):

$$q_{rad}(x, r) = C^*(x/L_{vis})S_{rad} / 4\pi r^2 \qquad \textbf{[E.2.1b]}$$

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* can 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 CH_4, C_2H_2 and C_2H_4 as the fuel (Sivanthanu and Gore, 1993) as well as the measurements of Schefer *et al.* (2006, 2007) for large-scale H_2 jet flames.

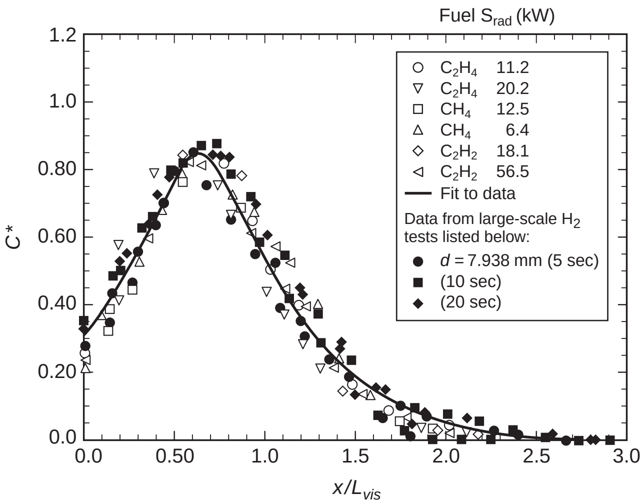


FIGURE E.2.1(a) Axial Variation of Normalized Radiative Heat Flux.

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 percent CO/43 percent H_2 mixture. A plot of the radiant fraction data from Turns and Myhr (1991) along with the radiant fraction data for large-scale H_2 flames is shown in Figure E.2.1(b). The radiant fraction data, X_{rad}, is plotted versus the global flame residence time where the residence time is given by an expression of the following form:

$$\tau_f = \left(\rho_f W_f^2 L_{vis} f_s\right) / \left(3\rho_j d_j^2 u_j\right) \qquad \textbf{[E.2.1c]}$$

where ρ_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, ρ_f, is calculated from the expression $\rho_f = p_\infty W_{mix}/(R_u T_{ad})$, where p_∞ 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 CO/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.

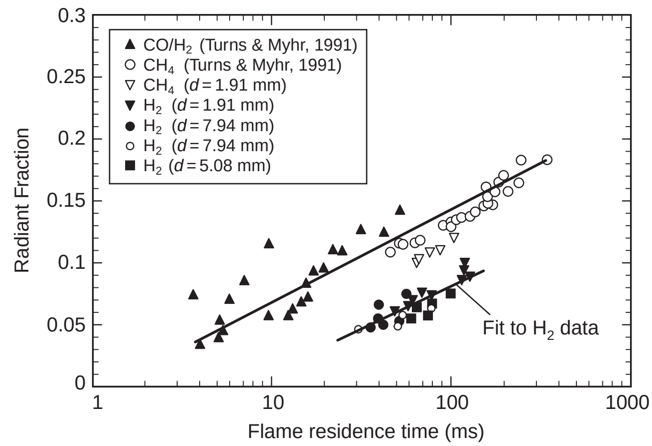


FIGURE E.2.1(b) Radiant Fraction as a Function of Flame Residence Time (Lab H_2 Flame Data for Diameters of 1.905 mm and 3.75 mm, Large-Scale H_2 Flame Test Data at Diameter of 7.94 mm).

The visible flame length, L_{vis}, is required for computing the global flame residence time, τ_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 follows:

$$Fr_f = \frac{u_j f_s^{3/2}}{\left(\rho_j/\rho_\infty\right)^{1/4}\left[\frac{\Delta T_f}{T\infty} g d_j\right]^{1/2}} \qquad \textbf{[E.2.1d]}$$

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 ΔT_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 follows:

$$L^* = \frac{L_{vis} f_s}{d_j\left(\rho_j/\rho\infty\right)^{1/2}} = \frac{L_{vis} f_s}{d^*} \qquad \textbf{[E.2.1e]}$$

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 (H_2, C_3H_8 and CH_4) and inlet flow conditions. In the buoyancy-dominated regime, L* is correlated by the following expression:

$$L^* = \frac{13.5 Fr_f^{2/5}}{\left(1 + 0.07 Fr_f^2\right)^{1/5}} \text{ for } Fr_f < 5 \qquad \textbf{[E.2.1f]}$$

and in the momentum-dominated regime by the following expression:

$$L^* = 23 \text{ for } Fr_f > 5 \quad \textbf{[E.2.1g]}$$

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 Equations E.2.1f and E.2.1g. For choked flow conditions, the concept of a notional expansion and effective source diameter *(see E.2.2)* 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 Equations E.2.1f and E.2.1g.

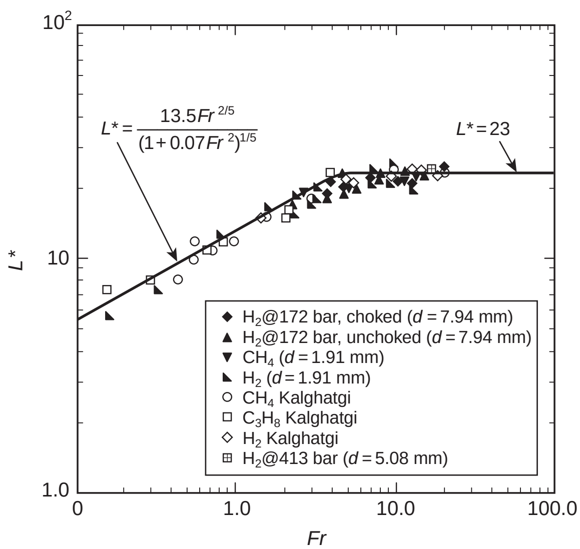


FIGURE E.2.1(c) Variation of Dimensionless Visible Flame Length with Flame Froude Number.

If the jet exit velocity and density of a hydrogen flame are known, then Equation E.2.1d can be used to calculate the flame Froude number and Equation E.2.1e and both Equation E.2.1f and Equation 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 $W_f = 0.17L_{vis}$ and used in Equation E.2.1c to compute the global flame residence time, τ_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), Equation 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, η_{cl}, (or mean mole fraction) along the centerline of the jet is given by an expression of the following form:

$$\eta_{cl}(x) = \frac{Kd_j}{x + x_o}\left(\frac{\rho\infty}{\rho_{gas}}\right)^{1/2} \quad \textbf{[E.2.2a]}$$

where K is the entrainment constant, $\rho\infty$ is the density of the ambient fluid, ρ_{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., Equation 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 as follows:

$$d_{eff} = \left(\frac{\rho_j u_j}{\rho_{gas} u_{eff}}\right)^{1/2} d_j \quad \textbf{[E.2.2b]}$$

where ρ_j is the jet exit density, u_j is the jet exit velocity, ρ_{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 following form:

$$u_{eff} = u_j + \left(P_j - P\infty\right)/\left(\rho_j u_j\right) \quad \textbf{[E.2.2c]}$$

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 Equation E.2.2a and centerline concentration decay equation becomes the following:

$$\eta_{cl}(x) = \frac{Kd_{eff}}{x + x_o}\left(\frac{\rho\infty}{\rho_{gas}}\right)^{1/2} \quad \textbf{[E.2.2d]}$$

At each axial position, x, the radial variation of the concentration is computed from the following expression:

$$\eta(x,r) = \eta_{cl}(x) e^{-K_c (r/x+x_o)^2} \quad \textbf{[E.2.2e]}$$

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 following form:

$$p = \frac{\rho R_{H_2} T}{(1 - b\rho)} \quad \textbf{[E.3.1]}$$

where the values of R_{H2} = 4,124.18 J/kg-K and b = 7.691 × 10^{-3} m^3/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 ±10 percent 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 percent 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 percent and a decrease in L* of –10 percent. Predictions from the model are found to be in good agreement with the measured hydrogen flame lengths.

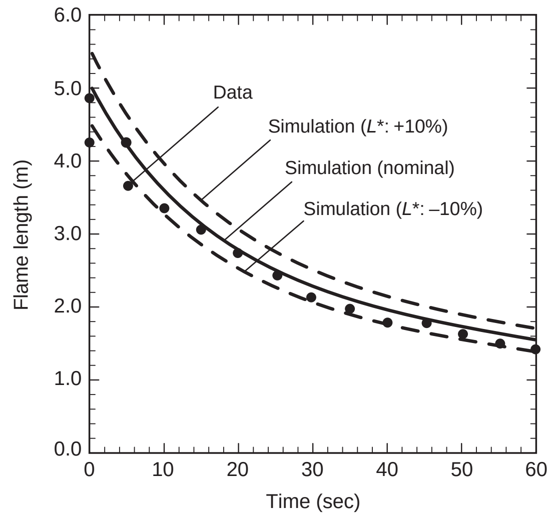


FIGURE E.3.1(a) Comparison of Simulation of Hydrogen Visible Flame Length with the Hydrogen Jet Flame Data of Schefer et al. (2006).

Figure E.3.1(b) shows a comparison of simulations and measured radiation heat flux data along the axis of a hydrogen 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 ±10 percent 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 percent to each of the 3 correlations (upper bound on radiative heat flux), and a decrease of –10 percent 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 with either an increase of 10 percent or decrease of 10 percent 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

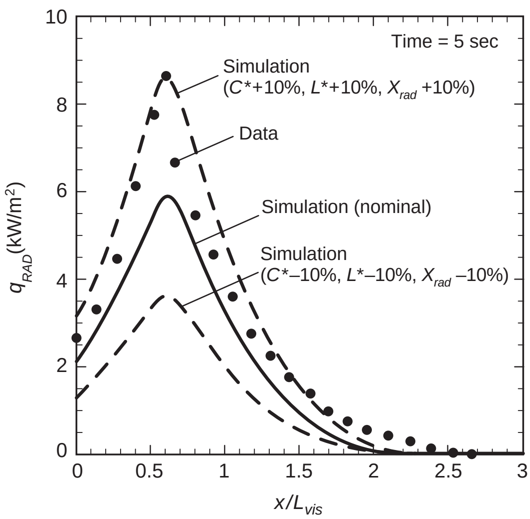


FIGURE E.3.1(b) Comparison of Simulation of Radiative Heat Flux from a Hydrogen Flame at a Radial Position of r = 1.83 m with the Data at 5 Seconds into the Blow-Down.

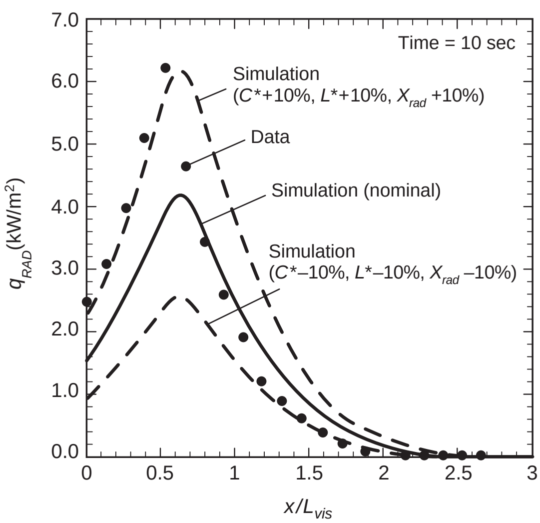


FIGURE E.3.1(c) Comparison of Simulation of Radiative Heat Flux from a Hydrogen Flame at a Radial Position of r = 1.83 m with the Data at 10 Seconds into the Blow-Down.

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 ($1/\eta_{cl}$) 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_∞ 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 ±10 percent variation in the value of the turbulent 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±10 percent 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 $x/(d_j(p_{supply}/p_\infty)^{0.5}$. 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.

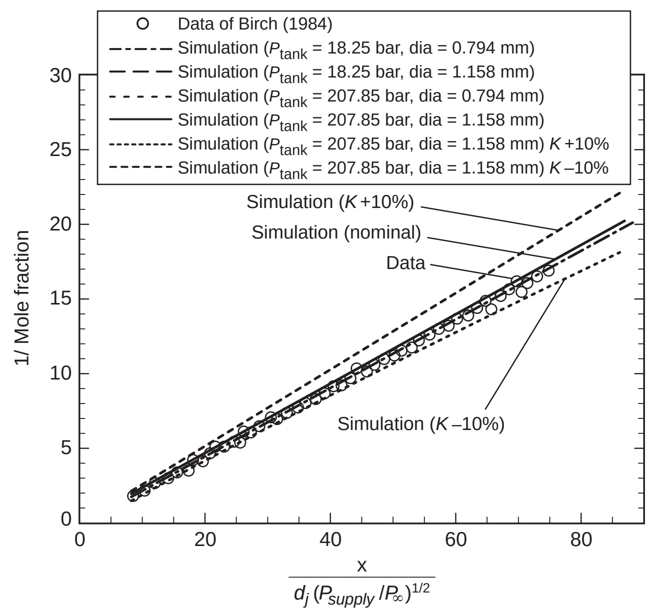


FIGURE E.3.2 Comparison of Simulation of Centerline Concentration Decay for Gas Unignited Jets with the Data of Birch [3].

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 (⅜ in.) to 0.25 mm were suggested for analysis.

For the simulations reported in this section a storage tank volume of 29.7 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 in.) and 6.35 mm (1⁄4 in.). 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 (294 K) with the end of the tubing exiting to the ambient environment (1.0133 bar, 294 K). Calculations were performed 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.

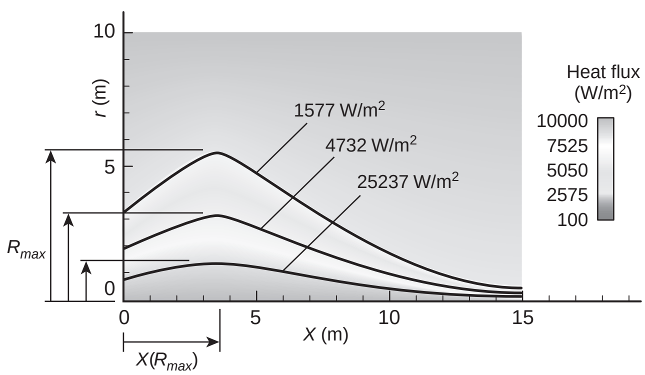


FIGURE E.4.1(a) Simulation of Radiation Heat Flux from a Hydrogen Jet Flame with a Leak Diameter of 3.175 mm and a Tank Pressure of 207.85 bar (3000 psig).

For the hydrogen jet flames, radiative heat flux contours were recorded for heat flux levels of 1577 W/m^2 (500 Btu/hr-ft^2), 4732 W/m^2 (1500 Btu/hr-ft^2), and 25237 W/m^2 (8000 Btu/hr-ft^2). 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 in.). Important safety related information recorded from the simulations includes the maximum radial position from the flame centerline for the given heat flux level, R_{max}, the axial location at which the maximum occurs, $X(R_{max})$, the combination of these two distances, D_{rad}= [R_{max}+$X(R_{max})$], and the visible flame length, L_{vis}. Figure E.4.1(b) shows a plot of D_{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_{rad} and L_{vis} assuming an uncertainty of ±10 percent in each of the values of C*, L*, and X_{rad}. Figure E.4.1(c) shows a plot of R_{max} and $X(R_{max})$ for various leak diameters for a tank pressure of 207.85 bar, including the upper and lower bounds for R_{max} and $X(R_{max})$ assuming ±10 percent uncertainty in each of the values of C*, L*, and X_{rad}. At this pressure the value of D_{rad} can be computed to approximately ±14 percent to ±18 percent depending on the jet diameter, while the flame length can be computed to approximately ±10 percent.

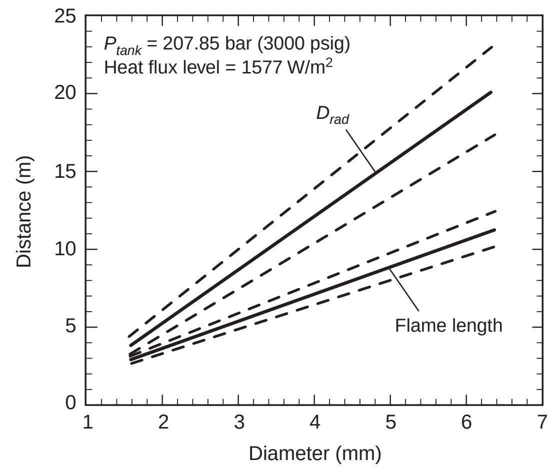


FIGURE E.4.1(b) Simulations of Hydrogen Jet Flame Radiation from a Tank at Pressure 207.85 bar (3000 psig) for Various Diameter Leaks. Results showing radiation distance, D_{rad} = ($X(R_{max})$ + R_{max}), for a heat flux level of 1577 W/m^2 and the visible flame length. Solid lines show distances using nominal values of C*, L*, and X_{rad}. Dashed lines show upper and lower bounds for D_{rad} and visible flame length with ±10 percent uncertainty in each of the values of C*, L*, and X_{rad}.

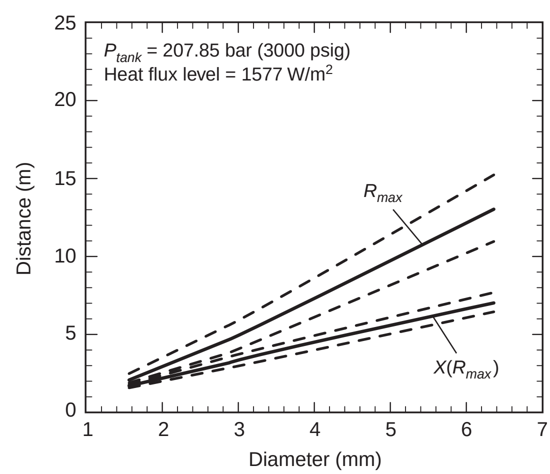


FIGURE E.4.1(c) Simulations of Hydrogen Jet Flame Radiation from a Tank at Pressure 207.85 bar (3000 psig) for Various Diameter Leaks. Results showing maximum radial distance from the flame centerline, R_{max}, for a heat flux level of 1577 W/m^2 and the axial location on centerline, $X(R_{max})$, where 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 ±10 percent uncertainty in each of the values of C*, L*, and X_{rad}.

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 in.). 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

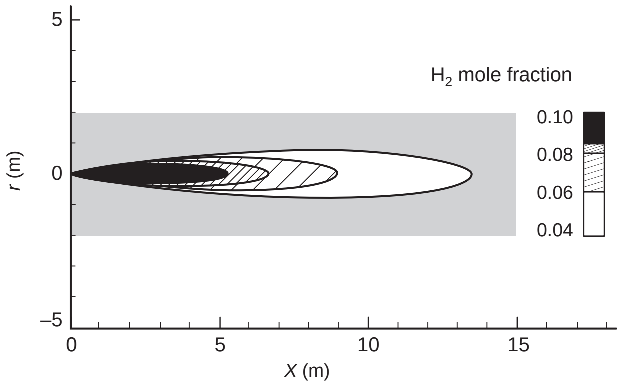


FIGURE E.4.1(d) Simulations of Concentration Decay of an Unignited Hydrogen Jet with a Diameter of 3.175 mm (⅛ in.) and a Tank Pressure of 207.85 bar (3000 psig). Contour lines correspond to mole fraction levels shown in the color legend.

upward-propagating lower flammability limit of hydrogen in air is 0.04 mole fraction, experimental data in the literature indicate that the limit can 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, 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 percent, x6 percent, x4 percent, and x2 percent 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 ±10 percent uncertainty in the turbulent jet entrainment constant *K*.

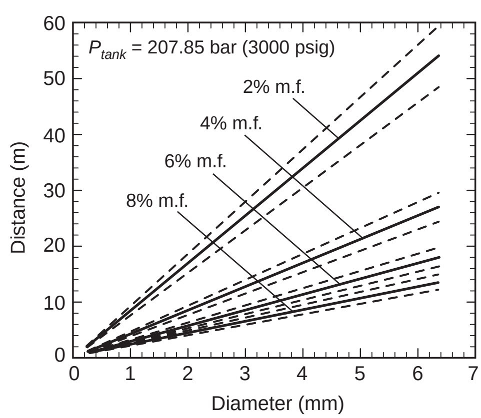


FIGURE E.4.1(e) Simulations of Concentration Decay for a Turbulent High-Momentum Supercritical Unignited Hydrogen Jet from a Tank at Pressure 207.85 bar (3000 psig) for Various Diameter Leaks. Results showing axial distance from jet origin to the point where jet concentration reaches 2.0 percent, 4.0 percent, 6.0 percent, and 8.0 percent 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 ±10 percent uncertainty in the value of K.

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(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_{rad}, for heat flux levels of 1577 W/m^2 and 4732 W/m^2. 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_{rad}) for exposure at property line (1577 W/m^2).

