

BELIZE STANDARD

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SPECIFICATION FOR CARBON DIOXIDE

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BELIZE STANDARD SPECIFICATION FOR CARBON DIOXIDE

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BELIZE STANDARD SPECIFICATION FOR CARBON DIOXIDE

0 FOREWORD

- 0.1 This standard provides information regarding carbon dioxide characteristics, safety, storage, filling, transportation and handling practices, when it is used for medical or industrial applications.
- 0.2 In preparing this draft, assistance was received from the following documents:
 - a) CGA G-6 - Carbon Dioxide
 - b) CGA G-6.2 - Commodity Specification for Carbon Dioxide
 - c) CGA G-6.3 - Carbon Dioxide, Cylinder Filling and handling procedures
 - d) USP 29 - United States Pharmacopeia and National Formulary (USP–NF)
 - e) 21 CFR - Title 21 of the U.S. Code of Federal Regulations, (21 CFR)

1 SCOPE

- 1.1 This standard specifies the physical and chemical properties, physiology, toxicity, hazards, production, regulations, storage, handling, transportation, and applications of carbon dioxide.
- 1.2 This document describes the specification requirements for gaseous, liquid, and solid carbon dioxide.
- 1.3 This standard covers only the filling system and process to fill cylinders by weight measure.
- 1.4 It is intended for carbon dioxide users, manufacturers and distributors.

2 NORMATIVE REFERENCES

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

- a) BZS 1: Part 8 - Belize Standard Specification for Labelling Part 8: Labelling and Marking of Medical Gas Cylinders
- b) CGA G-6 - Carbon Dioxide
- c) CGA G-6.2 - Commodity Specification for Carbon Dioxide
- d) CGA G-6.3 - Carbon Dioxide, Cylinder Filling and handling procedures

3 DEFINITIONS

For the purpose of this standard, the following definitions shall apply.

- 3.1 **Capacity** means the maximum weight of carbon dioxide a container holds when filled to the proper level.
- 3.2 **Carbon dioxide** means a chemical compound consisting of one atom of carbon bonded to two atoms of oxygen expressed by the chemical formula CO₂.
- 3.3 **Condemned cylinder** means a cylinder that is no longer fit for service.
- 3.4 **Container** means an insulated pressure vessel, which is American Society of Mechanical Engineers (ASME) coded for the storage of carbon dioxide.
- 3.5 **Critical point** means the highest pressure and temperature for a pure gas at which the liquid and vapor phases can exist in equilibrium.

NOTE: For carbon dioxide, this occurs at a temperature of 87.9 °F (31.1 °C) and a pressure of 1070.6 psia (7381.8 kPa, abs).

- 3.6 **Critical pressure** means pressure that shall be exerted to produce liquefaction at the critical temperature.

NOTE: For carbon dioxide the critical pressure is 1070.6 psia (7381.8 kPa, abs).

- 3.7 **Dry ice** means the common name for solid carbon dioxide.

NOTE: Its temperature is −109.3 °F (−78.5 °C) at atmospheric pressure.

- 3.8 **Insulated cylinder** means insulated DOT-approved pressure vessel with a water capacity not greater than 120 gal (454 L) or 1000 lb (454 kg) and a service pressure rating of less than 40 psi (276 kPa) but not greater than 500 psi (3448 kPa).

- 3.9 **Uninsulated cylinders** means single walled DOT approved pressure vessel having a circular cross section with a minimum rated service pressure of 1800 psi (124 bar) and a water capacity not greater than 120 gal (454 L).

NOTE: The minimum service pressure of 1800 psi (124 bar) is specific to carbon dioxide.

- 3.10 **Maximum allowable working pressure (MAWP)** means the maximum gauge pressure permissible at the top of a container in its operating position for a designated temperature.
- 3.11 **Saturated** means the condition at which the pressure and temperature of all existing physical states are at equilibrium.

- 3.12 **Sublimation** means the process of changing from the solid phase directly to the gas phase without passing through the liquid phase.
- 3.13 **Supercritical fluid** means the substance that is at a pressure and a temperature equal to or greater than its critical point and has complete mutual solubility of the liquid and the gas.
- 3.14 **Triple point** means the temperature and pressure at which a material exists simultaneously as a solid, liquid, and gas. For carbon dioxide the triple point is –69.9 °F and 75.1 psia (–56.6 °C and 518 kPa, abs).
- 3.15 **Filling density** means the percent ratio of the weight of gas in a cylinder to the weight of water that the cylinder will hold at 16 °C (60 °F)(1 lb of water = 27.737 in³ at 60 °F).
- 3.16 **Fill weight** means the weight of the cylinder valve, hose, and the net weight of the carbon dioxide in the cylinder.
- 3.17 **Gross weight** means the weight of an empty cylinder and valve assembly plus the weight of carbon dioxide when properly filled. This is the cylinder tare weight added to the contents weight without the hose attached.
- 3.18 **Hydrostatic cylinder test** means the procedure that measures the expansion of a cylinder pressurized with water to a given pressure.
- 3.19 **Liquid carbon dioxide** means carbon dioxide that can exist as a liquid only at pressures between 75.1 psia and 1070.6 psia (518 kPa, abs and 7382 kPa, abs) and temperatures between –69.9 °F and 87.9 °F (–56.6 °C and 31.1 °C).
- 3.20 **Mass weight (M)** means the weight of the cylinder only, does not include the valve or any other attachments or contents.
- 3.21 **Net weight** means the weight of the actual contents in the cylinder.
- 3.22 **Quality Verification Level (QVL)** means a parameter that specifies the maximum amount of impurities (also termed limiting characteristics) that can be present.
- 3.23 **Lot** means an amount of a product produced during a period and with the same characteristics, identified by a specific code.
- 3.24 **Pressure Relief Device (PRD)** means a device consisting of a frangible disk designed to burst under excessive pressure, or a combination disk backed with fusible metal with a low melting point designed to melt and release the gas in case of fire.

4. CARBON DIOXIDE REQUIREMENTS

4.1 Physical and chemical properties

- a) Carbon dioxide is a colorless, odorless, slightly acidic gas that is approximately 50% heavier than air. It is non- flammable and will not support combustion. The physical constants of carbon dioxide are summarized in Annex 1 - Table 1. Carbon dioxide can exist as a solid, liquid, gas, or supercritical fluid, depending upon conditions of temperature and pressure.
- b) Carbon Dioxide at its triple point exists simultaneously as a liquid, gas, and solid at -69.9°F and 75.1 psia (-56.6°C and 518 kPa, abs). Any change in pressure or temperature causes carbon dioxide to revert to a two-phase condition (see Annex 2 - Figure 1).
- c) Carbon dioxide at its critical point exists simultaneously as a liquid, gas, and supercritical fluid at 87.9°F and 1070.6 psia (31.1°C and 7381.8 kPa, abs). At pressures and temperatures greater than the critical point, carbondioxide exists only as a supercritical fluid.
- d) The solubility of carbon dioxide in water varies with temperature and pressure. See Annex 1 - Table 2 for various temperature and pressure conditions.
- e) See Annex 1 - Tables 3 and 4 for the thermodynamic and physical properties of carbon dioxide.

4.2 Carbon dioxide manufacture

- 4.2.1 Large quantities of carbon dioxide for commercial use are primarily obtained from one of the following processes:
 - a) acid neutralization;
 - b) ammonia;
 - c) coal gasification;
 - d) combustion;
 - e) ethylene oxide;
 - f) fermentation;
 - g) hydrogen;
 - h) phosphate rock; and
 - i) wells/geothermal.
- 4.2.2 Carbon dioxide is typically refined to the required purity by the following:
 - a) adsorption/desorption;
 - b) distillation;
 - c) filtration;
 - d) oxidation; and/or
 - e) scrubbing.

- 4.2.3 Carbon dioxide is generally liquefied by compression and refrigeration for storage or shipment. It is stored and shipped as a liquid at pressures and temperatures ranging from 200 psi and -20°F to 350 psi and 11°F (1380 kPa and -29°C to 2410 kPa and -12°C).
- 4.2.4 Solid carbon dioxide is manufactured by decreasing the pressure of the liquid below its triple point forming dry ice (snow) and cold vapor.
- 4.2.5 Solid carbon dioxide can be compressed into blocks of dry ice, cut or formed into slabs or slices, or extruded into pellets. Dry ice blocks are commercially available in 10-in (25.4-cm) nominal size cubes weighing 50 lb to 60 lb (23 kg to 27 kg) and having a density of approximately 94 lb/ft^3 (1500 kg/m^3). Slabs and slices are available in a variety of weights and dimensions, according to customer requirements. Extruded products are available in various sizes, see Annex 2 - Figure 2.

4.3 Hazards

4.3.1 Personal Protective Equipment (PPE)

- a) Contact between exposed skin and cold piping or carbon dioxide vapor can cause frost burns. Dry ice particles formed by depressurizing liquid carbon dioxide are extremely cold and can cause severe damage to unprotected eyes or skin. Appropriate gloves and eye protection shall be worn when handling equipment containing carbon dioxide.
- b) Additional PPE that may be required includes hearing protection, supplied air breathing apparatus, and safety shoes.

4.3.2 Dry ice blocking

- a) Liquid carbon dioxide in a hose or pipe flows like water. However, when the pressure is reduced below 75.1 psia (518 kPa, abs), the liquid changes into a mixture of vapor and solid carbon dioxide. Solid carbon dioxide, when formed in a pipe or hose as a result of improper purge, leaking valve, or inadequate design, can create a dry ice plug. This can result in over pressurization and/or forceful ejection of the plug.
- b) The pressure behind or within a plug can increase as the dry ice sublimates until the plug is forcibly ejected or the hose or pipe ruptures. A dry ice plug can be ejected from any open end of a hose or pipe with enough force to cause serious injury to personnel from the impact of the dry ice plug or the sudden whip of the hose or pipe as the plug ejects or both.

4.3.3 Liquid line depressurization

Any residual liquid carbon dioxide in the hose or pipe shall be purged from the hose or pipe with vapor prior to reducing the pressure below 75.1 psia (518 kPa, abs) to prevent dry ice blockage. This is typically done by supplying 200 psi (1380 kPa) or greater vapor to one end of the hose or piping system to maintain the pressure above the triple point while removing the liquid from the other end. This can be accomplished by using a crossover line connecting a vapor source to the liquid line.

4.3.4 Liquid line pressurization to prevent dry ice blockage when liquid is introduced

- a) Liquid piping shall be pressurized with carbon dioxide vapor to greater than 75.1 psia (518 kPa, abs) prior to introducing liquid carbon dioxide to prevent dry ice blocking. This is typically done by supplying 200 psi (1380 kPa) or greater vapor to the hose or piping system prior to introducing the liquid. This also prevents the introduction of liquid carbon dioxide colder than the system design temperature.
- b) Bending hoses that contain residual dry ice can result in the fracturing of the inner liner, which can lead to catastrophic failure.

4.3.5 Low temperature effects on materials

- a) Depressurization of a liquid carbon dioxide system can result in low temperature liquid carbon dioxide and the formation of dry ice placing the container, piping, and hoses in an upset condition colder than the system design temperatures.
- b) Many materials safe to use at normal liquid carbon dioxide temperatures become brittle and can fail if stressed while subjected to dry ice temperatures (-109.3°F [-78.5°C]). Materials used in the construction of carbon dioxide transfer systems including hoses shall be compatible with carbon dioxide and the temperature and pressure conditions encountered.
- c) Piping systems subject to operating temperatures below ambient will contract. Allowances shall be made in piping and support systems to compensate for these changes in dimensions. Commonly used copper tubing will shrink approximately 1 in per 100 ft for every 100°F (2.5 cm per 30.5 m for every 55.6°C) reduction in temperature.

4.3.6 Trapped liquid

- a) When liquid carbon dioxide is forced to occupy a fixed volume such as between two closed valves or within a valve, the pressure will increase as the carbon dioxide warms and expands. If there is vapor space in the valve or pipe, the pressure rises approximately 5 psi per

°F (62 kPa per °C). When the pipe or valve becomes liquid full, the hydrostatic pressure rises at the rate of 80 psi per °F (990 kPa per °C). As the temperature continues to increase, the pressure of the trapped liquid can exceed what the piping and hoses can withstand. This will cause rupture of the hose or piping with possible injury and property damage.

- b) To prevent trapped liquid from becoming a hazard, all liquid carbon dioxide piping and transfer lines shall be equipped with pressure relief devices (PRDs) located in all parts of the system in which liquid can be trapped such as between valves, check valves, and pumps. These PRDs shall be set to discharge within the design pressure of the part of the system they protect and should discharge into a well-ventilated area.

4.3.7 Trapped solid (dry ice and water ice) in discharge and blowdown piping.

The design of piping and valves for the discharge of liquid carbon dioxide to atmosphere shall be configured to prevent blockage with dry ice, water ice, or a combination of both. Piping downstream of the blowdown valve shall be minimized to prevent formation of dry ice blockage, internal water condensation, and be designed to prevent movement. Dry ice formed by depressurized liquid can accumulate inside the piping and discharge device such that the flow can be obstructed. This solid blockage can lead to the unintended pressurization of piping or components to greater than the design pressures and colder than the design temperatures.

4.3.8 Personnel overexposure

- a) When carbon dioxide is used in an enclosed area, ventilate the area to maintain a safe working environment for personnel. Carbon dioxide in the gaseous state is colorless and odorless and not easily detectable. Since gaseous carbon dioxide is 1.5 times denser than air, it will be found in greater concentrations at lower elevations. Therefore, ventilation systems should be designed to exhaust from the lowest level and allow make-up air to enter at a higher point in the enclosed area.
- b) Do not depend on measuring the oxygen content of the air because carbon dioxide can be dangerous even with adequate oxygen for life support.
- c) Areas with conflicting ventilation requirements shall have engineered ventilation systems.
- d) A carbon dioxide detector with an appropriate alarm system should be installed to detect dangerous concentrations of carbon dioxide. Carbon dioxide leak detection systems should be equipped with

audible and visual warning devices located in the area leading to the location of the leak detector to warn personnel of a hazardous condition before entering this location. Carbon dioxide can cause asphyxiation because vapors accumulate in low elevations, such as basements, and in nonventilated rooms not necessarily limited to the location of the container. Slow leaks of small percentages of the system capacity can cause hazardous gas concentrations.

- e) Enclosed, improperly ventilated areas can include but are not limited to basements and outside locations such as one with four solid walls and no ceilings. See Annex 2 - Figures 3, 4, 5, and 6.
- f) Carbon dioxide systems may be enclosed in fenced outdoor enclosures. Any enclosed space shall have a minimum of 25% open area at ground level on a minimum of two sides as indicated in Annex 2 - Figure 7.

NOTE: Some enclosures may use concrete block or other solid materials that shall provide the same 25% open area at ground level to prevent the dense carbon dioxide vapors from accumulating in unsafe concentrations.

- g) Carbon dioxide storage containers installed outdoors should be above grade and in an unenclosed free airflow area. See Annex 2 - Figures 8 and 9. An unenclosed area shall have:
 - i. At least 25% of the perimeter area shall be open to atmosphere;
 - ii. Openings spaced to create cross ventilation and located as low as possible to ensure that carbon dioxide will not pool and cause exposure to occupants; and
 - iii. Openings in direct conveyance with ground level, whenever possible.

NOTE: Any installation that does not meet these criteria should be considered an enclosed installation.

4.3.9 Carbon dioxide leak detection system

- a) Indoor areas, rooms, or enclosed outdoor locations where carbon dioxide systems are filled or used shall be provided with a leak detection and alarm system. This system shall be capable of detecting and notifying the building occupants of a gas release of carbon dioxide at, or in excess of, the Time-Weighted Average–Permissible Exposure Limit (TWA–PEL) of 5000 ppm (0.5% CO₂ in air) averaged over an 8-hour period.
- b) The carbon dioxide leak detection system when activated shall sound an audible alarm within the room or area in which the system is

installed. Gas detection systems shall be installed and maintained in accordance with the manufacturer's instructions.

