LA-UR-16-21833

Title: Flammable Gas Safety Self-Study 52827

Author(s): Glass, George

Intended for: Training manual

Issued: 2016-03-17

Flammable Gas Safety

Self-Study 52827

March 2016

Los Alamos
NATIONAL LABORATORY
EST. 1943
Operated by Los Alamos National Security, LLC for the NNSA

Central Training-Institutional Training Services Group Leader
Cindy Dutro

Course Manager
George Glass

Technical Advisor
George Hrbek

Editor/Compositor
Lisa Rothrock

Course Number: 52827
March 2016
LA-UR-
Controlled Document Number: Flam_Gas_Safety_SS_52827,R0.3

Contents

Introduction

Course Overview

This course, *Flammable Gas Safety Self-Study* (COURSE 52827), presents an overview of the hazards and controls associated with commonly used, compressed flammable gases at Los Alamos National Laboratory (LANL).

Course Objectives

Terminal Objective

Upon completion of this course, you will have a basic knowledge of the hazards and controls associated with commonly used flammable gases at LANL.

Enabling Objectives

- Recognize properties and hazards associated with flammable gases.
- Recognize regulations, requirements, standards, and guidelines that address the safe use and handling of flammable gases.
- Recognize controls designed for the safe handling and use of flammable gases.
- Recognize controls and requirements specified in LANL P101-34 for working with acetylene, hydrogen, and carbon monoxide.
- Recognize actions to take before an emergency involving a flammable gas occurs.
- Recognize recommended emergency response actions in case of a flammable gas leak, carbon monoxide release, small hydrogen fire, or acetylene flashback.

Target Audience

This course is required by LANL Procedure (P) 101-34, *Pressure Safety,* for those who work with hydrogen gas or other flammable gases.

Course Prerequisites

This course has no prerequisites; however, additional training is required for personnel who work with pressurized systems. See page 30 for specific courses.

Course Limitations

This course does NOT address the following:

- the function or use of standard components of pressurized systems, including regulators, pressure relief devices, and valves; such information is presented in *Pressure Safety Orientation* (COURSE 769);
- requirements for inspecting, handling, using, and storing gas cylinders; such information is presented in *Gas Cylinder Safety* (COURSE 9518);
- unique hazards and controls that may arise from your operations with flammable gases;
- task- or facility-specific work control documents for working with flammable gases;
- site- or job-specific training requirements; or
- hazards or controls associated with pyrophoric gases.

About This Self-Study Course

The *Flammable Gas Safety Self-Study* (COURSE 52827) consists of an introduction, four modules, and a references section. To receive credit in UTrain for completing this course, you must score 80% or better on the 10-question quiz. Directions for initiating the quiz are appended to the end of this training manual.

This course contains several links to LANL websites. UTrain might not support active links, so please copy and paste these links into the address line in your browser.

Acronyms

C	Celsius
CFR	Code of Federal Regulations
CNG	compressed natural gas
DDT	deflagration-to-detonation transition
DOT	(U.S.) Department of Transportation
ESH	Environment, Safety, and Health
H2	hydrogen
HMPT	Hazardous Material Packaging and Transportation
IDLH	immediately dangerous to life or health
IS	intrinsically safe
IWD	integrated work document
LAFD	Los Alamos Fire Department
LANL	Los Alamos National Laboratory
LEL	lower explosive limit
LFL	lower flammable limit
LPG	liquefied petroleum gas
MW	molecular weight
NEC	National Electrical Code
NFPA	National Fire Protection Association
OEL	occupational exposure limit
OPD	overfill prevention device
P	Procedure
PEL	permissible exposure limit
PPE	personal protective equipment
ppm	parts per million
psi	pounds per square inch
psig	pounds per square inch gauge
PSO	pressure safety officer
SWPF	Salt Waste Processing Facility
TLV	threshold limit value
TWA	time-weighted average
UEL	upper explosive limit
UFL	upper flammable limit
µJ	microjoule

Module 1: Flammable Gas Properties and Hazards

Module Overview

This module presents an overview of the general hazards of flammable gases. The properties and hazards of specific flammable gases—including acetylene, hydrogen, and carbon monoxide—are also presented.

Module Objectives

When you complete this module, you will be able to recognize properties of and hazards associated with flammable gases.

Properties of Flammable Gases

20°C = 68°F

Flammable gases are defined by the U.S. Department of Transportation (DOT) as any material with a boiling point (in other words, is a gas) at 20°C or less and 14.7 pounds per square inch (psi) of pressure AND which

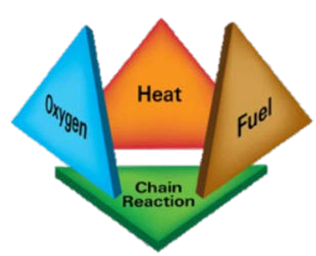
- is ignitable at 14.7 psi when in a mixture of 13% or less by volume with air OR
- has a flammable range at 14.7 psi with air of at least 12%, regardless of the lower limit.

Flammable Gas Hazards

General physical and health dangers of flammable gases include the ability of a gas to be a flammable, pressure, or exposure hazard.

Fire triangle

The **fire triangle** identifies the three needed components of fire: fuel, heat (ignition source), and oxygen. All three components must be present at the same time to have a fire. Fire will burn until one or more of the components is removed. Some models include a fourth component: the self-sustaining chain reaction that provides the heat necessary to maintain the fire. With this fourth component added, the fire triangle is often called the **fire tetrahedron**.



Fire tetrahedron

Flammability and Explosivity

For a gas to be a flammable or explosion hazard, the concentration of the gas in the air must be within a specific range for each gas.

The LEL may also be referred to as the lower flammable limit (LFL).

The UEL may also be referred to as the upper flammable limit (UFL).

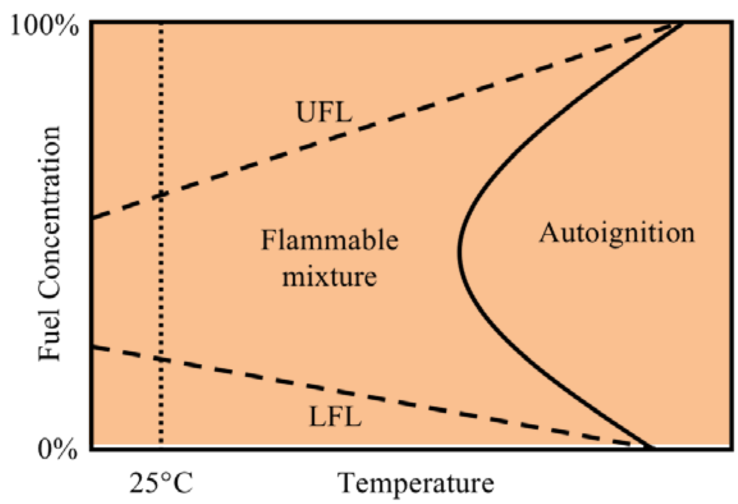
The **lower explosive limit (LEL)** is the lowest concentration (percentage) of a gas or vapor in air capable of producing fire or explosion in the presence of an ignition source; below the LEL, the concentration of the gas or vapor in air is too lean to support combustion.

The **upper explosive limit (UEL)** is the highest concentration (percentage) of a gas or vapor in air capable of producing fire or explosion in the presence of an ignition source; above the UEL, the concentration of the gas or vapor in air is too rich to support combustion.

The **flammable range** is the range of a concentration of a gas or vapor that will burn (or explode) in the presence of sufficient oxygen and an ignition source. The LEL and the UEL form the boundaries for the flammable range, which is different for every flammable gas. A comparison of the flammable ranges for several flammable gases is shown on page 15.

Although compressed oxygen is not in itself flammable, it enhances the flammability of all flammables and combustibles.

The heat needed to initiate combustion often comes from an external ignition source, such as a spark. However, in the presence of sufficient heat, an external ignition source may not be needed. **Autoignition temperature** is the minimum temperature required to initiate or cause self-combustion without ignition from an external source of energy. As with flammable range, the autoignition temperature is different for every flammable gas.



Flammable range as a function of temperature.