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 can 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 ±10 percent in each of the three experimentally measured correlations (C*, L*, X_{rad}), indicates that the radiation distance, D_{rad}, can be computed to approximately ±14 percent to ±18 percent for the jet diameters studied. The flame length can be computed to approximately ±10%. Assuming a ±10 percent uncertainty in the experimentally measured turbulent jet entrainment constant, *K*, an uncertainty analysis of the unignited jet concentration decay model indicates that concentration decay distances can be computed to ±10 percent. Figure E.7(a) through Figure E.7(e) give detailed plots of the hydrogen jet flame radiation hazard distances [D_{rad}, $X(R_{max})$, R_{max}] and unignited jet concentration decay distances (including upper and lower bounds) 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) over a range of leak diameters from 0.25 mm to 6.35 mm.

E.6 Acknowledgements. This work was supported by the U. S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Hydrogen, Fuel Cells and Infrastructure Technologies Program.

E.7 Appendix. Figure E.7(a) shows simulation results of unignited hydrogen jet concentration decay distances and their uncertainty for the range of leak diameters and tank pressures studied. Figure E.7(b) through Figure E.7(e) show simulation results of hydrogen jet flame radiation distances and their uncertainty for the range of leak diameters and tank pressures studied.

Table E.4.1(a) Hydrogen Jet Flame Radiation Distances for Selected Leak Diameters and Tank Pressures

P_{tank} (bar)	d_j (mm)	$X(R_{max})$ (m)	R_{max} (m)	D_{rad} (m)	L_{vis} (m)	Heat Flux (W/m^2)
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

Note: Assuming worst case of no pressure loss in tubing.

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Table E.4.1(b) Unignited Hydrogen Jet Concentration Decay Distances on Jet Centerline for Selected Leak Diameters, Tank Pressures, and Mole Fractions

P_{tank} (bar)	d_j (mm)	X 2% (m)	X 4% (m)	X 6% (m)	X 8% (m)
18.25	0.25	0.67	0.33	0.22	0.16
18.25	0.50	1.34	0.67	0.44	0.33
18.25	1.00	2.67	1.34	0.89	0.67
18.25	2.3810	6.36	3.18	2.12	1.59
18.25	4.2333	11.31	5.65	3.77	2.82
18.25	6.35	16.97	8.48	5.65	4.24
207.85	0.25	2.13	1.07	0.71	0.53
207.85	0.50	4.26	2.13	1.42	1.07
207.85	1.00	8.53	4.26	2.84	2.13
207.85	2.3810	20.30	10.15	6.76	5.07
207.85	4.2333	36.10	18.05	12.03	9.02
207.85	6.35	54.13	27.06	18.04	13.53
518.11	0.25	3.19	1.59	1.06	0.80
518.11	0.50	6.38	3.19	2.13	1.60
518.11	1.00	12.77	6.38	4.25	3.19
518.11	2.3810	30.39	15.19	10.13	7.598
518.11	4.2333	54.03	27.01	18.01	13.50
518.11	6.35	81.03	40.51	27.01	20.25
1035.21	0.25	4.18	2.09	1.39	1.05
1035.21	0.50	8.37	4.18	2.79	2.09
1035.21	1.00	16.74	8.37	5.58	4.18
1035.21	2.3810	39.86	19.93	13.29	9.96
1035.21	4.2333	70.85	35.42	23.62	17.71
1035.21	6.35	106.24	53.12	35.41	26.56

X2 percent indicates the distance from jet origin to the point where the centerline concentration has decayed to a mean concentration of 2 percent mole fraction.

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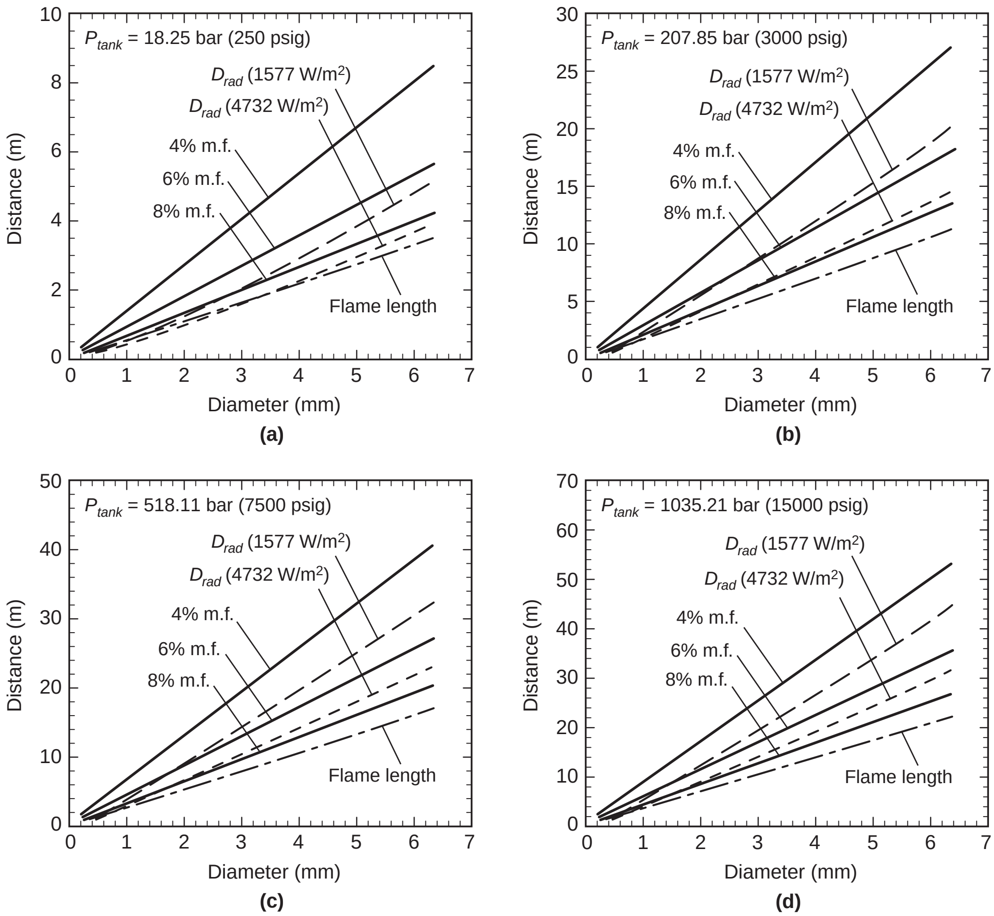

FIGURE E.4.1(f) Comparison of Simulations of Hydrogen Jet Flame Radiation Hazard Distances with Unignited Hydrogen Jet Centerline Concentration Decay Distances for Various Tank Pressures [18.25 bar (250 psig), 207.85 bar (3000 psig), 518.11 bar (7500 psig), 1035.21 bar (15000 psig)] and Leak Diameters. Dashed lines show the radiation hazard distance, $D_{rad} = (X(R_{max}) + R_{max})$, for radiation heat flux levels of 1577 W/m² and 4732 W/m² and the visible flame length. Solid lines show unignited jet concentration decay distances along jet centerline for concentration levels of 4 percent, 6 percent, and 8 percent mole fraction.

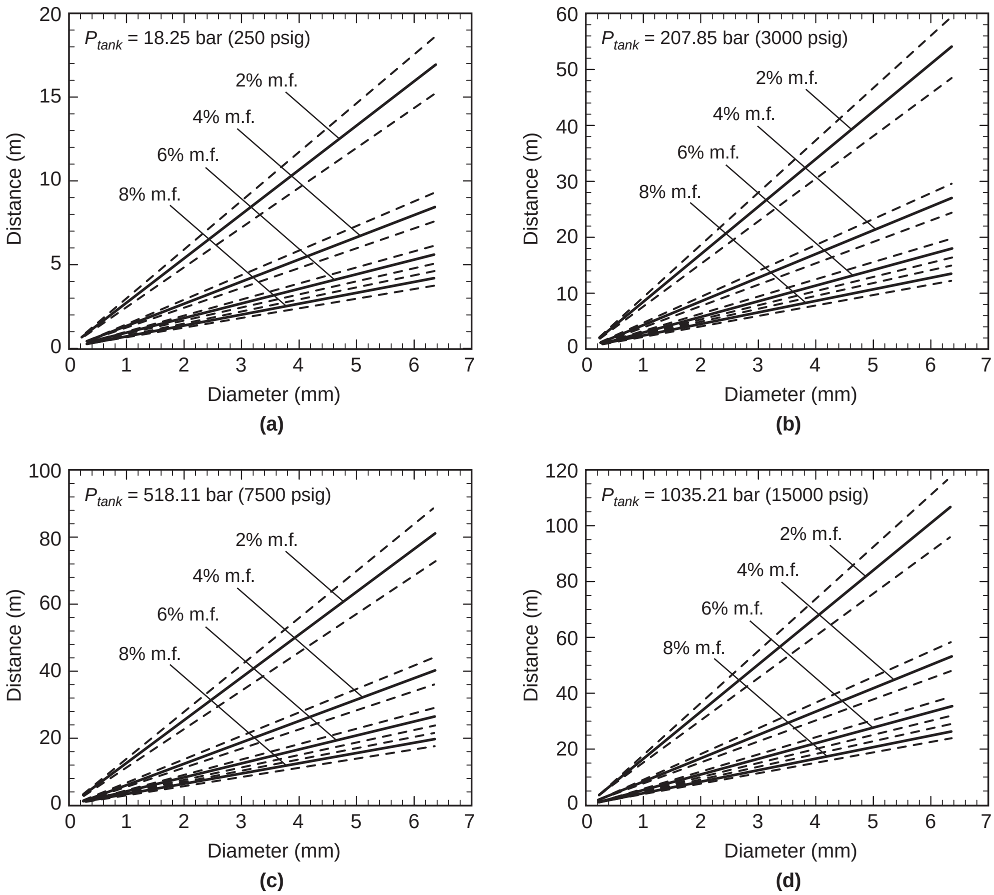

FIGURE E.7(a) Simulations of Concentration Decay for Turbulent High-Momentum Supercritical Unignited Hydrogen Jets from Tanks at Pressures from 18.25 bar (250 psig) to 1035.21 bar (15000 psig) for Various Diameter Leaks. Results showing axial distance from jet origin to the point where jet concentration reaches 2.0 percent, 4.0 percent, 6.0 percent, and 8.0 percent 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 ±10 percent uncertainty in the value of *K*.

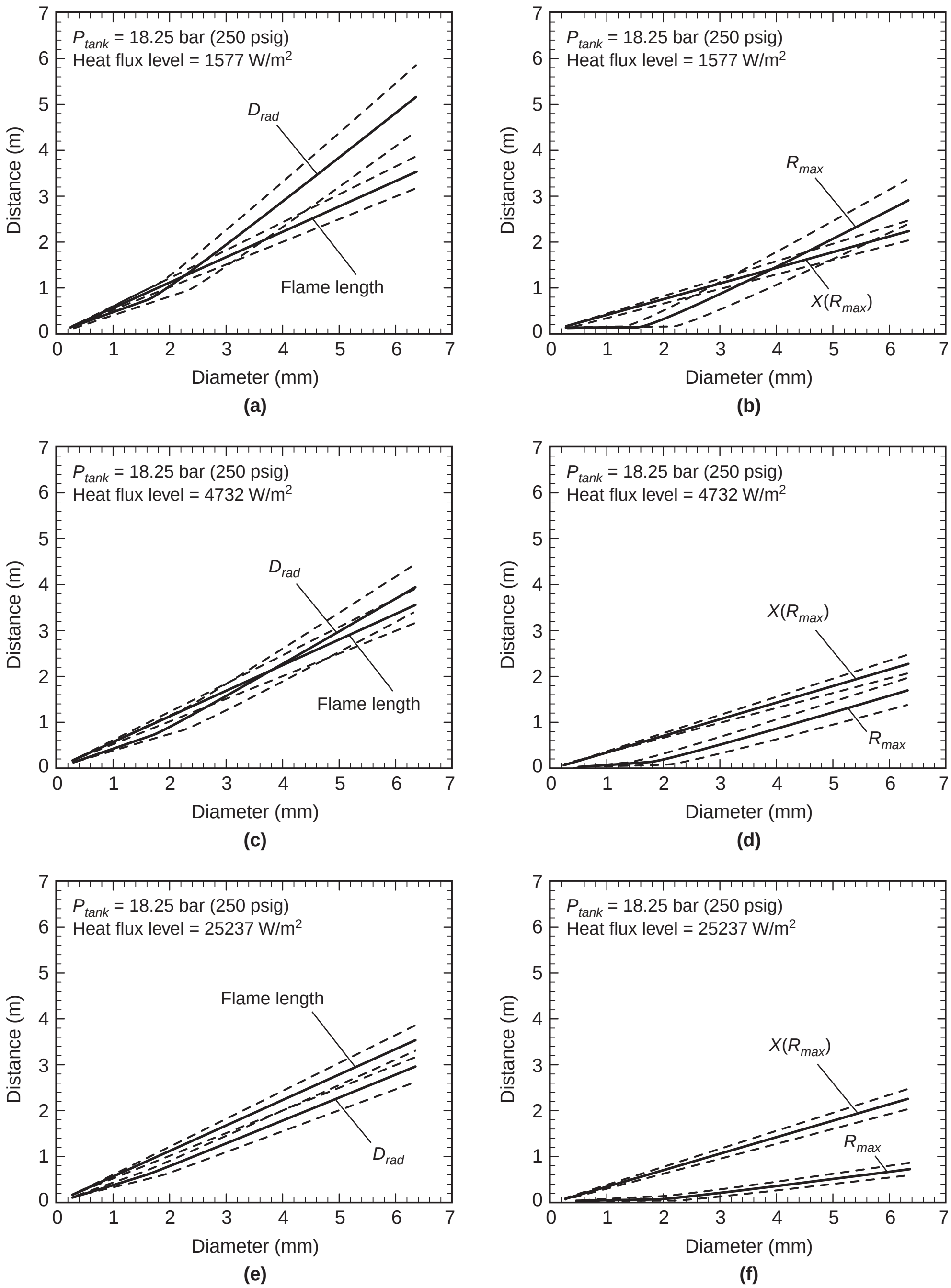

FIGURE E.7(b) Simulations of Hydrogen Jet Flame Radiation from a Tank at Pressure 18.25 bar (250 psig) for Various Diameter Leaks. Results showing maximum radial distance from the flame centerline, R, for a heat flux levels of 1577, 4732, and 25237 W/m^2 and the axial location on centerline, $X(R_{max})$, 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 ±10 percent uncertainty in each of the values of C*, L*, and X_{rad}.

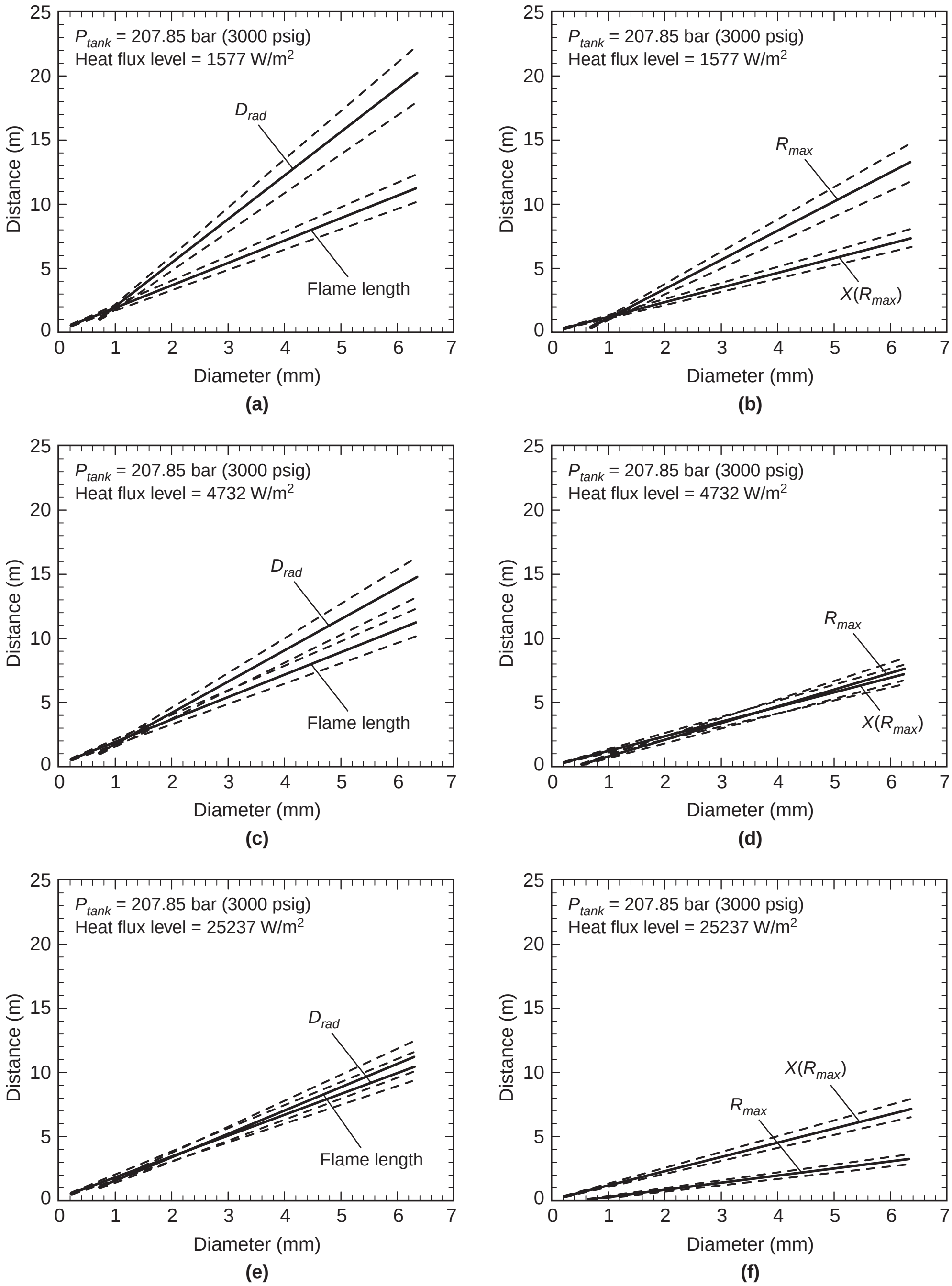

FIGURE E.7(c) Simulations of Hydrogen Jet Flame Radiation from a Tank at Pressure 207.85 bar (3000 psig) for Various Diameter Leaks. Results showing maximum radial distance from the flame centerline, R_{max}, for a heat flux levels of 1577, 4732, and 25237 W/m^2 and the axial location on centerline, $X(R_{max})$, 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 ±10 percent uncertainty in each of the values of C*, L*, and X_{rad}.

