



CGA P-12—2023

GUIDELINE FOR SAFE HANDLING OF CRYOGENIC AND REFRIGERATED LIQUIDS

SEVENTH EDITION

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1 Introduction

Large quantities of cryogenic and refrigerated liquids have been safely transported, handled, and stored for over half a century. Liquid oxygen was first shipped by tank truck in 1932. Today, it is common to see portable liquid containers, cryogenic trailers, trucks, and railroad tank cars transporting large quantities of cryogenic and refrigerated liquids over land. Cryogenic tanker ships transport liquefied natural gas (LNG) overseas. Air transportation is used to transport some liquefied gases, especially liquid helium.

The cost of large-scale transportation and storage of cryogenic and refrigerated liquids is lower than the cost of transporting and storing compressed gases. Cryogens can be used in the liquid state (e.g., liquid nitrogen refrigeration systems), but the liquid is usually vaporized and used as a gas (e.g., vaporized liquid oxygen used in hospitals, welding, and steelmaking).

Safe handling practices are based on understanding each cryogenic and refrigerated liquid's specific properties, using procedures that were developed based on those specific properties, and knowing each liquid's material compatibility. The compressed gas industry has developed safe handling, delivery, and equipment design methods that are specific to each cryogenic and refrigerated liquids discussed in this publication by obtaining a thorough understanding of the risks and hazards associated with each cryogenic and refrigerated liquid. This individualized approach makes the handling and use of cryogenic and refrigerated products as risk free as possible. Anyone handling cryogenic or refrigerated products should strictly adhere to the safety practices.

2 Scope

This publication provides general information about the properties, transportation, storage, safe handling, and safe use of the cryogenic and refrigerated liquids commonly used by industry and institutions. It is intended for cryogenic and refrigerated liquid users, shippers, carriers, distributors, equipment designers or installers, safety administrators, and anyone seeking an introduction to cryogenic and refrigerated liquids. If more detailed or specialized information is required, consult your cryogenic and refrigerated liquid supplier. The information in this publication is intended to complement federal, state, provincial/territorial, local, and insurance company safety requirements.

Among common industrial gases that are transported, handled, and stored as cryogenic liquids, the most prevalent cryogenic liquids are oxygen, nitrogen, argon, hydrogen, and helium. Three rare atmospheric gases, neon, krypton, and xenon, are also transported, handled, and stored as cryogenic liquids. Typical refrigerated liquids include carbon dioxide and nitrous oxide. Although not usually classified as industrial gases, LNG, liquid methane, ethylene, and carbon monoxide are also transported, handled, and stored as cryogenic liquids.

Some gases, including fluorine (boiling point -306.8°F [-188.2°C]) and nitric oxide (boiling point -241.2°F [-151.8°C]), can exist as cryogenic liquids due to their low boiling points. Both fluorine and nitric oxide are extremely reactive and hazardous to handle without extraordinary precautions; they are not normally handled as cryogenic liquids due to their reactive nature; it is more common for them to be handled as gases at ambient temperatures in the compressed gases industry. They are not discussed in this publication due to their specialized nature and hazards.

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions**3.2.1 Backflow**

Backflow is the diffusion or cryopumping of air or other gases into liquid helium and liquid hydrogen vessels and equipment.

3.2.2 Cryogenic liquid

Refrigerated liquefied gas having a boiling point colder than $-130\text{ }^{\circ}\text{F}$ ($-90\text{ }^{\circ}\text{C}$) at 14.7 psia (101.3 kPa, abs)^{1, 2}

NOTE—Also referred to as cryogen in this publication.

3.2.3 Refrigerated liquid

Liquid that shall be maintained at temperatures below the ambient for storage and transportation in the liquid state below the maximum allowable working pressure (MAWP) of the container.

4 Standards and specifications

Many industry and government standards are available to guide the user in the proper selection of equipment for use in specific cryogenic operations, installations, and required maintenance practices. In some applications, additional requirements may be specified by federal, state, provincial, territorial, or local authorities. The user should check the requirements when preparing for specific operations.