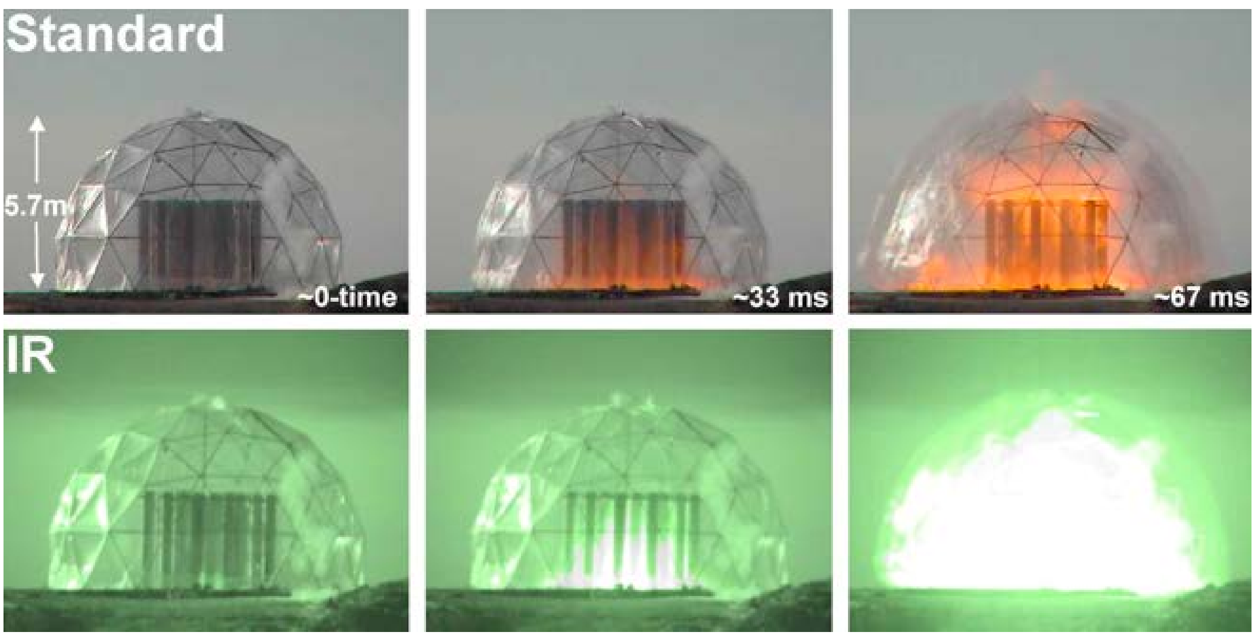
When the minimum conditions of the fire triangle are met or exceeded, flammable gases can deflagrate or detonate.

In some cases, a deflagration can become a detonation in what is known as a deflagration-to-detonation transition (DDT).

Deflagration is a combustion wave that moves at subsonic speed (slower than the speed of sound). An example of deflagration is a fast-burning fire with a flame speed of about 0.5 to 1 meter per second.

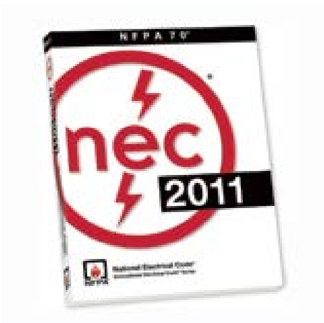
Detonation is a combustion wave that moves at supersonic speed (faster than the speed of sound). The supersonic velocity of the shock wave (on the order of kilometers per second) creates a blast or explosion. Because detonations generate high pressures, they are usually much more destructive than deflagrations. In some cases, a detonation can be produced when a deflagration accelerates because of obstacles and confinement. This event is known as a deflagration-to-detonation transition (DDT).

Conditions that affect whether a flammable gas will deflagrate or detonate include reactivity of the gas, degree of confinement, obstacles, temperature, pressure, and ignition energy.



Frames from standard video and infrared (IR) video of the effect of obstacles on a hydrogen deflagration.
(From M. Groethe et al., *Large-Scale Hydrogen Deflagration and Detonations*, International Conference on Hydrogen Safety, September 2005.)

Hazardous Location Classification



The National Electrical Code (NEC) classifies hazardous locations where fire or explosion hazards may exist because of the presence of flammable or explosive substances. Electrical equipment can become a source of ignition in these areas, and the NEC classification is used to determine the minimal requirements of the electrical equipment that can be used. NEC hazardous locations are classified by type, condition, and nature.

- **Type** identifies three classes (I, II, and III) of hazardous locations based on the type of fire or explosion hazard (flammable gases or liquids, combustible dust, and ignitable fibers or filings). This manual focuses on flammable gases within NEC Class I locations.
- **Condition** addresses the two conditions under which these hazards may be present: normal and abnormal.
  - Division 1 (normal) - the hazard is expected to be present in everyday operations or during frequent repair and maintenance activity.
  - Division 2 (abnormal) - the hazard is expected to be present only through accidental rupture, breakage, or unusual faulty operation.
- **Nature** addresses the flammable characteristics of the substance. The gases and vapors of Class I locations are broken into four groups (A, B, C, and D) according to their properties, such as ignition temperature and explosion pressure. Each group has minimal specifications for the electrical equipment that can be used.
  - Group A is acetylene, a gas with extremely high explosion pressures.
  - Group B includes hydrogen and other materials with similar characteristics.
  - Group C includes carbon monoxide and other materials with similar characteristics.
  - Group D includes many common flammable gases, such as methane, propane, and butane.

To determine the type, condition, and nature of a potentially hazardous location, the characteristics of the flammable gases that will be used and the conditions of operation must be evaluated by qualified personnel. For assistance with such an evaluation, contact your pressure safety officer (PSO) or area industrial hygiene and safety representative.

Pressure

In many cases, flammable gases will be compressed within a cylinder or system. The large amount of potential energy resulting from compression of the gas can cause a pressurized system or cylinder to rupture violently. Hazards from the sudden release of any pressurized gas, including flammable gases, include

- high-velocity fragments and/or propulsion of pressure system components, such as valves or piping;
- a gas cylinder missile; and
- gas penetration into the body from leaking high-pressure jets or orifices that are discharging gas.

Hazards and controls for pressurized systems and pressurized cylinders are addressed in *Pressure Safety Orientation* (COURSE 769) and *Gas Cylinder Safety* (COURSE 9518). To register for these classes, call 667-0059.

Health Hazards

The general health hazards that can occur from exposure to flammable gases include

- contact,
- oxygen displacement, and
- toxicity.

Contact

Another health hazard of flammable gases is the possibility of cold burns to the eyes or skin caused by direct contact. If the flammable gas is a cryogen, such as hydrogen, direct contact can freeze the skin tissue and cause severe damage, including frostbite.

Flammable gases that are not cryogenic can also be contact hazards. A rapidly escaping gas from a cylinder or a pressurized system expands very quickly, causing very cold temperatures. Direct skin or eye contact with the gas or a component that has been in the path of the gas can result in cold burns. For more information about cryogen contact hazards, register for *Cryogen Safety* (COURSE 8876).

Oxygen Displacement

If a flammable gas ignites, it will use oxygen as part of the fire triangle. However, even if the flammable gas does not ignite, it can displace oxygen, reducing the amount of oxygen that is available for a person to breathe. Any gas (including a flammable gas) that is released into an enclosed or poorly ventilated area can displace oxygen. If enough oxygen is displaced, an oxygen-deficient atmosphere can occur.

NEVER enter an oxygen-deficient atmosphere!

Normal air contains about 21% oxygen. Air that contains less than 19.5% oxygen is called *oxygen deficient*. As the concentration of oxygen drops further below 19.5%, people become confused and disoriented. At very low concentrations of oxygen, asphyxiation can occur. Asphyxiation is the impairment of normal breathing leading to loss of consciousness or death. Signs and symptoms associated with an oxygen-deficient atmosphere are shown in the following table.

Signs and Symptoms of Reduced Oxygen Levels*

% Oxygen	Signs and Symptoms
19.5%	minimum level for normal body function*
15%–19%	perception and judgment affected; dizziness
10%–15%	confusion; loss of coordination; lips turn blue
6%–10%	mental failure; death possible in 6 minutes
4%–6%	loss of consciousness with just one breath

** Persons who are not acclimated to the elevation of Los Alamos may be more susceptible to low oxygen concentrations.*

Toxicity

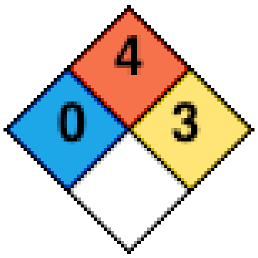
All compressed gases have the ability to displace oxygen (except compressed oxygen). Some gases are also toxic, meaning that they can react chemically with the body and cause harm.

A toxic gas disrupts the body's ability to function at a cellular or organ level. A toxic gas can cause permanent injury or death at very low concentrations—often at a level of parts per million (ppm). Carbon monoxide is an example of a commonly used flammable gas that is also toxic. See page 12 for more information about the toxic effects of carbon monoxide.

Note: *Toxic byproducts can be generated by fires involving an otherwise nontoxic flammable gas. For example, the burning of plastics in any fire may produce irritating or poisonous gases.*

In addition to possessing some or all of the hazards just presented, some flammable gases have specific hazards that handlers and users must be aware of and control. Acetylene, hydrogen, carbon monoxide, and fuel gases are examples of flammable gases that are commonly used at LANL.

Acetylene



Acetylene is a colorless, highly flammable NEC Class 1, Group A, gas with a very low ignition energy (17 microjoules [µJ]) and a very wide flammable range (2.5%–81%). Pure acetylene has an ether-like odor, whereas commercial-grade acetylene has a garlic-like odor. Acetylene acts as a simple asphyxiant that displaces oxygen. However, industrial-grade acetylene may be contaminated with phosphine, a chemical asphyxiant that can pose a greater threat to human health than acetylene alone.

Stability

The static charge developed by walking across a carpet floor on a dry day can be 1700 times greater than that needed to ignite acetylene!

Acetylene is chemically unstable, making it very sensitive to conditions of excess pressure, excess temperature, static electricity, or mechanical shock. Acetylene is shipped in a cylinder packed with a porous mass material and a liquid solvent, normally acetone. It is dissolved in the acetone solution and dispersed throughout the porous medium. When the valve of a charged acetylene cylinder is opened, the acetylene comes out of solution in gaseous form.