4.3.10 Overfilling containers and cylinders

- a) When liquid carbon dioxide is stored in a container with little or no product withdrawal, heat leak causes the temperature and pressure to increase and the liquid to expand.
- b) As long as there is vapor space in the container, the pressure increases approximately 5 psi per °F (62 kPa per °C). When the container becomes liquid full, the hydrostatic pressure increases at the rate of 80 psi per °F (990 kPa per °C). Table 5 and Figure 10 illustrate this phenomenon with data for pressure increase in a container originally filled to 92.6% with –20 °F (–28.9 °C) liquid carbon dioxide.
- c) Although storage containers are generally equipped with refrigeration systems to maintain the liquid temperature near 0 °F (–17.8 °C), power failures can occur. Small and portable containers are not equipped with refrigeration. All storage containers can potentially become liquid full.
- d) To prevent undue stresses to the container and nuisance cycling of the PRD with consequent product loss, liquid carbon dioxide storage containers should not be filled to a level that allows them to become liquid full before reaching the PRD setting, which is generally 350 psi (2410 kPa).
- e) Typical symptoms of overfilling containers include the refrigeration unit operating but not decreasing pressure, erratic level gauge operation, and excessive frost on vapor lines. Contact the supplier or a qualified carbon dioxide technician to resolve these problems.
- f) The safe filling level depends on the temperature of the liquid being transferred into the container. The colder the liquid, the more vapor space is required for liquid expansion. Annex 2 - Figure 9 shows safe filling levels for a range of liquid temperatures. Filling above the safe filling level leads to an overfilled condition. Please note that Figure Annex 2 – Figure 9 only applies to filling insulated containers with PRDs set at 350 psi (2410 kPa) or less. Those quantities would be a significant overfill of uninsulated high-pressure cylinders and also would exceed the maximum filling density allowed for DOT-4L/TC-4LM insulated cylinders with PRDs set greater than 350 psi (2410 kPa). DOT tables for filling density go as high as a maximum 625 psi (4310 kPa) PRD setting with an 86% maximum filling density.

4.3.11 Static electricity

- a) The manufacture of solid dry ice produces static electricity charges (greater than 100 000 volts). This can lead to a discharge of the static electricity to any grounded object or person.
- b) Liquid carbon dioxide should not be used for inerting combustible atmospheres because of the extremely high static charges produced during the formation of dry ice.
- c) Gaseous carbon dioxide can be used for inerting combustible atmospheres without the risk of generating static charges.

5 PHYSIOLOGICAL EFFECTS OF CARBON DIOXIDE

5.1 General

- a) The physiological effects of carbon dioxide are unique because it is a product of normal metabolism, a requirement of the body's normal internal chemical environment, and an active messenger substance in the linking of respiration, circulation, and vascular response to the demands of metabolism both at rest and in exercise.
- b) The respiratory control system maintains carbon dioxide pressure at a relatively high level of approximately 50 mm Hg pressure in the arterial blood and tissue fluids. This maintains the acidity of the tissue and cellular fluids at the proper level for essential metabolic reactions and membrane functions. Changes in the normal carbon dioxide tissue pressure can be damaging. If tissue pressure becomes excessively low, which can occur from hyperventilation, failure of critical neuromuscular function or loss of consciousness can occur.
- c) Inhaled carbon dioxide produces the same physiological effects as metabolically produced carbon dioxide.
- d) Toxic effects of carbon dioxide, namely severe and disruptive acidosis, occur when high concentrations of carbon dioxide are inhaled.
- e) The effects produced by low and moderate concentrations of carbon dioxide are physiological and reversible, but the effects of high concentrations are toxic and damaging.
- f) The response to carbon dioxide inhalation depends on the degree and duration of exposure, and it varies greatly, even in healthy individuals. The medical term for the physiological effects of excess carbon dioxide in the blood is hypercapnia.
- g) Carbon dioxide can be toxic even when normal oxygen levels are present. Low concentrations of inspired carbon dioxide can be tolerated for a

considerable period of time without noticeable effect or may merely cause an unnatural feeling of shortness of breath.

- h) Sustained exposure to 5% carbon dioxide produces stressful rapid breathing. When the level of inspired carbon dioxide exceeds 7%, the rapid breathing becomes labored (dyspnea) and restlessness, faintness, severe headache, and dulling of consciousness occur. At 15%, unconsciousness accompanied by rigidity and tremors occurs in less than 1 minute, and in the 20% to 30% range, it produces unconsciousness and convulsions in less than 30 seconds.
- i) The reason these effects occur quickly is that carbon dioxide diffuses in the tissue fluids at a rate approximately 20 times more rapidly than oxygen. High concentrations of carbon dioxide can asphyxiate quickly without warning and with no possibility of self-rescue regardless of the oxygen concentration.

5.2 Physical effects of overexposure to carbon dioxide

Skin, mouth, or eye contact with solid carbon dioxide that has a temperature of -109.3°F (-78.5°C) can cause severe frostbite, skin lesions, corneal burn, or more serious injury from deep-freezing of the tissues. Liquid discharging from a container produces high velocity carbon dioxide snow particles that are abrasive in addition to being cold and will cause similar injuries.

5.3 Standards

- a) Carbon dioxide is present in the atmosphere at approximately 350 ppm (0.035%) by volume. Employee exposure to carbon dioxide in any 8-hour shift of a 40-hour workweek shall not exceed the 8-hour TWA–PEL of 5000 ppm (0.5%) (9000 mg/m³).
- b) According to the ACGIH (The American Conference of Governmental Industrial Hygienists), the STEL for 15 minutes or less is 30 000 ppm (3%) (54 000 mg/m³).

5.4 Safety precautions

- a) Appropriate warning signs shall be placed at the entrance to areas where high concentrations of carbon dioxide gas can accumulate. A typical warning is shown in Annex 2 - Figure 10.
- b) Carbon dioxide monitoring shall be performed prior to entering a confined space or low area in which carbon dioxide vapor could have accumulated. The carbon dioxide shall be removed by ventilation to a concentration below 3% or a supplied-air respirator shall be donned before entering the confined space or low area.

5.5 Rescue and first aid

- a) Do not attempt to remove anyone exposed to high concentrations of carbon dioxide without using proper rescue equipment or the potential rescuer could also become a casualty. Rescuers account for over 60% of confined space fatalities. If the exposed person is unconscious, obtain assistance and use established emergency procedures.
- b) If a person has inhaled large amounts of carbon dioxide and is exhibiting adverse effects, move the exposed individual to fresh air at once.
- c) If breathing has stopped, perform artificial respiration. Only qualified personnel may give oxygen to the victim.
- d) Keep the affected person warm and at rest.
- e) Get medical attention as soon as possible.
- f) Fresh air and assisted breathing are appropriate for all cases of overexposure to gaseous carbon dioxide. With prompt response to a carbon dioxide emergency, recovery is usually complete and uneventful.

NOTE: Supplied-air respirators should only be used by authorized personnel with appropriate training and qualifications for use of the respirator.

- g) If dry ice or compressed carbon dioxide gas comes in contact with the skin or mouth, stop the exposure immediately. If frostbite has occurred, obtain medical attention. Do not rub the area. Immerse in warm water, 100 °F to 105 °F (37.8 °C to 40.6 °C).

6 CLASSIFICATION

6.1 Types

- a) Carbon dioxide above the triple point temperature of –69.9 °F (–56.6 °C) and below the critical point temperature of 87.9 °F (31.1 °C) can exist in both a gaseous and a liquid state.
- b) Carbon dioxide in cylinders at ambient temperature is at relatively high pressure (see Figure 1).
- c) Bulk carbon dioxide is commonly maintained as a refrigerated low temperature liquid and vapor from 200 psig to 350 psig (1380 kPa to 2410 kPa).
- d) Carbon dioxide can also exist as a white opaque solid with a temperature of –109.3 °F (–78.5 °C) at atmospheric pressure.

6.2 Quality verification levels

- a) Annex 1 - Table 7 presents the component maxima in parts per million (ppm [v/v]) unless otherwise shown for the quality verification levels (QVLs) of carbon dioxide. The absence of a value in a listed QVL does not imply that the limiting characteristic is or is not present but merely indicates that the test is not required for compliance with the specification.
- b) Typical uses are listed in Annex 1 - Table 8.
- c) QVLs E, G, H, and I generally refer to carbon dioxide as a liquid. QVL J refers to carbon dioxide as a solid (dry ice).

6.3 Quality tests

The supplier ensures by standard practice the QVL of carbon dioxide. Other control procedures not listed in this specification are acceptable if agreed upon between the supplier and the customer.

6.4 Typical sources

Carbon dioxide is produced as the by-product of many different natural and chemical processing mechanisms. This capability of multiple source types makes it unique in the industrial gas market. The variation of sources results in a variety of impurities that can be expected in carbon dioxide. Typical sources and their respective anticipated impurities are listed in Annex 1 - Table 9.

7 QUALITY VERIFICATION SYSTEMS

7.1 Source Evaluations

Due to the variation in sources, the supplier should perform an extensive analysis of the source stream before beginning the design of the purification plant. The specific anticipated impurities listed in Annex 1 - Table 9 should be analyzed at a minimum and on a periodic basis. Additional analysis by mass spectrometry or other general survey technology should also be done to guard against potential unknown impurities in any new carbon dioxide source.

7.2 Lot acceptance tests

Lot acceptance tests are analyses performed on the carbon dioxide in the shipping container or a sample thereof that are representative of the lot.

7.3 Lot definitions

Selection of the appropriate lot definition can be subject to regulations for some QVLs. One of the following shall be used:

- a) no specific quantity or any quantity of carbon dioxide agreed to by the supplier and the customer;

- b) all of the carbon dioxide supplied during the contract period;
- c) all of the carbon dioxide supplied or containers filled during a calendar month;
- d) all of the carbon dioxide supplied or containers filled during seven consecutive days;
- e) all of the carbon dioxide supplied or containers filled during a consecutive 24-hour period;
- f) all of the carbon dioxide supplied or containers filled during one continuous work shift;
- g) all of the carbon dioxide supplied in one shipment;
- h) all of the carbon dioxide supplied in one shipping container;
- i) all of the carbon dioxide in the containers filled from one unreplenished bulk storage container; or
- j) all of the carbon dioxide supplied or containers filled during an uninterrupted filling sequence.

7.4 Number of samples per lot

The number of samples per lot shall be in accordance with either one sample per lot or any number of samples agreed upon by the supplier and customer.

8 SAMPLING

8.1 Sample volume

The quantity of carbon dioxide in a single sample cylinder should be sufficient to perform the analyses for all limiting characteristics except for the nonvolatile residue test, which can be performed from a separate sample. The filled sample cylinder shall be allowed to reach ambient temperature before testing. For unrefrigerated containers (cylinders), the cylinder temperature at the time of sampling shall be below 87 ° F (30.6 ° C) to ensure the sampling of liquid. Samples shall be representative of the carbon dioxide supply.

CAUTION: The Occupational Safety and Health Administration (OSHA) has established an 8-hour Time - Weighted Average-Permissible Exposure Limit (TWA-PEL) of 5000 ppm (9000 mg/m³) for carbon dioxide. The American Conference of Governmental Industrial Hygienists (ACGIH) also recommends a Threshold Limit Value-Short Term Exposure Limit (TLV-STEL) of 30 000 ppm (54 000 mg/ml³). All sampling and analytical procedures should lessen operator exposure to carbon dioxide.

CAUTION: For safety reasons, sample cylinders shall conform to DOT specifications and shall not be filled to a quantity greater than 68% of their water capacity by weight, the maximum allowable fill density. The high pressure that can result from overfilling a sample cylinder is shown in Figure 9. The minimum service pressure rating of the cylinders shall be 1800 psig (12 410 kPa).

WARNING: High concentrations of carbon dioxide can asphyxiate quickly without warning with no possibility of self-rescue regardless of the oxygen concentration.

8.2 Gaseous samples

Gaseous samples taken from the top of the bulk tank or cylinder are not representative of the liquid carbon dioxide supply and cannot be used to determine the QVL in Annex 1 - Table 7.

8.3 Liquid samples

Liquid samples shall be representative of the carbon dioxide supply. Care should be taken to obtain the sample from a point that is representative of the bulk liquid. Vaporizers, liquid level gauge lines, and certain other equipment known to accumulate impurities should not be used as a sampling point. Samples can be taken in either a single-ended or double-ended cylinder.

CAUTION: Provide adequate pressure relief devices (PRDs) to prevent possible hydrostatic rupture from liquid-filled lines and overfilled sampling cylinders.

9 ANALYTICAL PROCEDURES

9.1 Parameters of analysis

The parameters for analytical techniques contained in this section are:

9.1.1 Percent

percent (v/v) = parts per hundred by volume

9.1.2 Parts per million by volume

ppm (v/v) = parts per million by volume

9.1.3 Parts per million by weight

ppm (wt/wt) = parts per million by weight (nonvolatile residue and oil/grease only)

9.1.4 Water/dew point

Water/dew point is expressed in ppm (v/v) as °F at 1 atm abs, 101 kPa, abs (760 mm Hg).

9.1.5 Total hydrocarbon content

Total hydrocarbon content (THC) as methane equivalent is defined as the single carbon atom equivalent for the purposes of this specification.

9.1.6 Total sulfur content

Total sulfur content as sulfur equivalent is defined as the single sulfur atom equivalent for the purposes of this specification.

9.1.7 United States Pharmacopeia and National Formulary

The most recent edition of USP-NF refers to the test requirements for carbon dioxide.

NOTE: To comply with the USP-NF procedure, the tests are designed to reflect the quality of carbon dioxide that is present in previously unopened containers in both vapor and liquid phases. Withdraw the samples for the tests with the least possible release of carbon dioxide consistent with proper purging of the sample apparatus. Perform the tests in the sequence listed in USP-NF.

9.1.8 Calibration gas standards

Calibration gas standards containing the applicable gaseous components can be required to calibrate the instruments used to determine the limiting characteristic levels of carbon dioxide.

9.1.9 Analytical equipment

Analytical equipment shall be operated and properly calibrated in accordance with manufacturer's instructions or with procedures validated by the user.

9.1.10 Sample cylinders

Sample cylinders shall reach ambient temperature before withdrawing portions for analysis.

9.1.11 Other analytical procedures

Analytical procedures not listed in this specification are acceptable if agreed to by the supplier and the customer.

9.2 Carbon dioxide identification

The most recent editions of USP-NF refer to the test requirements for carbon dioxide.

NOTE: To comply with the USP-NF procedure as appropriate, the tests are designed to reflect the quality of carbon dioxide that is present in previously unopened containers in both vapor and liquid phases. Withdraw the samples for the tests with the least possible release of carbon dioxide consistent with proper purging of the sample apparatus. Perform the tests in the sequence listed in FCC and USP-NF.

9.3 Carbon dioxide purity

The carbon dioxide purity shall be determined by using one of the following procedures.

9.3.1 Gas chromatograph

A gas chromatograph can be used to determine many of the limiting characteristics listed in this section. Appropriate impurity concentrating techniques can be used. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristics as defined in Annex 1 - Table 7.

9.3.2 Mass spectrometer

A mass spectrometer can be used to determine many of the limiting characteristics listed in this section. Appropriate impurity concentrating techniques can be used. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristics as defined in Annex 1 - Table 7.

9.3.3 Pressure differential

By measuring the pressure differential between a standard control cylinder that has been charged and certified to be 99.9% and a sample cylinder transfilled from a liquid storage unit.

9.4 Acetaldehyde content

The acetaldehyde content shall be determined by using one of the following procedures:

- i. An apparatus using a detector tube filled with a color-reactive chemical. The degree of accuracy depends on the precision of the measurements and the analytical bias of the tube; or

- ii. A gas chromatograph.

9.5 Ammonia content

The ammonia content shall be determined by using one of the following procedures:

- a) An apparatus using a detector tube filled with a color-reactive chemical. The degree of accuracy depends on the precision of the measurements and the analytical bias of the tube;
- b) A wet chemical analyzer specific to ammonia. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- c) A gas chromatograph;

NOTE: Calibration gas standards for ammonia are available only with an inert balance gas.

- d) A gas cell equipped infrared analyzer. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards at a wavelength of approximately 2.9 (the characteristic absorption wavelength for ammonia). The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7; or
- e) An analyzer using mass spectrometry. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7.

9.6 Benzene content

The benzene content shall be determined by using one of the following procedures:

- a) An apparatus using a detector tube filled with a color-reactive chemical. The degree of accuracy depends on the precision of the measurements and the analytical bias of the tube; or
- b) A gas chromatograph..

9.7 Carbon monoxide content

The carbon monoxide content shall be determined by using one of the following procedures:

- a) An apparatus using a detector tube filled with a color-reactive chemical. The degree of accuracy depends on the precision of the measurements and the analytical bias of the tube;

- b) A gas cell equipped infrared gas analyzer. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards and for dispersive infrared gas analyzers at a wavelength of approximately 4.6 μ (the characteristic absorption wavelength for carbon monoxide). The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7; or
- c) A gas chromatograph or a catalytic methanator equipped gas chromatograph.

9.8 Carbonyl sulfide content

The carbonyl sulfide content shall be determined by using one of the following procedures:

- a) An apparatus using a detector tube filled with a color-reactive chemical. The degree of accuracy depends on the precision of the measurements and the analytical bias of the tube; or
- b) A gas chromatograph.