A partial list of standards and specifications developed by regulatory and standards-setting organizations in the United States and Canada includes the following:

- Title 49 of the U.S. *Code of Federal Regulations* (49 CFR) Parts 100-180, particularly Part 173, 178, and 179 [2];
- *ASME Boiler and Pressure Vessel Code* (ASME Code), Section VIII, Division 1 [3];
- CGA S-1.1, *Pressure Relief Device Standards—Part 1—Cylinders for Compressed Gases* [4];
- CGA S-1.2, *Pressure Relief Device Standards—Part 2—Portable Containers for Compressed Gases* [5];
- CGA S-1.3, *Pressure Relief Device Standards—Part 3—Stationary Storage Containers for Compressed Gases* [6];
- CGA-341, *Specification for Insulated Cargo Tank for Nonflammable Cryogenic Liquids*, [7];
- AAR M-1002, *Manual of Standards and Recommended Practices*, Section C, Part III, “Specifications for Tank Cars” [8];
- NFPA 55, *Compressed Gases and Cryogenic Fluids Code* [9];
- NFPA 99, *Health Care Facilities Codes* [10];
- NFPA 59A, *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)* [11];

¹ References are shown by bracketed numbers and are listed in order of appearance in the reference section.

² psi, bar, and kPa shall indicate gauge pressure unless otherwise noted as (psia; bar, abs; and kPa, abs) for absolute pressure or (psid; bar, dif; and kPa, dif) for differential pressure. All kPa values are rounded off per CGA P-11, *Guideline for Metric Practice in the Compressed Gas Industry* [1].



Documents

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- IATA *Dangerous Goods Regulations* (DRG), Air Shipment of Cryogenic Liquid [12];
- *Transportation of Dangerous Goods Regulations* [13];
- CSA B620, *Highway Tanks and TC Portable Tanks for the Transportation of Dangerous Goods* [14];
- CSA B622, *Selection and use of Highway Tanks, TC Portable Tanks, and Ton Containers for the Transportation of Dangerous Goods, Class 2* [15];
- CSA B339, *Cylinders, Spheres and Tubes for the Transportation of Dangerous Goods* [16];
- CSA B340, *Selection and Use of Cylinders, Spheres, Tubes, and Other Containers for the Transportation of Dangerous Goods, Class 2* [17];
- CGSB 43.147, *Construction, Modification, Qualification, Maintenance, and Selection and Use of Means of Containment for the Handling, Offering for Transport, or Transporting of Dangerous Goods by Rail* [18];
- CSA B51, *Boiler, Pressure Vessel and Pressure Piping Code* [19]; and
- CSA C22.1, *Canadian Electrical Code, Part 1* [20].

5 Properties of cryogenic and refrigerated liquids

5.1 Extremely low temperature

Cryogenic and refrigerated liquids are extremely cold. The normal boiling point for cryogenic liquids is less than -130°F (-90°C). The normal boiling point for a refrigerated liquid is above -130°F (-90°C) but is still extremely cold.

Cryogenic liquids and their cold boil-off vapors can rapidly freeze human tissue and can cause many common materials such as carbon steel, plastic, and rubber to become brittle or even fracture under stress. Liquids in poorly insulated or uninsulated containers and piping at temperatures at or less than the boiling point of liquefied air, -318°F (-194°C), can condense the surrounding air into a liquid. This liquid air can easily become oxygen rich and should be treated as liquid oxygen. Extremely cold cryogenic liquids such as helium, hydrogen, and neon can solidify directly exposed to air or other gases.

Refrigerated liquefied gases such as carbon dioxide and nitrous oxide, while not having a boiling point low enough to be called cryogenic liquids, are sufficiently cold to pose the same hazards as cryogenic liquids. Carbon dioxide is an unusual gas that evaporates from its solid state directly to the gaseous phase without becoming a liquid. This phenomenon is called sublimation and the sublimation point is -109.3°F (-78.5°C) at 1 atmosphere of pressure. Nitrous oxide, unlike liquid carbon dioxide, evaporates from the liquid phase to the gaseous phase at the boiling point of -127.4°F (-88.56°C).