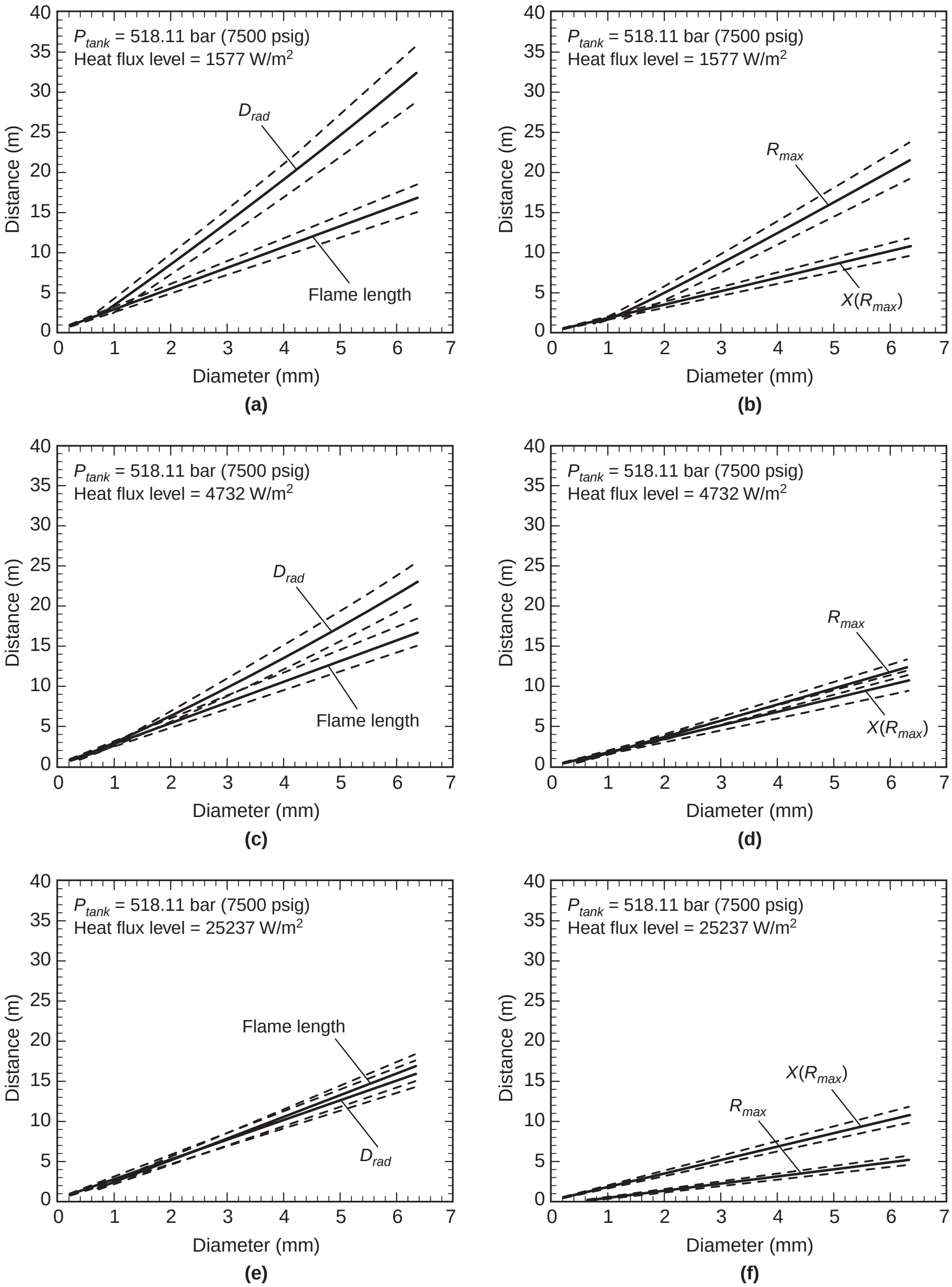

FIGURE E.7(d) Simulations of Hydrogen Jet Flame Radiation from a Tank at Pressure 518.11 bar (7500 psig) for Various Diameter Leaks. Results showing maximum radial distance from the flame centerline, R_{max}, for a heat flux levels of 1577, 4732, and 25237 W/m^2 and the axial location on centerline, 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 ±10% uncertainty in each of the values of C*, L*, and X_{rad}.

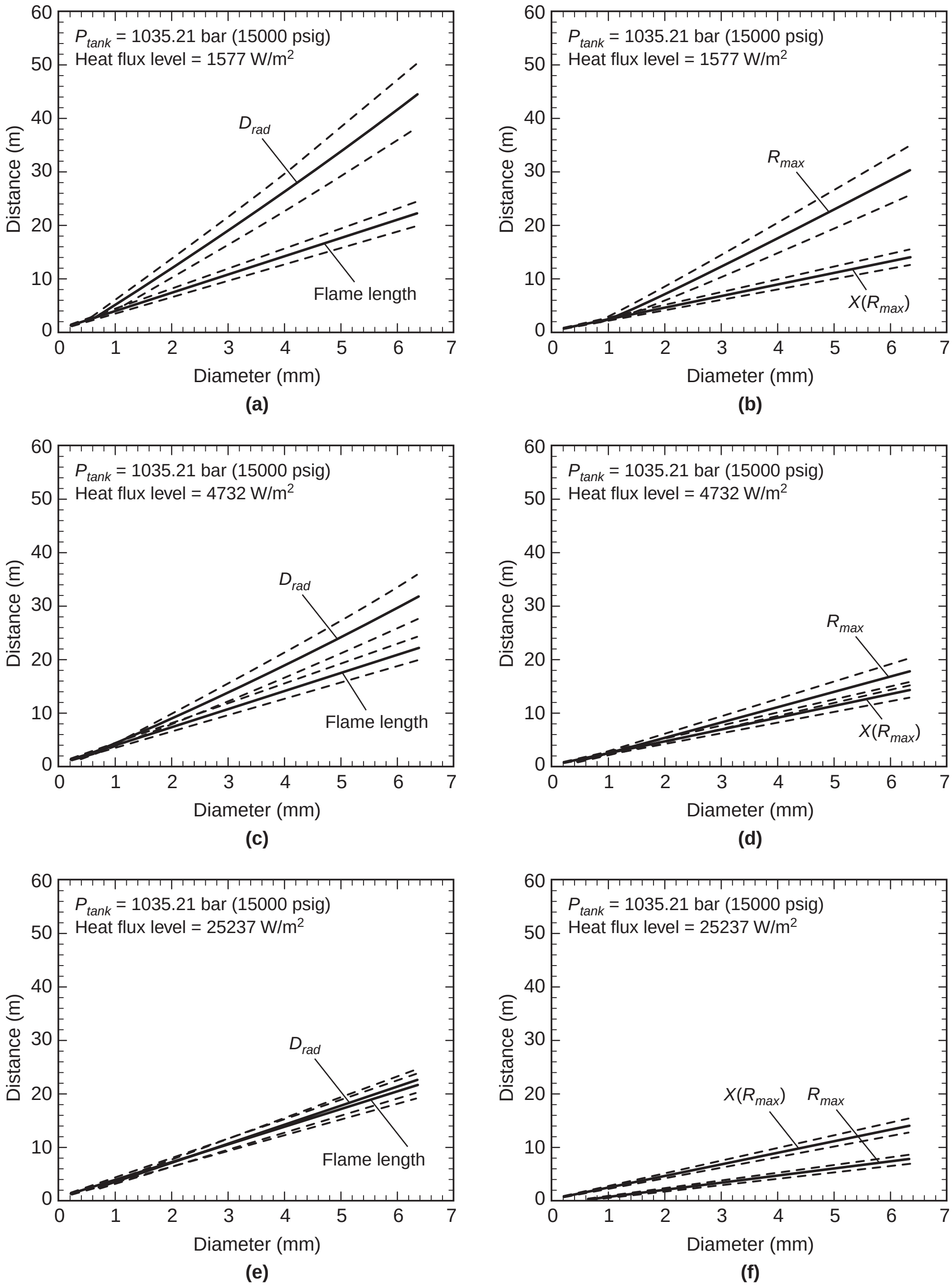

FIGURE E.7(e) Simulations of Hydrogen Jet Flame Radiation from a Tank at Pressure 1035.21 bar (15000 psig) for Various Diameter Leaks. Results showing maximum radial distance from the flame centerline, R_{max}, for a heat flux levels of 1577, 4732, and 25237 W/m^2 and the axial location on centerline, $X(R_{max})$, 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 ±10 percent uncertainty in each of the values of C*, L*, and X_{rad}.

Annex F Example of Class C Furnace Operational and Maintenance Checklist

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

F.1 Visual Operational Checklist. The following operational checks should be performed:

(1) Check burners for ignition and combustion characteristics.
(2) Check pilots or igniters, or both, for main burner ignition.
(3) Check air–fuel ratios.
(4) Check operating temperatures.
(5) Check sight drains or gauges, or both, for cooling waterflow and water temperature.
(6) Check that burners or pilots, or both, have adequate combustion air.
(7) Check the operation of ventilating equipment.

[**86:** G.1]

F.2 Regular Shift Checklist. The following regular shift checks should be performed:

(1) Take the necessary gas analyses; if automatic gas analyzers are used, the manual and automatic readings should coincide. Recalibrate automatic gas analyzers.
(2) Check the set point of control instrumentation.
(3) Check positions of hand valves, manual dampers, secondary air openings, and adjustable bypasses.
(4) Check blowers, fans, compressors, and pumps for unusual bearing noise and shaft vibration; if they are V-belt driven, check belt tension and belt fatigue.
(5) Perform lubrication in accordance with manufacturer's requirements.

[**86:** G.2]

F.3 Weekly Checklist. The following weekly checks should be performed:

(1) Inspect flame-sensing devices for condition, location, and cleanliness.
(2) Inspect thermocouples and lead wire for shorts and loose connections.
(3) Check setting and operation of low and high temperature limit devices.
(4) Test visual or audible alarm systems, or both, for proper signals.
(5) Check igniters and verify proper gap.
(6) Check all pressure switches for proper pressure settings.
(7) Check control valves, dampers, and actuators for free, smooth action and adjustment.

[**86:** G.3]

F.4 Periodic Checklist. The following maintenance checklist should be completed at intervals based on the recommendations of the manufacturer and the requirements of the process:

(1) Test the interlock sequence of all safety equipment. If possible, the interlocks should be made to fail manually, verifying that the related equipment operates as specified by the manufacturer.
(2) Test the safety shutoff valves for tightness of closure as specified by the manufacturer.
(3) Test the main fuel manual valves for operation.
(4) Test the pressure switches for proper operation.
(5) Visually inspect electrical switches, contacts, or controls for signs of arcing or contamination.
(6) Test instruments for proper response to thermocouple failure.
(7) Verify the results of a timed purge procedure, if used.
(8) Clean the air blower filters.
(9) Clean the water, gas compressor, and pump strainers.
(10) Clean the fire-check screens and valve seats and test for freedom of valve movement.
(11) Inspect burners and pilots; if necessary, clean them.
(12) Check orifice plates, air–gas mixers, flow indicators, meters, gauges, and pressure indicators; if necessary, clean or repair them.
(13) Check the ignition cables and transformers.
(14) Check the operation of modulating controls.
(15) Check the interior of the equipment, ductwork, and ventilation systems for cleanliness and flow restrictions.
(16) Test pressure-relief valves; if necessary, clean or replace them.
(17) Inspect air, water, fuel, and impulse piping for leaks.
(18) Inspect radiant tubes and heat exchanger tubes for leakage; if necessary, repair them.
(19) Lubricate the instrumentation, valve motors, valves, blowers, compressors, pumps, and other components.
(20) Test instrumentation in accordance with manufacturers' recommendations.
(21) Test flame safeguard units.

[**86:** G.4]

F.5 Maintenance of Gas Equipment.

F.5.1 General. These recommendations are prepared for maintenance of gas equipment. Special types of equipment need special attention. A preventive maintenance program that includes adherence to the manufacturer's recommendations should be established and followed. This program should establish a minimum maintenance schedule that includes inspection and action on the recommendations provided in G.6.2 through G.6.5. An adequate supply of spare parts should be maintained. [**86:** G.5.1]

F.5.2 Burners and Pilots. Burners and pilots should be kept clean and in proper operating condition. Burner refractory parts should be examined at frequent, regular intervals to ensure good condition. [**86:** G.5.2]

F.5.3 Flame Safeguard Equipment. Where automatic flame safeguards are used, a complete shutdown and restart should be made at frequent intervals to check the components for proper operation. [**86:** G.5.3]

F.5.4 Other Safeguard Equipment. Accessory safeguard equipment — such as manual reset valves, automatic safety shutoff valves, pressure or vacuum switches, high temperature limit switches, draft control, manual shutoff valves, airflow switches, door switches, and gas valves — should be operated at frequent, regular intervals to ensure proper functioning. If inoperative, they should be repaired or replaced promptly. [**86:** G.5.4]

Where fire checks are installed in air–gas mixture piping, the pressure loss across the fire checks should be measured at regular intervals. Where excessive pressure loss is found, screens should be removed and cleaned. Water-type backfire checks should be inspected at frequent intervals, and the liquid level should be maintained. [**86:** G.5.4]

F.5.5 Safety Shutoff Valves. All safety shutoff valves should be checked for leakage and proper operation at frequent, regular intervals. An example procedure for testing gas safety shutoff valves is outlined in A.7.4.9 of NFPA 86. [**86:** G.5.5]

F.6 Maintenance of Electric Furnaces and Equipment.

F.6.1 General. A program of regular inspection and maintenance of electric furnaces is essential to the safe operation of that equipment. Manufacturer's recommendations should be followed rigorously, resulting in a long, trouble-free furnace life. Suitable spare parts should be stocked to ensure quick replacement as needed. [**86:** G.6.1]

F.6.2 Heating Elements. The heating elements should be inspected at regular intervals and any foreign contamination removed. Repair is essential if elements are dislodged or distorted, causing them to touch alloy hearths or furnace components so that grounding or shorting can occur. Element terminals should be checked periodically and tightened because loose connections cause arcing and oxidation that can result in burn-out of the terminal. [**86:** G.6.2]

F.6.3 Insulation and Refractory Materials. Furnace linings need attention where protective atmospheres are used, to make certain that excessive carbon has not been deposited. Grounding or shorting of the elements can occur unless recommended burn-out procedures are followed. Cracked or broken refractory element supports should be replaced as necessary. [**86:** G.6.3]

F.6.4 Thermocouples. A regular replacement program should be established for all control and safety thermocouples. The effective life of thermocouples varies, depending on the environment and temperature, and these factors should be considered in setting up a replacement schedule. [**86:** G.6.4]

F.6.5 Auxiliary and Control Devices. Contactors should be checked and replaced periodically where pitting due to arcing could result in welding of the contacts and uncontrolled application of power to the furnace. All control components, including pyrometers and relays, should be checked periodically to ensure proper operation or control accuracy. Instructions provided by the manufacturer of each control component should be followed with care. [**86:** G.6.5]

F.6.6 Voltage. The voltage supplied to electric furnaces should be maintained within reasonable limits to ensure against overloading of control devices and transformers. Undervoltage can result in operational failure of relays and solenoid valves. [**86:** G.6.6]

F.6.7 Water Cooling. If components are water-cooled, it is important to check the flow and temperature of the cooling water frequently. [**86:** G.6.7]

F.6.8 Interlocks. Periodic checks of all safety interlocks are essential. High-frequency generators should have functioning door interlocks to prevent operators from entering the enclosure while any power is on. These safety devices should be checked frequently. [**86:** G.6.8]

Annex G Information on Explosion Hazards and Protection in Laboratories

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

G.1 Scope. This annex is intended to provide laboratory management with information to assist in understanding the potential consequences of an explosion in a laboratory and the need for adequately designed protection. It is not intended to be a design manual. [**45:** C.1]

G.2 General. [45:C.2]

G.2.1 Where a laboratory work area or a laboratory unit is considered to contain an explosion hazard great enough to cause property damage outside that laboratory work area or injury outside that laboratory area requiring medical treatment beyond first aid, appropriate protection should be provided for the occupants of the laboratory work area, the laboratory unit, adjoining laboratory units, and non-laboratory areas. [**45:** C.2]

G.2.2 Protection should be provided by one or more of the following [**45:** C.2.2]:

(1) Limiting amounts of flammable or reactive chemicals or chemicals with unknown characteristics used in or exposed by experiments
(2) Special preventive or protective measures for the reactions, equipment, or materials themselves (e.g., high-speed fire detection with deluge sprinklers, explosion-resistant equipment or enclosures, explosion suppression, and explosion venting directed to a safe location)
(3) Explosion-resistant walls or barricades around the laboratory work area containing the explosion hazard
(4) Remote control of equipment to minimize personnel exposure
(5) Sufficient deflagration venting in outside walls and/or roofs to maintain the integrity of the walls separating the hazardous laboratory work area or laboratory unit from adjoining areas
(6) Conducting experiments in a detached or isolated building or outdoors

G.2.3 Explosion-Resistant Construction. [45:C.2.3] Where explosion-resistant construction is used, adequately designed explosion resistance should be achieved by the use of one of the following methods:

(1) Reinforced concrete walls
(2) Reinforced and fully grouted concrete block walls
(3) Steel walls
(4) Steel plate walls with energy-absorbing linings
(5) Barricades, such as those used for explosives operations, constructed of reinforced concrete, sand-filled/wood-sandwich walls, wood-lined steel plate, or earthen or rock berms
(6) Specifically engineered construction assemblies

G.2.4 Explosion Venting. [45:C.2.4] Where explosion venting is used, it should be designed to ensure the following:

(1) Fragments will not strike other occupied buildings or emergency response staging areas.
(2) Fragments will not strike critical equipment (e.g., production, storage, utility services, and fire protection).
(3) Fragments will be intercepted by blast mats, energy-absorbing barrier walls, or earthen berms.

G.2.5 Unauthorized Access. [45:C.2.5] Properly posted doors, gates, fences, or other barriers should be provided to prevent unauthorized access to the following:

(1) Laboratory work areas containing an explosion hazard
(2) Laboratory units containing an explosion hazard
(3) The space between explosion vents and fragment barriers

G.2.6 Inspection and Maintenance. [45:C.2.6]

G.2.6.1 Inspection of all protective construction devices and systems should be conducted at least annually.

G.2.6.2 Required maintenance should be done to ensure integrity and operability.

G.2.6.3 Explosion shields and special explosion-containing hoods should be inspected prior to each use for deterioration, especially transparent shields and sight panels in special explosion-containing hoods.

G.3 Explosion. An explosion is the bursting or rupture of an enclosure or a container due to the development of internal pressure from a deflagration. [**69,** 2014]

Reactive explosions are further categorized as deflagrations, detonations, and thermal explosions. [**45:** G.3]

G.3.1 Container Failure. When a container is pressurized beyond its burst strength, it can violently tear asunder (explode). A container failure can produce subsonic, sonic, or supersonic shock waves, depending on the cause of the internal pressure. [**45:** C.3.1]

G.3.1.1 The energy released by failure of a vessel containing a gas or liquid is the sum of the energy of pressurization of the fluid and the strain energy in the vessel walls due to pressure-induced deformation. [**45:** C.3.1.1]

G.3.1.2 In pressurized gas systems, the energy in the compressed gas represents a large proportion of the total energy released in a vessel rupture, whereas in pressurized liquid systems, the strain energy in the container walls represents the more significant portion of the total explosion energy available, especially in high-pressure systems. [**45:** C.3.1.2]

G.3.1.3 Small-volume liquid systems pressurized to over 34,500 kPa (5000 psi), large-volume systems at low pressures, or systems contained by vessels made of materials that exhibit high elasticity should be evaluated for energy release potential under accident conditions. This does not imply that nonelastic materials of construction are preferred. Materials with predictable failure modes are preferred. [**45:** C.3.1.3]

G.3.1.4 Liquid systems containing entrained air or gas store more potential energy and are, therefore, more hazardous than totally liquid systems because the gas becomes the driving force behind the liquid. [**45:** C.3.1.4]

G.3.1.5 For gas-pressurized liquid systems, such as nitrogen over oil, an evaluation of the explosion energy should be made for both the lowest and highest possible liquid levels. [**45:** C.3.1.5]

G.3.1.6 For two-phase systems, such as carbon dioxide, an energy evaluation should be made for the entire system in the gas phase, and the expansion of the maximum available liquid to the gas phase should then be considered. [**45:** C.3.1.6]

G.3.2 Deflagration. A deflagration is propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium. [**68,** 2013]

G.3.2.1 The reaction rate is proportional to the increasing pressure of the reaction. A deflagration can, under some conditions, accelerate and build into a detonation. [**45:** C.3.2.1]

G.3.2.2 The deflagration-to-detonation transition (D-D-T) is influenced by confinement containment that allows compression waves to advance and create higher pressures that continue to increase the deflagration rates. This is commonly called *pressure piling*. [**45:** C.3.2.2]

G.3.3 Detonation.

G.3.3.1 A detonation is propagation of a combustion zone at a velocity that is greater than the speed of sound in the unreacted medium. [**68,** 2013]

G.3.3.2 A detonation causes a high-pressure shock wave to propagate outwardly, through the surrounding environment, at velocities above the speed of sound. [**45:** C.3.3.2]

G.3.4 Thermal Explosion. A thermal explosion is a self-accelerating exothermic decomposition that occurs throughout the entire mass, with no separate, distinct reaction zone. [**45:** C.3.4]

G.3.4.1 A thermal explosion can accelerate into a detonation. [**45:** C.3.4.1]

G.3.4.2 The peak pressure and rate of pressure rise in a thermal explosion are directly proportional to the amount of material undergoing reaction per unit volume of the container. This is quite unlike gas or vapor explosions, where the loading density is normally fixed by the combustible mixture at one atmosphere. Frank-Kamenetskii's "Calculation of Thermal Explosion Limits" is useful in evaluating the critical mass in the thermal explosion of solids. [**45:** C.3.4.2]

G.4 Effects of Explosions.

G.4.1 Personnel Exposure. Personnel exposed to the effects of an explosion are susceptible to injury from the following:

(1) Missiles and explosion-dispersed materials
(2) Thermal and corrosive burns
(3) Inhalation of explosion products
(4) Overpressure, including incident, reflection-reinforced incident, and sustained overpressure
(5) Body blowdown and whole-body displacement

Injuries from missiles and explosion-dispersed materials, burns, and inhalation of toxic gases account for the majority of injuries related to small explosions. Approximation of physiological damage due to explosions is given in Table G.4.1(a) and Table G.4.1(b).