When not dissolved in a solvent, acetylene can begin to decompose (dissociate) at pressures above 15 pounds per square inch gauge (psig). The products of decomposition are carbon and hydrogen. Large amounts of heat are generated by decomposition, which can produce violent explosions. The porous filler in an acetylene cylinder absorbs the solvent and prevents large voids in which decomposition might occur. Acetylene will decompose violently with cylinder failure.

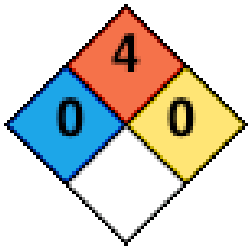
Compatibility

In some conditions, acetylene can form explosive compounds when it comes in contact with copper, copper salts, mercury/mercury salts, silver/silver salts, or nitric acid. Copper acetylide is a heat- and shock-sensitive high explosive that can form inside pipes made of copper or alloys with a high copper content. Explosions caused by copper acetylides in several acetylene plants led to the abandonment of copper as a construction material in such plants.

Flashback

In oxyacetylene welding applications, *flashback* is the burning of combined gases within a hose or torch body. A flashback can occur if a flammable mixture of fuel gas and oxygen is in the hoses when the torch is lit. If not stopped, the flame will ignite the mixture and travel backward from the torch, through the hoses and regulator, and into the cylinder. A flashback can trigger decomposition of the acetylene in the fuel hose, in the regulator, and in the cylinder itself. If the cylinder contents are burning internally, as indicated by a hot cylinder surface, a buildup of pressure could cause the cylinder to burst, despite the use of a fusible relief device set at 100°C.

Hydrogen



Hydrogen is a highly flammable NEC Class 1, Group B gas with a wide flammable range (4%–75%). Hydrogen is colorless, odorless, tasteless, and nontoxic and can act as a simple asphyxiant through oxygen displacement. It is the lightest of all gases, rises rapidly in air, and disperses quickly.

Flammability/Explosivity

Hydrogen has very low ignition energy and a wide flammable range. The ignition energy for hydrogen is only 17–20 µJ, one-tenth that needed to ignite gasoline vapor. The flow of the gas can generate many times this static energy, so it should be assumed that any release of hydrogen will ignite at the source if oxygen is present. Hydrogen burns with a nearly invisible blue flame, unless it contains impurities, which turn the flame a pale yellow.

Hydrogen burns with a nearly invisible blue flame.

Invisible Hydrogen Fire Injures Technician

A technician was welding a cable suspended over a stainless steel hydrogen instrument line. During the welding process, two holes were accidentally burned through the hydrogen tubing. The operator heard a hissing sound and closed the valve, but the hydrogen had already ignited and burned his hand while he was feeling for a leak. A short during welding caused the pinholes in the hydrogen tubing.

H_2 Incident Reporting and Lessons Learned at http://www.h2incidents.org/

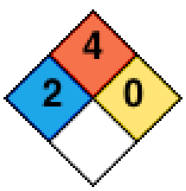
Unlike most other gases, hydrogen's temperature increases during expansion. Many hydrogen fires result from the self-ignition of sudden hydrogen release through rupture disks and pressure-relief valves. Hydrogen detonations, although rare, are characterized by pressure increases so rapid that pressure-relief devices are usually ineffective. When using hydrogen in enclosed areas, consult National Fire Protection Association (NFPA) 68. (See page 19).

Embrittlement

Bolt failure caused by hydrogen embrittlement.

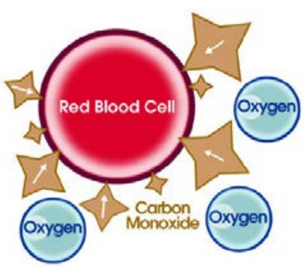
Hydrogen can reduce the performance of some containment and piping materials, such as carbon steel. Because of its small molecular size, hydrogen can leak from openings through which other gases cannot pass. It can pass easily through porous materials, and it may be absorbed by some containment materials. This absorption can result in embrittlement, which is a loss of toughness and/or ductility (the ability to be easily molded or shaped). For more information, register for *Cryogen Safety* (COURSE 8876).

Carbon Monoxide



Carbon monoxide is an NEC Class 1, Group C flammable gas with a wide flammable range (12.5%–74%). It is colorless, odorless, tasteless, invisible, and toxic.

Toxicity



Red blood cells pick up carbon monoxide quicker than they pick up oxygen, which affects their ability to carry oxygen through the body.

Carbon monoxide is a chemical asphyxiant that prevents the body from using oxygen effectively. When inhaled, carbon monoxide binds with the hemoglobin of red blood cells and affects the ability of red blood cells to carry oxygen. The bond between hemoglobin and carbon monoxide is nearly 230 times stronger than the bond between hemoglobin and oxygen, which means that once carbon monoxide binds to hemoglobin, it is very hard to remove. People who have been exposed to carbon monoxide should always receive a medical checkup, even if they think they are okay.

Signs and Symptoms of Exposure

Signs and symptoms of exposure to carbon monoxide may include tightness across the chest, nausea, vomiting, headache, dizziness, confusion, fatigue, or unconsciousness. Large amounts of carbon monoxide can overcome a person in minutes without warning. Depending on how long a person is exposed, death can occur in carbon monoxide concentrations as low as 800 ppm.

Signs and Symptoms of Carbon Monoxide Exposure	
4,000+ ppm	death
0.5 hour at 2500 ppm	unconsciousness
0.5 hour at 1200 ppm	immediately dangerous to life or health (IDLH)
1 hour at 800 ppm	headache and discomfort
2–3 hours at 200 ppm	headache possible

Occupational Exposure Levels

To prevent worker health effects from exposure to carbon monoxide in the workplace, LANL uses the following occupational exposure limits (OELs):

- 25 ppm, 8-hour time-weighted average (TWA) and
- 1200 ppm, IDLH.

Occupational Exposure Limits

An OEL is an upper limit on the amount of a hazardous substance in workplace air. An OEL is often an 8-hour TWA concentration, which is based on the length of a normal workday. Two common OELs are the Occupational Safety and Health Administration permissible exposure limit (PEL) and the American Conference of Governmental Industrial Hygienists threshold limit value (TLV). Unless otherwise specified, LANL uses the lower (more conservative) of the PEL or TLV.

Compatibility

Under certain conditions of elevated pressure (above 500 psi), carbon monoxide can form toxic, corrosive, and/or highly reactive compounds with some metals. For example, combining carbon monoxide with heavy metals, such as nickel, iron, or chromium, can create explosive metal carbonyls.

Fuel Gases

Liquefied Petroleum Gas

Some material safety data sheets indicate a "2" for health hazards associated with LPG.

Liquefied petroleum gas (LPG) is mostly propane (about 90%). Propane (C_3H_8) is a flammable NEC Class 1, Group D gas with ignition energy of about 260 µJ and a flammable range of 2.1%–9.5%. Although LPG is transported and stored as a liquid, it is a gas at atmospheric pressure and normal temperatures. LPG is colorless, odorless, and heavier than air. Because LPG has little or no natural odor, an odorant such as ethyl mercaptan is added to warn users of its presence. LPG can act as a simple asphyxiant through oxygen displacement. In high-enough concentrations, LPG may act as an anesthetic, causing a loss of some body sensations.

LPG is heavier than air and tends to collect and remain in low-lying areas, such as pits, trenches, and below-grade building openings. If ignition is delayed after release, LPG can travel hundreds of feet and settle in such low-lying areas. If ignited, the resulting flashback may travel all the way back to the original containment.

Overfill Protection Devices
All propane cylinders made after 1998 that are designed to contain 4–40 pounds of propane must have an overfill prevention device (OPD). The OPD is a secondary means of protecting against overfilling. The primary means is to determine the fill limit by weight. Cylinders with OPDs have a triple-notched valve hand wheel with the letters "OPD."

Compressed Natural Gas

Compressed natural gas (CNG) is about 90%–100% methane. Methane is a flammable NEC Class 1, Group D gas with an ignition energy of about 300 µJ and a flammable range of 5%–15%. Methane is colorless and odorless. As with LPG, an odorant such as ethyl mercaptan is added to warn users of its presence.

Methane can act as a simple asphyxiant through oxygen displacement. Because the molecular weight (MW) of methane is about the same as that of air, CNG does not tend to settle or rise but is more influenced by ventilation.

Properties of Some Common Flammable Gases

The following table lists properties of some flammable gases that are commonly used at LANL.

Properties of Some Common Flammable Gases

Property	Acetylene	Hydrogen	Carbon Monoxide	Methane	Propane
Color	none	none	none	none	none
Odor	ether or garlic	none	none	none[a]	none[a]
Toxicity	nontoxic	nontoxic	toxic	nontoxic	OEL
Molecular Weight[b]	26	2	28	16	44
Boiling Point (1 atm)	-85°C	-253°C	-191°C	-162°C	-42°C
Minimum Ignition Energy[c]	17 µJ	20 µJ	([d])	300 µJ	260 µJ
Autoignition Temperature[e]	305°C	585°C	609°C	540°C	480°C
Flammable Range	2.5%–81%[f]	4%–75%	12.5%–74%	5%–15%	2.1%–9.5%
NEC Classification	Class 1, Group A	Class 1, Group B	Class 1, Group C	Class 1, Group D	Class 1, Group D

[a] *Mercaptan is added to aid detection of this gas.*

[b] *The MW of air is ~28.8. A gas with a much higher MW (such as propane) will tend to sink in air, whereas a gas with a lower MW (such as hydrogen) will tend to rise in air.*

[c] *Minimum ignition energy is the energy needed at a specified concentration of fuel in air to initiate combustion.*

[d] *Not found in literature.*

[e] *Autoignition temperature is the minimum temperature required to initiate or cause self-combustion without ignition from an external source of energy.*

[f] *Although acetylene is not flammable at concentrations above the UFL, it can undergo an explosive decomposition reaction, even at concentrations of up to 100%.*

Energy in the amount of 20 µJ is comparable to the energy of a grain of sand moving at 9 miles per hour.