5.2 High liquid-to-gas expansion ratios

All cryogenic and refrigerated liquids produce large volumes of gas when they vaporize. For example, 1 vol of liquid nitrogen at its boiling temperature at 1 atm vaporizes to approximately 700 vol of nitrogen gas when warmed to room temperature at 1 atm. The volume expansion ratio of oxygen is approximately 860 to 1. Liquid neon has the highest expansion ratio of any industrial gas at 1445 to 1. If these liquids are vaporized in a sealed container, they will produce enormous pressures. For example, 1 vol of liquid helium at 1 atm when vaporized and warmed to room temperature in a totally enclosed container has the potential to generate a pressure greater than 14 500 psi (100 000 kPa). For this reason, pressurized cryogenic containers are protected with multiple devices for pressure relief. For example, a pressure relief system may consist of a pressure relief valve for primary protection and a frangible disk for secondary protection.

5.3 Fogging

A visible fog or vapor cloud is produced by the significant cooling effect of a cryogenic or refrigerated liquid when it vaporizes into still or moving ambient air. The extent of the vapor cloud is determined by the distance it takes for the vaporized gas to warm to the dew point or frost point of the ambient air. Once the cryogenic or refrigerated liquid is warmed, it can no longer cool the air and condense out moisture. The concentration of cryogenic or refrigerated liquid substances in air can extend beyond the visible fog or vapor cloud since the vaporized gas will continue to mix with the air even though it can no longer cool the air. This mixing effect results in an elevated concentration of the vaporized gas in air extending from the source to some distance away.

For releases of cryogens, the composition of the vapor cloud/air mixture varies as listed:

- For the release of oxygen and nitrogen, the composition of the mixture varies from 100% gas at the source to the normal composition of oxygen or nitrogen in air (when sufficient mixing occurs); and
- For release of cryogens other than oxygen or nitrogen, the composition of mixture varies from 100% gas at the source to very low concentrations of the gas in air (when sufficient mixing occurs).

The extent of the hazardous zone from all cryogens shall be determined by atmospheric monitoring to ensure that the air beyond the visible vapor cloud is safe to breathe or work in.

5.4 Asphyxiant

All of the cryogenic vapors from all cryogenic liquids, except oxygen, can cause asphyxiation in an enclosed workspace by displacing breathable air. A worker cannot detect the presence of these gases without instrumentation. Therefore, workers can be asphyxiated before they realize a problem exists. For additional guidance on safe working practices in oxygen-deficient atmospheres, see CGA P-76, *Hazards of Oxygen-Deficient Atmospheres* [21].

5.5 Hazardous properties

Liquid argon, helium, krypton, neon, nitrogen, and xenon are inert, chemically inactive, and noncorrosive at cryogenic temperatures. Liquid oxygen is an oxidizer and will vigorously support the combustion of other materials but will not burn by itself. For additional guidance on safe working practices in oxygen-enriched atmospheres, see CGA P-45, Fire Hazards of Oxygen and Oxygen-Enriched Atmospheres [22]. Due to the risk of combustion, containers previously used to store carbon dioxide should not be used to store oxygen. Carbon dioxide containers are likely to be contaminated with hydrocarbons that could ignite when exposed to oxygen. Liquid carbon monoxide, ethylene, LNG, and liquid hydrogen are flammable materials and shall be handled accordingly.

Carbon monoxide is a unique cryogenic liquid because it is both highly toxic and flammable. The hazard of exposure to low concentrations of carbon monoxide is due to its strong affinity for hemoglobin in the blood. Carbon monoxide is toxic because it reacts with hemoglobin to prevent the blood from carrying oxygen throughout the body. The affinity of hemoglobin to react with carbon monoxide is not only strong, it bioaccumulates. This means that carbon monoxide builds up in the blood over time, even though the exposure is to low concentrations of the gas.

5.6 Physical properties

Table 1 is a useful guide to the physical properties of certain cryogenic liquids that can influence their safe handling procedures. The cryogens are listed in order of decreasing boiling point. LNG is a mixture of methane and other hydrocarbons and its boiling point depends on its composition. However, LNG is primarily methane, and methane data is listed in Table 1.