[**45:** C.4.1]

G.4.2 Damage to Structural Elements. The potential for damage to high-value buildings and equipment also warrants special consideration. Failure of building components should not be overlooked as a source of injury to personnel. [**45:** C.4.2]

G.4.2.1 Where the incident impulse is reinforced by reflection, as will be the case in large explosions within or near structures, the incident peak pressures for given damage are substantially lowered. The reflected pressure might be from 2 to 19 times greater than the incident pressure, depending on the magnitude of the incident pressure and the distance from reflecting surfaces. However, when a small explosion located more than a few inches from a reflecting surface has a TNT equivalence of less than 100 gm (3.5 oz), the reinforcement phenomenon is negligible because of the rapid decay of both the incident pressure wave and the reflected pressure wave with distance. [**45:** C.4.2.1]

G.4.2.2 Thermal explosions and deflagrations having impulses with rates of pressure rise greater than 20 milliseconds require peak pressures approximately three times those of detonations in order to produce similar damage. [**45:** C.4.2.2]

Table G.4.1(a) Blast Effects from Detonations

	Range (ft) for Indicated Explosive Yield (TNT Equivalent)					
Blast Effect	**0.1 g**	**1.0 g**	**10 g**	**100 g**	**Criteria**	
1% eardrum rupture	1.1	2.4	5.2	11	23.5 kPa	(P_i = 3.4 psi)
50% eardrum rupture	0.47	1.0	2.2	4.7	110 kPa	(P_i = 16 psi)
No blowdown	0.31	1.3	6.9	~30	57 kPa · msec 0.9 m/sec	($I_i + I_q$ = 1.25 psi · msec) (V_{max} = 0.3 ft/sec)
50% blowdown	<0.1	0.29	1.1	4.1	57 kPa · msec 0.6 m/sec	($I_i + I_q$ = 8.3 psi · msec) V_{max} = 2.0 ft/sec
1% serious displacement injury	<0.1	<0.2	<0.5	~1.1	373 kPa · msec V_{max} 4 msec	($I_i + I_q$ = 54 psi · msec) (V_{max} = 13 ft/sec)
Threshold lung hemorrhage	<0.1	<0.2	0.5	1.8	180 kPa · msec	($I_i + I_q$ = 26 psi · msec)
Severe lung hemorrhage	<0.1	<0.2	<0.5	~1.1	360 kPa · msec	($I_i + I_q$ = 52 psi · msec)
1% mortality	<0.1	<0.2	<0.5	<1	590 kPa · msec	($I_i + I_q$ = 85 psi · msec)
50% mortality	<0.1	<0.2	<0.5	<1	900 kPa · msec	($I_i + I_q$ = 130 psi · msec)
50% large 1.5 m^2 to 2.3 m^2 (16 ft^2 to 25 ft^2) windows broken	0.26	1.1	5.7	~30	21 kPa · msec	(I_r = 3 psi · msec)
50% small 0.12 m^2 to 0.56 m^2 (1.3 ft^2 to 6 ft^2) windows broken	0.17	0.40	1.9	9.9	55 kPa · msec	(I_r = 8 psi · msec)

For U.S. Customary units, 1 g = 0.04 oz; 1 m = 3.3 ft.
P_i = peak incident overpressure kPa (psi)
V_{max} = maximum translational velocity for an initially standing man m/sec (ft/sec)
I_i = impulse in the incident wave kPa · msec (psi · msec)
I_q = dynamic pressure impulse in the incident wave kPa · msec (psi · msec)
I_r = impulse in the incident wave upon reflection against a surface perpendicular to its path of travel kPa · msec (psi · msec)
Note: The overpressure-distance curves of thermal explosions and deflagrations do not match those of TNT detonations. Nondetonation explosions have lower overpressures in close for comparable energy releases but carry higher overpressures to greater distances. The critical factor is impulse. Impulse is the maximum incident overpressure (psi) multiplied by the pulse duration (msec).
[**45:** Table C.4.1(a)]

Table G.4.1(b) Criteria for Estimating Missile Injuries

		Related Impact Velocity	
Kind of Missile	**Critical Organ or Event**	**m/sec**	**ft/sec**
Nonpenetrating 4.5 kg (10 lb) object	Cerebral concussion:		
	Threshold	4.6	15
	Skull fracture:		
	Threshold	4.6	15
	Near 100%	7.0	23
Penetrating* 10 gm (0.35 oz) glass fragments	Skin laceration:		
	Threshold	15	50
	Serious wounds:		
	Threshold	30	100
	50%	55	180
	100%	91	300

*Eye damage, lethality, or paralysis can result from penetrating missiles at relatively low velocities striking eyes, major blood vessels, major nerve centers, or vital organs.
[**45:** Table C.4.1(b)]

G.4.2.3 A sustained overpressure will result when a large explosion occurs in a building with few openings or inadequate explosion venting. This sustained overpressure is more damaging than a short duration explosion of equivalent rate of pressure rise and peak pressure. Explosions with TNT equivalencies of less than 100 gm (3.5 oz) would not be expected to create significant sustained overpressures, except in small enclosures. (For small explosions, burns, inhalation of toxic gases, and missile injuries usually exceed blast wave injuries.) [**45:** C.4.2.3]

G.5 Hazard Analysis.

G.5.1 The determination of the degree of hazard presented by a specific operation is a matter of judgment. An explosion hazard should be evaluated in terms of likelihood, severity, and the consequences of an explosion, as well as the protection required to substantially reduce the hazard. A review of the explosion hazard analysis by an appropriate level of management is recommended. [**45:** C.5.1]

G.5.2 The severity of an explosion is measured in terms of the rate of pressure rise, peak explosion pressure, impulse, duration of the overpressure, dynamic pressure, velocity of the propagating pressure wave, and residual overpressures. The effects of an explosion within an enclosure, such as a laboratory hood, laboratory work area, or laboratory unit can be far more severe than the effects of a similar explosion in an open space. Of primary importance is the missile hazard. Some explosions, such as in overpressurized lightweight glassware, can generate pressure waves that, in themselves, do not endanger personnel, but the resulting fragments can blind, otherwise injure, or kill the experimenter. An explosion that develops pressures sufficient to endanger personnel in a laboratory work area usually will present a serious missile hazard. Consideration of missile hazards should include primary missiles from the vessel in which the explosion originates, secondary missiles accelerated by the expanding blast wave, and the mass, shape, and velocity of the missiles. It should be noted that an improperly anchored or inadequately designed shield also can become a missile. The possibility of flames and dispersion of hot, corrosive, or toxic materials likewise should be considered. [**45:** C.5.2]

G.5.3 The likelihood of an explosion is estimated by considering such factors as the properties of the reactants; history of the reaction based on literature search, and so forth; possible intermediates and reaction products; pressure, volume, stored energy, design integrity, and safety factors of reaction vessels; pressure relief provisions, in the case of pressure vessels; and explosive limits, quantities, oxygen enrichment, and so forth, of flammable gases or vapors. The term *likelihood*, rather than *probability*, is used to describe an estimated event frequency based on experience, knowledge, or intuitive reasoning, rather than on statistical data. In general, there will be insufficient data to develop mathematical probabilities. [**45:** C.5.3]

G.5.4 The consequences of an explosion can be estimated by considering the interactions of the explosion with personnel, equipment, and building components at varying distances from the center of the explosion. This analysis should include the following:

(1) Numbers and locations of personnel
(2) Injury and fatality potentials
(3) Repair or replacement cost of equipment
(4) Ability of the building or room or equipment to withstand the explosion and the cost to restore the facility and equipment
(5) Adverse impact on research and development and business interruption costs as a result of loss of use of the facility

[**45:** C.5.4]

G.5.5 Items G.5.5.1 through G.5.5.4 contain recommendations for protecting against explosion hazards of reactions conducted above atmospheric pressures. [**45:** C.5.5]

G.5.5.1 High-pressure experimental reactions should be conducted behind a substantial fixed barricade that is capable of withstanding the expected lateral forces. The barricade should be firmly supported at top and bottom to take these forces. At least one wall should be provided with explosion venting directed to a safe location. *(See NFPA 68.)* [**45:** C.5.5.1]

G.5.5.2 Reaction vessels should be built of suitable materials of construction and should have an adequate safety factor. [**45:** C.5.5.2]

G.5.5.3 All reaction vessels should be provided with a pressure relief valve or a rupture disc. [**45:** C.5.5.3]

G.5.5.4 Low-pressure reactions should be conducted in or behind portable barricades. [**45:** C.5.5.4]

G.6 Explosion Hazard Protection.

G.6.1 It is important to remember that a conventional laboratory hood is not designed to provide explosion protection. [**45:** C.6.1]

G.6.2 The design of explosion hazard protection measures should be based on the following considerations:

(1) Blast effects, as follows:
    (a) Impulse
    (b) Rate and duration of pressure rise
    (c) Peak pressure
    (d) Duration of overpressure
    (e) Velocity of the propagating pressure wave
    (f) Residual overpressure and underpressure
(2) Missiles, as follows:
    (a) Physical properties of the material
    (b) Mass
    (c) Shape
    (d) Velocity

[**45:** C.6.2]

G.6.3 Protection can be provided by one or more of the following methods:

(1) Providing special preventive or protective measures (such as explosion suppression, high-speed fire detection with deluge sprinklers, explosion venting directed to a safe location, or explosion-resistant enclosures) for reactions, equipment, or the reactants themselves
(2) Using remote control to minimize personnel exposure
(3) Conducting experiments in a detached or isolated building, or outdoors
(4) Providing explosion-resistant walls or barricades around the laboratory
(5) Limiting the quantities of flammable or reactive chemicals used in or exposed by the experiments
(6) Limiting the quantities of reactants of unknown characteristics to fractional gram amounts until the properties of intermediate and final products are well established
(7) Providing sufficient explosion venting in outside walls to maintain the integrity of the walls separating the hazardous laboratory work area from adjacent areas (Inside walls should be of explosion-resistant construction.)
(8) Disallowing the use of explosion hazard areas for other nonexplosion hazard uses
(9) Locating offices, conference rooms, lunchrooms, and so forth, remote from the explosion hazard area

[**45:** C.6.3]

G.6.4 Explosion-Resistant Hoods and Shields. Laboratory personnel can be protected by specially designed explosion-resistant hoods or shields for TNT equivalencies up to 1.0 g (0.04 oz). For slightly greater TNT equivalencies, specially designed hoods provided with explosion venting are required. For TNT equivalencies greater than 2.0 g (0.07 oz), explosion-resistant construction, isolation, or other protective methods should be used. [**45:** C.6.4]

G.6.4.1 Conventional laboratory hoods are not designed to provide explosion protection. [**45:** C.6.4.1]

G.6.4.2 When explosion-resistant hoods or shields are used, they should be designed, located, supported, and anchored so as to do the following:

(1) Withstand the effects of the explosion
(2) Vent overpressures, injurious substances, flames, and heat to a safe location
(3) Contain missiles and fragments
(4) Prevent the formation of secondary missiles caused by failure of hood or shield components

[**45:** C.6.4.2]

G.6.4.3 Commercially available explosion shields should be evaluated against the criteria of G.6.4.2 for the specific hazard. [**45:** C.6.4.3]

G.6.4.4 Mild steel plate offers several advantages for hood and shield construction. It is economical, easy to fabricate, and tends to fail, at least initially, by bending and tearing, rather than by spalling, shattering, or splintering. [**45:** C.6.4.4]

The use of mirrors or closed-circuit television to view the experiments allows the use of nontransparent shields without hampering the experimenter. [**45:** C.6.4.4]

G.6.4.5 When transparent shields are necessary for viewing purposes, the most common materials used are safety glass, wire-reinforced glass, and acrylic or polycarbonate plastic. Each of these materials, although providing some missile penetration resistance, has a distinct failure mode. [**45:** C.6.4.5]

Glass shields tend to fragment into shards and to spall on the side away from the explosion. Plastics tend to fail by cracking and breaking into distinct pieces. Also, plastics can lose strength with age, exposure to reactants, or mechanical action. Polycarbonates exhibit superior toughness compared to acrylics. [**45:** C.6.4.5]

Glass panels and plastic composite panels (safety glass backed with polycarbonate, with the safety glass toward the explosion hazard) have been suggested as an improved shield design. The glass blunts sharp missiles, and the polycarbonate contains any glass shards and provides additional resistance to the impulse load. [**45:** C.6.4.5]

G.6.5 Explosion-Resistant Construction. As explained in G.6.4, explosion-resistant construction can be required for TNT equivalencies greater than 2.0 g (0.07 oz). Explosion-resistant construction should be designed based on the anticipated blast wave, defined in terms of peak impulse pressure and pulse duration, and the worst-case expected missile hazard, in terms of material, mass, shape, and velocity. Missile velocities of 305 m/sec to 1220 m/sec (1000 ft/sec to 4000 ft/sec) normally can be expected. [**45:** C.6.5]

G.6.5.1 The response of a wall to an explosive shock is a function of the pressure applied and of the time period over which the pressure is applied. The pressure-time product is known as impulse. [**45:** C.6.5.1]

Detonations of small quantities of explosive materials usually involve very short periods of time (tenths of milliseconds) and high average pressure. [**45:** C.6.5.1]

Gaseous deflagrations usually involve longer time periods and low average pressures. [**45:** C.6.5.1]

G.6.5.2 Information on design of explosion-resistant walls and barricades can be obtained from references in Annex I. [**45:** C.6.5.2]

G.6.6 Explosion Venting. Peak pressure and impulse loadings resulting from deflagrations (not detonations) can be significantly reduced by adequate explosion venting. *(See NFPA 68 for information on calculating required vent areas.)* [**45:** C.6.6]

G.6.6.1 Explosion vents should be designed and located so that fragments will not strike occupied buildings or areas where personnel could be located. Blast mats, energy-absorbing barriers, or earthen berms can be used to interrupt the flight of fragments. [**45:** C.6.6.1]

G.6.6.2 An air blast, unlike a missile, is not interrupted by an obstacle in its line of travel. Instead, the blast wave will diffract around the obstacle and, except for slight energy losses, is essentially fully reconstituted within five to six obstacle dimensions beyond the obstacle. However, in the case of a small [TNT equivalence of 100 g (3.5 oz) or less] explosion, the wave decay with distance can more than offset the reinforcement phenomena. [**45:** C.6.6.2]

Annex H Safety Tips for Compressed Gas Users

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

H.1 General Hazards. Thoroughly know the hazards of the gas you are using. All compressed gases have the pressure hazard, but a gas can also have more hazards; gases can be toxic, corrosive, flammable, asphyxiating, oxidizing, pyrophoric, and/or reactive. All these factors can impact the design of the system and how the gases are utilized. [**45:** F.1]

H.2 Eye Protection. Always wear eye protection when working on or near compressed gas systems. Make it your job not to let anyone without eye protection into any area where compressed gases are used or stored. [**45:** F.2]

H.3 Train Users. Never let anyone use or connect a cylinder to any system unless that person is trained and knowledgeable in the dangers of pressure, the chemical properties of the compressed gas, and the proper Compressed Gas Association (CGA) compressed gas fittings and connections. [**45:** F.3]

H.4 Cylinder Identification. Do not use a compressed gas cylinder unless the cylinder is clearly marked or labeled with the cylinder's contents. Reject any cylinder that is unmarked or has conflicting markings or labels. Never rely on the color of the cylinder to identify the contents. If there is any conflict or doubt concerning the contents, do not use the cylinder. Return it to your vendor. [**45:** F.4]

H.5 Cylinder Content. Be certain that the content of the cylinder is the correct product for use in the system to which you are connecting it. [**45:** F.5]

H.6 Regulator Use. Never use a compressed gas cylinder without a pressure-reducing regulator or device that will safely reduce the cylinder pressure to the pressure of your system. Only use regulators that have both a high-pressure gauge and a low-pressure gauge. This allows you to monitor both the pressure in the compressed gas cylinder and the pressure in the system. [**45:** F.6]

H.7 Pressure Gauge Use. As per ANSI B 40.1, *Pressure Gauges and Gauge Attachments*, never use a gauge above 75 percent of its maximum face reading. For example, a 20,700 kPa (3,000 psi) system should use at least 27,600 kPa (4,000 psi) gauges. If your system can achieve a maximum pressure of 517 kPa (75 psi), the gauge monitoring the system should be at least 690 (100 psi). (Immediately replace any gauge whose pointer does not go back to its zero point when pressure is removed.) [**45:** F.7]

H.8 Valves. Be sure the valve on the compressed gas cylinder and the pressure-reducing regulator you are using have the proper CGA connections for the pure gas (CGA V-1) or gas mixture (CGA V-7) you are using. NEVER USE AN ADAPTOR BETWEEN A CYLINDER AND A PRESSURE-REDUCING REGULATOR. [**45:** F.8]

H.9 Proper Connection. Be certain the CGA connection(s) on the cylinder and the pressure-reducing regulator fit together properly without being too loose or too tight. Proper connections will go together smoothly. Never use excessive force to connect a CGA connection. NEVER USE AN AID, such as pipe dope or Teflon® tape, TO CONNECT A REGULATOR TO A CYLINDER. [**45:** F.9]

H.10 Connections. Be certain that the pressure-reducing regulator you are using is compatible with the gas, and be certain that it is rated and marked for the maximum pressure rating of the CGA connection on the compressed gas cylinder valve you are attaching it to. All compressed gas cylinder connections can be found listed with their recommended gases and the maximum allowed pressures in CGA/ANSI V-1, Standard for Compressed Gas Cylinder Valve Outlet and Inlet Connections. [**45:** F.10]

H.11 Regulator Compatibility. Never replace the CGA connection that the regulator manufacturer has put on a regulator with one for a different gas service. Only the regulator manufacturer or a trained service representative knows the gas compatibility of the regulator's internal design and can properly reclean the regulator. [**45:** F.11]

H.12 Procedures. After attaching a pressure-reducing regulator to a compressed gas cylinder, do the following:

(1) Turn the regulator's adjustment screw out (counterclockwise) until it feels loose.
(2) Stand behind the cylinder with the valve outlet facing away from you.
(3) Observe the high-pressure gauge on the regulator from an angle; do not pressurize a gauge while looking directly at the glass or plastic faceplate.
(4) Open the valve handle on the compressed gas cylinder S-L-O-W-L-Y, until you hear the space between the cylinder valve gently fill the gas. (You can also watch the pressure rise on the high-pressure gauge. If you turned the regulator's adjustment screw back properly, there should be no gas flow out of the regulator or pressure rise on the low-pressure gauge.)
(5) If you are using a nontoxic, nonflammable gas, you can ensure purity by shutting off the cylinder valve and gently cracking the CGA connection at the cylinder valve. (Generally, three pressurizations with venting will ensure the interior of the connection has a clean, representative sample of the gas in the compressed gas cylinder. For toxic or flammable gases, you can purchase special venting regulators that can be safely vented to a fume hood or vented gas cabinet.)
(6) When you are ready to use the compressed gas cylinder, fully open the cylinder valve until you feel it stop. Then, close it one-quarter turn. (A fully open valve that has no play in it can confuse a person who is checking to see if it is open. Many accidents have been recorded by people trying to open a previously fully opened valve by using a large wrench.)
(7) Use the following practices on acetylene cylinders to allow quick closing of the valve in the event of an emergency:
    (a) Open acetylene cylinder valves no more than one and one-half turns.
    (b) Leave the wrench on the valve spindle when the cylinder is being used, if the acetylene cylinder has a T-wrench instead of a hand-wheel valve.