9.9 Hydrogen cyanide content

The hydrogen cyanide content shall be determined by using one of the following procedures:

- a) An apparatus using a detector tube filled with color-reactive chemical. The degree of accuracy depends on the precision of the measurements and analytic bias of the tube; or

NOTE: Some hydrogen cyanide tubes give a false positive indication in the presence of water.

- b) A gas cell equipped infrared analyzer. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards at a wavelength of approximately 4.1 μ (the characteristic absorption wavelength for hydrogen cyanide). The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7.

9.10 Hydrogen sulfide content

The hydrogen sulfide content shall be determined by using one of the following procedures:

- a) An apparatus using a detector tube filled with a color-reactive chemical. The degree of accuracy depends on the precision of the measurements and the analytical bias of the tube;
- b) An automated wet chemical analyzer specific to hydrogen sulfide. The analyzer shall be calibrated at appropriate intervals by using calibration gas

standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;

- c) A fuel cell analyzer specific to hydrogen sulfide. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- d) A gas chromatograph; or
- e) An analyzer using the principles of chemiluminescence. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The range used shall be no greater than 10 times the specified maximum amount of hydrogen sulfide. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7.

9.11 Methanol content

The methanol content shall be determined by using one of the following procedures:

- a) A gas chromatograph; or
- b) A gas cell equipped infrared analyzer. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards at a wavelength of approximately 3.5 μ (the characteristic absorption wavelength for carbon-hydrogen stretching). The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7.

9.12 Nitric oxide content

The nitric oxide content shall be determined by using one of the following procedures:

- a) An apparatus using a detector tube filled with a color-reactive chemical. The degree of accuracy depends on the precision of the measurements and the analytical bias of the tube;
- b) An automated wet-chemical analyzer specific to nitric oxide. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- c) An analyzer using the principles of chemiluminescence. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The range used shall be no greater than 10 times the specified maximum amount of the nitric oxide. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7; or
- d) An analyzer using mass spectrometry. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall

be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7.

9.13 Nitrogen dioxide content

The nitrogen dioxide content shall be determined by using one of the following procedures:

- a) An apparatus using a detector tube filled with a color-reactive chemical. The degree of accuracy depends on the precision of the measurements and the analytical bias of the tube;
- b) An automated wet-chemical analyzer specific to nitrogen dioxide. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- c) An analyzer using the principles of chemiluminescence. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards (see 5.1.8). The range used shall be no greater than 10 times the specified maximum amount of nitrogen dioxide. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- d) A gas cell equipped with an infrared analyzer. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards at a wavelength of approximately 3.5 μ (the characteristic absorption wavelength for nitrogen dioxide). The analyzer shall be operated so that it accurately measures the limiting characteristics as defined in Annex 1 - Table 7; or
- e) An analyzer using mass spectrometry. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7.

9.14 Nonvolatile residue content

The nonvolatile residue content shall be determined by one of the following gravimetric methods:

- a) By collecting a known weight of sample of liquid carbon dioxide from a storage container or sample cylinder as carbon dioxide snow. The carbon dioxide snow is allowed to sublime completely to prevent ambient contamination. The residual is transferred with a suitable residue-free solvent to a clean, weighed watch- glass, petri dish, or other suitable receptacle and the solvent is allowed to evaporate until the receptacle is at a constant weight. Use gentle heating or other suitable means to remove the last traces of solvent or moisture. The weight of residue is determined by difference;

- b) By weighing the sample container containing the sample, then releasing the gas through a small orifice. The empty container is allowed to warm to room temperature and is again weighed and the sample size determined by difference. The container valve is removed and the interior of the container rinsed with a suitable residue-free solvent. The rinse solution is then filtered into a clean, weighed watch-glass, petri dish, or other suitable receptacle and the solvent is allowed to evaporate until the receptacle is at a constant weight. Use gentle heating or other suitable means to remove the last traces of solvent or moisture. The weight of residue is determined by difference; or
- c) By collecting a known weight of sample of carbon dioxide solid either from the interior of a solid block or the interior of a batch of solid pellets. The carbon dioxide solid is allowed to sublime completely so that it prevents ambient contamination. Transfer the residual with a suitable residue-free solvent to a clean, weighed watch-glass, petri dish, or other suitable receptacle and the solvent is allowed to evaporate until the receptacle is at a constant weight. Use gentle heating or other suitable means to remove the last traces of solvent or moisture. The weight of residue is determined by difference.

9.15 Odor/taste

- a) Because carbon dioxide is classed as a toxic compound, its odor shall not be determined by direct inhalation.
- b) The presence of an odor shall be determined by one of the following methods:
 - i. Bubble approximately 500 ml carbon dioxide from the liquid phase of the container through 250 ml of cool distilled water in an Erlenmeyer flask. Allow the flask to stand for 15 minutes. Cautiously smell the gas space above the water in the flask for the presence of any foreign odor. The water may be cautiously tasted if desired;

CAUTION: When performing the odor test, do not take deep breaths. Discontinue sniffing any gas at the first indication of irritation of the nasal passage, dizziness, or physical discomfort. Discontinue the odor test on carbon dioxide if respiration increases.

- ii. Expand the liquid carbon dioxide into a clean cloth to collect the resultant carbon dioxide snow. Place the snow into an Erlenmeyer flask containing cold distilled water. When all of the snow has sublimed, cautiously sniff the vapor space above the water for any foreign odor; or

- iii. Test a dry ice sample, whether cut from a solid block or from expanded liquid, by allowing a layer of frost to form on the solid while exposed to the air in an odor-free area. Collect this frost layer onto a clean dry cloth and allow it to melt, cautiously sniffing it as it melts.

9.16 Oil/grease content

The oil and grease content shall be determined by either any of different gravimetric methods available (see 9.14) or infrared analysis.

9.17 Oxygen content

The oxygen content shall be determined by using one of the following procedures:

- a) An electrochemical-type analyzer containing solid or aqueous electrolyte. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards or internally in accordance with Faraday's Law. The range used shall be no greater than 10 times the specified maximum oxygen content. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- b) A gas chromatograph; or
- c) A mass spectrometer capable of separating and detecting oxygen. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7.

9.18 Phosphine content

The phosphine content shall be determined by using one of the following procedures:

- a) An apparatus using a detector tube filled with a color-reactive chemical. The degree of accuracy depends on the precision of the measurements and the analytical bias of the tube;
- b) A gas chromatograph; or
- c) A gas cell equipped with an infrared analyzer. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards at a wavelength of approximately 4.2 μ (the characteristic absorption wavelength for phosphine). The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7.

9.19 Sulfur dioxide content

The sulfur dioxide content shall be determined by using one of the following procedures:

- a) An apparatus using a detector tube filled with a color-reactive chemical. The degree of accuracy depends on the precision of the measurements and the analytical bias of the tube;
- b) A wet-chemical analyzer specific to sulfur dioxide. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- c) A gas chromatograph;
- d) A gas cell equipped with an infrared analyzer. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards at a wavelength of approximately $7.3\ \mu$ (the characteristic absorption wavelength for sulfur dioxide). The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- e) An analyzer using mass spectrometry. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristics as defined in Annex 1 - Table 7; or
- f) A fluorescent sulfur dioxide analyzer capable of detecting total sulfur dioxide. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7.

9.20 Total hydrocarbon content

THC (as methane) shall be determined by using one of the following procedures:

- a) A flame ionization type analyzer. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards having a carbon dioxide balance. The range used shall be no greater than 10 times the specified maximum total hydrocarbon content expressed as methane. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- b) A gas cell equipped with an infrared analyzer. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards (see 5.1.8) at a wavelength of approximately $3.5\ \mu$ (the characteristic absorption wavelength for carbon-hydrogen stretching). The analyzer shall be operated

so that it accurately measures the limiting characteristics as defined in Annex 1 - Table 7; or

- c) A mass spectrometer capable of separating and detecting hydrocarbons from carbon dioxide. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7.

9.21 Total sulfur content

The total sulfur content (as sulfur) shall be determined by using one of the following procedures:

- a) An automated wet-chemical analyzer specific to sulfur. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- b) A fuel cell analyzer specific to sulfur. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- c) A fluorescent sulfur analyzer capable of detecting total sulfur. The analyzer shall be calibrated at appropriate intervals by using calibration gas standards. The analyzer shall be operated so that it accurately measures the limiting characteristics as defined in Annex 1 - Table 7; or
- d) A gas chromatograph.

9.22 Water/dew point content

The water content shall be determined by using one of the following procedures:

- a) An apparatus using a detector tube filled with a color-reactive chemical. The degree of accuracy depends on the precision of the measurements and the analytical bias of the tube;
- b) An electrolytic hygrometer having an indicator graduated in ppm (v/v) on a range that is no greater than 10 times the specified maximum moisture content. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- c) A dew point analyzer in which the temperature of a viewed surface is measured at the time moisture condensation first begins to form (see Table 10). The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7;
- d) A piezoelectric oscillating quartz crystal hygrometer. The analyzer shall be operated so that it accurately measures the limiting characteristics as defined in Annex 1 - Table 7; or

- e) A metal oxide capacitor-equipped analyzer on a range that is no greater than 10 times the specified maximum moisture content. The analyzer shall be operated so that it accurately measures the limiting characteristic as defined in Annex 1 - Table 7.

10 CONTAINERS

10.1 Carbon dioxide containers

Carbon dioxide containers offered for transportation shall comply with the regulations of the appropriate authority.

10.2 Container preparation

The quality of carbon dioxide in a container depends on the quality of the source carbon dioxide and the condition of the container before filling. Container and transfer equipment preparation shall be adequate to ensure that the container contents meet the required QVL of carbon dioxide.

10.3 Carbon dioxide USP

Carbon dioxide labeled as USP is classified as a drug and shall be labeled in accordance with the appropriate food and drug regulations.

10.4 Container preparation

- a) Container preparation shall be in accordance with an acceptable technique including evacuation, cleaning, drying, and purging to ensure the containers, closures, and other component parts are suitable for their intended use.
- b) The containers shall be prepared so that they are not reactive, additive, or absorptive to an extent that significantly affects the identity, strength, quality, or purity of the carbon dioxide. In addition, they shall furnish adequate protection against the deterioration or contamination of the carbon dioxide.

10.5 Valves on carbon dioxide containers

The valve outlet connection and PRDs should conform to recognized standards and shall be properly engineered for the intended gas service and pressure.

11 SUPPLEMENTAL DATA

11.1 Pressure and temperature data

A pressure-temperature graph showing the pressure in a cylinder filled with carbon dioxide to various percentages of its water capacity is illustrated in Annex 2 - Figure 11.

11.2 Moisture conversion data

Water/dew point is expressed in ppm (v/v) or °F at 1 atm abs, 101 kPa, abs (760 mm Hg). To convert to other units, use Annex 1 - Table 10.

12 CYLINDER VALVES

12.1 Standard fill valve

The standard fill valve on carbon dioxide cylinders uses the CGA 320 connection. See Annex 2 - Figure 12. There are two types of sealing methods used to prevent leakage during filling or use. Fiber or plastic washers may be inserted between the cylinder valve outlet and its connection, or an O-ring seal may be incorporated into the mating connection.

12.2 Fire extinguishing cylinder valves

- a) Carbon dioxide fire extinguishing cylinders may require special adapters other than the CGA 320 connection. Fire extinguishing valves are siphon-tube type to facilitate liquid withdrawal.
- b) Certain types of high flow fire discharge cylinder valves rely upon a mechanical locking pin system to keep the valve closed during filling and transportation (see Annex 2 - Figures 13 and 14). Care must be taken when filling or transporting these cylinders to prevent an accidental uncontrolled release of pressure and potential resulting injury.

12.3 Residual pressure valve

A residual pressure valve can be used to prevent backflow of foreign material into the cylinder. The valve retains a small amount of gas to stop the cylinder from being completely emptied and exposed to atmospheric contaminants. The residual pressure valve uses the same inlet and outlet connections as a standard carbon dioxide cylinder valve. A special adapter is needed for filling or completely emptying the cylinder.

13 CYLINDER INSPECTION AND REQUALIFICATION

13.1 General

- a) General procedures used for determining the suitability of a cylinder for refilling are explained in this section.
- b) Persons inspecting, filling, and handling carbon dioxide cylinders shall be trained in matters which includes but may not be limited to the following:
 - i. types of cylinders in which carbon dioxide are shipped;
 - ii. charging of the cylinders as to amount of carbon dioxide and conditions of filling;
 - iii. marking and labeling of the cylinders for transportation;

- iv. qualifying, maintaining, and requalifying the cylinders; and
 - v. conditions under which the cylinder are permitted to be transported.
- c) Persons who fill carbon dioxide cylinders should also be trained in the hazards associated with liquid carbon dioxide.

13.2 External inspection

13.2.1 All cylinders shall be visually inspected before each fill.

13.2.2 The external surfaces of the cylinder shall be sufficiently clean to permit visual examination.

13.2.3 External Corrosion

- a) Considerable judgment and experience are required in evaluating cylinders fit for service.
- b) If there are any concerns regarding the amount of corrosion present, remove the cylinder from service for further inspection by a cylinder requalifier or qualified inspector.
- c) Special attention shall be given to attachments. Foot rings or “boots” are designed to keep the cylinder stable and upright, and neck rings provide for attachment of the valve protection cap. Attachments shall be examined for distortion, looseness, and failure of seals. If they do not adhere tightly, severe corrosion can occur in the space between the attachment and the cylinder metal.
- d) The attachment of the threaded neck ring to a cylinder shall not be changed from the original design since moisture can enter causing hidden corrosion between the cylinder and the neck ring. Look for other external defects such as neck cracks.

13.2.4 Damage

- a) Each steel cylinder shall be inspected to ensure the cylinder is free of arc burns, evidence of exposure to fire or excessive heat, cuts, digs, gouges, dents, corrosion, and pitting. Flat-bottom cylinders shall stand upright without leaning. Cylinders should not be bulged, out of round, bowed, or have other defects.
- b) Each aluminum alloy cylinder shall be inspected to ensure the cylinder is free of evidence of exposure to fire or excessive heat, cuts, digs, gouges, dents, and corrosion. Flat-bottom cylinders shall stand upright without leaning. Cylinders should not be bulged, out of round, bowed, or have other defects. Where aluminum alloy cylinders are provided with a heat exposure indicating coating, inspect the cylinder for indications of heat impingements or

exposures in accordance with the heat exposure indicating system's requirements.

- c) Composite cylinders shall further be inspected for loss of resin, broken fibers, lifting of fibers from the surface, loose fibers, or areas where there is a "frost" appearance in the composite material larger than half a square inch.
- d) Cylinders with suspected defects shall be removed from service for further evaluation, remediation, or condemnation.

13.2.5 Valve inspection

- a) Remove the valve protection cap if present. Typically, small cylinders are not equipped with valve protection caps. Cylinders without valve protection are vulnerable to valve damage if dropped. Structural damage, especially if the valve stem is impacted, could cause a malfunction of the valve or unsafe operation. Valves should operate smoothly. If not, they shall be replaced or repaired. Valves that are bent or broken shall be removed from service.
- b) Inspect the cylinder outlet for damage. Outlet threads, pin-indexed holes, and sealing surfaces should not be damaged, defective, or worn. Valves that are damaged shall be removed from service.

CAUTION: Only trained personnel shall repair or remove the cylinder valve.

CAUTION: Carbon dioxide cylinders removed from service for maintenance due to valve damage can contain carbon dioxide gas under pressure from residual dry ice.

13.2.6 Pressure relief device inspection

13.2.6.1 General

- a) A pressure relief device (PRD) is intended to prevent the pressure inside the cylinder from exceeding its test pressure.
- b) Under conditions such as overfilling or excessive heat, the pressure could rise above the burst pressure of the cylinder.
- c) For carbon dioxide service, a frangible (burst) disk PRD with a nominal burst pressure not to exceed the cylinder hydrotest pressure is required. An 1800 psi (12 400 kPa) cylinder is equipped with a PRD incorporating a frangible disk rated at 3000 psi (20

680 kPa) since the test pressure is 5/3 times the working pressure.

13.2.6.2 Pressure relief device construction

- a) Annex 2 - Figure 12 illustrates a carbon dioxide cylinder valve and two types of PRDs. The relief device cap assembly has three separate components: threaded cap shell, frangible disk, and washer, which are pre-assembled by the manufacturer as a single unit. The assembly is screwed directly to the threaded relief approach channel of the cylinder valve.
- b) The earlier use of individual pieces is now discouraged because of the dangers caused by misassembling the individual pieces.

NOTE: It is extremely important that only one frangible disk and one washer are used and that they are assembled in the order indicated by the manufacturer. Multiple disks or PRDs assembled improperly can cause the cylinder to rupture before the relief device functions.

13.2.6.3 Inspection

Each time a compressed gas cylinder is received for refilling, all PRDs shall be externally inspected for corrosion, damage, plugging of external PRD discharge channels, and mechanical defects such as leakage. If there is any doubt regarding the suitability of the PRD, the cylinder shall not be filled until it is equipped with a suitable device.