Table 1—Physical properties of cryogenic liquids

	Ethylene	Xenon	Krypton	Methane	Oxygen	Argon	Carbon monoxide	Nitrogen	Neon	Hydrogen	Helium
Chemical symbol	C ₂ H ₄	Xe	Kr	CH ₄	O ₂	Ar	CO	N ₂	Ne	H ₂	He
Boiling point (at 1 atm) °F (°C)	−154.8 (−103.8)	−163 (−108)	−244 (−153)	−259 (−161)	−297 (−183)	−303 (−186)	−313 (−192)	−320 (−196)	−411 (−246)	−423 (−253)	−452 (−268)
Melting point (at 1 atm) °F (°C)	−268 (−167)	−169 (−112)	−251 (−157)	−296 (−182)	−362 (−219)	−309 (−189)	−341 (−207)	−346 (−210)	−416 (−249)	−435 (−259)	¹⁾ ¹⁾
Density (at boiling point and 1 atm) lb/ft ³ (kg/m ³)	35.42 (567.47)	191 (3059.5)	151 (2418.8)	26 (416.5)	71 (1137.3)	87 (1393.6)	49 (784.9)	50 (800.9)	75 (1201.4)	4.4 (70.48)	7.8 (124.94)
Heat of vaporization (at boiling point) Btu/lb (kJ/kg)	208 (484)	41.4 (96.3)	46.2 (107.5)	219.2 (509.91)	91.7 (213)	69.8 (162.3)	92.8 (215.8)	85.6 (199.1)	37.1 (86.3)	191.7 (446)	8.72 (20.28)
Volume expansion ratio (liquid at 1 atm and boiling point to gas at 70 °F [21.1 °C] and 1 atm)	450	559	693	625	860	842	680	696	1445	850	745
Flammable	Yes	No	No	Yes	No ²⁾	No	Yes	No	No	Yes	No

¹⁾ Helium does not solidify at 1 atm.

²⁾ Oxygen does not burn, but it does support and accelerate combustion. However, high concentration oxygen atmospheres substantially increase combustion rates of other materials and can form explosive mixtures with other combustibles. Flame temperatures are higher in oxygen than in air.

6 Safety

Section 6 contains general safety practices for personnel transporting, handling, and using cryogenic and refrigerated liquids as well as special precautions for specific cryogenes.

6.1 Safety training

The best single investment in safety is properly trained personnel. Some personnel only need detailed training on a particular type of equipment, cryogenic liquid, refrigerated liquid, or repair operation. Others require broader training in safe handling practices for a variety of cryogenic and refrigerated liquids. Training should include the following:

- Information on the nature and properties of the cryogenic or refrigerated liquid in both the liquid and gaseous phase;
- Specific instructions for the equipment;
- Approved materials that are compatible with the cryogenic or refrigerated liquid;
- Use and care of protective equipment and clothing;
- Safety, first aid, and self aid when first aid and/or medical treatment is not immediately available;
- Handling emergency situations such as fire, leaks, and spills;
- Good housekeeping practices;

- Familiarity with the U.S. Occupational Safety and Health Administration's (OSHA) *Hazard Communications Regulations* (right-to-know laws). See Title 29 of the U.S. *Code of Federal Regulations* (29 CFR) [23]; and

NOTE—The *Hazard Communications Regulations* require that employees handling hazardous materials have access to safety data sheets (SDS) and are aware of the requirements for containers to have warning labels and pipe systems to be identified [23].

- Familiarity with the Canada's Workplace Hazardous Materials Information System (WHMIS) [24].

6.2 **Procedures for safely handling cryogenics and refrigerated liquids**

Safety procedures shall be developed and implemented to protect personnel handling cryogenic liquids.

Safety equipment should be maintained in good operating condition and conveniently located.

Subcontractors and personnel working in hazardous areas shall be informed of the location of all necessary safety equipment before entering a potentially hazardous area.

6.2.1 **Skin or eye frostbite**

Always handle cryogenic and refrigerated liquids carefully. Because of their extremely low temperatures, cryogenic and refrigerated liquids can cause frostbite on exposed skin and exposed eye tissue. When spilled, cryogenics tend to cover a surface completely, cooling a large area.

The vapors from cryogenic and refrigerated liquids are also extremely cold. Delicate tissues, such as eyes, can be damaged by exposure to these cold gases, even when the contact is too brief to affect the skin of the hands or face.

6.2.2 **Boiling and splashing**

Stand clear of a boiling or splashing cryogenic or refrigerated liquid and their vapors. Boiling and splashing occur when filling a warm container with a cryogenic or refrigerated liquid, or when inserting warm objects into these cold liquids. Always perform these operations slowly to minimize boiling and splashing. If cold liquid or vapor contacts the skin or eyes, follow the first aid recommendations in 6.2.5.