[**45:** F.12]

H.13 Pressure Relief. Make sure any system you are pressurizing (piping, manifolds, containers, etc.) that can be isolated or closed off has its own pressure-relief device. It is the user's responsibility to see that the system has proper pressure-relief device(s) built into it. Do not rely on the relief device on the compressed gas cylinder's regulator; it is not designed to protect downstream systems. This is very critical when cryogenic liquids are used. Pressure-relief discharge points should be vented to safe locations (not directed towards people or routed to safe locations for hazardous gases). [**45:** F.13]

H.14 Cylinders Not in Use. Shut off cylinders that are not in use. Always have a cylinder cap on any cylinder that is being stored or is not in use. [**45:** F.14]

H.15 Backflow Precautions. Use backflow check valves where flammable and oxidizing gases are connected to a common piece of equipment or where low- and high-pressure gases are connected to a common set of piping. Do not rely on a closed valve to prevent backflow. [**45:** F.15]

H.16 Pressure Relief. The relief device on a cylinder of liquefied flammable gas (generally found on the cylinder valve) always should be in direct contact (communication) with the vapor space of the cylinder in both use and storage. Never lay a cylinder of liquefied flammable gas on its side unless it is so designed (and so marked) to allow that positioning, as in the case of propane cylinders for forklift trucks. [**45:** F.16]

H.17 Protection of Cylinders in Use. Cylinders in use should be secured by a holder or device specifically designed to secure a cylinder. Never stand a single cylinder in an open area unsecured. Always protect cylinders from dangers of overhead hazards, high temperatures, and other sources of damage, such as vehicle traffic. [**45:** F.17]

H.18 Moving Cylinders. Always use a cylinder cart to move large cylinders or specially designed cylinder holders to carry small cylinders. Never pick up a cylinder by its cap. [**45:** F.18]

H.19 Refilling. Never refill a cylinder or use a cylinder for storing any material. If gas is accidentally forced back or sucked back into a cylinder, mark the cylinder well and inform your gas supplier. (Almost all recent deaths involving compressed gas cylinders occurred as users were putting gas back into cylinders and fillers at the compressed gas plants.) [**45:** F.19]

H.20 Asphyxiation. Possibly the greatest hazard to a user of compressed gases — and especially users of cryogenic fluids — is asphyxiation. Remember, that except for oxygen and for air with at least 19.5 percent oxygen, ALL GAS IS AN ASPHYXIANT. Vent gas only into safe and properly ventilated locations outside of the building or fume hood. EXPOSURE TO AN ATMOSPHERE THAT HAS 12 PERCENT OR LESS OXYGEN WILL BRING ABOUT UNCONSCIOUSNESS WITHOUT WARNING AND SO QUICKLY THAT THE INDIVIDUALS CANNOT HELP OR PROTECT THEMSELVES. [**45:** F.20]

H.21 Cryogenic Gases. If you are transferring cryogenic gases inside or have equipment using cryogenic gases that vents anything more than a few cubic centimeters of gas per minute inside (i.e., not to a hood), you should have adequate 24-hour ventilation and install continuous oxygen meter(s)/monitor(s) with a "low oxygen" alarm. [**45:** F.21]

Remember, all compressed gases are hazardous; understand those hazards completely and design your system accordingly. The major compressed gas vendors have the technical expertise available to support users. NEVER BECOME COMPLACENT WHEN USING A COMPRESSED GAS. Always respect the hazards and treat them accordingly. [**45:** F.21]

Annex I Design Standard References

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only. This annex is extracted from NFPA 55, Annex G and Annex H.

I.1 Introduction. The Occupational Safety and Health Administration (OSHA) establishes requirements for hydrogen systems in 29 CFR 1910.103. The tabular distances reflect those values published in the July 1, 2006, edition of the CFR. The criteria established in OSHA's tables of distances are based on the 1969 edition of NFPA 50A, 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 because the requirements for compressed gases and cryogenic fluids were broadened. [**55:** G.1]

Throughout the eight revision cycles of NFPA 55, the tabular distances were revised as the technology in the use of hydrogen advanced. However, the tabular 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 OSHA tables may, in fact, be accurate, it should also be recognized that the OSHA tables in some cases lack clarity and that, in other cases, hazards recognized by the ongoing evolution of the separation tables have not been acknowledged. [**55:** G.1]

For an example of lack of clarity, consider row 1 of Table I.2(a) (Building or structure). The OSHA table refers to buildings by construction types, including wood frame, heavy timber, ordinary, and fire resistive. 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 current editions of either NFPA 220, or *NFPA 5000*. [**55:** G.1]

Other examples where clarity is needed include rows 3, 4, and 5, which specify separation distance from flammable liquids, raising the question as to whether combustible liquids should be considered or ignored. Examples of hazards 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 tables and the distance tables found in the 2005 edition of NFPA 55 reveals a number of discrepancies. [**55:** G.1]

I.2 OSHA Tables. The OSHA tables [Table I.2(a) and Table I.2(b)] 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 traditionally has been a fire official, but that person might not be the only official who exercises regulatory control for installations of this nature. [**55:** G.2]

The evaluation of separation distances for bulk gaseous hydrogen systems was the subject of study of a joint task group that comprised members of NFPA's Hydrogen Technology Technical Committee and the Industrial and Medical Gases Technical Committee. The task of the group was to examine the exposure distances published in Table 10.3.2.2.1 of the 2005 edition of NFPA 55 for the purpose of validation or revision based on a scientific approach that could be substantiated either through testing or through generally accepted scientific means. [**55:** H.1]

The determination of separation distance was initially approached through the use of a consequence-based approach in which the consequences of a release of hydrogen from a system resulted either in ignition and its attendant jet flame or in an envelope of unignited gas, which was subject to dispersion. In each instance, the effects of a release on a receptor were considered within the context of hazard scenarios developed in the performance approach foundational to determining the design scenarios outlined in the performance-based option integral to NFPA 1. [1] [**55:** H.1]

Notes for each of the rows found in Table 10.4.2.2.1(a) and Table 10.4.2.2.1(b) [of NFPA 55] have been developed to inform the user of the rationale considered for each of the exposures listed in Table I.2(c) and Table I.2(d). Table I.2(c) is cross-referenced to Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b) [of NFPA 55] by row number. [**55:** H.1]

Notes are provided to indicate the specific rationale considered for each of the exposures listed. The notes are then cross-referenced to specific hazard scenarios further defined in Table I.2(d). The performance criteria and design scenarios have been extracted from NFPA 1 as indicated in the extracts provided. In the event alternative materials or methods are to be employed when bulk systems are installed, code users should be aware of the specific hazard scenarios attendant to each exposure. [**55:** H.1]

Studies by Houf and Schefer of Sandia National Laboratories predicted the radiative heat flux at various distances resulting from the ignition of turbulent jet releases of hydrogen from systems at various pressures. In addition, the concentrations of an unignited hydrogen jet in the surrounding air and the envelope of locations where the concentration falls below the lower flammability limit for hydrogen were determined. [2] Understanding the consequences of release in terms of thermal flux or the boundaries of the unignited cloud could then be used to determine distances that were believed to be appropriate based on the consequence of a release. The consequence approach is referred to as a deterministic approach because distances are determined based on consequence alone. Another consequence-based approach, found in a project sponsored by NFPA's Fire Research Foundation, to determine appropriate separation distances for certain installations of bulk gaseous hydrogen systems was also reviewed by the task group, and comparisons were made to the existing requirements in the 2005 edition of NFPA 55. [3] [**55:** H.1]

As the group evaluated the impact of the deterministic tables, it became apparent that the probability of occurrence of events could have a bearing on determining a reasonable level of safety. NFPA 55 addresses the installation of bulk hydrogen systems used for any application. Whether the installation is to serve an industrial use or an emerging technology

Table I.2(a) OSHA Table: Minimum Distance from Liquefied Hydrogen Systems to Exposure

	Size of Hydrogen System					
	<3,000 scf (85 Nm³)		3,000 to 15,000 scf (85 Nm³ to 425 Nm³)		>15,000 scf (425 Nm³)	
Type of Outdoor Exposure	**ft**	**m**	**ft**	**m**	**ft**	**m**
1. Building or structure						
Wood frame construction[1]	10	3.1	25	7.6	50	15.2
Heavy timber, noncombustible, or ordinary construction[1]	0	0	10	3.1	25	7.6
Fire resistive construction[1]	0	0	0	0	0	0
2. Wall openings						
Not above any part of a system	10	3.1	10	3.1	10	3.1
Above any part of a system	25	7.6	25	7.6	25	7.6
3. Flammable liquids above ground						
0–1000 gal (3785 L)	10	3.1	25	7.6	25	7.6
In excess of 1000 gal (3785 L)	25	7.6	50	15.2	50	15.2
4. Flammable liquids below ground — 0–1000 gal (3785 L)						
Tank	10	3.1	10	3.1	10	3.1
Vent of fill opening of tank	25	7.6	25	7.6	25	7.6
5. Flammable liquids below ground, in excess of 1000 gal (3785 L)						
Tank	20	6.1	20	6.1	20	6.1
Vent of fill opening of tank	25	7.6	25	7.6	25	7.6
6. Flammable gas storage, either high pressure or low pressure						
0–15,000 scf (425 Nm³) capacity	10	3.1	25	7.6	25	7.6
In excess of 15,000 scf (425 Nm³) capacity	25	7.6	50	15.2	50	15.2
7. Oxygen storage						
12,000 scf (340 Nm³) or less[4]				—		
More than 12,000 scf (340 Nm³)[5]				—		
8. Fast-burning solids such as ordinary lumber, excelsior, paper	50	15.2	50	15.2	50	15.2
9. Slow-burning solids such as heavy timber, coal	25	7.6	25	7.6	25	7.6
10. Open flames and welding	25	7.6	25	7.6	25[2]	7.6[2]
11. Air compressor intakes or inlets to ventilating or air-conditioning equipment	50	15.2	50	15.2	50	15.2
12. Concentration of people[3]	25	7.6	50	15.2	50	15.2

[1]Refer to NFPA 220 for definitions of various types of construction (1969).
[2]But not less than one-half the height of adjacent side wall of the structure.
[3]In congested areas such as offices, lunchrooms, locker rooms, time-clock areas.
[4]Refer to NFPA 51 (1969).
[5]Refer to NFPA 566.
[**55:** Table G.2(a)]

that uses hydrogen as an alternative fuel, the installation standards have a common basis in which the safety of the user, employees, and members of the public is of concern. Recent work undertaken by the U.S. Department of Energy to develop a scientific basis for control of this material has resulted in substantial technological advancement in the safety aspects involved in the use of hydrogen as an alternative fuel. Whether the material is used as a vehicle fuel or in classic industrial processes, the hazards of a bulk installation are similar. It was also recognized that use as an alternative fuel would have the impact of increasing the number of installations such that there would be broader exposure to the public at large. [**55:** H.1]

The work of the task group integrated the efforts of Sandia National Laboratories' risk and reliability department. LaChance, in a paper discussing the use of risk in determining acceptable separation distances, explains the focus of ongoing work to provide a defensible analysis strategy for risk and consequence assessment of unintended releases from hydrogen systems, generally referred to as a scientific

Table I.2(b) OSHA Table: Minimum Distance (Feet) from Liquefied Hydrogen Systems to Exposure[1,2]

	Liquefied Hydrogen Storage					
	39.63–3,500 gal (150–13,249 L)		3,501–15,000 gal (13,249–56,780 L)		15,001–30,000 gal (56,780–113,559 L)	
Type of Outdoor Exposure	ft	m	ft	m	ft	m
1. Fire resistive building and fire walls[3]	5	1.5	5	1.5	5	1.5
2. Noncombustible building[3]	25	7.6	50	15.2	75	22.9
3. Other buildings[3]	50	15.2	75	22.9	100	30.5
4. Wall openings, air-compressor intakes, inlets for air-conditioning or ventilating equipment	75	22.9	75	22.9	75	22.9
5. Flammable liquids (above ground and vent or fill openings if below ground) (See 513 and 514)	50	15.2	75	22.9	100	30.5
6. Between stationary liquid hydrogen containers	5	1.5	5	1.5	5	1.5
7. Flammable gas storage	50	15.2	75	22.9	100	30.5
8. Liquid oxygen storage and other oxiders (See 513 and 514)	100	30.5	100	30.5	100	30.5
9. Combustible solids	50	15.2	75	22.9	100	30.5
10. Open flames, smoking and welding	50	15.2	50	15.2	50	15.2
11. Air compressor intakes or inlets to ventilating or air-conditioning equipment	50	15.2	50	15.2	50	15.2
12. Concentrations of people[4]	75	22.9	75	22.9	75	22.9

[1]The distances in Nos. 2, 3, 5, 7, 9, and 12 may be reduced where protective structures such as fire walls equal to the top of the container, to safeguard the liquefied hydrogen storage system, are located between the liquefied hydrogen installation and the exposure.

[2]Where protective structures are provided, ventilation and confinement of product should be considered. The 5 ft (1.5 m) distance in Nos. 1 and 6 facilitates maintenance and enhances ventilation.

[3]Refer to NFPA 220 for definitions of various types of construction (1969).

[4]In congested areas such as offices, lunchrooms, locker rooms, time-clock areas.

[**55:** Table G.2(b)]

basis for the establishment of separation distances, and describes the work in pertinent part as follows: [**55:** H.1]

As part of the U.S. Department of Energy Hydrogen, Fuel Cells & Infrastructure Technologies Program, Sandia National Laboratories is developing the technical basis for assessing the safety of hydrogen-based systems for use in the development/modification of relevant codes and standards. The project impacts most areas of hydrogen utilization, including bulk transportation and distribution, storage, production and utilization. Sandia is developing benchmark experiments and a defensible analysis strategy for risk and consequence assessment of unintended releases from hydrogen systems. This work includes experimentation and modeling to understand the fluid mechanics and dispersion of hydrogen for different release scenarios, including investigations of hydrogen combustion and subsequent heat transfer from hydrogen flames. The resulting technical information is incorporated into engineering models that are used for assessment of different hydrogen release scenarios and for input into quantitative risk assessments (QRA) of hydrogen facilities. [**55:** H.1]

The QRAs are used to identify and quantify scenarios for the unintended release of hydrogen, identify the significant risk contributors at different types of hydrogen facilities, and to identify potential accident prevention and mitigation strategies to reduce the risk to acceptable levels. The results of the QRAs are one input into a risk-informed codes and standards development process that can also include other considerations by the code and standard developers. Examples of these other considerations can include the results of deterministic analyses of selected accidents scenarios, the need for defense-in-depth for certain safety features (e.g., overpressure protection), the use of safety margins for high-pressure components, and requirements identified from the actual occurrences at hydrogen facilities. [4] [**55:** H.1]

To evaluate risk, the history of leakage data from high pressure compressed gas systems was needed. Hydrogen-specific leak data were provided by one of the major suppliers through the use of a 5-year documented collection of leak data from both industrial and fueling uses. These data were augmented with data from other sources after being reviewed for applicability, and representative values were selected. The source documents considered in augmentation of hydrogen-specific data included the following publications [**55:** H.1]:

(1) "Determination of Safety Distances," European Industrial Gases Association, IGC Doc 75/07/E, 2007
(2) A. W. Cox, F. P. Lees, and M. L. Ang, "Classification of Hazardous Locations," Institution of Chemical Engineers, May 2003
(3) C. H. Blanton and S. A. Eide, "Savannah River Site Generic Data Base Development," WSRC-TR-93-262, Westinghouse Savannah River Company, June 30, 1993
(4) J. Spouge, "New Generic Leak Frequencies for Process Equipment," *Process Safety Progress* (Vol. 24, No. 4), December 2005

[**55:** H.2]

A hierarchy was developed that gave hydrogen-specific data the highest priority, followed by non-gas-specific data where available for high pressure components. Piping and instrumentation drawings (P&IDs) were then prepared to define a standard bulk supply system in terms of modules that might be found in the typical system. The P&IDs can be found in A.3.3.227.2. The P&IDs were reviewed by suppliers and the typical nature verified. [**55:** H.1]

Frequency and size of leaks encountered were evaluated across a number of systems, including both industrial and fueling operations. The leak/failure data were then applied to "typical" fitting counts (components) integral to each of the modules identified in the P&IDs for each of the components. The failure data were based on the most recent 5-year history for high pressure systems. Hydrogen-specific data were provided by Compressed Gas Association (CGA) representatives. These data were augmented by failure data from other resources obtained by researchers from Sandia National Laboratories and combined to quantify a probability for failure on a component-by-component basis [hoses (pigtails), valves, elbows, tees, pipe, gauges, etc.]. The analysis resulted in a probability for failure being developed for each component, which could then be wrapped into failures expected across the spectrum of the various modules included in the array of P&IDs developed. [**55:** H.1]

A Bayesian approach to the determination of probability was used in the analysis of data by researchers at Sandia National Laboratories. The technical approach and supporting details can be found in the articles listed in Annex E and informational articles found in M.2. The advantage of the Bayesian approach is that it can combine data from different sources to include uncertainty. This approach is contrary to what has been done in other sources. For example, judgment can be used as a means to determine risk; however, that method does not provide for uncertainty. Such methods are qualitative at best. By comparison, the use of specific leak data results in a quantitative approach. [**55:** H.1]

Table I.2(c) Hazard Scenario

Row	Exposure	Hazard Scenario Rationale*
1	Lot lines	1, 2, 3, 4, 5
2	Exposed persons other than those involved in servicing of the system	4
3	Buildings and structures Combustible construction Noncombustible non-fire-rated construction Fire-rated construction with fire resistance rating of not less than 2 hours	2
4	Openings in buildings of fire-rated or non-fire-rated construction (doors, windows, penetrations) Openable Fire-rated or non fire-rated Unopenable Fire-rated or non fire-rated	1, 2
5	Air intakes (HVAC, compressors, other)	1
6	Fire barrier walls or structures used to shield bulk system from exposures	2, 4
7	Unclassified electrical equipment	2, 5
8	Utilities (overhead), including electric power, building services, hazardous materials piping	2, 10
9	Ignition sources such as open flames and welding	3, 5
10	Parked cars	4
11	Flammable gas storage systems, including other hydrogen systems above ground Nonbulk Bulk	2
12	Aboveground vents or exposed piping and components of flammable gas storage systems, including other hydrogen systems below ground Gaseous or cryogenic	6, 7
13	Hazardous materials (other than flammable gases) storage below ground Physical hazard materials or health hazard materials	6, 7
14	Hazardous materials storage (other than flammable gases) above ground Physical hazard materials or health hazard materials	8, 9
15	Ordinary combustibles, including fast-burning solids such as ordinary lumber, excelsior, paper, combustible waste, vegetation other than that found in maintained landscaped areas	2
16	Heavy timber, coal, other slow-burning combustible solids	2

*See Table I.2(d)for explanation of notes.
[**55:** Table H.1(a)]

Table I.2(d) Hazard Scenario Rationale Notes to Table I.2(c)

Note Number	Statement	Performance Criteria	Hazardous Materials Design Scenario
1	Gas release and subsequent entrainment or accumulation by the receptor	**Explosion Conditions.** The facility design shall provide an acceptable level of safety for occupants and for individuals immediately adjacent to the property from the effects of unintentional detonation or deflagration. [**1:**5.2.2.2]	**Hazardous Materials Design Scenario 1.** Hazardous Materials Design Scenario 1 involves an unauthorized release of hazardous materials from a single control area. This design scenario shall address the concern regarding the spread of hazardous conditions from the point of release. [**1:**5.4.4.1]
2	Fire spread to or from adjacent equipment or structure	**Property Protection.** The facility design shall limit the effects of all required design scenarios from causing an unacceptable level of property damage. [**1:**5.2.2.4]	**Hazardous Materials Design Scenario 2.** Hazardous Materials Design Scenario 2 involves an exposure fire on a location where hazardous materials are stored, used, handled, or dispensed. This design scenario shall address the concern regarding how a fire in a facility affects the safe storage, handling, or use of hazardous materials. [**1:**5.4.4.2]
3	Gas explosion hazard on site or affecting adjacent property	**Explosion Conditions.** The facility design shall provide an acceptable level of safety for occupants and for individuals immediately adjacent to the property from the effects of unintentional detonation or deflagration. [**1:**5.2.2.2]	**Hazardous Materials Design Scenario 1.** Hazardous Materials Design Scenario 1 involves an unauthorized release of hazardous materials from a single control area. This design scenario shall address the concern regarding the spread of hazardous conditions from the point of release. [**1:**5.4.4.1]
4	Threat of injuries on site or adjacent property	**Hazardous Materials Exposure.** The facility design shall provide an acceptable level of safety for occupants and for individuals immediately adjacent to the property from the effects of an unauthorized release of hazardous materials or the unintentional reaction of hazardous materials. [**1:**5.2.2.3]	**Hazardous Materials Design Scenario 2.** Hazardous Materials Design Scenario 2 involves an exposure fire on a location where hazardous materials are stored, used, handled, or dispensed. This design scenario shall address the concern regarding how a fire in a facility affects the safe storage, handling, or use of hazardous materials. [**1:**5.4.4.2] **Hazardous Materials Design Scenario 4.** Hazardous Materials Design Scenario 4 involves an unauthorized discharge with each protection system independently rendered ineffective. This set of design hazardous materials scenarios shall address concern regarding each protection system or protection feature, considered individually, being unreliable or becoming unavailable. [**1:**5.4.4.4.1]
5	Ignition of an unignited release/vented hydrogen	**Explosion Conditions.** The facility design shall provide an acceptable level of safety for occupants and for individuals immediately adjacent to the property from the effects of unintentional detonation or deflagration. [**1:**5.2.2.2]	**Hazardous Materials Design Scenario 1.** Hazardous Materials Design Scenario 1 involves an unauthorized release of hazardous materials from a single control area. This design scenario shall address the concern regarding the spread of hazardous conditions from the point of release. [**1:**5.4.4.1]
6	Damage to exposed components of underground system that are exposed above ground	**Property Protection.** The facility design shall limit the effects of all required design scenarios from causing an unacceptable level of property damage. [**1:**5.2.2.4]	**Hazardous Materials Design Scenario 1.** Hazardous Materials Design Scenario 1 involves an unauthorized release of hazardous materials from a single control area. This design scenario shall address the concern regarding the spread of hazardous conditions from the point of release. [**1:**5.4.4.1]