13.2.6.4 Pressure relief device replacement

- a) PRDs shall only be repaired or replaced by trained personnel.
- b) Personnel shall not attempt to tighten, replace, or repair the PRD on a cylinder under pressure. The pressure on the PRD is always communicating with the gas stream even if the valve is turned off. The cylinder shall be completely emptied prior to any work being performed on PRDs.

CAUTION: Do not use a PRD or any component parts from one

manufacturer on a PRD or valve made by another manufacturer, as qualifications of components or thread design can vary.

WARNING:

Use of a combination or backed frangible disk/fusible plug PRD on any carbon dioxide cylinder is prohibited. The disk on this type of device can only burst after the fusible metal has melted, which occurs at either 165 °F (73.9 °C) or 212 °F (100 °C). A backed device cannot protect an improperly overfilled (liquid full) cylinder from rupturing due to hydrostatic pressure at room temperatures because the fusible metal prevents the disk from rupturing.

13.3 Hammer test (steel cylinders only)

After a steel cylinder is visually inspected and emptied, it is given the hammer test. A free standing cylinder with a clean internal surface and containing no foreign liquids will have a clear, bell-like ring. A dull ring is a failure of the test and an indication of liquid in the cylinder or internal corrosion.

13.4 Internal inspection

- a) In addition to the normal internal inspection of carbon dioxide cylinders performed by an authorized requalifier, carbon dioxide cylinders shall be inspected internally under any of the following conditions:
 - i. failure of the hammer test;
 - ii. empty weight exceeding the stamped tare weight indicating the potential for presence of water or other liquid or solid contaminants in the cylinder; or
 - iii. stamped tare weight exceeding the empty weight indicating potential corrosion.
- b) Internal inspection requires the removal of the valve and consists of lowering a light into the cylinder to inspect for cracks, corrosion, foreign materials, or any other defects. This inspection shall be performed by a trained employee or an authorized cylinder requalifier, see Annex 2 - Figures 15 and 16.

13.5 Cylinder requalification

- a) Cylinder requalification may be performed by either hydrostatic test or ultrasonic examination. Carbon dioxide cylinders require requalification

every 5 years. The requalification shall be performed by an authorized requalifier who holds a current requalifier identification number. If the method of requalification requires valve removal, an internal inspection shall be performed.

NOTE: Requalification by ultrasonic examination requires a DOT special permit.

- b) Cylinders may be distributed past their requalification date. However, when the cylinder is returned to the supplier, the cylinder shall not be refilled until it has been requalified. Cylinders that fail requalification shall be condemned and destroyed.

13.6 Disposing of condemned or unserviceable cylinders

- a) The most hazardous aspect of disposing of a condemned or unserviceable cylinder is confirming that the cylinder has no internal pressure.

CAUTION: Only trained personnel shall dispose of condemned cylinders.

CAUTION: Condemned carbon dioxide cylinders can contain carbon dioxide gas under pressure from residual dry ice.

- b) If the cylinder valve is functional, move the cylinder to an isolated, well-ventilated location, open the valve slightly, and allow the contents to discharge slowly. Verify that all products are vented by weighing the cylinder and ensure that it matches the stamped tare weight. Always verify that a cylinder is empty by means other than a pressure check before removing a valve.
- c) Remove nonfunctional (stuck) valves by following the cylinder and valve manufacturers' recommendations.

14 TYPICAL CYLINDER FILLING SYSTEM

14.1 General

- a) Carbon dioxide in a cylinder is a liquefied gas under its own vapor pressure. Therefore, carbon dioxide cylinders shall always be filled by weight and not by pressure. To ensure that cylinders are not overfilled, cylinders shall be filled individually on a scale so that the amount of liquid carbon dioxide pumped into them can be accurately weighed.
- b) The weight set on the scale is determined by adding the amount of liquid carbon dioxide to be filled to the tare weight referenced on the cylinder. A cylinder without a permanently marked tare weight shall not be filled until the tare weight is determined and marked.

- c) The filling system includes a liquid carbon dioxide transfer pump that receives liquid carbon dioxide at about 300 psi (2070 kPa) and discharges the liquid into cylinders at regulated pressures of 600 psi to 1000 psi (4140 kPa to 6900 kPa).
- d) Standard cylinders typically require filling pressures of 600 psi to 800 psi (4140 kPa to 5520 kPa). Siphon-tube or dip-tube style cylinders as used in fire extinguishing systems require filling pressure of 800 psi to 1000 psi (5520 kPa to 6900 kPa).

14.2 System components

The components of a typical cylinder filling system include:

- a) Liquid carbon dioxide storage and supply container;
- b) Single-stage piston type liquid transfer pump designed specifically for liquid carbon dioxide service;
- c) Drive motor and on/off switch;
- d) Discharge pressure regulator (bypass relief valve) to limit the filling pressure and to return excess carbon dioxide to the storage system;
- e) Pressure gauge showing delivery pressure to cylinder;
- f) Bleed-off valves to discharge liquid contained in lines when filling is completed or interrupted;
- g) PRDs to protect the operator and the equipment from pressure buildup caused by residual liquid trapped in lines after filling;
- h) Flexible charging lines;
- i) Check valve on filling system to prevent backflow of cylinder contents into bulk supply;
- j) Platform scales (one per cylinder); and
- k) Supply and return piping to connect the cylinder filling system to the liquid storage system.

14.3 Installation

Installation shall be carried out in accordance with the manufacturers' instructions and applicable regulations. It is particularly important that each line or portion of a line between shutoff valves, which can at any time contain liquid carbon dioxide, be provided with a thermal expansion relief valve and a blow-down valve. It is important to minimize the pipe length between the storage container and pump because carbon dioxide cylinder filling units pump refrigerated liquid at its boiling point.

14.4 Filling limits for cylinders

- a) The maximum weight of carbon dioxide in a cylinder shall not exceed the allowable percentage of the cylinder's water weight capacity as shown in Annex 1 - Table 2.
- b) For example, if a DOT-3AL1800 cylinder has a water capacity of 100 lb it can be legally filled with up to 68 lb of carbon dioxide. The 68% fill capacity for this cylinder is required to prevent overfilling of these cylinders and to allow for increased pressure caused by the expansion of the liquid carbon dioxide as it warms up to ambient temperature conditions.
- c) Overfilled cylinders develop excessive pressures from expansion of the liquid carbon dioxide as the temperature rises, as shown in the overfilled portion of Annex 2 - Figure 11 Approximate pressure in uninsulated carbon dioxide cylinders filled to indicated densities at selected temperatures.

14.5 Operation

14.5.1 Filling the cylinder

- a) DOT 39 cylinders are nonreusable and nonrefillable. Initial fill shall follow the same steps as outlined in this publication.
- b) The filling of cylinders with carbon dioxide involves systems at high pressures. To minimize accidents or loss of product, components subjected to cylinder pressure, including valves, piping, flexible lines, and connectors, shall be designed for a minimum service pressure of 2000 psi (13 790 kPa).
- c) The filling system is designed to pump liquid carbon dioxide. The filling system operating procedure shall include steps to minimize the possibility of dry ice (solid carbon dioxide) from forming in the pump, which can cause damage.
- d) The operator shall be trained and qualified to operate the filling system in accordance with the filling system's operating procedures. The following is a typical operating sequence of the system shown in Annex 2 - Figure 17. Specific parts of the drawing are noted in the text in parenthesis as parts are explained.
- e) Make sure that the cylinder filling valves (6) and the bleed-off valve (12) are closed and that the flexible charging line (5) connections are tight on the pump module. This is to avoid possible leaks or uncontrolled release of carbon dioxide when lines are charged. Valves should always be opened slowly to the full open position and then closed 1/4 turn. This ensures that the handwheel turns easily when the valve position is checked.

- f) Place one cylinder on each scale (7). Record the weight of each cylinder and compare it with the tare weight marked on each cylinder. If the weights are not within $\pm 1.5\%$ of the stamped tare weight then remove the cylinder and set it aside for internal inspection. If the weights match, connect the flexible charging line (5) and determine the fill weight for each cylinder. Open both cylinder valves (8).
- g) To prime the pump open the pressure regulating valve (9) and the liquid supply valve (13), then open the storage tank liquid valve (18) to pressurize the pump.
- h) With the handle of the pressure-regulating valve (9) raised, open the liquid return valve (10) and storage tank liquid return valve (19). The system is now at storage tank pressure.
- i) Open bleed-off valve (12) until a white cloud of carbon dioxide vapor is discharged, indicating the presence of liquid carbon dioxide in the line. Close bleed-off valve (12).
- j) Start the pump with switch (3) and allow liquid carbon dioxide to recirculate through the system and back to the storage tank.
- k) When the pump is primed and cooled down, fill one cylinder at a time by opening the cylinder fill valve (6) leading to the cylinder to be filled. Listen for the sound of liquid carbon dioxide flowing into the cylinder and lower the pressure regulating valve handle (9) to start pumping. Check the scale and pressure gauge (11) readings that indicate filling is taking place.
- l) The filling rate may be varied to some extent by adjusting the pressure setting screw on pressure regulating valve (9). Standard gas cylinders can reach pressures of 600 psi to 800 psi (4140 kPa to 5520 kPa) during filling. Cylinders equipped with siphon tubes can reach 1200 psi to 1500 psi (8270 kPa to 10 340 kPa) when filling.

NOTE: Dependent on cylinder size and fill rate the pressure regulating valve may need to be adjusted to compensate for fill rate, so the cylinder is not filled too quickly, resulting in an overfilled cylinder.

- m) Calibrate the scales in accordance with applicable regulations. This is done in accordance with a company's standard operating procedure (SOP), typically at least once a year.
- n) In addition, the scales should be periodically checked for proper function in accordance with the scale manufacturer's instructions. Typically, scale function checks are performed at least once a day on each day that liquefied gas cylinders are being filled. If a scale function check weight is used, it shall have a known value

appropriate for the scale being used. The range and sensitivity of the scale shall be appropriate for the size cylinder being weighed.

- o) When the maximum fill weight is reached on the first cylinder, close the valve on the first cylinder (14), the cylinder fill valve to the first cylinder (6); open the charging line bleed-off valve (20). Disconnect charging line (5) on first cylinder, recheck the fill weight, and remove the full cylinder from the scale. If necessary, remove any excess or overfilled product by safely venting it to the atmosphere.

WARNING: Do not overfill. Overfilling will result in an unsafe condition that can lead to a catastrophic failure of the cylinder.

14.5.2 Filling the second and subsequent cylinders

- a) While the second cylinder is being filled, the next empty cylinder can be placed on the vacated scale. After the second cylinder is full, repeat the sequence as stated previously. The alternate filling of cylinders on two scales allows the pump to run continuously and saves set-up time.
- b) It is possible to fill using only one scale by opening the pressure-regulating valve (9) after each fill. This reduces the pump discharge pressure by allowing the pump to recirculate liquid carbon dioxide back to the storage container. It is not recommended that the pump be operated with the pressure-regulating valve closed unless a cylinder is being filled.

14.5.3 Shutting down

To shut down the cylinder filling system after filling has been completed:

- a) Open the pressure regulating valve (9);
- b) Close the cylinder valve (8);
- c) Close the fill line valves (6);
- d) Open the charging line bleed-off valves (20) to bleed the carbon dioxide trapped in the flexible charging lines (5);
- e) Stop the pump by placing motor switch (3) in “off” position;
- f) Close the liquid supply valve (13);
- g) Close the liquid return valve (10);
- h) Open the bleed-off valve (12) to reduce pressure on the gauge below 100 psi (690 kPa); and

- i) Close the bleed-off valve (12).

NOTE: This is a generally accepted sequence for shutting down the cylinder filling system.

14.5.4 Operating details

- a) The level and condition of oil in the pump crankcase should be checked at regular intervals. It is advisable to change the oil when moisture condensation has caused it to become thin or foamy or follow the manufacturers recommendations for changing the oil.
- b) The piston packing gland may need to be tightened periodically to lessen leakage of carbon dioxide. Excessive leakage of carbon dioxide could either freeze or seize the piston and severely damage the pump. The packing should be replaced if normal tightening does not stop leakage.

NOTE: Follow all manufacturers recommendations for maintenance or replacement of the packing.

- c) Insulated gloves and safety glasses with side shields and face shield or goggles shall always be worn while filling.
- d) Liquid carbon dioxide is cold and contact with piping or cold vapor can cause frost burns.
- e) Dry ice particles formed by depressurizing liquid carbon dioxide are extremely cold and abrasive and can cause severe damage to unprotected eyes or skin.
- f) If a cylinder is accidentally overfilled, bleed off product from the cylinder on a scale until the proper and safe fill weight is achieved.
- g) Maintain a safe environment wherever carbon dioxide is handled through adequate ventilation, by keeping the carbon dioxide content below the established exposure limits listed in the safety data sheet (SDS).
- h) The supply line between the liquid storage container and the pump inlet should be as short as possible and well insulated.
- i) In any line where liquid carbon dioxide can be trapped between shutoff or check valves, a PRD shall be installed. This prevents over pressurization or bursting of the line caused by thermal expansion. A blow-down valve may also be installed.

NOTE: To prevent trapped liquid from becoming a hazard in ball- and gate-type valves, they shall be adequately designed to prevent liquid carbon dioxide from being trapped within the valve.

15 CYLINDER FILLING PROCEDURE

15.1 Filling procedure

- a) The carbon dioxide supply used to fill cylinders shall meet or exceed the QVL for its intended use.
- b) The filling operator shall be equipped with personal protective equipment (PPE).
- c) Before filling each cylinder shall be inspected as follows:
 - i. The pressure rating stamped on the cylinder shall be 1800 psi (12 400 kPa) or higher service pressure;
 - ii. The last requalification date shall be determined. If a cylinder requalification period has expired, the cylinder shall not be filled and shall be sent to a requalifier for inspection and requalification before refilling;
 - iii. Each cylinder, cylinder valve, and relief device shall be inspected as prescribed above; and
 - iv. Cylinders failing to meet the above requirements shall not be filled.
- d) Carbon dioxide cylinders are used in a wide variety of applications including, but not limited to:
 - i. beverage carbonation;
 - ii. chemical extraction;
 - iii. chemical reactions;
 - iv. food applications;
 - v. incubators;
 - vi. lasers;
 - vii. medical applications;
 - viii. modified atmosphere;
 - ix. pH control
 - x. refrigeration;
 - xi. surface blasting; and
 - xii. welding shielding gases

Each of these applications and others present risks for contamination of the interior of the carbon dioxide cylinder.

- e) A common example is beverage carbonation where the carbon dioxide is combined with syrup and water. If syrup is drawn back into a cylinder and

not detected and removed prior to the next refill of the cylinder it can impact the product purity. If water is drawn back into a cylinder, and not detected and removed prior to next refill, it can cause internal corrosion by the formation of carbonic acid. See Annex 2 - Figures 15 and 16 for examples of typical corrosion that could result in cylinder failure.

- f) Risk of cylinder contamination hazards shall be assessed by the company filling the cylinder based on the market applications, known hazards, prior incidents, and/or available literature.
- g) Carbon dioxide cylinder contamination could represent a personnel safety hazard for the cylinder filler, customer, and user; an environmental hazard; and/or a food safety hazard.
- h) If a gas cylinder is not equipped with a residual pressure valve, at least two preventive and/or mitigation measures shall be implemented for identified contamination hazards and documented in a company's written procedures. These measures can include, but are not limited to:
 - i. Analysis and/or examination of residual gas for identified contamination hazards;
 - ii. Controlled cylinder market application use;
 - iii. A method to accurately compare the empty cylinder weight to the marked tare weight. If a significant amount of water or liquid is present, this can be detected by a cylinder weight check. This method is appropriate for carbon dioxide when the tare weight of the empty cylinder is checked. The sensitivity of this method depends on the size of the cylinder, the accuracy of the scale used and of the stamped tare weight;
 - iv. Cylinder inversion that does not allow pooled liquid in the shoulder; and/or
 - v. Visual internal examination.
- i) Alternative technologies that address the identified contamination hazard may be used. All mitigation measures should be validated to ensure they meet the objective of reducing risk by identifying and removing any contamination.
- j) Any evidence of water or other fluids requires internal inspection.

WARNING: Filling cylinders that contain liquid water or other fluids can cause internal corrosion and can cause overfilling resulting in over pressurization which can result in serious injury or death.