Module 2: Regulations and Guidelines

Module Overview

This module presents a listing of regulations, requirements, standards, and guidelines that address the safe handling, use, and storage of flammable gases.

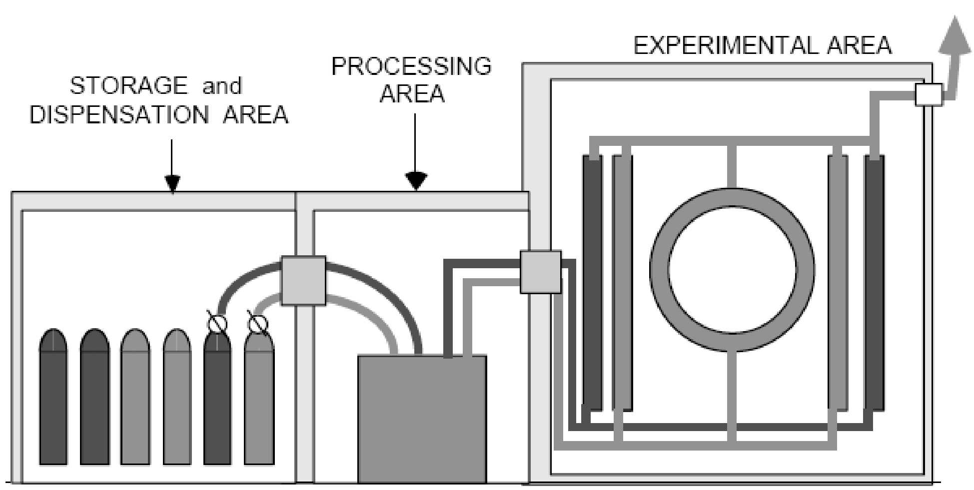
Module Objectives

When you complete this module, you will be able to recognize regulations, requirements, standards, and guidelines that address the safe use and handling of flammable gases.

Regulations, Requirements, Standards, and Guidelines

Regulations, requirements, standards and guidelines that address the safe use, handling, and storage of flammable gases are listed on the following pages.

The list of documents on the following pages is NOT meant to be all-inclusive. Other documents, such as facility-specific procedures, could affect your flammable gas operations. If you have questions about which documents apply to your flammable gas operations, contact your PSO or health and safety professional.



Typical flammable gas installation.

Federal Regulations

Generally, personnel working at LANL are required to meet or exceed all applicable regulations that affect health and safety in the workplace. Federal regulations that could affect or assist you with your flammable gas operations are listed below.

10 CFR 851 – Worker Health and Safety, Appendix A, Part 4
Requires contractors to establish safety policies and procedures to ensure that pressure systems are designed, fabricated, tested, inspected, maintained, repaired, and operated by trained and qualified personnel in accordance with applicable and sound engineering principles.

29 CFR 1910.102 – Acetylene
Incorporates by reference requirements for the transfer, handling, storage, and use of acetylene cylinders and the generation of acetylene.

29 CFR 1910.103 – Hydrogen
Contains requirements for hydrogen gas and liquid hydrogen systems and containers based on the origin and amount of hydrogen.

29 CFR 1910.110 – Storage and Handling of Liquefied Petroleum Gases
Contains requirements for the storage and handling of LPG, including odorizing, construction, and testing of containers, location requirements, excess flow valve parameters, tubing and piping materials, discharge rates, relief valves, cylinder systems, loading requirements, nearby electrical facilities, and safety device requirements.

29 CFR 1910.307 – Hazardous (Classified) Locations
Addresses the requirements for electric equipment and wiring in classified locations based on the properties of the flammable or combustible material and the likelihood that a flammable or combustible concentration or quantity is present. Hazardous location classifications are defined in 29 CFR 1910.399 and are very similar to the NEC definitions.

LANL Requirements Documents

P101-34, Pressure Safety
Contains LANL requirements for personnel who work with or may be exposed to pressure systems and other pressure-related hazards. Also applies to personnel who work with vacuum systems or with cryogenic systems that are not open to the atmosphere at all times. Presents hazards and controls of compressed gases and pressure systems, including

- Attachment B, *Hazardous Compressed Gases*
  - Section 2.1, *Flammable Gases*
  - Section 2.2, *Liquefied Compressed Gases*
  - Section 2.3, *Hydrogen*
  - Section 2.4, *Acetylene*, and
  - Section 2.5, *Carbon Monoxide*.

P101-5, Cryogens
Contains LANL requirements for personnel who may be exposed to cryogens in the course of their work. Applies to subcontractors and their employees to the degree specified in their subcontract. Presents hazards and controls of cryogenic fluids, including controls for flammable cryogens and carbon monoxide.

A link to Chapter 17 is found in STD-342-100, which is a link in P342.

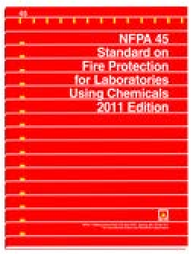
P342, Engineering Standards Manual
Applies to personnel performing design, fabrication, construction, and maintenance on pressure systems at LANL. Pressure systems at LANL must meet the design and certification requirements that are specified in Chapter 17, *Pressure Safety*; ADMIN-2, *Design and Documentation*; Part K, *Hydrogen and Flammable Fluid Pressure Systems*:

- Pressure systems containing such fluids must be designed and evaluated against the requirements of ESM Chapter 10, *Hazardous Process*, and its appendices.
- Hydrogen systems must be evaluated for embrittlement.
- Bonding and grounding must be evaluated for storage vessels and systems containing such fluids.
- Electrical components (solenoid valves, power strips, and control cabinets) must be intrinsically safe when required by the NEC.

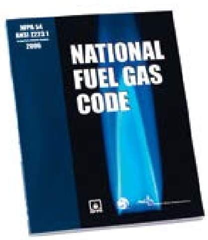
Standards and Guidelines

NFPA standards typically are revised every 3 years.

Standards and guidelines may be required or recommended depending on whether they are incorporated by reference into regulatory or requirements documents. Some of the standards and guidelines that may affect or assist you with your flammable gas operations are listed below.



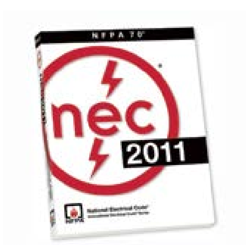
NFPA 45, Standard on Fire Protection for Laboratories Using Chemicals
Provides recommendations for the construction of laboratories that use flammable chemicals. Chapter 7 addresses fume hoods, and Chapter 10 addresses general ventilation requirements for the use of flammable gases in cylinders.



NFPA 54, National Fuel Gas Code
Applies to the installation of fuel gas piping systems, appliances, equipment, and related accessories.

NFPA 55, Compressed Gases and Cryogenic Fluids Code
Addresses flammability in the following chapters: 6.9 *Explosion Control*; 7.6 *Flammable Gases*; 7.8 *Pyrophoric Gases*; 10 *Gaseous Hydrogen*; 11 Bulk *Liquefied Hydrogen*.

NFPA 68, Standard on Explosion Protection by Deflagration Venting
Applies to the design, location, installation, maintenance, and use of devices and systems that vent the combustion gases and pressures resulting from a deflagration within an enclosure so that structural and mechanical damage is minimized.



NFPA 70, National Electric Code
Defines hazardous locations with respect to types of flammable vapors and/or gases present. Wiring and component requirements for each of the classified locations are specified.

CGA G-1, Acetylene
Addresses the characteristics of acetylene and its handling. The material in this document is of a general nature. Technical details must be obtained from acetylene manufacturers.

CGA G-5.4, Standard for Hydrogen Piping Systems at User Locations
Recommended specifications and general principles for gaseous or liquid hydrogen onsite, from the point where hydrogen enters the distribution system to final use point.

Module 3: Flammable Gas Controls

Module Overview

This module presents controls designed for the safe handling, use, and storage of flammable gases. Specific LANL requirements for working with acetylene, hydrogen, and carbon monoxide are also presented.

Module Objectives

When you complete this module, you will be able to recognize

- controls designed for the safe handling and use of flammable gases; and
- controls and requirements specified in LANL P101-34 for working with acetylene, hydrogen, and carbon monoxide.

Warning! *The function and use of standard controls for pressurized systems—including regulators, pressure relief devices, and valves—are not addressed in this manual. Information about these essential pressurized system controls is presented in* Pressure Safety Orientation *(COURSE 769).*

Warning! *Requirements for the safe inspection, handling, use, and storage of gas cylinders are not addressed in this manual unless they are unique for flammable gases. Such information is presented in* Gas Cylinder Safety *(COURSE 9518).*

Types of Flammable Gas Controls

As previously stated, controls for pressurized systems and for gas cylinders are addressed in other courses. This module focuses on controls for flammable gases, including

- intrinsically safe/explosion-proof equipment,
- flashback (flame) arrestors,
- ventilation,
- detectors and alarms,
- grounding and bonding,
- gas rooms and gas cabinets,
- safe work practices,
- training,
- personal protective equipment (PPE), and
- transportation and storage.