Table I.2(d) ***Continued***

Note Number	Statement	Performance Criteria	Hazardous Materials Design Scenario
7	Damage to aboveground system due to function of explosion control system used to vent underground vault or structure	**Property Protection.** The facility design shall limit the effects of all required design scenarios from causing an unacceptable level of property damage. [**1:**5.2.2.4] **Explosion Conditions.** The facility design shall provide an acceptable level of safety for occupants and for individuals immediately adjacent to the property from the effects of unintentional detonation or deflagration. [**1:**5.2.2.2]	**Hazardous Materials Design Scenario 3.** Hazardous Materials Design Scenario 3 involves the application of an external factor to the hazardous material that is likely to result in a fire, explosion, toxic release, or other unsafe condition. This design scenario shall address the concern regarding the initiation of a hazardous materials event by the application of heat, shock, impact, or water onto a hazardous material being stored, used, handled, or dispensed in the facility. [**1:**5.4.4.3]
8	Fire or explosion in other hazardous materials resulting in release of hydrogen	**Hazardous Materials Exposure.** The facility design shall provide an acceptable level of safety for occupants and for individuals immediately adjacent to the property from the effects of an unauthorized release of hazardous materials or the unintentional reaction of hazardous materials. [**1:**5.2.2.3]	**Hazardous Materials Design Scenario 3.** Hazardous Materials Design Scenario 3 involves the application of an external factor to the hazardous material that is likely to result in a fire, explosion, toxic release, or other unsafe condition. This design scenario shall address the concern regarding the initiation of a hazardous materials event by the application of heat, shock, impact, or water onto a hazardous material being stored, used, handled, or dispensed in the facility. [**1:**5.4.4.3]
9	Fire or explosion in hydrogen system resulting in release of other hazardous materials	**Hazardous Materials Exposure.** The facility design shall provide an acceptable level of safety for occupants and for individuals immediately adjacent to the property from the effects of an unauthorized release of hazardous materials or the unintentional reaction of hazardous materials. [**1:**5.2.2.3]	**Hazardous Materials Design Scenario 2.** Hazardous Materials Design Scenario 2 involves an exposure fire on a location where hazardous materials are stored, used, handled, or dispensed. This design scenario shall address the concern regarding how a fire in a facility affects the safe storage, handling, or use of hazardous materials. [**1:**5.4.4.2]
10	Failure of equipment exposing hydrogen system to electrical hazard, physical, or health hazard; failure of system exposing utilities to failure	**Property Protection.** The facility design shall limit the effects of all required design scenarios from causing an unacceptable level of property damage. [**1:**5.2.2.4] **Public Welfare.** For facilities that serve a public welfare role as defined in 4.1.5 of NFPA 1, the facility design shall limit the effects of all required design scenarios from causing an unacceptable interruption of the facility's mission. [**1:**5.2.2.5]	**Hazardous Materials Design Scenario 3.** Hazardous Materials Design Scenario 3 involves the application of an external factor to the hazardous material that is likely to result in a fire, explosion, toxic release, or other unsafe condition. This design scenario shall address the concern regarding the initiation of a hazardous materials event by the application of heat, shock, impact, or water onto a hazardous material being stored, used, handled, or dispensed in the facility. [**1:**5.4.4.3]

The tables developed for inclusion in Chapter 7 are said to be *risk informed*, not *risk based*, the difference being that integral to the risk tables is a series of decisions based on the applicability of various factors. For example, with respect to thermal flux, one could use a series of exposures from *no harm* to *fatality*, and those exposures could then be taken from the point of various receptors (workers, people on the property where the installation is located, people off the property, etc.). One of the primary decisions made by the group was that in the final analysis the risk presented for the typical GH_2 installation (either industrial or fueling applications) should present no greater risk to the public in terms of fatalities or injuries than does an existing gasoline service station. The average frequency of a fatality or injury associated with the operation of a single gasoline station has been reported to be approximately 2E-5/yr and 7E-4/yr, respectively. [5] Other key decisions of the group included the parameters given in Sections I.3 through I.6. [**55:** H.1]

I.3 Lower Flammable Limit — 4 Percent H_2 by Volume. In scenarios where the concern is that a plume of unignited GH_2 from a release may reach an ignition source, the separation distance was determined using a computational fluid dynamics (CFD) model to determine the distance required to reduce the GH_2 concentration to 4 percent by volume. A concentration of 4 percent hydrogen in air has been shown to be the lower bounds of an ignitible mixture under ideal conditions for burning. As such, 4 percent is the established lower flammable limit for hydrogen mixtures in air. In other situations, such as the design of flammable gas detection systems, target concentrations of 2 percent, or 1 percent GH_2 by volume, are commonly used to provide a factor of safety and account for uncertainties in the configuration that can affect the detection system. This fact could lead one to conclude that 1 percent or 2 percent should be used as the basis for establishing a separation distance as well. However, the inherent uncertainties associated with detection systems, such as room configuration, ventilation rates, and so forth, that drive conservatism in the design of a hydrogen detection system do not exist in the case of this CFD model, and therefore no additional reduction of the conservative 4 percent value is warranted. [**55:** H.2]

I.4 Use of 3 Percent of Internal Pipe Diameter (ID) as Leak Size. The development of separation distances for hydrogen facilities can be determined in several ways. A conservative approach is to use the worst possible accidents in terms of consequences. Such accidents can be of very low frequency such that they likely would never occur. Although this approach bounds separation distances, the resulting distances are generally prohibitive. The current separation distances do not reflect this approach. An alternative deterministic approach that is often utilized by standards development organizations (SDOs) and allowed under some regulations is to select accident scenarios that are more probable but do not provide bounding consequences. In this approach, expert opinion is generally used to select the accidents used as the basis for the prescribed separation distances. Although anecdotal experience often forms the basis for the selection of the accidents, the frequency of accidents can also be used as a selection criterion. [**55:** H.3]

A detailed description of the process used and the results achieved are provided in a technical article included in Annex E. [6] This process follows guidance by the Fire Protection Research Foundation published in March 2007 that encourages NFPA Technical Committees to use risk concepts in their decision-making process. [7] A risk-informed process, as opposed to a risk-based process, utilizes risk insights obtained from quantitative risk assessments (QRAs) combined with other considerations to establish code requirements. The QRAs are used to identify and quantify scenarios for the unintended release of hydrogen, identify the significant risk contributors at different types of hydrogen facilities, and to identify potential accident prevention and mitigation strategies to reduce the risk to acceptable levels. [**55:** H.3]

The risk-informed approach included two considerations: the frequency of hydrogen system leakage and the risk from leakage events. Unfortunately, hydrogen component leakage data are very limited. Past QRAs of hydrogen facilities have thus been forced to utilize leakage rates based on data from non-hydrogen facilities. The European Industrial Gas Association (EIGA) [8], for example, assessed the frequencies presented in five different sources and then used values that were deemed appropriate for the assessment rather than performing any further analysis. [**55:** H.3]

Rather than selecting a value from different generic sources, a different approach was utilized in this assessment. Data from different sources were collected and combined using Bayesian statistics. [9] This approach has three major advantages over the approach utilized by EIGA and other QRA guidance documents. First, it allows for the generation of leakage rates for different amounts of leakage. Second, it generates uncertainty distributions for the leakage rates that can be propagated through the QRA models to establish the uncertainty in the risk results. Finally, it provides a means for incorporating limited hydrogen-specific leakage data to establish estimates for leakage rates for hydrogen components. Limited hydrogen-specific leakage data were obtained through the efforts of the CGA for use in the Bayesian analysis. [**55:** H.3]

Component leak frequencies as a function of leak size were generated for several hydrogen components. The hydrogen-specific leakage rates were used to estimate the leakage frequency for four example systems used as the basis for the risk evaluation used in the study. The cumulative probability for different leak sizes was then calculated to determine what range of leaks represents the most likely leak sizes. The results of this analysis indicated that leaks less than 0.1 percent of the component flow areas represent 95 percent of the leakage frequency for the example systems. Leak areas less than 10 percent of the flow area are estimated to result in 99 percent of the leaks that could occur based on the results of the analysis. [**55:** H.3]

The risks resulting from different size leaks were also evaluated for four standard gas storage configurations. The risk evaluations indicate that the use of 0.1 percent of the component flow area as the basis for determining separation distances results in risk estimates that significantly exceed the 2×10^{-5}/yr risk guideline selected by the NFPA separation distance working group, particularly for the 7500 psig and 15,000 psig systems. On the other hand, use of a leak size equal to between 1 percent and 10 percent of the component flow area results in risk estimates that are reasonably close to the risk guideline. The fact that the risk estimates are a factor of 2 higher than the risk guideline for the 7500 psig and 15,000 psig example systems was weighed against the uncertainties in the QRA models, most of which result in conservative risk estimates. [**55:** H.3]

Based on the results of both the system leakage frequency evaluation and the associated risk assessment, a diameter of 3 percent of the flow area corresponding to the largest internal pipe downstream of the highest pressure source in the system is used in the model. The use of a 3 percent leak area results in capturing an estimated 98 percent of the leaks that have been determined to be probable based on detailed analysis of the typical systems employed. Typical systems to include components have been established in the form of P&IDs and incorporated into the work so that the basis for the statistical determinations reached can be documented. [**55:** H.3]

I.5 Selected Heat Flux Values. The values for heat flux used in development of the separation distance tables are as follows: [**55:** H.4]

(1) 1,577 W/m^2 (500 Btu/hr-ft^2)
(2) 4,732 W/m^2 (1,500 Btu/hr-ft^2)
(3) 20,000 W/m^2 (6,340 Btu/hr-ft^2)
(4) 25,237 W/m^2 (8,000 Btu/hr-ft^2)

[**55:** H.4]

The basis for using each value is as follows:

(1) 1,577 W/m^2 (500 Btu/hr-ft^2) is used as the "no harm" value. This heat flux is defined by API 521, *Recommended Practice, Guide for Relieving Depressuring Systems*, as the heat flux threshold to which personnel with appropriate clothing can be continuously exposed. [10] This value is slightly less than what the Society of Fire Protection Engineers determined to be the "no harm" heat flux threshold (540 Btu/hr-ft^2), that is, the maximum heat flux to which people can be exposed for prolonged periods of time without experiencing pain. [11] [**55:** H.4]
(2) 4,732 W/m^2 (1,500 Btu/hr-ft^2) is defined by API 521 as the heat flux threshold in areas where emergency actions lasting several minutes may be required by personnel without shielding but with appropriate clothing. [10] It is also defined by the *International Fire Code* as the threshold for exposure to employees for a maximum of 3 minutes. [12] [**55:** H.4]
(3) 20,000 W/m^2 (6,340 Btu/hr-ft^2) is generally considered the minimum heat flux for the nonpiloted ignition of combustible materials, such as wood. [13] [**55:** H.4]
(4) 25,237 W/m^2 (8,000 Btu/hr-ft^2) is the threshold heat flux imposed by the *International Fire Code* for noncombustible materials. [12] [**55:** H.4]

I.6 Pressure as a Controlling Parameter in Lieu of Volume. The traditional approach of using volume as a determinant in the establishment of distance was revised in favor of using pressure as the determinate factor. The work of Houf and Schefer demonstrated that the flame radiation heat flux and flame length varied with the pressure of gas released across a given orifice. [2] In cases where the high pressure leak of hydrogen was unignited, a turbulent jet is formed and the area of the flammable envelope can be calculated. [**55:** H.5]

Peak flows were used as a means to determine acceptable distances, and comparisons were made to contents. It was determined that once the threshold for a bulk supply had been exceeded, gas pressure, not volume, was the determining factor in establishing the radiant flux or the unignited jet concentration. Detailed analysis over a series of 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) over a range of leak diameters were examined. [**55:** H.5]

Transient effects varying the quantity and pressure decay over time were ruled out as controlling parameters. Volume was then considered to be at its worst case, which assumed that pressure was constant due to the volume contained. This is especially true for large systems typically encountered in commercial applications. Small systems using small-diameter tubing are accounted for by the use of tables that allow the user to calculate the benefit from the use of small-diameter systems. [**55:** H.5]

I.7 References. [**55:** H.6]

(1) NFPA 1, *Fire Code*, 2009 edition, National Fire Protection Association, Quincy, MA, Chapter 5.
(2) W. Houf and R. Schefer, "Predicting Radiative Heat Fluxes and Flammability Envelopes from Unintended Releases of Hydrogen," *International Journal of HydrogenEnergy*, Elsevier Publishing, 2007, Vol. 32, pp. 136–151.
(3) J. Floyd, *Siting Requirements for Hydrogen Supplies Serving Fuel Cells in Non-Combustible Enclosures*, Hughes Associates, Inc., 3610 Commerce Drive, Suite 817, Baltimore, MD 21227, HAI Project #3250-000, November 30, 2006.
(4) J. LaChance, *Risk-Informed Separation Distances for Hydrogen Refueling Stations*, Risk and Reliability Department, Sandia National Laboratories, Albuquerque, NM, May 2007. (Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DEAC04-94-AL85000.)
(5) Ibid, p. 11, reference to *Fires in or at Service Stations and Motor Vehicle Repair and Paint Shops,* NFPA, April 2002.
(6) J. LaChance, W. Houf, B. Middleton (all of Sandia National Laboratories), and L. Fluer (of Fluer, Inc.), "Analyses to Support Development of Risk-Informed Separation Distances for NFPA Hydrogen Codes and Standards," SAND 2009-0874, Sandia National Laboratories, Albuquerque, NM 87185, and Livermore, CA 94550, March 2009.
(7) S. E Rose, S. Flamberg, and F. Leverenz, "Guidance Document for Incorporating Risk Concepts into NFPA Codes and Standards," Fire Protection Research Foundation, March 2007.
(8) "Determination of Safety Distances," European Industrial Gases Association, IGC Doc. 75/07/E, 2007.
(9) C. L. Atwood, J. L. LaChance, H. F. Martz, D. J. Anderson, M. Englehardt, D. Whitehead, and T. Wheeler, "Handbook of Parameter Estimation for Probabilistic Risk Assessment," NUREG/CR-6823, U.S. Nuclear Regulatory Commission, Washington, D.C., 2003.
(10) API Recommended Practice 521, *Guide for Pressure Relieving and Depressuring Systems*, 4th edition, March 1997, API Publishing Services, 1220 L. St. N.W., Washington, DC 20005, Table 8, p. 41.
(11) "Predicting 1st and 2nd Degree Skin Burns from Thermal Radiation," *SFPE Engineering Guide*, Society of Fire Protection Engineers, Bethesda, MD 20814, March 2000, p. 8.
(12) ICC, *International Fire Code*™, 2006 edition, International Code Council, 4051 West Flossmoor Road, Country Club Hills, IL 60478-5795, Table 2209.5.4.3.6(1), p. 210.
(13) V. Babrauskas, "Ignition of Wood: A Review of the State of the Art," Interflam 2001, Interscience Communications Ltd., London, 2001, pp. 71–88.

[**55:** H.6]

Annex J Design Standard References

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

J.1 Mechanical Design Standards for Vacuum Furnace Manufacturers. The following is a list of design standards for vacuum furnace manufacturers:

(1) Vessels: ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1
(2) Hydraulic: Joint Industrial Council (JIC) *Hydraulic Standards for Industrial Equipment*
(3) Steel pipe flanges: ANSI B16.1, *Cast Iron Pipe Flanges and Flanged Fittings;* ANSI B16.5, *Pipe Flanges and Flanged Fittings*
(4) Copper pipe and fittings: ANSI B16.22, *Wrought Copper and Copper Alloy Solder Joint Pressure Fittings*; ANSI B16.23, *Cast Copper Alloy Solder Joint Drainage Fittings — DWV*; ANSI B16.24, *Cast Copper Alloy Pipe Flanges and Flanged Fittings Class 150, 300, 400, 600, 900, 1500, and 2500*
(5) General: OSHA and Walsh/Healy

[**86:** L.1]

J.2 Electrical Design Standards for Vacuum Furnace Manufacturers. The following is a list of electrical associations whose publications can be used as a guide for safe installation and application of electrical equipment and installation:

(1) National Fire Protection Association (NFPA), publisher of *NFPA 70*
(2) National Electrical Manufacturer's Association (NEMA)
(3) Joint Industrial Council (JIC)
(4) Electronic Industries Association (EIA)
(5) Canadian Standards Association (CSA)
(6) FM Global

[**86:** L.2]

Annex K Hydrogen Explosion Control

This annex is not a part of the enforceable requirements of this NFPA document but is included for informational purposes only. The information below is intended to provide voluntary guidance related to explosion control for hydrogen. The text is presented below in a format similar to text that is anticipated to be included in Chapter 9 (which is currently reserved) in the next edition of NFPA 2.

The guidance in Annex K pertains to explosion prevention measures as follows:

(1) *Providing criteria to determine where explosion control measures are needed*
(2) *Providing continuous or emergency ventilation to dilute inadvertently released hydrogen in confined areas*
(3) *Inerting hydrogen contained in process equipment and piping*
(4) *Eliminating potential ignition sources associated with electrical equipment and wiring*
(5) *Avoiding highly obstructed confined and partially confined areas containing hydrogen storage vessels, processing equipment, and piping*
(6) *Containing hydrogen deflagrations within equipment and vessels so as to prevent equipment or vessel rupture, and to prevent deflagration propagation to interconnected equipment*
(7) *Conducting explosion risk analyses to identify site-specific potential explosion scenarios and implement appropriate measures to reduce the likelihood of those scenarios actually occurring*

Annex K guidance also covers explosion damage mitigation by deflagration venting and avoiding deflagration-to-detonation transitions.

K.1 General.

K.1.1 Applicability. The storage, use, and handling of GH_2 in any quantity should also comply with the requirements of Chapter 1 through 4 and the applicable requirements of Chapters 5 through 8.

K.1.1.1 Vehicles regulated by approved motor vehicle safety standards used for commercial or noncommercial application should not be required to comply with Annex K.

K.2 Explosion Control.

K.2.1 Explosion control should be provided where there are any of the following conditions:

(1) The amounts of GH_2 or LH_2 in storage or use exceed the quantity thresholds requiring special provisions.
(2) At outdoor or partially confined locations as follows:
    (a) When the amount of GH_2 or LH_2 in storage or use exceed the quantity thresholds requiring special provisions, as specified in Table 6.4.1.1 for indoor control areas
    (b) Where one or more of the following exist:
        i. A flame acceleration hazard exists due to hydrogen being stored or used along with piping and equipment in a congested space
        ii. The area containing the GH_2 or LH_2 is partially enclosed by either three or more walls, or two walls plus a weather cover or ceiling.

An example of a congested space could be small regularly spaced obstacles such as a congested equipment or piping array. The following list provides an approximate criteria to help identify congested spaces where flame acceleration hazard would exist:

(1) Three or more rows or tiers of piping, spaced at less than 10 to 12 pipe diameters
(2) Three or more hydrogen process or storage units, spaced at one to five times the smallest process/storage unit dimension

The following references describe analysis methods to account for the effects of flammable gas cloud volume and obstructions on pressures generated from vapor cloud explosions due to large releases of flammable gas: Baker et al. (1997), Cleaver et al. (1997), Dorofeev, (2007a), Mercx and van den Berg (1997), Pierorazio et al. (2005), and Tang and Baker (1999). Note: Unconfined hydrogen explosions only occur with at least 40 kg hydrogen released into an unobstructed open area in such a way that at least 20 kg develops near-stoichiometric concentrations, or with at least 0.50 kg hydrogen into a highly obstructed area. Test data on unconfined hydrogen deflagrations are available in the following references: Groethe et al. (2005), Molkov et al. (2005), Wabayashi et al. (2005). The experiments of Groethe et al. showed that blast walls constructed to protect equipment and structures behind them are only effective for structures within a distance of two-to-three wall heights on the side of the wall away from the hydrogen explosion.

Note: The threat of a hydrogen explosion in a partially confined area depends on the hydrogen concentration distribution, potential ignition sources, the amount of confinement, the enclosure length/diameter ratio, and the presence of various types of obstructions. Although there are no definitive research results for every quantitative value and combination of these four parameters,there has been extensive research and guidelines on the congestion levels and gas burning velocities that are conducive to hydrocarbon vapor cloud explosions *[see Baker-Strehlow-Tang (2005) and Zalosh (2008)]* has provided a comprehensive review of the effects of different types and quantities of obstructions on the pressures developed in vented hydrocarbon gas explosions. As an example these reviews indicate that closely spaced piping at three or more elevations and evenly spaced small equipment represent the type of congestion that allows explosions to develop in open or partially confined areas. Test data and computational models providing data and calculations to assess the effects of certain important ranges of hydrogen concentrations, confinement and obstruction configurations, and ignition source locations in partially confined areas are available in the following references: Friedrich et al. (2007), Schneider (2005), Shirvill and Roberts (2007), and Tanaka et al. (2005).