- k) When water or other foreign liquids are detected an inverting rack or fixture may be used to ensure safe and complete removal of water and other fluids prior to returning to service, see Annex 2 - Figure 18.
- l) Another method is to clean and dry the cylinder inside and outside, to ensure it's free from any contaminant.
- m) Liquid use cylinders have internal siphon tubes that withdraw carbon dioxide from the bottom of the cylinder. The cylinder valve is typically stamped with an S on the valve body or has a special high-capacity fire protection discharge valve on top. Siphon-tube and fire cylinders shall be depressurized in the upright position.
- n) Vacuum evacuation or other methods may be used if such a system is properly validated to ensure liquid removal.
- o) Cylinders should be kept internally free from moisture, sludge, or residue. If such substances are suspected to be present, or found to be present, in the cylinder, the cylinder shall be internally inspected and cleaned, if necessary, by properly trained personnel according to the company's SOP. When properly trained personnel are not available, the cylinder should be sent to an authorized requalifier for internal examination and/or requalification. See Annex 2 - Figure 18 for a typical inverting rack. Pneumatically operated inverters are also available.

NOTE: Vacuum evacuation should consider that heat may be required to ensure all liquids are vaporized. This is to ensure that the vacuuming of the cylinder does not create condition where the liquid can freeze or dehydrate leading to a false vacuum reading in the cylinder.

- p) Weigh the cylinder when depressurized and compare this weight with the tare weight stamped on the cylinder. Cylinder valves, siphon tubes, and permanently attached valve protective devices are included in the tare weight.
- q) Aluminum and steel cylinders do not have the same tare weight for the same capacity cylinder.
- r) Any deviation in observed tare weight 1.5% more or less than the stamped tare weight requires the cylinder to be quarantined for internal and external inspection by trained personnel prior to returning to service.
- s) Any deviation in observed tare weight from the stamped tare weight for steel cylinders shall be quarantined for further inspection or condemnation by an authorized requalifier.
- t) After filling each cylinder, check the gross weight to make sure that the cylinder is not overfilled. It is extremely dangerous to ship an overfilled carbon dioxide cylinder.

- u) Use Annex 1 - Table 12 to determine the rated capacity of a cylinder based on its size.
- v) Carbon dioxide cylinders shall always be filled by weight, not by pressure. The scales used shall be calibrated in accordance with company SOPs and applicable regulations. Each day prior to use scales shall be checked for function and accuracy by methods established by company SOPs. If used, check weights shall have a known value approximately that of the gross weight of the cylinders being weighed. A record or log of this function and accuracy check should be maintained.
- w) Fill the cylinder with the net capacity of carbon dioxide. The company SOP shall indicate how the final fill weight is determined.
- x) Cylinders shall not be filled to more than the percent of the water weight capacity allowed in Annex 1 - Table 12. If a cylinder is filled to a higher percentage, a rise in temperature could cause the cylinder to become “liquid full” resulting in rapidly rising pressures and the rupturing of the frangible disk in the PRD. Annex 2 - Figure 11 illustrates the relationship of percent water weight filled to equilibrium pressure at different temperatures for a DOT-3AL1800 cylinder. It also illustrates the danger of overfilling and demonstrates the importance of protecting cylinders from excessive heat.
- y) Full carbon dioxide cylinders should be properly nested, secured, or put in holders to prevent them from falling.

15.2 Typical steps performed when filling carbon dioxide cylinders

The following are typical steps for filling carbon dioxide into a cylinder. Cylinders equipped with a back-flow preventive residual pressure valve may require different steps. These steps shall be documented in a company’s SOPs. Steps should include:

- a) check cylinder DOT specification and pressure rating;
- b) check cylinder test date;
- c) perform external visual inspection;
- d) depressurize cylinder;
- e) perform hammer test (steel cylinders only);
- f) check cylinder labels;
- g) check cylinder tare weight;
- h) determine cylinder fill capacity;
- i) determine scale target weight;
- j) connect cylinders and fill to net capacity (target weight);
- k) disconnect cylinders and check gross weight; and
- l) secure full cylinders by nesting.

16 CYLINDER STORAGE, HANDLING, SHIPPING, AND USE

16.1 Storage

- a) Carbon dioxide cylinders should be stored and handled in cool, dry, well-ventilated locations.

Protect carbon dioxide cylinders from sunlight when ambient temperature exceeds (125 °F) 52 °C.

- b) Do not store cylinders near radiators, furnaces, or other sources of heat.

Carbon dioxide is heavier than air and will seek out and settle in low areas or near the floor.

- c) Storage in basements or other confined storage areas shall be accompanied by gas detection and adequate ventilation.
- d) Cylinders in storage should be secured to prevent falling. Nesting of cylinders is considered an equivalent safe manner of storage.
- e) Store full and empty cylinders separately.
- f) Store empty cylinders with the valve tightly closed.

16.2 Handling

Personnel who handle carbon dioxide cylinders shall be trained in the proper handling of cylinders.

16.3 Shipping

- a) Do not ship a leaking cylinder.
- b) Cylinders in transit should be secured upright or on their sides.
- c) Cylinders should not be transported in an enclosed vehicle unless the driver is separated from the cargo area by a gas-tight barrier to protect the driver from exposure to hazardous levels of carbon dioxide.
- d) Cylinder valves should be closed on empty cylinders in transit.

16.4 Use

- a) Carbon dioxide cylinders should not be used at temperatures exceeding 125 °F (52 °C).
- b) For applications that require gaseous carbon dioxide, cylinders should be used in the upright position and not equipped with a siphon tube. This ensures liquid carbon dioxide is not introduced into the valve and regulators.
- c) For applications that require liquid carbon dioxide, cylinders are equipped with a siphon tube and used in the upright position. The user shall be aware of the presence or absence of the siphon tube to assure the proper carbon dioxide phase is used for the intended application. Cylinders equipped with a siphon tube shall be identified with the letters “S,” “ET,” “DT” or “GN”

stamped on the cylinder or valve; labeled with “siphon,” “eductor tube,” “dip tube,” or “goose neck;” or other visual identifier (e.g., color coding).

WARNING: Do not use a siphon-tube cylinder to carbonate beverages since liquid carbon dioxide can damage the pressure reducing regulator.

- d) Cylinders containing carbon dioxide shall only be discharged or depressurized in a well-ventilated space in a manner that does not create a hazard.

17 LABELING AND PLACARDING

17.1 Labels

For information on labeling requirements use Belize Standard Specification for Labelling Part 8: Labelling and Marking of Medical Gas Cylinders.

17.2 Placards

17.2.1 Full cylinder shipments

- a) Vehicles carrying more than 1000 lb (454 kg) gross weight of carbon dioxide cylinders shall be placarded with clearly visible nonflammable gas placards on all four sides.
- b) The background color shall be green, and the cylinder symbol, text, hazard class number and inner border shall be white. Annex 2 - Figure 19 shows nonflammable gas placards; the hazard class words are optional.

17.2.2 Shipments of empty cylinders

Empty cylinder shipments in excess of 1000 lb (454 kg) gross weight being returned for refilling may contain residual carbon dioxide and should be placarded as full cylinders. The only exception, in which the vehicle shall not be placarded, for this is if the cylinders have been completely emptied and purged.

Annex 1: Carbon Dioxide Reference Tables

Table 1: Physical constants of carbon dioxide

	U.S. Units	SI Units
Chemical formula	CO ₂	CO ₂
Molecular weight	44.01	44.01
Vapor pressure ¹⁾ at 2 °F (−16.7 °C)	302 psi	2082 kPa
Specific gravity of the gas at 70 °F (21.1 °C) and 1 atm	1.522	1.522
Solid to gas expansion ratio (specific volume of the gas) at 70 °F (21.1 °C) and 1 atm	8.741 ft ³ /lb	0.5457 m ³ /kg
Density of the gas at 70 °F (21.1 °C) and 1 atm	0.1144 lb/ft ³	1.833 kg/m ³
Density of the liquid saturated at 2 °F (−16.7 °C)	63.3 lb/ft ³ (8.46 lb/gal)	1014 kg/m ³
Density of solid (dry ice) at 1 atm and −109.3 °F (−78.5 °C)	97.6 lb/ft ³	1563 kg/m ³
Sublimation temperature at 1 atm	−109.3 °F	−78.5 °C
Critical temperature	87.9 °F	31.1 °C
Critical pressure	1070.6 psia	7381.8 kPa, abs
Critical density	29.2 lb/ft ³	468 kg/m ³
Triple point	−69.9 °F at 75.1 psia	−56.6 °C at 518 kPa, abs
Latent heat of vaporization at 2 °F (−16.7 °C)	119.0 Btu/lb	276.8 kJ/kg
Latent heat of fusion at 1 atm and −69.9 °F (−56.6 °C)	85.6 Btu/lb	199 kJ/kg
Latent heat of sublimation at 1 atm and −109.3 °F (−78.5 °C)	245.5 Btu/lb	571.0 kJ/kg
Specific heat of the gas at 77 °F (25.0 °C) and 1 atm C_p C_v	0.203 Btu/(lb)(°F) 0.157 Btu/(lb)(°F)	0.850 kJ/(kg)(°C) 0.657 kJ/(kg)(°C)
Ratio of specific heats (C_p/C_v) at 59 °F (15.0 °C)	1.304	1.304
Solubility in water, vol/vol at 68 °F (20.0 °C)	0.90	0.90
Viscosity of saturated liquid at 2 °F (−16.7 °C)	0.287 lb/(ft)(hr)	0.000119 Pa · s

¹⁾ All psi values are referenced to 14.696 psia (101.325 kPa, abs).

Table 2: Solubility of carbon dioxide in water (volume carbon dioxide/volume water)

Water pressure psi (kPa)	Water temperature °F (°C)												
	32 (0)	36 (2.2)	40 (4.4)	44 (6.7)	48 (8.9)	55 (12.8)	60 (15.6)	65 (18.3)	70 (21.1)	75 (23.9)	80 (26.7)	85 (29.4)	90 (32.2)
15 (103)	3.46	3.19	2.93	2.70	2.50	2.20	2.02	1.86	1.71	1.58	1.48	1.35	1.27
20 (138)	4.04	3.73	3.42	3.15	2.92	2.57	2.36	2.17	2.00	1.84	1.69	1.58	1.48
25 (172)	4.58	4.27	3.92	3.61	3.35	2.95	2.69	2.48	2.29	2.10	1.93	1.80	1.70
30 (207)	5.21	4.81	4.41	4.06	3.77	3.31	3.03	2.80	2.58	2.37	2.18	2.03	1.91
35 (241)	5.80	5.35	4.91	4.52	4.19	3.69	3.37	3.11	2.86	2.63	2.42	2.26	2.13
40 (276)	6.37	5.89	5.39	4.97	4.61	4.05	3.71	3.42	3.15	2.89	2.67	2.49	2.34
45 (310)	6.95	6.43	5.88	5.43	5.03	4.43	4.06	3.74	3.44	3.16	2.91	2.72	2.56
50 (345)	7.53	6.95	6.36	5.89	5.45	4.80	4.40	4.05	3.73	3.42	3.16	2.94	2.77
55 (379)	8.11	7.48	6.86	6.34	5.87	5.17	4.74	4.37	4.02	3.69	3.40	3.17	2.99
60 (414)	8.71	8.02	7.35	6.79	6.29	5.53	5.08	4.68	4.31	3.95	3.64	3.39	3.20
70 (483)	9.86	9.09	8.33	7.70	7.13	6.27	5.76	5.30	4.89	4.49	4.14	3.86	3.63
80 (552)	11.02	10.17	9.31	8.61	7.98	7.00	6.43	5.92	5.46	5.02	4.62	4.31	4.06
90 (621)	12.18	11.25	10.30	9.52	8.82	7.74	7.11	6.54	6.04	5.55	5.12	4.77	4.49
100 (690)	13.34	12.33	11.29	10.43	9.66	8.40	7.79	7.18	6.62	6.08	5.60	5.22	4.91

NOTE—This table shows the equivalent volume of carbon dioxide measured at 32 °F (0 °C) and 0 psi (0 kPa) that dissolves in one volume of water at the pressure and temperature indicated.

Table 3: Thermodynamic properties of saturated carbon dioxide solid, liquid, and vapor phases (customary units)

Temp °F		Pressure		Density	Specific volume	Enthalpy ¹⁾		Entropy ¹⁾	
		psia	psi	lb/ft³	ft³/lb	Btu/lb		Btu/(lb)(°R)	
				solid or liquid	vapor	solid or liquid	vapor	solid or liquid	vapor
Solid and Vapor	−150	1.793	26.26 ²⁾	99.7	41.81	53.55	305.50	0.3394	1.1530
	−140	3.171	23.46 ²⁾	99.2	24.41	56.36	306.90	0.3483	1.1318
	−130	5.405	18.92 ²⁾	98.8	14.69	59.22	308.30	0.3571	1.1126
	−120	8.923	11.75 ²⁾	98.3	9.131	62.15	309.62	0.3658	1.0945
	−110	14.34	7.725 ²⁾	97.5	5.829	65.16	310.81	0.3743	1.0770
	−109.3	14.70	0.000	97.5	5.683	65.38	310.90	0.3748	1.0758
	−105	17.94	3.244	97.2	4.708	66.69	311.45	0.3786	1.0687
	−100	22.28	7.584	96.9	3.814	68.24	312.01	0.3829	1.0606
	−95	27.67	12.97	96.6	3.103	69.80	312.50	0.3872	1.0527
	−90	34.14	19.44	96.2	2.531	71.41	312.89	0.3915	1.0449
	−85	41.63	26.93	95.7	2.074	73.01	313.11	0.3959	1.0372
	−80	50.58	35.88	95.3	1.714	74.63	313.22	0.4002	1.0292
	−75	61.72	47.02	94.9	1.418	76.28	313.29	0.4045	1.0215
	−70	74.76	60.06	94.4	1.182	77.96	313.42	0.4089	1.0151
	−69.9	75.13	60.43	94.4	1.157	78.01	313.42	0.4112	1.0150
Triple point									
Liquid and Vapor	−69.9	75.13	60.43	73.53	1.157	163.6	313.42	0.6308	1.0150
	−68	78.48	63.78	73.30	1.117	164.4	313.49	0.6318	1.0128
	−66	82.34	67.64	73.05	1.060	165.3	313.58	0.6340	1.0107
	−64	86.35	71.65	72.79	1.011	166.1	313.67	0.6362	1.0088
	−62	90.50	75.80	72.54	0.9659	167.0	313.76	0.6384	1.0070
	−60	94.76	80.06	72.28	0.9254	167.9	313.85	0.6406	1.0053
	−58	99.15	84.45	72.01	0.8876	168.8	313.94	0.6427	1.0038
	−56	103.7	89.00	71.76	0.8501	169.6	314.03	0.6448	1.0024
	−54	108.4	93.70	71.49	0.8145	170.5	314.12	0.6469	1.0010
	−52	113.2	98.50	71.23	0.7809	171.4	314.23	0.6490	0.9996
	−50	118.2	103.50	70.97	0.7489	172.3	314.33	0.6511	0.9982
	−48	123.4	108.70	70.71	0.7184	173.2	314.44	0.6533	0.9967
	−46	128.8	114.10	70.44	0.6896	174.1	314.57	0.6555	0.9952
	−44	134.3	119.60	70.16	0.6622	175.0	314.68	0.6577	0.9938
	−42	140.0	125.30	69.88	0.6361	175.9	314.78	0.6599	0.9924
	−40	145.9	131.20	69.60	0.6113	176.8	314.89	0.6621	0.9910
	−38	152.0	137.30	69.33	0.5876	177.7	314.98	0.6642	0.9897
	−36	158.1	143.40	69.04	0.5648	178.7	315.09	0.6663	0.9883
	−34	164.6	149.90	68.76	0.5432	179.6	315.20	0.6684	0.9869
	−32	171.2	156.50	68.48	0.5227	180.5	315.31	0.6704	0.9855
	−30	178.0	163.30	68.20	0.5031	181.4	315.40	0.6725	0.9842
	−28	184.9	170.20	67.92	0.4844	182.3	315.49	0.6746	0.9829
	−26	192.1	177.40	67.64	0.4665	183.2	315.58	0.6767	0.9817
	−24	199.6	184.90	67.35	0.4492	184.3	315.67	0.6788	0.9805
	−22	207.2	192.50	67.06	0.4325	185.2	315.74	0.6810	0.9793
	−20	215.0	200.30	66.77	0.4166	186.1	315.81	0.6831	0.9781
	−18	223.1	208.40	66.47	0.4014	187.0	315.86	0.6852	0.9769
	−16	231.3	216.60	66.17	0.3868	188.1	315.92	0.6873	0.9756
	−14	239.8	225.10	65.87	0.3731	189.0	315.95	0.6894	0.9743
	−12	248.7	234.00	65.56	0.3599	189.9	315.99	0.6916	0.9730
	−10	257.6	242.90	65.25	0.3473	191.0	316.01	0.6937	0.9717