Intrinsically Safe/Explosion-Proof Equipment

IS noise dosimeter.

A location in which a fire or explosion hazard exists may require the installation and use of equipment that is specially designed for use in hazardous locations. Two types of such equipment are defined below.

- **Intrinsically safe (IS)** equipment is defined as equipment and wiring that is incapable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific hazardous atmospheric mixture in its most easily ignited concentration.

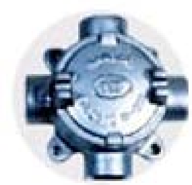
  IS equipment and wiring limit the amount of power (voltage, current, etc.) to and in a device so that a spark cannot be generated. For this reason, IS can be used only for low-power circuits. In addition, each IS device is certified for different levels of IS approval and should be used only in specific hazardous environments.

- **Explosion-proof** equipment is defined as equipment that is capable of containing an internal explosion without allowing flames or hot gases to escape from the housing to trigger an explosion in the surrounding atmosphere. Both IS and explosion-proof equipment must be certified by a national rating agency such as Underwriters Laboratories or Factory Mutual.

IS two-way radio.

Explosion-proof equipment lighting.

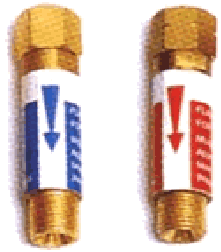
Examples of IS and explosion-proof equipment.



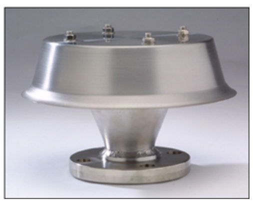
Explosion-proof conduit fitting.

Label for IS headlamp.

Explosion-proof capacitor.



In oxy-acetylene welding, flashback arrestors are used on both the fuel and oxygen lines.



End-of-line deflagration arrestor.

Flashback (Flame) Arrestors

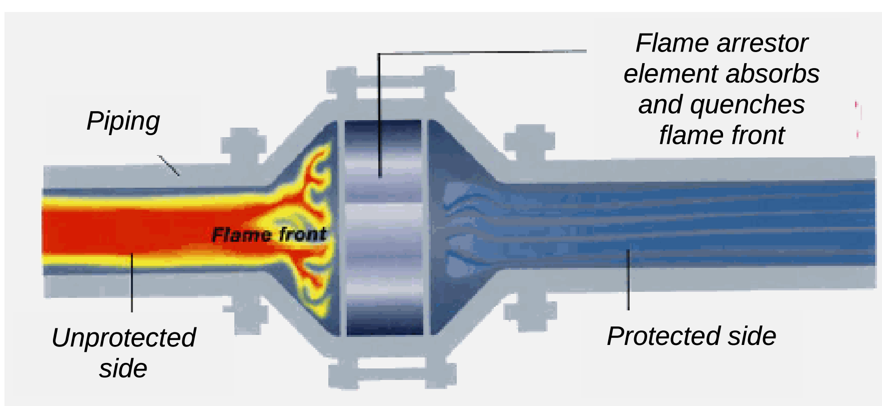
Flashback can be an unwanted progression of a flame downstream (with the flow) or upstream (against the flow). Arrestors are used to control flashback that can result in deflagration or detonation.

Detonation arrestors are located within a process line (with piping on both sides of it) and offer protection against high flame velocities, where the velocity is supersonic and is accompanied by a shock wave.

Deflagration arrestors are available for both in-line and end-of-line applications. In-line deflagration arrestors offer protection against low flame velocities (subsonic speeds) within a process line. End-of-line deflagration arrestors are located at the end of the pipe (with no piping after it) and are designed for protection against unconfined deflagrations. Two methods of arresting deflagration are presented below.

- Venturi flame arrestors create a restriction in the gas/air mixture delivery pipe so that the gas velocity is faster than the flame speed. This restriction prevents a flashback from traveling upstream; however, if gas flow stops, flashback in the direction of flow can still occur. In some cases, equipment may be used to measure flow and add an inert gas (such as nitrogen).
- Mechanical flame arrestors are filled with metal or ceramic, which absorbs heat from a flashback, keeps the temperature below what is needed for ignition, and stops the flame. However, if the flame travels to the face of a mechanical flame arrestor, temperatures can increase to the point where flashback can proceed on the upstream side of the arrestor. In some cases, a temperature switch is installed on the flame side of each arrestor. If an elevated temperature is detected, flow is automatically stopped.

Mechanical flame arrestors absorb heat from a flashback, keeping the temperature below what is needed for ignition.



Ventilation

Ventilation may be used in flammable gas operations to reduce the danger in a hazardous location to a lower level (for example, Division 1 to Division 2) or to create or maintain a nonhazardous area within a hazardous area. Ventilation is also used to control personnel exposure to toxic flammable gases and to ensure that oxygen levels remain above 19.5%.

Natural ventilation (wind and air currents) is used in outdoor locations where flammable gas is stored. Mechanical ventilation (such as fans) is used indoors. Types of mechanical ventilation used with flammable gases are listed below.

- Local exhaust ventilation (such as fume hoods) can be used to prevent concentrations of flammable gas from exceeding flammable and exposure limits.
- A suction fan can be used to minimize or maintain the concentration of flammable gas in an area so that the condition of the hazardous location can be reduced to Division 2.
- A pressure fan can be used to pressurize an enclosed area, preventing the entry of flammable gas from surrounding areas. This pressurization can allow the location to be classified as nonhazardous (as long as the location does not contain a source of the hazard).
- In some cases, ventilation systems are equipped with nitrogen-purging systems that prevent the concentration of exhausted flammable gas from reaching the LEL.

Laboratory Technician Fatally Burned when Leaking Hydrogen Ignites

Employees in a laboratory were conducting high-pressure, high-temperature experiments with animal and vegetable oils under a gas blanket. They were using an LPG burner to supply heat in the process. It is believed that a large volume of hydrogen leaked into the room through a pump seal or a pipe union, spread throughout the laboratory, and ignited after contact with the LPG burner about 15 feet away. A laboratory technician died, and three others were injured when the flash fire engulfed the people in the room. The building in which the incident occurred was not equipped with automatic gas detection or fire suppression systems.

This incident emphasizes the need for proper gas detection, ventilation systems, and fire suppression systems in laboratories that use and store hydrogen, especially when open flame burners are in close proximity. Experienced consultants/engineers should be involved in the design of gas detection and ventilation systems before hydrogen cylinders are employed in any laboratory. Procedures that require periodic maintenance of hydrogen system fittings, valves, and critical components should be developed.

paraphrased from H_2 Incident Reporting and Lessons Learned at http://www.h2incidents.org/

Detectors and Alarms

Flammable gas detection is one of the main controls associated with the use of flammable gases. Gas detectors and sensors can be used to identify

- hazardous concentrations of flammable gases,
- low concentrations of oxygen, and
- pressurized system leaks.

Fixed detectors are mounted in a particular location and provide continuous monitoring of flammable gas concentrations in a specific area. Fixed detectors can provide early warning of leaks or accumulations of flammable gases. They are particularly useful for detecting leaks into enclosed or partially enclosed spaces where flammable gases could accumulate. Multiple fixed detectors are commonly linked to a control area.

Portable detectors are usually small, handheld devices used for early warning of potentially hazardous flammable gas concentrations, tracing leaks, and testing the atmosphere of a confined space. Some single-gas portable detectors are specifically designed to check for leaks.

Point detectors measure the concentration of the gas at the sampling point of the instrument. Some point detectors are designed with a sampling pump and tubing that allows remote sampling, as may be needed for a confined space.

Beam detectors (also called open-path detectors) measure the average concentration of gas along the path of a beam. These detectors usually consist of a radiation source (such as infrared or ultraviolet light) and a separate, remote detector. A limitation of the beam detector is that it does not indicate whether an elevated reading is caused by a high concentration along a small part of the beam or a lower concentration over a longer length.

Multigas detectors are often portable point detectors that typically measure flammability in %LEL, oxygen, and one or two other gases. Some multigas detectors provide a selection of up to 60 sensors for detection of different gases.

Note: *P101-34 requires the use of carbon monoxide detectors in indoor systems where cylinder concentrations of carbon monoxide exceed 1000 ppm (see page 36 of this course manual). P101-34 also requires the use of hydrogen detectors when hydrogen could accumulate at or above the LEL (see page 34).*

Detector Selection and Placement

Other detector selection criteria include cost to purchase and maintain, life expectancy, and frequency of calibration.

Many factors affect the selection of a flammable gas detector and the placement of a fixed gas detector. Well-placed detectors can improve the performance of a detection system, whereas poorly placed detectors can provide a false sense of security. Factors that must be considered before detector selection and placement include the properties of the gas that will be detected, the limitations of the detector, and the likely vulnerabilities of the pressurized system and the immediate environment.

Flammable gas properties: Will the gas tend to rise, sink, or mix somewhat uniformly within the atmosphere? Is the gas likely to escape from the system? For example, because of its small molecular size, hydrogen can leak from apertures through which other gases cannot pass.

Hydrogen sensor mounted near a ceiling, where gaseous hydrogen is most likely to concentrate.