(1) Indoors or in enclosures if the static volume of GH_2 or LH_2 (STP) contained in a process or transported in piping systems in the enclosure is equal to or greater than 0.004 (0.4 percent) times the enclosure volume and the piping or container or equipment is disconnected during normal operations while at least some hydrogen remains pressurized.

Note: Hydrogen–air deflagrations can occur when a flammable hydrogen-air mixture encounters a capable ignition source in an enclosure. The likelihood of formation of a flammable hydrogen–air mixture depends on the likelihood of releasing hydrogen at a rate and location such that it cannot be readily or rapidly diluted below the lower flammable limit. Since the existing NFPA standards do not contain a systematic and general description of the risk of a hydrogen deflagration occurring, the Hydrogen Technologies Committee has generated the deflagration risk criteria in Section K.4 based on semi-quantitative considerations of the risk of a hydrogen release, and the following quantitative determination of the minimum amount of hydrogen required to produce enclosure damage and injuries once ignited in an enclosure.

The least amount of flammable gas that can produce deflagration pressure damage can be determined from considerations of partial volume deflagrations in which a local flammable mixture exists in an enclosure in which most of the enclosure volume has concentrations below the lower flammable limit. The deflagration pressure, P, produced from ignition at atmospheric pressure, P_{atm}, of a local near-stoichiometric mixture of volume, V_{pv}, in an enclosure of volume, V, is given by the following equation (see Ogle, 1999, and Jo and Park, 2004).[1]

$$\frac{P}{P_{atm}} = \left[1-\left(\frac{V_{pv}}{V}\right)+\left(\frac{V_{pv}}{v}\right)\left(\frac{P_{\exp}}{P_{atm}}\right)^{1/\gamma}\right]^{\lambda} \qquad \textbf{[K.2.1a]}$$

where P_{exp} is the deflagration explosion pressure corresponding to a uniform near-stoichiometric gas mixture throughout the enclosure, and γ is the gas mixture ratio of specific heats.

Values of P_{exp}/P_{atm} and γ for a stoichiometric hydrogen–air mixtures (29.6 percent volume hydrogen in dry air), and for hydrogen–air mixtures with hydrogen concentrations in the range 25.15 volume percent to 33.5 volume percent) have been obtained using the GASEQ software package. Using these values of P_{exp}/P_{atm} and γ, the equation above has been used to calculate P (kPa g) as a function of the partial volume fraction V_{pv}/V. Results are shown in Figure K.2.1(a). The curves of P versus partial volume fraction are linear for partial volume fractions less than about 0.08 because the preceding equation can be approximated as follows:

$$\frac{P}{P_{atm}} - 1 \approx \left(\frac{V_{pv}}{V}\right)\left(\frac{P_{\exp}}{P_{atm}}\right) \qquad \textbf{[K.2.1b]}$$

for these small values of V_{pv}/V.

The volume of hydrogen in the locally uniform hydrogen–air mixture partial volume is given by $\chi_{H2}V_{pv}$, where $_{H2}$ is the volume fraction of hydrogen in the near-stoichiometric hydrogen–air mixture. If the hydrogen concentration distribution in the enclosure is idealized as a sharp discontinuance boundary between the locally uniform flammable gas mixture and the air in the rest of the enclosure, the volume of hydrogen in the enclosure is given by $\chi_{H2}(V_{pv}/V)$. Figure K.2.1(b) is a plot of the deflagration P (kPag) versus $\chi_{H2}(V_{pv}/V)$, which is the ratio of the hydrogen volume to the enclosure volume.

The minimum hydrostatic pressure at which limited minor structural damage can occur is approximately 0.4 psig to 0.5 psig (2.8 kPa to 3.5 kPa) according to Tables 2.18a and 2.18b of the CCPS Guidelines for Chemical Process Quantitative Risk Analysis, 2nd edition. Therefore, injuries to any exposed personnel due to broken glass and other debris from minor structural damage can be anticipated at pressures at and above about 4 kPa (0.58 psig). A horizontal line at about 4 kPa in Figure K.2.1(b) intersects the curve for a 25 percent partial volume deflagration at a ratio of hydrogen volume to enclosure volume of about 0.004. The intersection for the stoichiometric mixture concentration occurs at a slightly higher ratio of $\chi_{H2}(V_{pv}/V)$. Therefore, the hydrogen volume that can, in principle, cause minor damage and injuries is 0.4 volume percent — that is, at about 1/10th LFL if the hydrogen volume was uniformly distributed throughout the enclosure volume.

As an example, consider a hydrogen vehicle repair garage containing a single hydrogen fueled vehicle with a 80 liter fuel tank containing hydrogen at an absolute pressure of 34 MPa. The volume of room temperature hydrogen corresponding to the release of the tank contents through an inadvertently actuated pressure relief device is equal to $(0.080\ m^3\ H_2)(34\ MPa)/(0.101\ MPa) = 26.93\ m^3\ H_2$. The minimum repair garage volume to prevent the ratio of hydrogen volume to enclosure volume from reaching 0.004 is equal to $26.93\ m^3/0.004 = 6733\ m^3 = 238{,}000\ ft^3$. This volume is larger than the volume of a garage with a footprint of 100 ft x 100 ft (30.5 m x 30.5 m) and a ceiling height of 20 ft (6.1 m).

K.2.2 Explosion Control Methods.

K.2.2.1 Explosion Protection. Where explosion control is recommended by K.2.1, explosion protection should consist of one or more of the following:

(1) Deflagration prevention by gas concentration reduction per K.2.2.2
(2) Deflagration prevention by oxidant concentration reduction per K.2.2.3
(3) Deflagration venting per K.2.2.4
(4) Deflagration containment per K.2.2.5

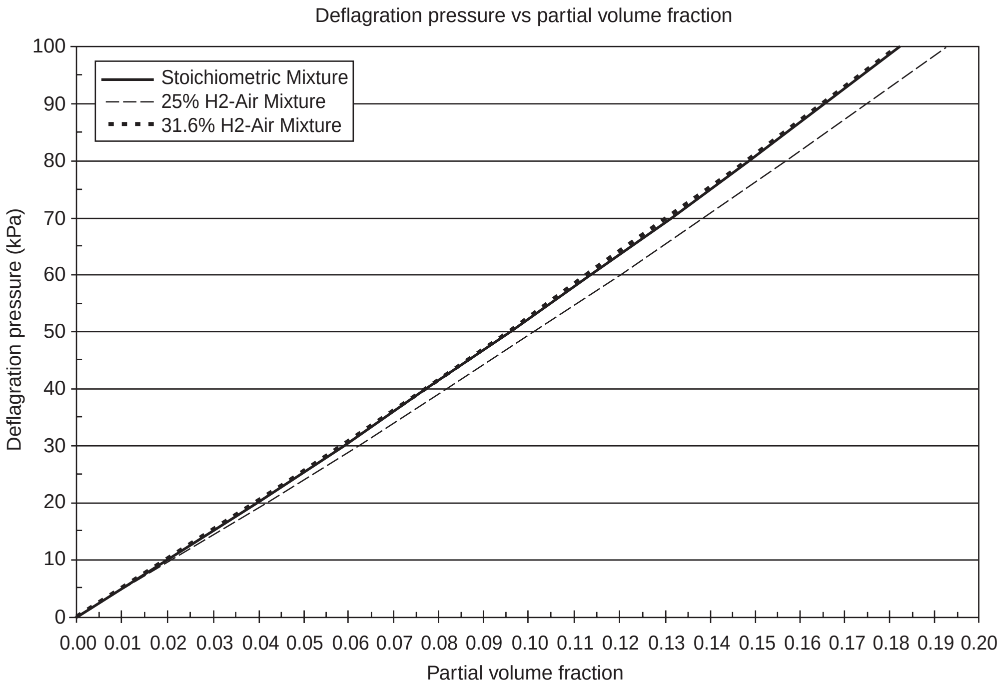

FIGURE K.2.1(a) Hydrogen Deflagration Pressure Versus Flammable Hydrogen–Air Mixture Partial Volume Fraction for Three Different Hydrogen Concentrations.

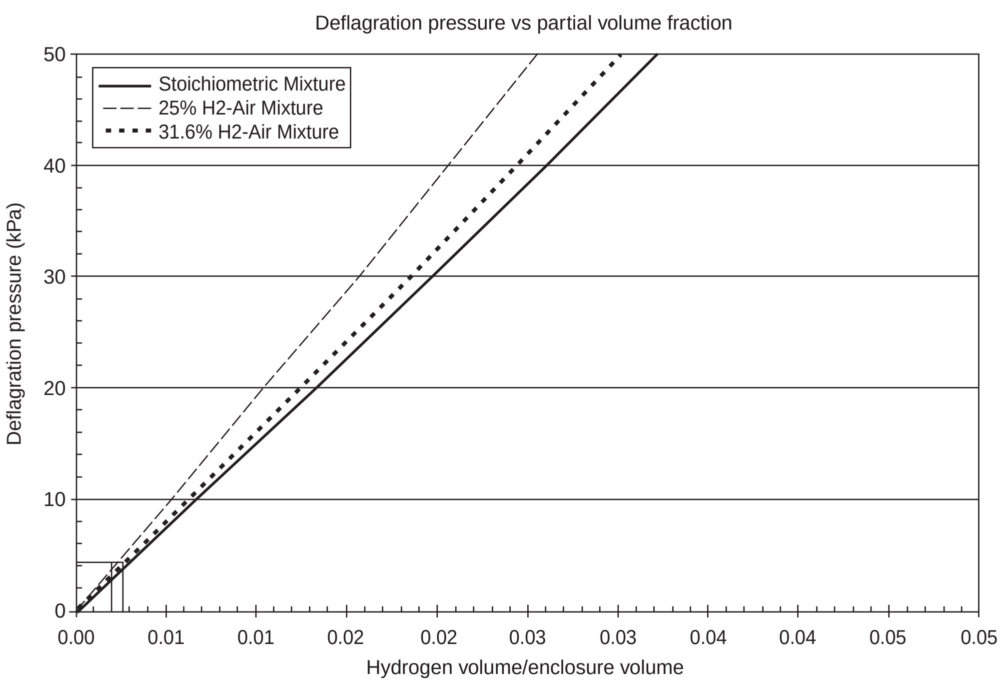

FIGURE K.2.1(b) Hydrogen Partial Volume Deflagration Pressure Versus Ratio of Hydrogen Volume to Enclosure Volume for Different Hydrogen Partial Volume Concentrations.

Note: In addition to the explosion control measures, the control of ignition sources will decrease the potential for an explosion. Typical ignition sources include thermal, mechanical, electrical, and electrostatic. The use of ignition control measures to address these sources will not eliminate the potential for spontaneous ignition.

Electrical ignition sources can be mitigated by utilizing the requirements for electrical equipment and wiring in classified locations in accordance with Article 500 of *NFPA 70*. NFPA 497 provides guidance for establishing classified locations.

Through the exercise of ingenuity in the layout of electrical installations for hazardous (classified) locations, it is frequently possible to locate much of the equipment in a reduced level of classification or in an unclassified location and, thus, to reduce the amount of special equipment required. It is important that the authority having jurisdiction be familiar with recorded industrial experience as well as with the standards of the National Fire Protection Association (NFPA), the American Petroleum Institute (API), and the Instrumentation, Systems, and Automation Society (ISA) that can be of use in the classification of various locations, the determination of adequate ventilation, and the protection against static electricity and lightning hazards.

Electrostatic ignition can be controlled by utilizing the methods identified in NFPA 77.

Other potential ignition sources including, but not limited to, smoking, open flames, heating, and spark producing equipment should be eliminated or located a safe distance from potential leak sources.

K.2.2.1.1 The explosion protection methods specified in K.2.2.1 can be partially or totally eliminated where supported by an approved hazard analysis.

Note: The hazard analysis should give consideration to the following:

(1) The location of the storage system and associated exposures
(2) The potential for deflagration to detonation transition
(3) Prevention of pressurized equipment and piping breaches or releases
(4) Identification of additional preventive measures
(5) Identification of additional mitigation controls
(6) Documented test data applicable to the identified scenarios

K.2.2.1.1.1 The hazard analysis should identify and document the applicable explosion hazard scenarios.

K.2.2.1.1.2 The hazard analysis should be validated by qualified personnel with proven expertise in hazard analysis and should be subject to approval by the AHJ.

Note: For hydrogen, reliance upon prevention of ignition by controlling ignition sources is not sufficient by itself due to the low ignition energy of ignitable clouds of GH_2 and the fact that certain releases can self-ignite due to buildup and discharge of static electricity. Therefore, control of ignition sources must be combined with either fuel reduction (typically) by ventilation of the area to lower GH_2 concentration or by deflagration venting, or both, to achieve sufficient defense in depth.

K.2.2.1.1.3 When the hazard analysis has determined that there is a potential deflagration-to-detonation transition (DDT), the system parameters should be redesigned to eliminate the hazard.

K.2.2.2 Deflagration Prevention by Hydrogen Gas Concentration Reduction.

K.2.2.2.1 Deflagration prevention by gas concentration reduction can be considered where a mixture of a combustible material and an oxidant is confined to an enclosure and where the concentration of the hydrogen can be maintained below the lower flammable limit (LFL) of hydrogen (4.0 volume percent at room temperature and pressure).

Note: See NFPA 69, Annex B, for a discussion of the control of flammable gas mixtures. See also NFPA 69, Annex D, for information on calculating the time required for concentration reduction by ventilation.

K.2.2.2.2 Deflagration prevention by hydrogen gas concentration reduction should be in accordance with Chapter 8 of NFPA 69, as supplemented by K.2.2.2.3.

K.2.2.2.3 Design Considerations. The following factors should be considered in the design of a system intended to reduce the combustible concentration below the LFL:

K.2.2.2.3.1 Ventilation or Air Dilution. [**69:**8.3.3]

(A) If ventilation is used, the outlets from the protected enclosures [should] be located so that hazardous concentrations of the exhausted air cannot enter or be drawn into the fresh air intakes of environmental air–handling systems. [**69:**8.3.3.1]

(B) The ventilation rate for hydrogen dilution should be based on a hydrogen release rate equal to either the storage pressure and an orifice diameter equal to 3 percent of the diameter of the largest hydrogen piping or equipment connection, or a risk-based analysis of release rates for the type of hydrogen piping and equipment in the room or building.

Note: The 3 percent of the pipe diameter requirement is based on the hydrogen leakage rate conditions described in Section E.1.

K.2.2.3 Oxygen Concentration Reduction Below the 3 Volume Percent Hydrogen Limiting Oxygen Concentration (LOC).

K.2.2.3.1 Application. Oxygen concentration reduction can be considered where a mixture of oxidant and hydrogen is confined to an enclosure within which the oxidant concentration can be controlled.

K.2.2.3.2 Oxygen concentration reduction should be in accordance with Chapter 7 of NFPA 69, as supplemented by K.2.2.3.3.

K.2.2.3.3 Design Considerations.

K.2.2.3.3.1 The following factors should be considered in the design of an oxygen concentration reduction system:

(A) Limiting Oxidant Concentrations LOCs. [69:7.2.3]

(1) The hydrogen LOC depends on the inert gas used, the flammability test method, and the initial temperature and pressure.
(2) The LOC for nitrogen inerting at standard temperature and pressure is 3.0 percent oxygen.
(3) The LOC for carbon dioxide inerting at standard temperature and pressure is 3.2 percent oxygen.
(4) The LOC value for other inert gases, temperatures, and pressures should be measured according to ASTM E2079, *Standard Test Method for Limiting Oxygen (Oxidant) Concentration for Gases and Vapors.*

(5) The use of oxidants other than oxygen can also require further investigation with respect to the limiting oxidant concentration.
(6) The design concentration should be a fraction of the LOC per 7.7.2.5 and 7.7.2.7 of NFPA 69.

Note: The LOC values for nitrogen and carbon dioxide are the adjusted values for hydrogen from Table C.1(a) of NFPA 69.

K.2.2.4 Deflagration Venting. Hydrogen deflagration venting for limiting explosion damage should be in accordance with the requirements in Section 6.9 of this standard and with NFPA 68.

K.2.2.5 Deflagration Containment.

K.2.2.5.1 Application. The technique for deflagration pressure containment [can] be considered for specifying the design pressure of a vessel and its appurtenances so they are capable of withstanding the maximum pressures resulting from an internal [hydrogen] deflagration. [**69:**13.1.1]

K.2.2.5.2 Deflagration containment should be in accordance with NFPA 69, Chapter 13 as supplemented by K.2.2.5.3.

K.2.2.5.3 Design Considerations. The following factors should be considered in the design of a deflagration venting system:

(A) Containment Design Basis.

(1) The deflagration containment design basis should be as described in Section 13.3 of NFPA 69.
(2) The value of the hydrogen–air deflagration pressure ratio, *R*, needed for the NFPA 69, Section 13.3 design basis is 8.3. Another value of the deflagration pressure ratio, *R*, can be used if a documented analysis of worst case hydrogen concentrations shows that near-stoichiometric hydrogen–air concentrations cannot occur.
(3) The value of the hydrogen–oxygen deflagration pressure ratio, *R*, needed for the NFPA 69, Section 13.3 design basis is 9.6. Another value of the deflagration pressure ratio, *R*, can be used if a documented analysis of worst case hydrogen concentrations shows that near-stoichiometric hydrogen–oxygen concentrations cannot occur.
(4) Where either deflagration venting or deflagration containment is relied on as an exclusive control measure for explosion protection, a documented risk assessment should be performed to evaluate the potential for a deflagration-to-detonation transition (DDT) when any of the following conditions exist:
    (a) The ratio of the volume of the equipment plus the volume of internal structures within the enclosure to the volume of the enclosure is greater than 0.10.
    (b) The ratio of surface area of the equipment plus the surface area of internal structures to the surface area of the enclosure (As) is less than 0.15.
    (c) There are uniformly spaced objects or obstacles including piping or equipment that obstruct more than 40 percent of the enclosure cross-section based on the least dimension of the space.
    Note: Uniformly spaced objects can include piping or equipment arranged in a repetitive manner such that the explosive effects are magnified as the flame propagates around these objects.
    (d) The enclosure length to diameter ratio is greater than 5.
    Note: The potential for deflagration-to-detonation transition (DDT) in obstructed or elongated enclosures is a complex subject often requiring expert analysis. Some of the contemporary references on this subject include the following:
    Dorofeev (2007b); Hansen et al. (2005); Lee and Berman (1997); Pethukov et al. (2007); Sherman and Berman (1988); Zalosh (FPRF report).

K.3 Explosion Prevention.

K.3.1 GH_2 or LH_2 should not be intentionally released from storage or use systems into areas where congested piping systems are present.

K.3.2 Hydrogen Explosions in Piping, Electrical Conduit, and Ducting.

K.3.2.1 Piping and Tubing Explosion Hazards and Protection.

K.3.2.1.1 An evaluation should be conducted to determine the potential of an adverse reaction where any of the following conditions exist:

(1) The formation of a mixture of hydrogen with atmospheric pressure air within piping that has a design pressure rating of less than 300 psi.
(2) The formation of a mixture of hydrogen with greater than atmospheric pressure air.
(3) A hydrogen–oxygen mixture within piping or tubing can occur.
(4) Where piping can be filled with air and is purged with hydrogen.
(5) There is a potential for degradation of fittings, gaskets, valves, and so forth, due to hydrogen embrittlement.

Note: If the process requires the hydrogen piping or tubing to carry a flammable mixture during any stage of operation, the ability of the piping to withstand a hydrogen explosion should be evaluated and, if necessary, strengthened to prevent pipe failure.

Methods to assess the structural response of piping and tubing to deflagrations and detonations are described by Shepherd (2006).

Hydrogen compatibility and embrittlement information is provided in documents such as SAND2008-1163, *Technical Reference on Hydrogen Compatibility of Materials*.

K.3.2.1.2 Corrective actions should be taken to reduce the likelihood of any significant adverse consequences of flammable mixture formation in piping.

K.3.2.1.3 Where piping connects two or more process vessels or equipment in which there are explosion hazards, the piping should be equipped with in-line deflagration arresters per 12.2.4, 12.2.5, or 12.2.6 of NFPA 69.

K.3.3 Electrical Conduit Explosion Hazards and Protection.

K.3.3.1 Electrical conduit and connectors in electrically classified (Class 1) areas should be installed per *NFPA 70*.