–8	266.9	252.20	64.93	0.3351	191.9	316.01	0.6958	0.9704
–6	276.3	261.6	64.62	0.3233	193.0	316.01	0.6979	0.9691
–4	285.8	271.1	64.29	0.3119	193.9	315.99	0.7000	0.9678
–2	295.7	281.0	63.96	0.3010	194.9	315.95	0.7022	0.9666

Temp °F		Pressure		Density	Specific volume	Enthalpy ¹⁾		Entropy ¹⁾	
		psia	psi	lb/ft ³	ft ³ /lb	Btu/lb		Btu/(lb)(°R)	
				solid or liquid	vapor	solid or liquid	vapor	solid or liquid	vapor
Liquid and Vapor	+ 0	305.8	291.1	63.63	0.2906	195.8	315.92	0.7043	0.9654
	2	316.3	301.6	63.30	0.2805	196.9	315.88	0.7064	0.9642
	4	327.0	312.3	62.97	0.2707	198.0	315.83	0.7085	0.9629
	6	337.9	323.2	62.64	0.2613	198.9	315.76	0.7106	0.9616
	8	349.0	334.3	62.30	0.2523	200.0	315.68	0.7127	0.9603
	10	360.5	345.8	61.99	0.2436	200.9	315.59	0.7148	0.9589
	12	372.2	357.5	61.69	0.2353	202.0	315.50	0.7169	0.9575
	14	384.3	369.6	61.32	0.2273	203.0	315.40	0.7190	0.9561
	16	396.5	381.8	61.02	0.2196	204.1	315.27	0.7211	0.9547
	18	409.0	394.3	60.67	0.2122	205.2	315.13	0.7232	0.9533
	20	421.9	407.2	60.32	0.2050	206.3	314.96	0.7253	0.9520
	22	435.1	420.4	59.91	0.1980	207.4	314.80	0.7275	0.9507
	24	448.7	434.0	59.57	0.1911	208.4	314.62	0.7297	0.9493
	26	462.5	447.8	59.17	0.1845	209.5	314.42	0.7319	0.9479
	28	476.6	461.9	58.78	0.1783	210.6	314.19	0.7341	0.9465
	30	490.8	476.1	58.40	0.1722	211.7	313.90	0.7363	0.9450
	32	505.5	490.8	58.02	0.1663	212.8	313.58	0.7385	0.9434
	34	520.5	505.8	57.59	0.1602	214.0	313.20	0.7407	0.9417
	36	536.0	521.3	57.12	0.1542	215.1	312.77	0.7429	0.9399
	38	551.7	537.0	56.70	0.1482	216.4	312.28	0.7452	0.9380
	40	567.7	553.0	56.29	0.1425	217.4	311.76	0.7475	0.9360
	42	584.0	569.3	55.89	0.1372	218.7	311.20	0.7598	0.9340
	44	600.8	586.1	55.44	0.1321	220.0	310.63	0.7521	0.9321
	46	617.8	603.1	54.95	0.1273	221.2	310.05	0.7544	0.9302
	48	635.2	620.5	54.43	0.1226	222.5	309.47	0.7568	0.9283
	50	652.9	638.2	53.91	0.1181	223.7	308.90	0.7593	0.9264
	52	671.2	656.5	53.45	0.1138	225.0	308.32	0.7618	0.9246
	54	689.7	675.0	52.95	0.1095	226.4	307.75	0.7643	0.9227
	56	708.6	693.9	52.37	0.1054	227.7	307.13	0.7668	0.9207
	58	727.9	713.2	51.81	0.1014	229.1	306.49	0.7694	0.9187
	60	747.6	732.9	51.17	0.09752	230.6	305.78	0.7720	0.9166
	62	767.7	753.0	50.47	0.09372	232.0	305.03	0.7746	0.9145
	64	788.3	773.6	49.78	0.08999	233.5	304.22	0.7773	0.9123
	66	809.3	794.6	49.08	0.08631	235.1	303.35	0.7801	0.9100
	68	830.8	816.1	48.39	0.08261	236.7	302.45	0.7830	0.9077
	70	852.7	838.0	47.62	0.07894	238.3	301.52	0.7861	0.9053
	72	875.0	860.3	46.80	0.07535	240.3	300.51	0.7894	0.9030
	74	897.8	883.1	45.90	0.07173	242.1	299.39	0.7930	0.9006
	76	921.1	906.4	44.94	0.06811	244.3	298.10	0.7970	0.8982
	78	945.1	930.4	43.90	0.06411	246.4	296.57	0.8013	0.8957
	80	969.5	954.8	42.67	0.06013	248.9	294.75	0.8060	0.8924
	82	994.5	979.8	41.23	0.05603	251.5	292.46	0.8112	0.8881
	84	1020	1005	39.59	0.05171	254.7	289.67	0.8170	0.8821
	86	1046	1031	37.03	0.04711	259.0	285.64	0.8249	0.8737
	87.9	1071	1056	29.21	0.03423	272.7	272.70	0.8483	0.8483

¹⁾ Based on 0 for the perfect crystal at absolute zero temperature, –459.67 °F (–273.15 °C).

²⁾ Inches of mercury below atmospheric pressure.

Table 4: Thermodynamic properties of saturated carbon dioxide solid, liquid, and vapor phases (SI units)

Temp °C		Pressure		Density	Specific volume	Enthalpy ¹⁾		Entropy	
		kPa, abs	kPa	kg/m ³	m ³ /kg x 10 ⁻³	kJ/kg		kJ/(kg)(K)	
				solid or liquid	vapor	solid or liquid	vapor	solid or liquid	vapor
Solid and Vapor	-102	11.36	-89.97	1597	2837	123.5	710.1	1.415	4.841
	-100	13.97	-87.36	1595	2327	125.8	711.3	1.428	4.809
	-98	17.15	-84.18	1593	1916	128.2	712.4	1.442	4.777
	-96	20.95	-80.38	1591	1583	130.5	713.6	1.455	4.746
	-94	25.49	-75.84	1588	1314	132.9	714.8	1.469	4.716
	-92	30.89	-70.44	1585	1095	135.3	715.9	1.482	4.687
	-90	37.27	-64.06	1582	917.3	137.7	717.1	1.495	4.658
	-88	44.76	-56.57	1579	771.9	140.2	718.2	1.508	4.630
	-86	53.53	-47.80	1576	651.3	142.6	719.3	1.521	4.603
	-84	63.77	-37.56	1573	550.7	145.1	720.4	1.534	4.376
	-82	75.72	-25.61	1569	467.1	147.6	721.4	1.548	4.550
	-80	89.62	-11.71	1565	397.7	150.1	722.4	1.561	4.523
	-78.5	101.3	0.0	1562	354.7	152.1	723.1	1.569	4.504
	-78	105.7	4.4	1561	339.8	152.7	723.4	1.574	4.498
	-76	124.2	22.9	1558	291.1	155.3	724.4	1.586	4.473
	-74	145.6	44.3	1554	249.9	157.9	725.4	1.599	4.449
	-72	170.0	68.7	1549	215.1	160.5	726.3	1.612	4.425
	-70	198.1	96.8	1545	185.7	163.1	727.1	1.625	4.402
	-68	230.2	128.9	1541	160.8	165.8	727.7	1.638	4.378
	-66	267.0	165.7	1536	139.5	168.4	728.1	1.651	4.353
	-64	308.9	207.6	1532	121.1	171.1	728.4	1.664	4.328
	-62	356.7	255.4	1527	105.1	173.9	728.6	1.677	4.304
	-60	409.8	308.5	1522	91.23	176.7	728.7	1.690	4.281
	-58	467.1	365.8	1517	81.00	179.5	728.8	1.703	4.262
	-56.6	518.0	416.7	1513	72.22	181.4	729.0	1.722	4.250
Triple point									
Liquid and Vapor	-56.6	518.0	416.7	1178	72.22	380.5	729.0	2.641	4.250
	-56	531.7	430.4	1176	71.10	381.5	729.1	2.643	4.244
	-54	578.9	477.6	1168	64.72	385.2	729.5	2.659	4.229
	-52	629.5	528.2	1161	59.78	388.9	729.8	2.675	4.215
	-50	683.6	582.3	1154	55.41	392.5	730.2	2.691	4.203
	-48	741.0	639.7	1146	51.36	396.2	730.6	2.707	4.192
	-46	801.9	700.6	1139	47.63	399.9	731.1	2.723	4.181
	-44	866.3	865.0	1131	44.20	403.7	731.5	2.739	4.170
	-42	934.3	833.0	1123	41.05	407.5	732.0	2.756	4.160
	-40	1006	904.7	1115	38.16	411.3	732.4	2.772	4.149
	-38	1082	981	1107	35.52	415.1	732.9	2.788	4.139
	-36	1162	1061	1099	33.11	419.0	733.3	2.803	4.129
	-34	1246	1145	1091	30.90	422.9	733.7	2.819	4.119
	-32	1335	1234	1083	28.87	426.8	734.1	2.835	4.109
	-30	1429	1328	1074	27.00	430.8	734.4	2.851	4.100
	-28	1527	1426	1066	25.27	434.8	734.7	2.867	4.091
	-26	1630	1529	1057	23.66	438.8	734.9	2.883	4.081
	-24	1739	1638	1048	22.16	442.8	735.0	2.899	4.072
	-22	1852	1751	1039	20.76	446.9	735.0	2.915	4.062
	-20	1971	1870	1030	19.45	451.0	735.0	2.931	4.053
	-18	2095	1994	1021	18.24	455.1	734.9	2.947	4.044
	-16	2226	2125	1011	17.13	459.3	734.7	2.963	4.034
	-14	2362	2261	1002	16.09	463.6	734.4	2.979	4.024
	-12	2503	2402	991.9	15.11	467.8	734.1	2.994	4.014
	-10	2649	2548	982.0	14.19	472.2	733.6	3.010	4.004

Temp °C		Pressure		Density	Specific volume	Enthalpy ¹⁾		Entropy	
		kPa, abs	kPa	kg/m³	m³/kg x 10 ⁻³	kJ/kg		kJ/(kg)(K)	
				solid or liquid	vapor	solid or liquid	vapor	solid or liquid	vapor
Liquid and Vapor	−8	2804	2703	971.8	13.34	476.6	733.0	3.027	3.993
	−6	2964	2863	961.5	12.54	481.1	732.2	3.043	3.983
	−4	3131	3030	951.5	11.79	485.6	731.4	3.059	3.973
	−2	3305	3204	940.7	11.07	490.3	730.5	3.076	3.962
	0.0	3485	3384	929.4	10.38	495.0	729.4	3.092	3.950
	2.0	3673	3572	917.4	9.703	499.8	727.7	3.109	3.937
	4.0	3869	3768	905.0	9.046	504.7	725.4	3.126	3.923
	6.0	4071	3970	892.1	8.435	509.8	723.1	3.143	3.908
	8.0	4282	4181	878.0	7.878	515.0	720.8	3.161	3.894
	10.0	4501	4400	863.6	7.375	520.4	718.5	3.179	3.879
	12.0	4730	4629	848.2	6.900	525.9	716.1	3.198	3.864
	14.0	4966	4865	831.9	6.446	531.6	713.5	3.217	3.849
	16.0	5210	5109	814.3	6.006	537.6	710.5	3.236	3.833
	18.0	5464	5363	795.5	5.577	543.8	707.2	3.256	3.817
	20.0	5727	5626	775.2	5.157	550.4	703.5	3.278	3.800
	22.0	6001	5900	753.6	4.745	557.8	699.4	3.303	3.783
	24.0	6285	6184	728.9	4.337	566.0	694.6	3.331	3.765
	26.0	6581	6480	696.4	3.914	575.4	688.2	3.364	3.745
	28.0	6890	6789	655.7	3.460	586.3	679.1	3.403	3.710
	30.0	7211	7110	593.1	2.910	602.5	664.4	3.454	3.658
	31.1	7382	7281	467.9	2.137	634.3	634.3	3.552	3.552

¹⁾ Based on 0 for the perfect crystal at zero Kelvin (−273.15 °C).

Table 5: Volume expansion upon warming of liquid carbon dioxide saturated at 200 psi (1380 kPa) for an insulated container with a 350 psi (2410 kPa) MAWP

Pressure		Temperature		<u>Maximum allowable volume occupied by liquid carbon dioxide</u> ¹⁾
psi	kPa	°F	°C	
200	1380	-20	-28.9	92.6
210	1450	-18	-27.8	93.1
220	1520	-15	-26.1	93.5
230	1590	-13	-25.0	94.1
240	1650	-11	-23.9	94.6
250	1720	-8	-22.2	95.1
260	1790	-6	-21.1	95.6
270	1860	-4	-20.0	96.1
280	1930	-2	-18.9	96.6
290	2000	0	-17.8	97.1
300	2070	2	-16.7	97.6
310	2140	4	-15.6	98.1
320	2210	5	-15.0	98.6
330	2280	7	-13.9	99.0
340	2340	9	-12.8	99.5
350	2410	11	-11.7	100.0

¹⁾ The percent liquid full is the percent of total vessel volume and should not be confused with the liquid level gauge reading.

Table 6: NFPA hazard label designations for carbon dioxide

Gas	
Health	3
Flammability	0
Instability	0
Special	SA ¹⁾
Liquid	
Health	3
Flammability	0
Instability	0
Special	SA ¹⁾
Solid	
Health	3
Flammability	0
Instability	0
Special	SA ¹⁾
NOTE—CGA's recommended rating of carbon dioxide using NFPA's rating system.	
¹⁾ CGA recommends SA to designate a simple asphyxiant. The SA symbol shall be used for refrigerated liquid, liquefied compressed gas, and nonliquefied compressed carbon dioxide systems and where large quantities of dry ice are used in confined areas.	

Table 7: Directory of limiting characteristics/QVLs (Units in ppm [v/v] unless otherwise stated)

Limiting characteristics	E	G	H	I	J
Carbon dioxide identification	Pass		Pass		
Carbon dioxide min. % (v/v)	99	99	99.5	99.9	
Acetaldehyde		0.5	0.5	0.2	
Ammonia	25			2.5	
Acidity				To pass JECFA test ¹⁾	
Benzene				0.02	
Carbon monoxide	10 (vapor) ²⁾		10	10	
Carbonyl sulfide			0.5	³⁾	
Hydrogen cyanide				None detected ⁴⁾	
Methanol				10	
Nitric oxide	2.5 (vapor) ²⁾		5 (total of NO + NO ₂)	2.5	
Nitrogen dioxide	2.5			2.5	
Oxygen		50	50	30	
Phosphine ⁵⁾				0.3	
Sulfur dioxide	5		5	1.0 ³⁾	
Total sulfur		0.5	0.5	0.1 ³⁾	
Total hydrocarbon content (as methane)		50	50	50 max including 20 max of nonmethane hydrocarbons	
Hydrogen sulfide	1 (vapor) ²⁾		0.5 (vapor)	³⁾	
Color					White opaque
Nonvolatile residues (wt/wt)		10	10	10	500
Oil/grease (wt/wt)				5	
Odor/taste	Free of foreign odor or				

		taste			
Water		200	32	20	20
Dew point	°F	−33	−61	−68	−68
	°C	−36.1	−51.7	−55.6	−55.6
<p>NOTE—A blank indicates no maximum limiting characteristic.</p> <p>¹⁾ Due to lack of sensitivity, this test is not required if the assay results are acceptable.</p> <p>²⁾ The use of vapor samples is required for USP. Also, the detection of impurities is determined based on the physical characteristics of the individual impurity and need to accurately represent the physical partitioning of impurities.</p> <p>³⁾ If total sulfur value exceeds 0.1 ppm v/v, a sulfur dioxide test should be performed and the sulfur dioxide result subtracted from a total sulfur value. Be advised that many sulfur impurities can potentially be present, therefore simple detector tubetests for hydrogen sulfide and carbonyl sulfide only are not adequate for a proper total sulfur measurement and should not be employed for this purpose. A separate 1.0 ppm v/v limit applies to sulfur dioxide only.</p> <p>⁴⁾ Applies only to carbon dioxide from coal gasification and combustion sources. Current detection level is 0.5 ppm.</p> <p>⁵⁾ Applies only to carbon dioxide from phosphate rock sources.</p>					

Table 8: Carbon Dioxide Typical Uses

QVL	Typical uses ¹⁾
E	Medical/USP
G	General commercial uses, inerting, fumigation, propellant
H	Food processing (Food Chemicals Codex) ²⁾
I	Beverages
J	Dry ice, refrigeration ³⁾
<p>NOTE—Typical uses defined in this table are not all inclusive.</p> <p>¹⁾ End user will specify QVL requirements for their intended use.</p> <p>²⁾ Food Chemicals Codex (FCC) functions include propellant and aerating agent; carbonating agent; direct-contact freezing agent [5].</p> <p>³⁾ The source should be Grade H for food applications.</p>	

Table 9: Possible trace level impurities by source type (excluding air gases and water)

Component	Combustion	Wells/ geothermal	Fermentation	Hydrogen or ammonia	Phosphate rock	Coal gasi- fication	Ethylene oxide	Acid neutrali- zation
Aldehydes	X	X	X	X		X	X	
Amines	X			X				
Benzene	X	X	X	X		X	X	X
Carbon monoxide	X	X	X	X	X	X	X	X
Carbonyl sulfide		X	X	X	X	X		X
Cyclicaliphatic hydrocarbons	X	X		X		X	X	
Dimethyl sulfide		X	X		X	X		X
Ethanol	X	X	X	X		X	X	
Ether		X	X	X		X	X	
Ethyl acetate		X	X			X	X	
Ethyl benzene		X		X		X	X	
Ethylene oxide						X	X	
Halocarbons	X					X	X	
Hydrogen cyanide	X					X		
Hydrogen sulfide	X	X	X	X	X	X	X	X
Ketones	X	X	X	X		X	X	
Mercaptans	X	X	X	X	X	X	X	
Mercury	X					X		
Methanol	X	X	X	X		X	X	
Nitrogen oxides	X		X	X		X	X	X
Phosphine					X			
Radon		X			X			X
Sulfur dioxide	X	X	X	X	X	X		X

Toluene		X	X	X		X	X	
Vinyl chloride	X					X	X	
Volatile hydrocarbons	X	X	X	X		X	X	
Xylene		X	X	X		X	X	

NOTE—The source types are generic sources, and there are variations in individual processes. Therefore, the supplier should assess whether or not all of the components listed are applicable to the actual plant.