Detector limitations: Are there chemicals or equipment in the area that may interfere with the sensor? For example, steam or water vapor can produce false readings in beam detectors. Radiofrequency can cause elevated readings on some carbon monoxide dosimeters. Will the detector calibration gas interfere with the detection limit for the gas you plan to detect?

System vulnerabilities: Are there ventilation dead spots where flammable gases could accumulate? Are there points in the system from which the gas is more likely to escape, such as joints, material transitions, etc.? Will the environment affect the performance of the detector? Reliable performance can be disrupted in environments with excessive temperatures, humidity, corrosivity, dust, etc.

Gas Cylinder Leaks

Pipefitters were soldering copper pipe on a metal worktable. They were using a partially full, 40-cubic-foot-capacity acetylene cylinder, positioned on the floor at the corner of the table and within 3 feet of the work piece. During the operation, flames were noticed emanating from the cylinder stem near the regulator. A fire watch was standing by with a 10-pound ABC dry chemical fire extinguisher and immediately extinguished the fire. Results of the investigation to determine the cause of the flames were inconclusive.

Lessons Learned: Leak testing of regulators, packing nuts, and hose connections should be conducted before placing acetylene or other fuel gas cylinders in-service. To check for leaks, apply a commercial leak-check fluid over the cylinder valve, packing nut, regulator, and hose connections after the cylinder valve has been opened. Any evidence of leaking must be corrected before welding, cutting, or heating operations are performed.

paraphrased from Lesson ID: 1995-RL-WHC-0001A

Alarms and Other Responses

Whenever a specified gas concentration or set point is exceeded, the detector system should trigger an alarm. Some alarm set points are already specified, and some need to be determined. For example, common alarm set points are used in many portable gas detectors that measure LEL and oxygen; above 10% of the LEL or below 19.5% oxygen, the detector alarms.

Some set points may be based on the OELs for the specific gas(es) being used or the desired concentration of gas within the pressurized system. Ideally, the alarm set point will allow a timely response to minimize the hazard of the situation. For assistance in selecting alarm set points, contact your PSO or your area industrial hygiene and safety personnel.

An alarm should be audible or visible, and preferably both. The alarm may be designed to be observed and acted upon by one person only or may require response by an entire facility. The alarm should continue until action is taken to stop or reset the alarm. Alarms may be needed for

- leaking pressurized system components,
- oxygen-deficient atmospheres,
- toxic gas concentrations, and
- proper ventilation flow.

In addition to audible and visible alarms, automated responses to gas concentrations that exceed set points may include

- interlocks that trip valves to stop flammable gas flow, close fire doors or dampers, initiate ventilation, and/or initiate fire suppression; and
- automatic notification of emergency response organizations such as fire protection or LANL emergency management and response.

Automated responses that may be interlocked with flammable gas alarms include fire dampers and fire suppression.

Grounding and Bonding

Almost any movement can create static electricity, such as combing your hair or walking across a carpet. The friction of the comb moving across your hair or your feet sliding on the carpet (however imperceptibly) creates static electricity. If you touch something, static electricity flows through your body and accumulates at the point you touch and may cause a spark.

Fires and explosions can result from electrostatic discharge in hazardous locations. Static electricity occurs when electrons are moved about on a surface. Static electricity can create sparks with sufficient energy to ignite many flammable gases.

You can reduce the unwanted effects of static electricity by grounding and bonding. **Grounding** is used to eliminate a difference in electrical potential between an object and ground, allowing the potential energy to safely dissipate rather than to accumulate. **Bonding** is used to eliminate a difference in electrical potential between objects so that a spark will not occur between them.

Static grounding and bonding clamps may be used where static electricity can occur. Each clamp should make a low resistance contact with the object to which it is attached, which allows static charges to be safely dissipated to ground through a suitable conductor before building up to dangerous levels.

***Note:** Coated surfaces and insulating layers, such as paint, resins, adhesives, and other products, can increase the resistance and interfere with the safe dissipation of static electricity.*

Items that you should ensure are properly grounded and bonded include

- all cylinders of flammable fuel gases, such as acetylene;
- all electrical equipment located in areas where hydrogen is used; and
- both systems when transferring liquid hydrogen from one system to another.

***Note:** Ensure that first electrical contact with any liquid hydrogen container is made away from any vent opening.*

Each clamp used for grounding or bonding should make a low-resistance contact with the object to which it is attached. Coated surfaces and insulating layers can increase the resistance.

Gas Rooms and Gas Cabinets

Gas rooms and gas cabinets are examples of controls that can be used for any type of compressed gas.

A gas room should be kept free of all combustible materials (empty boxes, trash containers, etc.) that are not essential to operations.

Gas Rooms

A gas room is a separately ventilated, fully enclosed room in which only compressed gases and necessary associated equipment and supplies are stored or used. A gas room has

- noncombustible walls with a fire-resistant rating (explosion venting may be required);
- fire doors that remain closed or are arranged to close automatically in case of fire;
- suitable ventilation within the room;
- correct posting at the entrance;
- lighting, heating, and electrical service rated according to the hazard classification; and
- automatic detection and/or suppression systems as needed.

Gas Cabinets

Gas cabinets are used to control airflow around compressed gas cylinders, isolate hazardous gases from personnel, and reduce hazards in the event of a fire within or outside the gas cabinet. Some of the features that should be considered before purchasing a gas cabinet are listed below:

- Ventilation inlet and exhaust—Some ventilation inlets have a temperature-activated link attached to a damper that will block the inlet (and air supply) in case of a fire
- Exhaust pressure monitor—Ensures that the cabinet is venting properly
- Leak detector(s) and alarms and/or warnings (if equipped with a digital readout screen)
- A door that locks for security
- A viewing window made of wire-reinforced safety glass that allows gauges within the cabinet to be seen without opening the cabinet door
- Sprinkler options in case of internal or external fire

Safe Work Practices

Many safe work practices that apply to the handling and use of compressed gases are addressed in other institutional environment, safety, and health (ESH) training courses and will not be repeated here. However, some general safe work practices for using flammable gas are listed below:

- Locate flammable gas systems in well-ventilated areas. If used indoors, the effluent from the system and from pressure-relief devices must be vented outside the building, directly or through hoods, away from windows and air intakes, or into suitable ventilation systems.
- DO NOT locate flammable gas piping in concealed spaces or in spaces where leaking gas could go undetected and accumulate.
- If the use of flammable gases makes the area of use a hazardous location according to NFPA 70, *National Electrical Code, Article 500*, then electrical equipment must meet the requirements of NFPA 70, Articles 501–510, as applicable.
- DO NOT use or store flammable gases near open flames, hot surfaces, oxidizers, electrical power lines, or any equipment that could produce heat or sparks.
- Place signs at the entrances of rooms that contain flammable gas to alert Emergency Operations personnel of its presence. “NO SMOKING” signs must be posted in areas where flammable gases are used or stored.

Post areas where flammable gases are used or stored.

- Read and understand your integrated work document (IWD) and material safety data sheet, both of which should specify flammable gas hazards and controls.
- Perform, or have someone perform, regular inspection, maintenance, and leak testing of the pressurized system(s) with which you work. Use leak detectors to periodically check for leaks in pressurized systems, especially in areas that may be more likely to leak, such as valves, flex tubing, etc.
- Limit the volume of flammable gas to the minimum needed for the work being done. Use just-in-time delivery when possible.
- Perform receipt inspections of all flammable gas cylinders. Contact the Compressed Gas Processing Facility if you have a concern.
- Locate compressed flammable gas cylinders so that they will NOT become part of an electrical circuit.
- If possible, use nonsparking tools when working on or with compressed flammable gas cylinders and systems.

Pressure safety and related training at LANL includes both live and self-study courses.

Only workers who complete the Compressed Gas Processing Facility qualification and training program are authorized to fill 160-liter dewars. For more information, contact the Compressed Gas Processing Facility at 667-4406.

Training

P101-34 requires that personnel who work with pressurized systems complete the training listed below, as appropriate. Pressure safety and related training at LANL includes both the following live and self-study courses:

- *Pressure Safety Orientation* (COURSE 769) – Required for those who work with systems containing gases or liquids at pressures greater than 15 psig
- *Gas Cylinder Safety* (COURSE 9518) – Required for those who handle or work with compressed gas cylinders or compressed gas cylinder systems
- *Flammable Gas Safety Self-Study* (COURSE 52827) – Required for those who work with flammable gases
- *Pressure Safety: Advanced* (COURSE 11459) – Required for workers who design, fabricate, install, operate, inspect, and/or test pressure-components systems, and/or maintain pressure systems. A self-study version (COURSE 30120) is available online.
- *Compression Fittings Assembly* (COURSE 30831) – Required for workers who assemble or maintain compression fittings

Additional training that you may also need includes the following:

- *Chemical Hazard Communication Introduction* (COURSE 25418) – Required for workers who may be exposed to chemical hazards under normal operating conditions and workers who may be exposed to chemical hazards in a foreseeable emergency. A self-study version (COURSE 25997) is available online.
- *Hazardous Material Packaging and Transportation (HMPT)* – A series of courses required for workers who perform hazardous material packaging and/or transportation functions. HMPT training and authorization are necessary for personnel who plan to transport or package compressed flammable gases. For more information, contact Institutional Training Services at 7-0059.
- Qualification requirements for pressure system designers and pressure system reviewers at LANL are found in Chapter 17 of the *Engineering Standards* (P342).