K.3.4 Hydrogen Explosion Hazards and Protection for Ducting.

K.3.4.1 The hydrogen concentration in exhaust ducting during normal operating conditions should not exceed 1 volume percent unless the duct and exhaust system are designed in accord with NFPA 69.

K.3.4.2 Higher hydrogen concentrations can be permitted for oven and furnace ducting if the ducting is designed in accord with NFPA 86.

K.3.4.3 Operations generating flames, sparks, or hot material such as from grinding wheels and welding should not be manifolded into any duct system potentially containing hydrogen.

K.3.4.4 Where ferrous materials can enter ducting carrying hydrogen, magnetic separators should be installed.

K.3.4.5 Ducting carrying hydrogen should be grounded.

K.3.5 Inspection of Hydrogen Pressure Vessels and Piping.

K.3.5.1 Hydrogen pressure vessels and piping should be inspected in accordance with the requirements of the code to which they were built. Where such inspection requirements are not provided, the owner of the pressure vessels should implement a mechanical integrity program.

K.3.5.1.1 The mechanical integrity program should consider the impact of hydrogen enhanced fatigue crack growth when the pressure vessels are in cyclic service.

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Annex L Hydrogen Detection Systems

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

L.1 General. The purpose of gas detectors is to detect an unintended release of hydrogen and send a signal to activate an alarm or other safety systems and measures (e.g., ventilation systems, system shutdown) and a device for recording the gas concentration. Hydrogen detectors can be configured to have multiple alarm levels, for example, a low-level alarm that activates an audible signal and increases ventilation and a high-level alarm that initiates a system shutdown and signals first responders of a potential emergency situation. Alarm levels should be some set fraction of the hydrogen lower flammable limit, which in air is 4 vol%.

L.2 Types of Gas Detectors that Effectively Detect Hydrogen. The following types of gas detectors (often called sensing elements in the detector or simply sensor) are most effective for detecting hydrogen:

(1) Thermal conductivity (TC) sensors
(2) Combustible gas (CGS) sensors
(3) Electrochemical (EC) sensors
(4) Metal oxide (MOX) sensors
(5) Sensing elements based on palladium thin films (PTF)

L.2.1 Hydrogen detectors based on the sensing elements listed in Section L.2 are commercially available. These sensing elements are used in many detector models, many of which have been optimized to detect gases other than hydrogen. Therefore, it is necessary to review and verify manufacturer specifications on detector performance to verify the detector's ability to respond to hydrogen. The relative merits and general performance characteristics of the hydrogen sensing elements listed in Section L.2 were reviewed and summarized by Buttner et al. [1]. Deployed sensors should be instrumented with the necessary control circuitry and user interface. The user interface can include displays, electrical output signals providing hydrogen concentration, and alarm interfaces. Critical sensor performance parameters and specifications that can be relevant to specific applications include, but are not limited to, the following:

(1) *Linear Range.* The sensor dynamic range is the concentration range in which the change in the sensor response is proportional to the change in analyte concentration. The sensor should respond up to the lower flammable limit of hydrogen (4 vol% in air). It is recommended that the sensor linear range extend beyond the LFL to a hydrogen concentration of 10 vol%.

(2) *Alarm Thresholds.* Facility monitors should have alarm set points at 25 percent of hydrogen LFL, or 1 vol% hydrogen, with lower alarm thresholds at 10 percent of the LFL (0.4 vol% hydrogen) or lower for critical applications.

(3) *Lower Detection Limit (LDL).* The smallest signal above background noise that the sensor can reliably detect and which is frequently calculated as three times the standard deviation of the background signal. The LDL of the deployed sensor should be at least 25 percent of the lowest alarm threshold.

(4) *Selectivity.* Hydrogen fueling stations will be co-deployed with conventional fueling operations. The CGS and MOX sensor platforms will respond to both hydrogen and to petroleum products and natural gas, although the relative sensitivity to hydrogen versus interferent (i.e., "cross-sensitivity") vapor varies significantly among model types. A review of manufacturers' specifications and in-house testing (or testing to a contract laboratory) is recommended to verify appropriate detector selectivity.

L.2.2 Furthermore, the impact of fluctuations in ambient environmental conditions such as temperature (T), relative humidity (RH), and barometric pressure (P) on the sensor should be considered. Temperatures can range from −40°F to +104°F (−40°C to +40°C) depending on prevailing weather conditions. Temperature extremes are more likely encountered with outdoor deployment. Sensors should be compatible with prevailing weather conditions. Electrochemical sensors typically do not perform well below 32°F (0°C). Although many detectors can be affected by pressure changes, local barometric pressure does not generally fluctuate significantly. However, detectors calibrated in one location (e.g., at sea level with 1 bar barometric pressure) might not be accurate at the deployment site (e.g., elevated deployments such as Denver). Although most detectors are not significantly affected by moderate fluctuations of RH, operation at extreme RH (less than 10 percent or greater than 90 percent) can adversely affect detector performance. Electrochemical sensors can degrade at low RH. The calibration curve of many MOX sensors is affected by RH extremes.

Detailed discussions on recommended sensor performance parameters and corresponding specifications for a range of hydrogen applications can be found in Buttner et al. [2].

L.3 Location of Gas Detectors to Effectively Detect Hydrogen. The following should be considered to effectively locate gas detectors where they are most likely to detect an unintended hydrogen release:

(1) Hydrogen buoyancy, which dictates that sensors should be placed above any potential release point.

(2) A gas detector mounting on the ceiling should be avoided because of elevated temperatures at the ceiling. Gas detectors should be mounted a foot or more below the ceiling — possibly using the wall.

(3) The gas detector should be mounted facing the potential release point. However, considerations should be given to the effect ventilation would have on air flow and how this alteration of air flow might impact the direction or orientation of the release point.
(4) The gas detector should be effectively downwind of any potential air flow.
(5) Hydrogen gas detectors should not be located in any structural entrapments.
(6) Hydrogen gas detectors can also be mounted on a wall close to but above the hydrogen dispensing system.

L.4 Number of Gas Detectors to Effectively Detect Hydrogen. In assessing the number of gas detectors required to detect a hydrogen release, the following should be considered:

(1) A minimum of one gas detector should be deployed per dispenser.
(2) If a canopy is used to protect the dispensing operation, the gas detector should be placed directly above the dispenser.
(3) Additional gas detectors can be placed along the length of the canopy to increase the probability of detecting a release.

L.5 Referenced Publications.

[1]. Buttner, W., et al., "An overview of hydrogen safety sensors and requirements," *International Journal of Hydrogen Energy*, 36, 2011.

[2]. Buttner, W., et al., "Summary and Findings from the NREL/DOE Hydrogen Sensor Workshop," NREL Technical Report Number: NREL/TP-5600-55645, July 2012. http://www.nrel.gov/docs/fy12osti/55645.pdf

Annex M Informational References

M.1 Referenced Publications. The documents or portions thereof listed in this annex are referenced within the informational sections of this code and are not part of the requirements of this document unless also listed in Chapter 2 for other reasons.

M.1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

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NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*, 2014 edition.

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NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*, 2012 edition.

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NFPA 853, *Standard for the Installation of Stationary Fuel Cell Power Systems*, 2015 edition.

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M.1.2.2 ANSI Publications. American National Standards Institute, Inc., 25 West 43rd Street, 4th Floor, New York, NY 10036.

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ANSI/ASSE Z117.1, *Safety Requirements for Confined Spaces,*2009.

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M.1.2.3 ASHRAE Publications. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329-2305.

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Note: ASME Publications: B31.12-2012 *Hydrogen piping and pipelines: ASME Code for Pressure Piping*, B31 is a use specific document for hydrogen service. A Section Committee was formed by the B31 Standards Committee to address gaps that existed between piping and pipeline codes and standards, and hydrogen infrastructure applications. The first edition of the B31.12 code applies to design, construction, operation, and maintenance requirements for piping, pipeline, and distribution in hydrogen service. ASME B31.12 includes information specific to hydrogen service by either reference or incorporation of applicable parts of B31.3, B31.1, B31.8, B31.8S, and Section VIII, Division 3 of the ASME *Boiler and Pressure Vessel Code*. Many materials included in B31.3 have been omitted from B31.12 tables due to their unsuitability for hydrogen service.

M.1.2.5 ASTM Publications. ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

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M.1.2.7 U.S. Government Publications. U.S. Government Printing Office, Washington, DC 20402.

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NFPA 72®, *National Fire Alarm and Signaling Code*, 2016 edition.

NFPA 86, *Standard for Ovens and Furnaces*, 2015 edition.

NFPA 88A, *Standard for Parking Structures*, 2015 edition.

NFPA *101*®, *Life Safety Code*®, 2015 edition.

NFPA 853, *Standard for the Installation of Stationary Fuel Cell Power Systems*, 2015 edition.

NFPA 5000®, *Building Construction and Safety Code*®, 2015 edition.

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Sequence of Events for the Standards Development Process

As soon as the current edition is published, a Standard is open for Public Input

Step 1: Input Stage

- Input accepted from the public or other committees for consideration to develop the First Draft
- Committee holds First Draft Meeting to revise Standard (23 weeks)
  Committee(s) with Correlating Committee (10 weeks)
- Committee ballots on First Draft (12 weeks)
  Committee(s) with Correlating Committee (11 weeks)
- Correlating Committee First Draft Meeting (9 weeks)
- Correlating Committee ballots on First Draft (5 weeks)
- First Draft Report posted

Step 2: Comment Stage

- Public Comments accepted on First Draft (10 weeks)
- If Standard does not receive Public Comments and the Committee does not wish to further revise the Standard, the Standard becomes a Consent Standard and is sent directly to the Standards Council for issuance
- Committee holds Second Draft Meeting (21 weeks)
  Committee(s) with Correlating Committee (7 weeks)
- Committee ballots on Second Draft (11 weeks)
  Committee(s) with Correlating Committee (10 weeks)
- Correlating Committee First Draft Meeting (9 weeks)
- Correlating Committee ballots on First Draft (8 weeks)
- Second Draft Report posted

Step 3: Association Technical Meeting

- Notice of Intent to Make a Motion (NITMAM) accepted (5 weeks)
- NITMAMs are reviewed and valid motions are certified for presentation at the Association Technical Meeting
- Consent Standard bypasses Association Technical Meeting and proceeds directly to the Standards Council for issuance
- NFPA membership meets each June at the Association Technical Meeting and acts on Standards with "Certified Amending Motions" (certified NITMAMs)
- Committee(s) and Panel(s) vote on any successful amendments to the Technical Committee Reports made by the NFPA membership at the Association Technical Meeting

Step 4: Council Appeals and Issuance of Standard

- Notification of intent to file an appeal to the Standards Council on Association action must be filed within 20 days of the Association Technical Meeting
- Standards Council decides, based on all evidence, whether or not to issue the Standards or to take other action

Committee Membership Classifications[1,2,3,4]

The following classifications apply to Committee members and represent their principal interest in the activity of the Committee.

1. M *Manufacturer:* A representative of a maker or marketer of a product, assembly, or system, or portion thereof, that is affected by the standard.
2. U *User:* A representative of an entity that is subject to the provisions of the standard or that voluntarily uses the standard.
3. IM *Installer/Maintainer:* A representative of an entity that is in the business of installing or maintaining a product, assembly, or system affected by the standard.
4. L *Labor:* A labor representative or employee concerned with safety in the workplace.
5. RT *Applied Research/Testing Laboratory:* A representative of an independent testing laboratory or independent applied research organization that promulgates and/or enforces standards.
6. E *Enforcing Authority:* A representative of an agency or an organization that promulgates and/or enforces standards.
7. I *Insurance:* A representative of an insurance company, broker, agent, bureau, or inspection agency.
8. C *Consumer:* A person who is or represents the ultimate purchaser of a product, system, or service affected by the standard, but who is not included in (2).
9. SE *Special Expert:* A person not representing (1) through (8) and who has special expertise in the scope of the standard or portion thereof.

NOTE 1: "Standard" connotes code, standard, recommended practice, or guide.

NOTE 2: A representative includes an employee.

NOTE 3: While these classifications will be used by the Standards Council to achieve a balance for Technical Committees, the Standards Council may determine that new classifications of member or unique interests need representation in order to foster the best possible Committee deliberations on any project. In this connection, the Standards Council may make such appointments as it deems appropriate in the public interest, such as the classification of "Utilities" in the National Electrical Code Committee.

NOTE 4: Representatives of subsidiaries of any group are generally considered to have the same classification as the parent organization.

Submitting Public Input / Public Comment through the Electronic Submission System (e-Submission):

As soon as the current edition is published, a Standard is open for Public Input.

Before accessing the e-Submission System, you must first sign-in at www.NFPA.org. *Note: You will be asked to sign-in or create a free online account with NFPA before using this system*:

a. Click in the gray Sign In box on the upper left side of the page. Once signed-in, you will see a red "Welcome" message in the top right corner.
b. Under the Codes and Standards heading, Click on the Document Information pages (List of Codes & Standards), and then select your document from the list or use one of the search features in the upper right gray box.

OR

a. Go directly to your specific document page by typing the convenient short link of www.nfpa.org/document#, (Example: NFPA 921 would be www.nfpa.org/921) Click in the gray Sign In box on the upper left side of the page. Once signed in, you will see a red "Welcome" message in the top right corner.

To begin your Public Input, select the link The next edition of this standard is now open for Public Input (formally "proposals") located on the Document Information tab, the Next Edition tab, or the right-hand Navigation bar. Alternatively, the Next Edition tab includes a link to Submit Public Input online

At this point, the NFPA Standards Development Site will open showing details for the document you have selected. This "Document Home" page site includes an explanatory introduction, information on the current document phase and closing date, a left-hand navigation panel that includes useful links, a document Table of Contents, and icons at the top you can click for Help when using the site. The Help icons and navigation panel will be visible except when you are actually in the process of creating a Public Input.

Once the First Draft Report becomes available there is a Public comment period during which anyone may submit a Public Comment on the First Draft. Any objections or further related changes to the content of the First Draft must be submitted at the Comment stage.

To submit a Public Comment you may access the e-Submission System utilizing the same steps as previous explained for the submission of Public Input.

For further information on submitting public input and public comments, go to: http://www.nfpa.org/publicinput

Other Resources available on the Doc Info Pages

Document information tab: Research current and previous edition information on a Standard

Next edition tab: Follow the committee's progress in the processing of a Standard in its next revision cycle.

Technical committee tab: View current committee member rosters or apply to a committee

Technical questions tab: For members and Public Sector Officials/AHJs to submit questions about codes and standards to NFPA staff. Our Technical Questions Service provides a convenient way to receive timely and consistent technical assistance when you need to know more about NFPA codes and standards relevant to your work. Responses are provided by NFPA staff on an informal basis.

Products/training tab: List of NFPA's publications and training available for purchase.

Community tab: Information and discussions about a Standard

Information on the NFPA Standards Development Process

I. Applicable Regulations. The primary rules governing the processing of NFPA standards (codes, standards, recommended practices, and guides) are the NFPA *Regulations Governing the Development of NFPA Standards (Regs)*. Other applicable rules include NFPA *Bylaws*, NFPA *Technical Meeting Convention Rules*, NFPA *Guide for the Conduct of Participants in the NFPA Standards Development Process*, and the NFPA *Regulations Governing Petitions to the Board of Directors from Decisions of the Standards Council*. Most of these rules and regulations are contained in the *NFPA Standards Directory*. For copies of the *Directory*, contact Codes and Standards Administration at NFPA Headquarters; all these documents are also available on the NFPA website at "www.nfpa.org."

The following is general information on the NFPA process. All participants, however, should refer to the actual rules and regulations for a full understanding of this process and for the criteria that govern participation.

II. Technical Committee Report. The Technical Committee Report is defined as "the Report of the responsible Committee(s), in accordance with the Regulations, in preparation of a new or revised NFPA Standard." The Technical Committee Report is in two parts and consists of the First Draft Report and the Second Draft Report. (See *Regs* at 1.4)

III. Step 1: First Draft Report. The First Draft Report is defined as "Part one of the Technical Committee Report, which documents the Input Stage." The First Draft Report consists of the First Draft, Public Input, Committee Input, Committee and Correlating Committee Statements, Correlating Input, Correlating Notes, and Ballot Statements. (See *Regs* at 4.2.5.2 and Section 4.3) Any objection to an action in the First Draft Report must be raised through the filing of an appropriate Comment for consideration in the Second Draft Report or the objection will be considered resolved. [See *Regs* at 4.3.1(b)]

IV. Step 2: Second Draft Report. The Second Draft Report is defined as "Part two of the Technical Committee Report, which documents the Comment Stage." The Second Draft Report consists of the Second Draft, Public Comments with corresponding Committee Actions and Committee Statements, Correlating Notes and their respective Committee Statements, Committee Comments, Correlating Revisions, and Ballot Statements. (See *Regs* at Section 4.2.5.2 and 4.4) The First Draft Report and the Second Draft Report together constitute the Technical Committee Report. Any outstanding objection following the Second Draft Report must be raised through an appropriate Amending Motion at the Association Technical Meeting or the objection will be considered resolved. [See *Regs* at 4.4.1(b)]

V. Step 3a: Action at Association Technical Meeting. Following the publication of the Second Draft Report, there is a period during which those wishing to make proper Amending Motions on the Technical Committee Reports must signal their intention by submitting a Notice of Intent to Make a Motion. (See *Regs* at 4.5.2) Standards that receive notice of proper Amending Motions (Certified Amending Motions) will be presented for action at the annual June Association Technical Meeting. At the meeting, the NFPA membership can consider and act on these Certified Amending Motions as well as Follow-up Amending Motions, that is, motions that become necessary as a result of a previous successful Amending Motion. (See 4.5.3.2 through 4.5.3.6 and Table1, Columns 1-3 of *Regs* for a summary of the available Amending Motions and who may make them.) Any outstanding objection following action at an Association Technical Meeting (and any further Technical Committee consideration following successful Amending Motions, see *Regs* at 4.5.3.7 through 4.6.5.3) must be raised through an appeal to the Standards Council or it will be considered to be resolved.

VI. Step 3b: Documents Forwarded Directly to the Council. Where no Notice of Intent to Make a Motion (NITMAM) is received and certified in accordance with the Technical Meeting Convention Rules, the standard is forwarded directly to the Standards Council for action on issuance. Objections are deemed to be resolved for these documents. (See *Regs* at 4.5.2.5)

VII. Step 4a: Council Appeals. Anyone can appeal to the Standards Council concerning procedural or substantive matters related to the development, content, or issuance of any document of the Association or on matters within the purview of the authority of the Council, as established by the *Bylaws* and as determined by the Board of Directors. Such appeals must be in written form and filed with the Secretary of the Standards Council (See *Regs* at 1.6). Time constraints for filing an appeal must be in accordance with 1.6.2 of the *Regs*. Objections are deemed to be resolved if not pursued at this level.

VIII. Step 4b: Document Issuance. The Standards Council is the issuer of all documents (see Article 8 of *Bylaws*). The Council acts on the issuance of a document presented for action at an Association Technical Meeting within 75 days from the date of the recommendation from the Association Technical Meeting, unless this period is extended by the Council (See *Regs at* 4.7.2). For documents forwarded directly to the Standards Council, the Council acts on the issuance of the document at its next scheduled meeting, or at such other meeting as the Council may determine (See *Regs* at 4.5.2.5 and 4.7.4).

IX. Petitions to the Board of Directors. The Standards Council has been delegated the responsibility for the administration of the codes and standards development process and the issuance of documents. However, where extraordinary circumstances requiring the intervention of the Board of Directors exist, the Board of Directors may take any action necessary to fulfill its obligations to preserve the integrity of the codes and standards development process and to protect the interests of the Association. The rules for petitioning the Board of Directors can be found in the *Regulations Governing Petitions to the Board of Directors from Decisions of the Standards Council* and in 1.7 of the *Regs*.

X. For More Information. The program for the Association Technical Meeting (as well as the NFPA website as information becomes available) should be consulted for the date on which each report scheduled for consideration at the meeting will be presented. For copies of the First Draft Report and Second Draft Report as well as more information on NFPA rules and for up-to-date information on schedules and deadlines for processing NFPA documents, check the NFPA website (www.nfpa.org/aboutthecodes) or contact NFPA Codes & Standards Administration at (617) 984-7246.

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- ❑ Inspector, Building Official, Fire Marshal (F03)
- ❑ Owner, President, Manager, Administrator (C10)
- ❑ Other (please specify): (G11)_______________________

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- ❑ Fire Service, Public and Private (AA1)
- ❑ Government (C12)
- ❑ Industrial Firm (Factory, Warehouse) (C11)
- ❑ Institutional (Health Care, Education, Detention, Museums) (B11)
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