6.2.3 **Flesh tearing**

Do not allow any unprotected part of the body to touch uninsulated pipes or vessels that contain cryogenic or refrigerated liquids. The extremely cold metal will cause the flesh to stick, and tearing will occur when removal is attempted. Even nonmetallic materials at cryogenic or refrigerated liquid temperatures are dangerous to touch. Use tongs and appropriate personal protective equipment (PPE) to immerse an object in or to withdraw an object from a cryogenic or refrigerated liquid.

6.2.4 **Selection of materials suitable for low temperature**

Consider low temperature characteristics when selecting materials to use with cryogenic or refrigerated liquids. Rubber or plastics objects that are soft and pliable at room temperature become hard and brittle at cryogenic temperatures and are easily broken.

6.2.5 **First aid for cold-contact burns**

Personnel should not come in direct contact with a cryogenic or refrigerated liquid if proper handling procedures are used. Contact with a cryogenic and refrigerated liquid or vapor can cause a cold-contact burn (i.e., the skin or eye tissue freezes). The following emergency treatment is recommended for treating a cold-contact burn:

- Remove any clothing not frozen to the skin that can restrict circulation to the frozen area. Do not rub frozen areas, as tissue damage could result. Obtain medical assistance as soon as possible;
- As soon as practicable place the affected area in a warm water bath that has a temperature less than or equal to 105 °F (40 °C). Never use dry heat. The victim should also be in a warm room, if possible;



- If there has been massive exposure and the general body temperature is depressed, prompt medical attention is imperative. If immediate medical assistance is unavailable, the victim shall be rewarmed by immersion into a warm water bath that is at a temperature less than or equal to 105 °F (40 °C). Supportive treatment for shock should be provided;
- Frozen tissue is painless and appears waxy with a slightly yellow color. It becomes swollen, painful, and prone to infection when thawed. If the accident occurs in the field and the victim cannot be transported to medical attention immediately, rewarm the tissue slowly. Thawing can require from 15-60 minutes and should be continued until the pale skin turns pink or red. Narcotics or tranquilizers may be needed to control pain during the thawing process and should be administered under professional medical supervision;
- If the frozen area thaws before medical attention is obtained, cover the area with a dry sterile dressing and a large, bulky protective covering; and
- Warm drinks and food may be administered to a conscious victim. Alcoholic beverages and smoking decrease blood flow to frozen tissue and should not be allowed.

6.2.6 Personal protective equipment (PPE)

6.2.6.1 Safety glasses

Safety glasses with side shields shall be worn at all times during the transfer and normal handling of cryogenic and refrigerated liquids within enclosed piping systems or containers. If spraying or splashing occurs, such as when transferring cryogenic liquids from open-top containers or open-ended piping, a face shield and either safety glasses equipped with side shields or safety goggles shall be worn for additional protection.

6.2.6.2 Insulated gloves

Insulated gloves should always be worn when handling anything that comes in contact with cryogenic or refrigerated liquids and their vapors. Gloves should be loose fitting so they can be removed quickly if liquids are spilled into them. Gloves used in areas where there is a risk of hose or line breakage, or other events that can cause spillage or spray, should be a gauntlet style to provide more protection to the lower arm. Gloves used to handle cryogenic and refrigerated liquids are generally made from leather. Avoid gloves made from polymers because most polymers become brittle if they get cold.

Work gloves used in liquid oxygen service should be kept clean and free of oil and grease. If they become contaminated, they should be discarded.

6.2.6.3 Trousers

Trousers should not have cuffs. Trousers should be left outside of boots or work shoes.

6.2.6.4 Protective equipment for flammables

Appropriate flame-resistant PPE, including flame-resistant clothing (FRC), shall be worn when handling flammable cryogenic liquids and gases because of the possibility of a flash fire. In the United States, all FRC shall meet the standard of NFPA 2112, *Standard on Flame-Resistant Garments for Protection of Industrial Personnel Against Flash Fire* [25].

6.2.6.5 Personal atmospheric monitors

Personal atmospheric monitors (PAMs) that can detect the hazard or chemical in the work area should be used whenever the hazard can be present.

6.3 Safety practices for oxygen

6.3.1 Atmospheric monitoring

Areas of oxygen production and distribution or as determined by a risk assessment where an oxygen-enriched atmosphere can occur shall be monitored by either an area monitoring system or with PAMs.