Personal Protective Equipment (PPE)

Natural fiber work clothes (cotton) generate less electrostatic charges than synthetic work clothes (nylon, polyester, etc.)

PPE requirements for working with compressed gases are addressed in *Gas Cylinder Safety* (COURSE 9518). One specific PPE requirement from P101-34 for flammable compressed gases is "Wear work clothes that minimize ignition sources, such as static electricity or sparking metals, in Class 1, Division 1, areas."

Transportation and Storage

Transportation of Flammable Gases

Requirements for the transportation of hazardous materials, including flammable gases, are regulated by the DOT. The quantity and hazard(s) of a flammable gas are used, in part, to determine the requirements and limitations for its transportation. Training and authorization must be obtained before transporting hazardous materials, such as compressed flammable gas, at LANL.

For more information about federal regulations and LANL requirements that address the transportation of hazardous materials, including flammable gas, contact the LANL Packaging and Transportation Operations Center at 664-0765.

For more information about LANL Hazardous Material Packaging and Transportation (HMPT) training requirements and availability, contact Institutional Training Services at 667-0059.

Storage of Flammable Gases

Specific storage requirements for acetylene cylinders are listed on page 32.

Storage of compressed gas cylinders is addressed in *Gas Cylinder Safety* (COURSE 9518). Flammable gases must NOT be stored near open flames, hot surfaces, oxidizers, electrical power lines, or equipment that could produce heat or sparks. Additional considerations for storing compressed flammable gases include, but are not limited to

- the specific flammable gases being stored;
- the quantity of flammable gases being stored;
- whether the storage is indoors or outdoors; and
- the distance from buildings, streets, air intakes, combustible materials, windows, doors, etc.

For questions about flammable gas storage area, contact your PSO or area industrial hygiene and safety personnel.

Acetylene, Hydrogen, and Carbon Monoxide Controls

Some of the flammable gases commonly used at LANL—acetylene, hydrogen, and carbon monoxide—have specific, required controls. Other flammable gases that may have unique hazards and controls are NOT addressed in this manual. If you have questions about the requirements below or about other compressed flammable gases, contact your PSO or area industrial hygiene and safety personnel.

Acetylene

NEVER use copper in acetylene systems!

General controls apply to flammable gases. Acetylene-specific controls are listed below:

- Materials used in acetylene systems must be compatible for acetylene service. NEVER use copper in acetylene systems!
- Inspect acetylene systems to ensure that pressure-relief devices are set at 15 psig or less.
- Ensure that flash arrestors and backflow-prevention devices are installed in piped systems.
- When using oxygen/acetylene equipment, fit flashback arrestors onto the pressure regulators on both the acetylene cylinder and the oxygen cylinder. For long lengths of hose, fit arrestors on both the blowpipe and the regulator.
- Store acetylene only in cylinders designed for acetylene. Such cylinders contain a porous mass that is saturated with acetone or another solvent into which acetylene dissolves, allowing the acetylene to be stored safely at up to 250 psig.
- Store and use acetylene cylinders in an upright position, or nearly so, with the valve end up.
- Store acetylene at least 20 feet from oxygen cylinders, or ensure that they are separated by a noncombustible wall at least 5 feet high that has a fire-resistant rating of at least 1 hour. ***Note:*** *Single cylinders of acetylene and oxygen may be secured on a cart or used next to each other without a partition. Single cylinders of acetylene and oxygen located at a workstation (i.e., chained to a wall, secured on a cart) are considered "in service."*

Emergency shutoff wrench.

- Keep valves closed when cylinders are not in service or empty. Close the cylinder shutoff valve first; then bleed the pressure off the regulator and torch equipment.
- Emergency shutoff wrenches or keys for the acetylene cylinder must be kept on the valve spindle when the cylinder is in use.
- Open an acetylene cylinder valve the minimum amount required to deliver acceptable flow (usually one and one-half turns) so that it can be closed as quickly as possible in an emergency.

Leaking Acetylene Cylinder Shutoff Valve

In January 2010 while cutting rebar at the Savannah River Salt Waste Processing Facility (SWPF) with an acetylene torch, a small fire (3-inch flame) occurred at the cylinder shutoff valve. Although the acetylene rig was covered in fire retardant blankets, ricocheting sparks ignited the gas underneath the blankets. A fire watch extinguished the fire. Investigators determined that the cylinder shutoff valve was leaking at the valve stem when the valve was open to allow gas flow to the regulator.

Following the determination that the cylinder shutoff valve was leaking, an extent of condition inspection was conducted on acetylene cylinders at the SWPF. Five out of eight cylinders were found to be leaking in the same location just below the top nut of the shutoff valve. The leaks occurred only when the valves were open. Each of the leaking cylinders had a shutoff valve with a double-nut configuration. Figure 1 shows a leaking shutoff valve that is similar to the one that was involved in the fire. The acetylene cylinders that did not leak used a shutoff valve with a single-nut configuration (Figure 2).

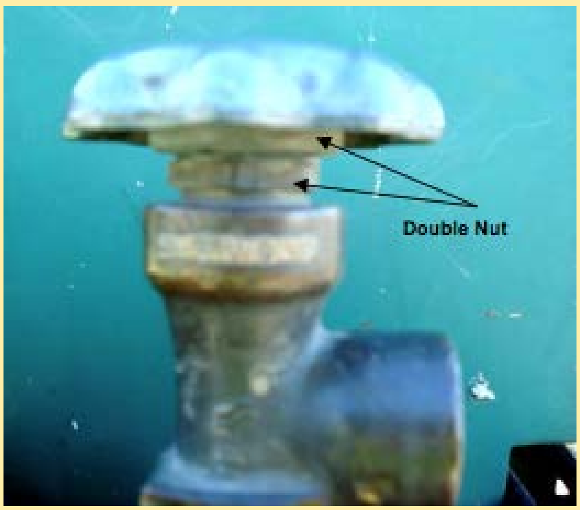


Figure 1. Leaking shutoff with a double-nut configuration.

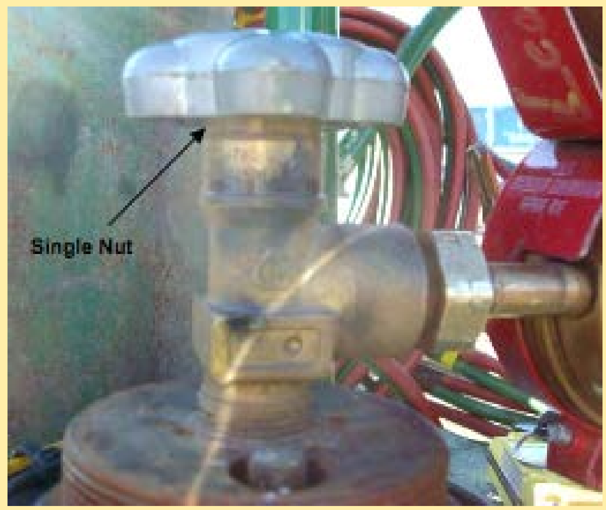


Figure 2. Nonleaking shutoff valve with a single-nut configuration.

Because acetylene is used widely throughout the DOE Complex for oxyacetylene cutting, heat treating, and welding, site personnel should check to see if they have any acetylene cylinders that use a shutoff valve designed with a double nut at the valve stem seal. Valves should be checked for leaks. If the leaks cannot be stopped, the cylinders should be returned to the supplier.

paraphrased from Office of Health, Safety and Security Safety Advisory 2010-02, January 2010

A fixed UV-light flame detector (above) and a portable H2 leak detector (below).

Hydrogen

In addition to general controls for flammable gases, hydrogen-specific controls from P101-34 are listed below. Contact your PSO for assistance in applying these requirements and choosing applicable standards.

- Single-cylinder systems using containers having a total hydrogen content of less than 400 standard cubic feet (scf) may be used in a well-ventilated room. Two individual systems, each having a total hydrogen content of less than 400 scf, may be located in the same well-ventilated room if located more than 10 feet apart.
- Systems containing more than 400 scf each or located less than 10 feet apart must comply with CGA G5.4, *Standard for Hydrogen Piping Systems at User Locations*. Contact your PSO for guidance regarding this issue.
- Where possible, perform hydrogen operations in well-ventilated areas, such as fume hoods.
- Use hydrogen detectors/alarms when hydrogen could exceed the LEL, particularly in trapped spaces near ceilings. Use gas monitors set to alarm at or below 25% of the LEL in areas of hydrogen use. If possible, place gas alarm sensors on or at the height of the ceiling immediately above the point of anticipated leakage. Verify gas alarms quarterly or in accordance with the manufacturer's instructions.
- Minimize potential ignition sources such as hot surfaces, electrical equipment, spark-producing tools, and static electricity, especially in areas where hydrogen could accumulate.

Hydrogen Release Causes Injuries

In 1961, the Rover Project (in which LANL participated) used large amounts of hydrogen as a rocket propellant in a nuclear rocket engine. In one event, hydrogen gas leaked into a large area enclosed by a removable sheet metal shed and exploded. Ten people inside the space received injuries that included bruises, ruptured eardrums, and fractured bones; the shed was destroyed.