Table 10: Moisture conversion data

Dew point °F	Dew point °C	Moisture contentppm (v/v)	Moisture contentmg/L
−130	−90.0	0.1	0.00008
−120	−84.4	0.25	0.00020
−110	−78.9	0.63	0.00051
−105	−76.1	1.00	0.00080
−104	−75.6	1.08	0.00087
−103	−75.0	1.18	0.00095
−102	−74.4	1.29	0.00104
−101	−73.9	1.40	0.00113
−100	−73.3	1.53	0.00123
−99	−72.8	1.66	0.00133
−98	−72.2	1.81	0.00146
−97	−71.7	1.96	0.00158
−96	−71.1	2.15	0.00173
−95	−70.6	2.35	0.00189
−94	−70.0	2.54	0.00204
−93	−69.4	2.76	0.00222
−92	−68.9	3.00	0.00241
−91	−68.3	3.28	0.00264
−90	−67.8	3.53	0.00284
−89	−67.2	3.84	0.00309
−88	−66.7	4.15	0.00334
−87	−66.1	4.50	0.00362
−86	−65.6	4.78	0.00384
−85	−65.0	5.3	0.00426
−84	−64.4	5.7	0.00458
−83	−63.9	6.2	0.00498
−82	−63.3	6.6	0.00531
−81	−62.8	7.2	0.00579
−80	−62.2	7.8	0.00627
−79	−61.7	8.4	0.00675
−78	−61.1	9.1	0.00732
−77	−60.6	9.8	0.00788
−76	−60.0	10.5	0.00844
−75	−59.4	11.4	0.00917
−74	−58.9	12.3	0.00989
−73	−58.3	13.3	0.01069

−72	−57.8	14.3	0.01150
−71	−52.2	15.4	0.01238
−70	−56.7	16.6	0.01335
−69	−56.1	17.9	0.01439
−68	−55.6	19.2	0.01544
−67	−55.0	20.6	0.01656
−66	−54.4	22.1	0.01777
−65	−53.9	23.6	0.01897
−64	−53.3	25.6	0.02058
−63	−52.8	27.5	0.02211
−62	−52.2	29.4	0.02364
−61	−51.7	31.7	0.02549
−60	−51.1	34.0	0.02734
−59	−50.6	36.5	0.02935
−58	−50.0	39.0	0.03136
−57	−49.4	41.8	0.03361
−56	−48.9	44.6	0.03586
−55	−48.3	48.0	0.03859
−54	−47.8	51	0.04100
−53	−47.2	55	0.04220
−52	−46.7	59	0.04744
−51	−46.1	62	0.04985
−50	−45.6	67	0.05387
−49	−45.0	72	0.05789
−48	−44.4	76	0.06110
−47	−43.9	82	0.06593
−46	−43.3	87	0.06994
−45	−42.8	92	0.07397
−44	−42.2	98	0.07879
−43	−41.7	105	0.08442
−42	−41.1	113	0.09085
−41	−40.6	119	0.09568
−40	−40.0	128	0.10291
−39	−39.4	136	0.10934
−38	−38.9	144	0.11578
−37	−38.3	153	0.12301
−36	−37.8	164	0.13186
−35	−37.2	174	0.13990
−34	−36.7	185	0.14874
−33	−36.1	196	0.15758
−32	−35.6	210	0.16884
−31	−35.0	222	0.17849
−30	−34.4	235	0.18894
−29	−33.9	250	0.20100
−28	−33.3	265	0.21306

−27	−32.8	283	0.22753
−26	−32.2	300	0.24120
−25	−31.7	317	0.25487
−24	−31.1	338	0.27175
−23	−30.6	358	0.28783
−22	−30.0	378	0.30391
−21	−29.4	400	0.32160
−20	−28.9	422	0.33929
−19	−28.3	448	0.36019
−18	−27.8	475	0.38190
−17	−27.2	500	0.40200
−16	−26.7	530	0.42612
−15	−26.1	560	0.45024
−14	−25.6	590	0.47436
−13	−25.0	630	0.50652
−12	−24.4	660	0.53064
−11	−23.9	700	0.56280
−10	−23.3	740	0.59496
−9	−22.8	780	0.62712
−8	−22.2	820	0.65928
−7	−21.7	870	0.69948
−6	−21.1	920	0.73968
−5	−20.6	970	0.77988
−4	−20.0	1020	0.82008
0	−17.8	1270	1.02108

Table 11: Maximum allowable filling densities

Packaging marked as shown in this column or of the same type with higherservice pressure must be used	Maximum allowable filling density ¹ (percent)
DOT-3A1800, DOT-3AX1800, DOT-3AA1800, DOT-3AAX1800, DOT-3, DOT-3E1800, DOT-3T1800, DOT-3HT2000, DOT-39, DOT-3AL1800	68%
DOT-3A2000, DOT-3AA2000, DOT-3AX2000, DOT-3AAX2000, DOT-3T2000	70.3%
DOT-3A2265, DOT-3AA2265, DOT-3AX2265, DOT-3AAX2265, DOT-3T2265	73.2%
DOT-3A2400, DOT-3AA2400, DOT-3AX2400, DOT-3AAX2400, DOT-3T2400	74.5%
¹⁾ Filling density means the percent ratio of the weight of gas in a packaging to the weight of water that the container willhold at 16 °C (60 °F). (1 lb of water = 27.737 in ³ at 60 °F). [3]	

Table 12: Typical dimensions and capacities of carbon dioxide cylinders

Nominal carbon dioxide capacity	Internal volume	Water weight capacity	Overall length	Diameter
(lb)	(in ³)	(lb)	(in)	(in)
0.22 (3.5 oz)	9	0.32	5 5/16	2
0.45 (7oz)	18	0.65	9 3/8	2
0.66 (10.5 oz)	27	0.97	13	2
0.75 (12 oz)	31	1.1	9 3/8	2 1/2
1	41	1.5	7 13/16	3 3/16
1.25	51	1.6	9 3/8	3 3/16
1.5	61	2.2	11 1/8	3 3/16
1.75	71	2.6	12 1/2	3 3/16
2	84	3	9 1/4	4 3/8
5	205	7.4	14 3/4	5 1/4
10	408	14.7	16 3/4	6 7/8
15	612	22.1	23 3/8	6 7/8
20	816	29.4	23 5/8	8
35	1429	51.5	38 5/8	8
50	2040	73.5	46 5/8	8 5/8
50	2370	85.2	51	8 1/2
60	2675	96	51	9
75	3055	110.3	56	9 5/16
100	4080	147.3	58	10 5/8
NOTE—Many cylinders have similar dimensions but have different water capacities. Check the marked tareweights and internal volume on any cylinders in question before filling.				

Annex 2: Carbon Dioxide Relevant Figures Information

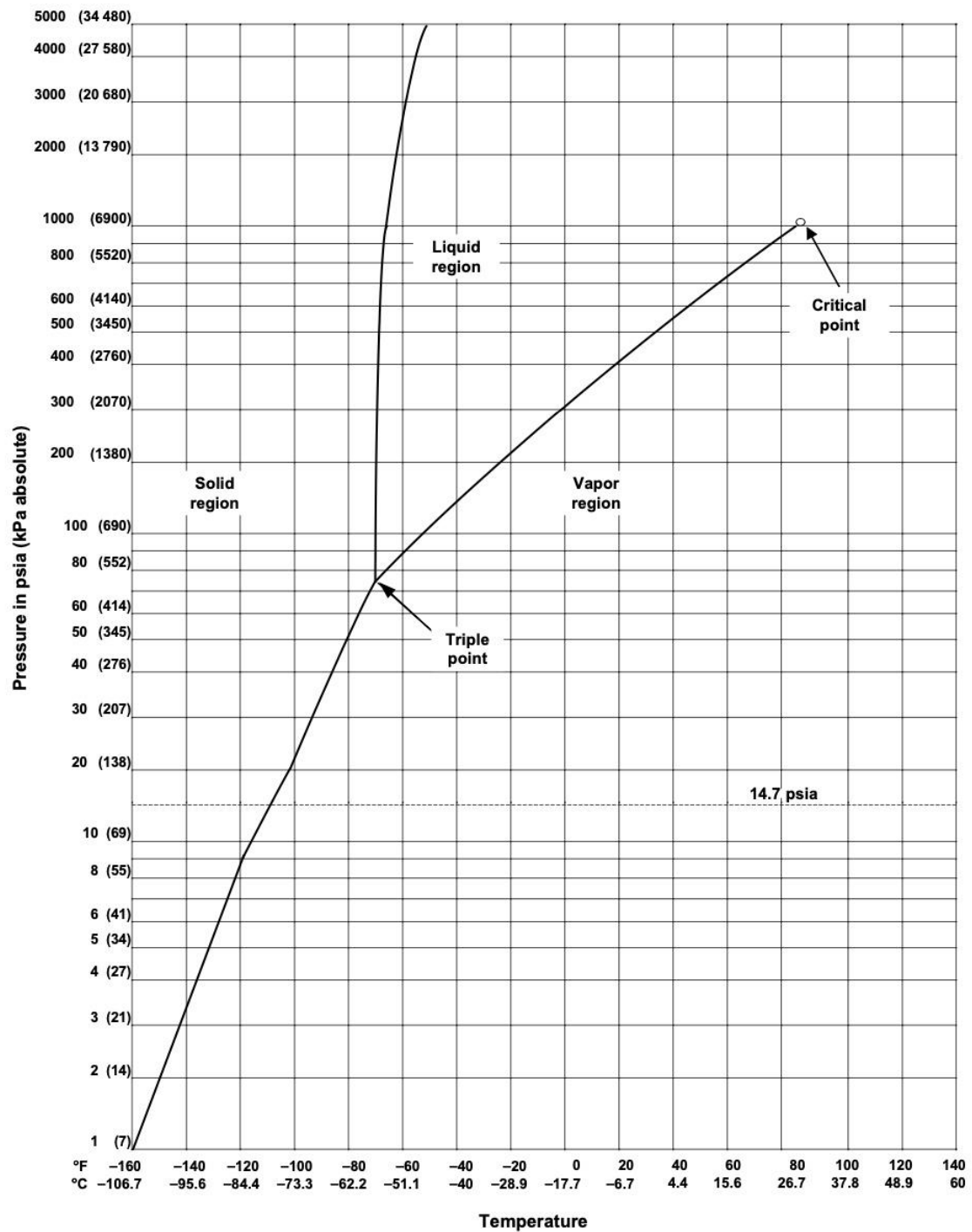


Figure 1: Carbon dioxide phase diagram

Extruded dry ice (1/4 in [0.635 cm])



Extruded dry ice pellets (1/2 in [1.27 cm])



Extruded dry ice pellets (5/8 in [1.588cm])



Cryo/high density/blasting ice (0.14 in [0.289 cm])



Extruded dry ice pellets (3/4 in [1.905 cm])



Whole block dry ice



Slab dry ice

Airline size dry ice

Figure 2: Typical block or formed product offerings

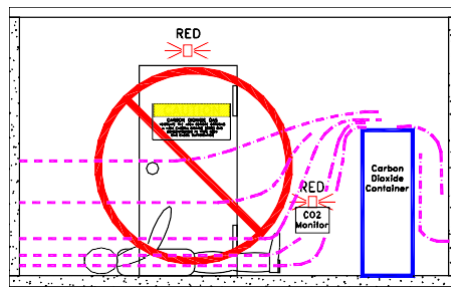


Figure 3: Example of an unsafe, enclosed space

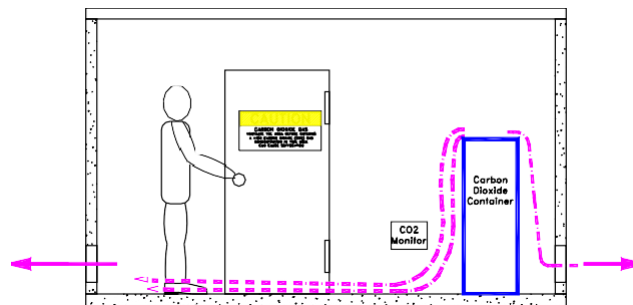


Figure 4: Example of a naturally ventilated and monitored enclosed space

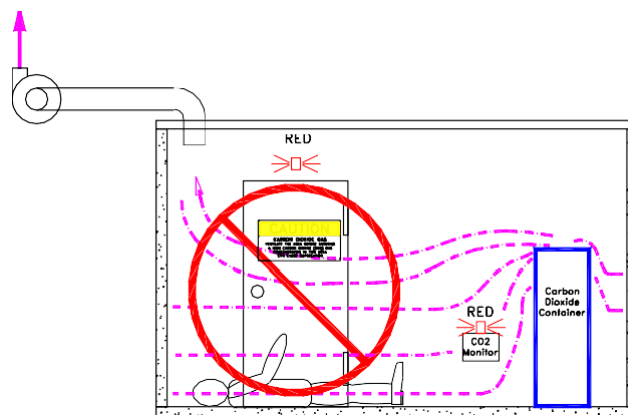


Figure 5: Example of a properly monitored but improperly ventilated enclosed space