Hydrogen had leaked through a defective valve into 500 feet of piping. When the valve was opened, the low-pressure hydrogen in the pipe flowed rapidly through a nozzle. It is believed that the rapidly moving particles generated sufficient friction upon exiting the nozzle to ignite the hydrogen-air mixture.

Controls that were implemented included

- a status board to better coordinate operations (maintenance) and experiments; and
- double-block-and-bleed valve configurations among the hydrogen source, a tank farm, and the experimental apparatus.

Grounding a hydrogen system.

- Design new hydrogen ventilation systems to ensure that the ductwork is independent of other systems and that sources of ignition are eliminated at the exhaust system outlet.
- Design and construct gaseous or liquid hydrogen systems supplied by boil-off from liquid hydrogen in accordance with 29 CFR 1910.103, *Hydrogen*.
- If possible, equip hydrogen ventilation systems with an inert gas (nitrogen) purge capability to prevent ignition of hydrogen and air mixtures at the start of venting.
- Ensure that flash arrestors for oxygen-hydrogen mix applications are rated for oxygen-hydrogen service.

  Note: *Most hydrogen flash arrestors are NOT rated to stop the flame propagation of an oxygen-hydrogen mix.*
- Ground and bond all electrical equipment. When transferring liquid hydrogen from one system to another, electrically bond both systems and the transfer tube(s), and solidly connect to a common earth ground.

To reduce the risk of liquid hydrogen embrittlement, select piping and component materials from 300-series stainless steel, copper, and brass. To learn more about hydrogen embrittlement, register for Cryogen Safety (COURSE 8876) training.

Carbon Monoxide

In addition to general controls for flammable gases, carbon monoxide-specific controls from P101-34 are listed below:

- Use an inert cryogen to test and purge vessels, pipelines, vaporizers, and controls at pressures and temperatures near actual operating conditions.
- Leak-check all indoor compressed gas pressure systems with more than 100 ppm of carbon monoxide at least twice a year.
- Use active ventilation, such as a fume hood or walk-in hood, for all carbon monoxide work.
- Use carbon monoxide detectors with indoor systems when the cylinder gas contains more than 0.1% (1000 ppm) carbon monoxide, regardless of the extent of ventilation.
- Install an alarming carbon monoxide sensor in work areas.
- Ensure that all personnel use a portable real-time carbon monoxide monitor when entering areas or rooms where carbon monoxide is used or stored.

  Note: *P101-34 recommends the use of a buddy system: one person stays outside of the room or area where carbon monoxide is being used while one person enters. The person outside of the room or area observes the person on the inside. If the person who entered the space is incapacitated by carbon monoxide, the outside person contacts emergency personnel but does NOT enter the area to perform a rescue.*

Monitoring Equipment Interference and Limitations

In 2009, a contractor reported a reading of about 40 ppm of carbon monoxide on a direct-reading carbon monoxide instrument. The Argonne Fire Department also observed a positive reading on a different brand of instrument, as did industrial hygiene support on a third brand of instrument.

Because no source of carbon monoxide was identified, it was thought that interference was the cause of the carbon monoxide reading. A slight leak from the fitting on an acetylene cylinder was identified. The leak was so small that none of the multigas instruments indicated a % LEL reading. The cylinder was removed, and the incident ended.

Many, but not all instruments used for carbon monoxide detection experience interference from other substances, such as acetylene. Such limitations are usually found in the operating manuals for the field instruments.

paraphrased from Lesson ID: 2009-ANL-003

Module 4: Emergency Actions and Resources

Module Overview

This module presents an overview of actions to take before an emergency involving a flammable gas occurs and recommended emergency response actions to take in case of a flammable gas leak, small hydrogen fire, acetylene flashback, or carbon monoxide release. LANL resources that can assist with the safe use of compressed flammable gases are also listed.

Module Objectives

When you complete this module, you will be able to recognize

- actions to take before an emergency involving a flammable gas occurs; and
- recommended emergency response actions in case of a flammable gas leak, carbon monoxide release, small hydrogen fire, or acetylene flashback.

Before an Emergency

Before any emergency involving a flammable gas (or any hazard, for that matter) occurs, prepare your response. At a minimum,

- ensure that you and everyone on your team is familiar with your emergency response procedures;
- verify the location and operation of safety showers, eyewashes, fire extinguishers, first aid kits, etc.;
- ensure that selected personnel have the necessary training (such as fire extinguisher training) and authorization to respond to an emergency;
- review your IWD for any specific actions required in case of emergency; and
- walk down your area(s) to ensure that all necessary prevention and detection equipment is in place and operational.

Flammable Gas Emergency Actions

Entry into areas containing flammable gas storage or processes under conditions of ventilation failure, power failure (or immediately following a power failure), process upset, or where the atmosphere conditions are unknown must be performed as stated in the IWD Required Emergency Procedures or the Facility Emergency Procedures.

Note: *The following emergency action steps are NOT meant to replace any site- or task-specific emergency response procedures at your facility. Emergency Operations and the Los Alamos Fire Department (LAFD) are the recognized emergency responders at LANL.*

Flammable Gas Leak

If a flammable gas leak is discovered or if a flammable gas alarm sounds, take the following steps if it is safe to do so:

1. Begin evacuation of all nonessential personnel from the immediate area.
2. Shut off the flammable gas source, and vent all flammable gas from the leaky system to a safe outside location.
3. If possible, increase the indoor ventilation with emergency, explosion-proof exhaust fans.
4. Call 911 or Emergency Operations at 7-6211, and initiate your facility emergency plan.

Carbon Monoxide Release

If a carbon monoxide detector alarms, take the following steps:

1. Evacuate the area immediately!
2. Call 911 or Emergency Operations at 7-6211, and initiate your facility emergency plan.

Acetylene Flashback

A flashback into an acetylene cylinder can initiate decomposition of the gas. The porous mass within an acetylene cylinder is designed to slow down or stifle any decomposition of the gas. The start of decomposition to the cylinder's exploding should take several hours, allowing time for emergency action.

If an acetylene flashback occurs, follow these precautions if it is safe to do so:

- Close the cylinder valves, both acetylene and oxygen. The flame should go out when the acetylene is shut off. If the flame cannot be put out at once, evacuate the area and call 911 or Emergency Operations at 7-6211.
- Check any acetylene cylinder that has been involved in a flashback or that may have been affected by fire or flames. If the cylinder becomes warm or starts to vibrate, evacuate the building immediately, and call 911 or Emergency Operations at 7-6211.
- DO NOT attempt to move an unstable cylinder. If possible, direct water spray at the cylinder body.

Note: *Before restart, check flashback arrestors and any other components that may have been damaged by the flashback; replace as necessary. If in doubt, talk to your PSO.*

Small Hydrogen Fire

A pure H_2 flame is nearly invisible. Special flame detectors using ultraviolet and/or infrared light are designed to detect H_2 flames. If you do not have such a detector, you can detect a small, local H_2 fire by using a piece of tissue paper on a stick: the paper will readily ignite when it contacts a flame.

Hydrogen flame detectors and alarms should be installed on systems that have the potential for large leaks.

If fire is present, take the following steps if it is safe to do so:

1. Shut off the H_2 source.

   Note: *Let the fire burn itself out; if the flame is snuffed out, it may reignite and cause greater damage.*
2. Vent H_2 to a safe outside location.
3. Evacuate the area.
4. Call 911 or Emergency Operations at 7-6211, and initiate your facility emergency plan.

LANL Resources

LANL resources for assistance in the design, setup, use, and/or maintenance of a flammable gas system are listed in the following table. Note that some of these contacts may change over time. If the phone number or link that is provided does not work, call the Safety Help Desk at 665-SAFE (665-7233).

Pressure Safety Area	Point of Contact	Phone
General hazards and controls	Industrial Hygiene and Safety Group	606-0295
Building/facility interface	Utilities and Institutional Facilities	665-2272
Operation, maintenance, and testing	Engineering Services - Design Engineering	667-4657
Fire-protection standards	Emergency Operations - Fire Protection	667-9045
Pressure-device calibration	Quality - Standards and Calibration Group	665-9981
Compressed gas procurement	Compressed Gas Processing Facility	667-4406
Packaging and transportation of hazardous materials	Packaging and Transportation Operations	664-0765
Safety basis (risk analysis for nuclear facilities)	Safety Basis - Programs	665-1951
Emergency response	Emergency Operations	667-6211
Institutional ESH training	Institutional Training Services	667-0059

References

Compressed Gas Association, CGA G-5, *Hydrogen,* Compressed Gas Association, Inc., 1235 Jefferson Davis Highway, Arlington, VA 22202 (1991).

Compressed Gas Association. CGA G-5.4, *Standard for Hydrogen Piping Systems at Consumer Locations*, Compressed Gas Association, Inc., 1235 Jefferson Davis Highway, Arlington, VA 22202 (1992).

Compressed Gas Association. CGA G-5.5, *Hydrogen Vent Systems*, Compressed Gas Association, Inc., 1235 Jefferson Davis Highway, Arlington, VA 22202 (1996).

F. J. Edeskuty and W. F. Stewart, *Safety in the Handling of Cryogenic Fluids*, Plenum Press, New York, ISBN 0-306-45161-1 (1996).

Los Alamos National Laboratory, *Pressure Safety*, Procedure P101-34, 2011.

National Fire Protection Association, *Guide for Venting Deflagrations*, NFPA 68.

National Fire Protection Association, *NFPA 70: National Electrical Code* (2008).