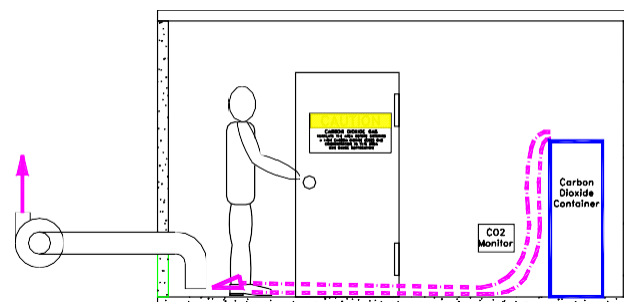


Figure 6: Example of a properly ventilated and monitored enclosed space

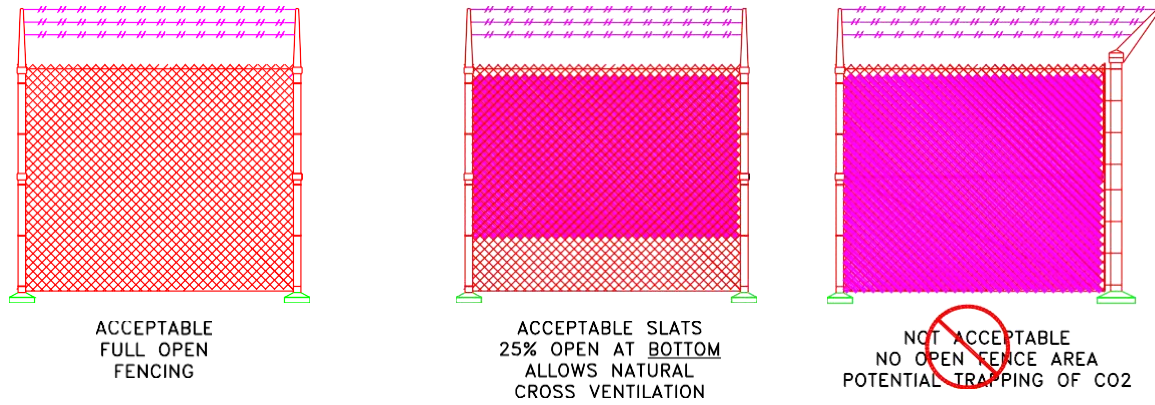


Figure 7: Fenced outdoor enclosures for carbon dioxide installations

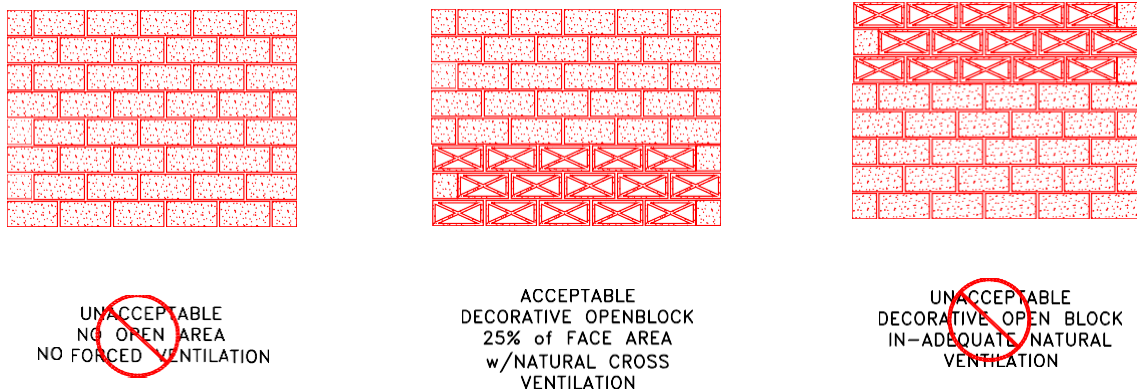


Figure 8: Outdoor walls or courtyards for carbon dioxide installations

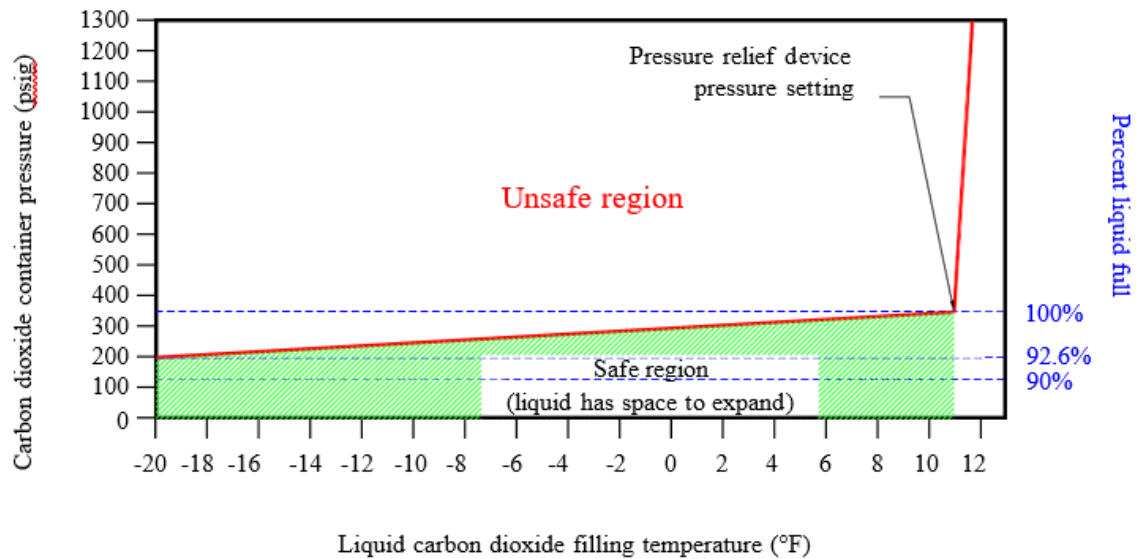


Figure 9: Safe filling volumes for 350 psi carbon dioxide containers

Recommended hazard ratings for carbon dioxide gas, liquid, and solid are shown in Table 6 in accordance with the United States National Fire Protection Association (NFPA) rating system,

For an example of an NFPA hazard label for liquid carbon dioxide, see Figure 10.

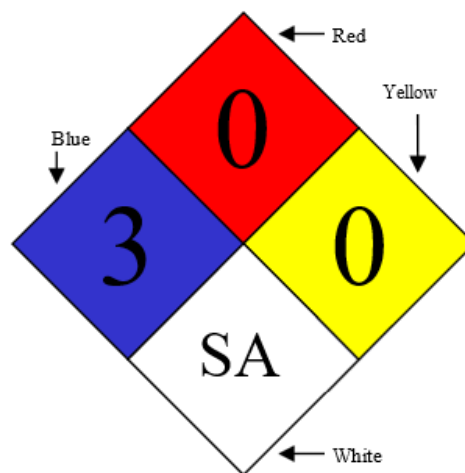


Figure 10: NFPA hazard label for liquid carbon dioxide

WARNING: Cartridge-style respirators shall not be substituted for supplied-air respirators.

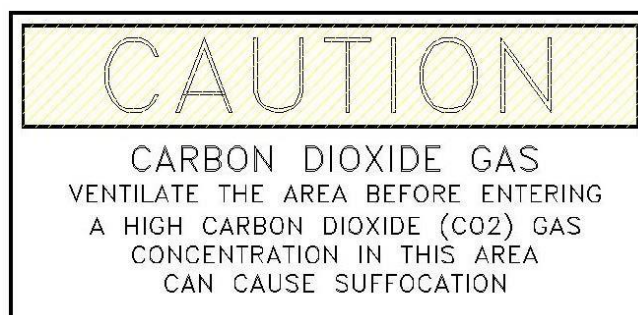
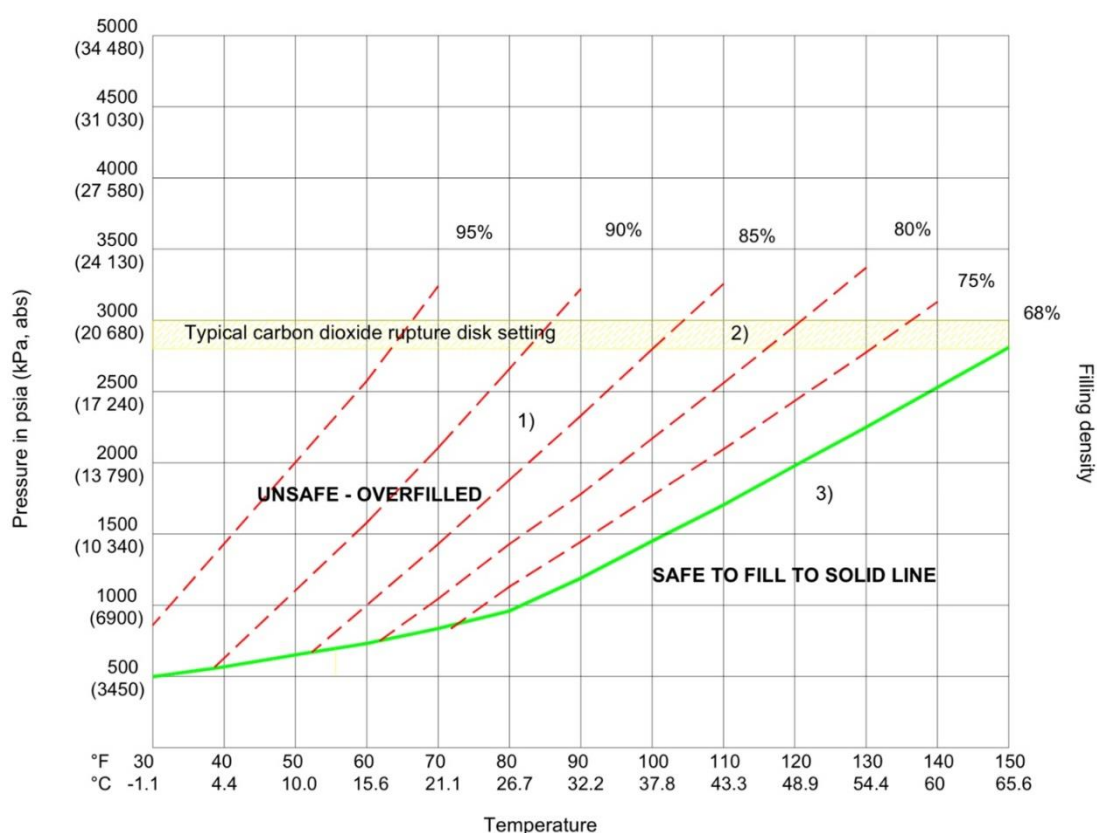


Figure 12: Typical caution sign



- 1) Dashed lines indicate temperature-pressure relationship when the cylinder is overfilled.
- 2) A correctly installed carbon dioxide cylinder rupture disk functions at 2800 psia to 3000 psia (19 310 kPa to 20 680 kPa) depending on design.
- 3) Maximum permitted filling capacity is 68%.

NOTE: This chart is based upon a cylinder filled to its correct maximum liquid carbon dioxide capacity of 68% of the total volume (water weight capacity). An overfilled cylinder obviously experiences enormous internal pressures from expansion of the liquid carbon dioxide as it warms to higher temperatures after filling.

Figure 11: Approximate pressure in uninsulated carbon dioxide cylinders filled to indicated densities at selected temperatures.

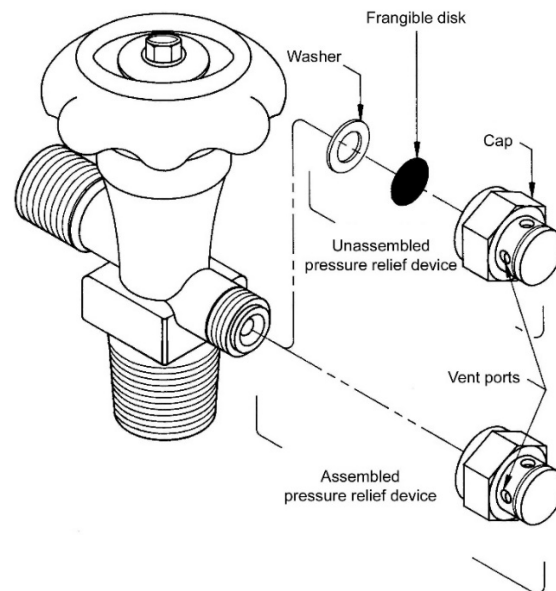


Figure 12: Carbon dioxide cylinder valve and typical pressure relief devices

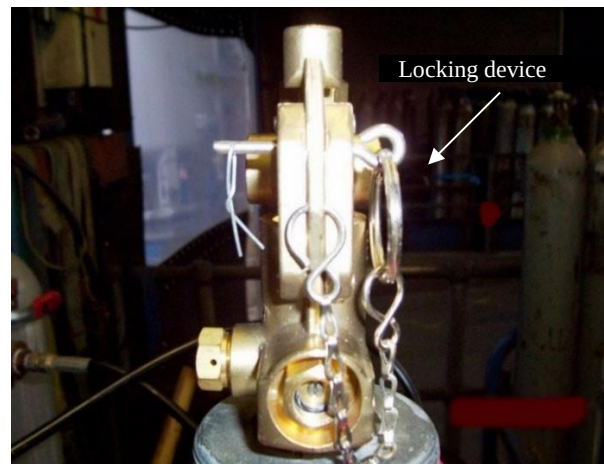


Figure 13: Quick opening cylinder valve for fire suppression system in closed position with locking device engaged



Figure 14: Quick opening cylinder valve for fire suppression system with locking device disengaged and valve open



Figure 15: Corrosion at the bottom of a condemned carbon dioxide cylinder

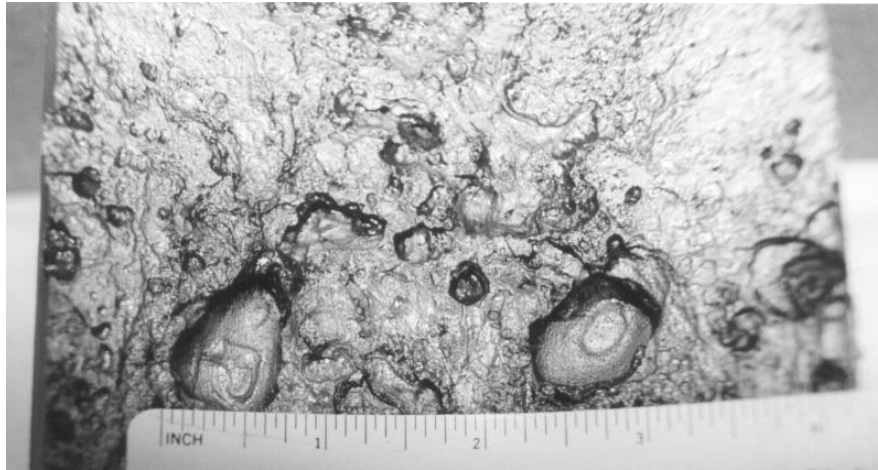


Figure 16: Sidewall corrosion of a condemned carbon dioxide cylinder

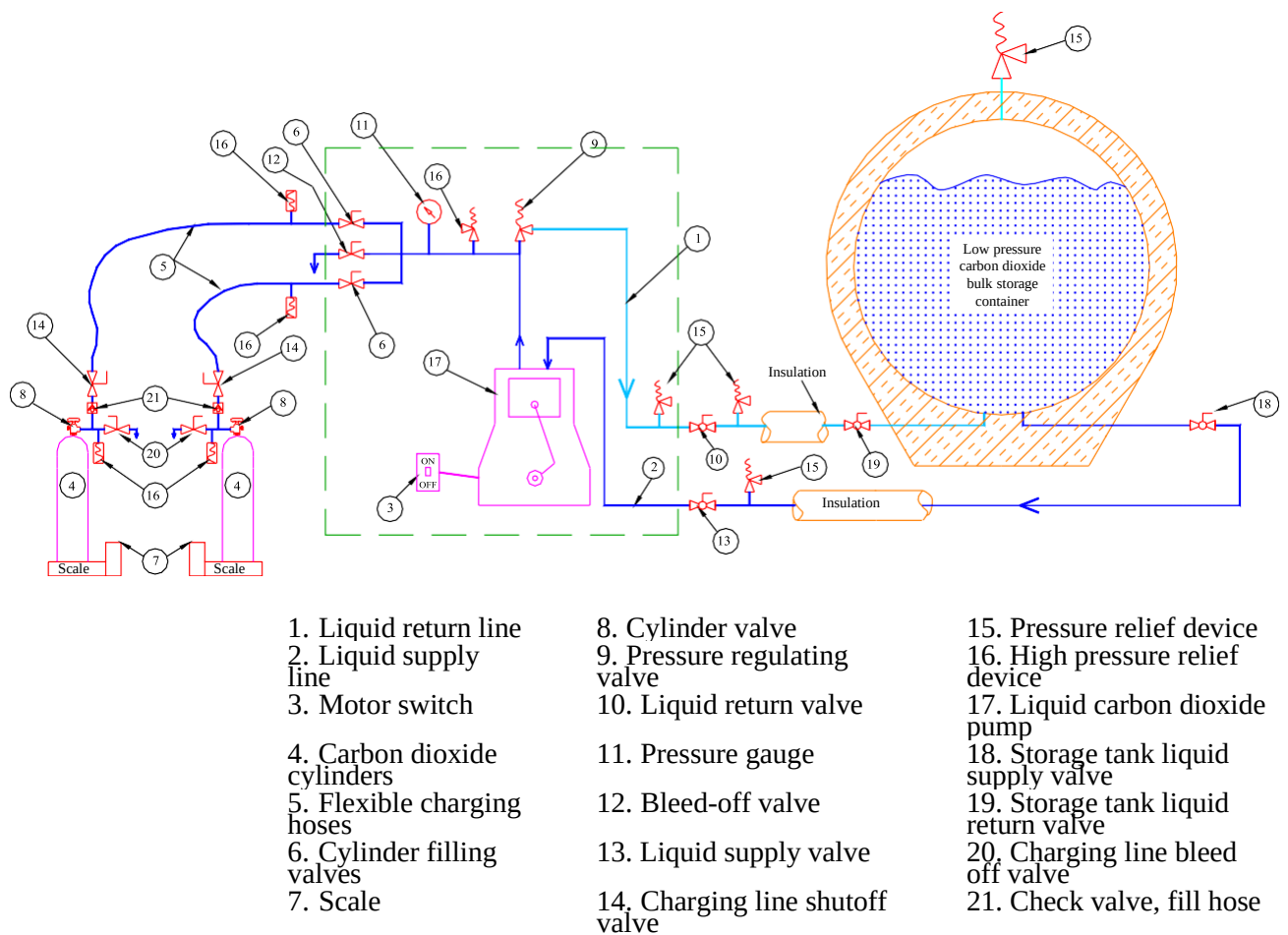
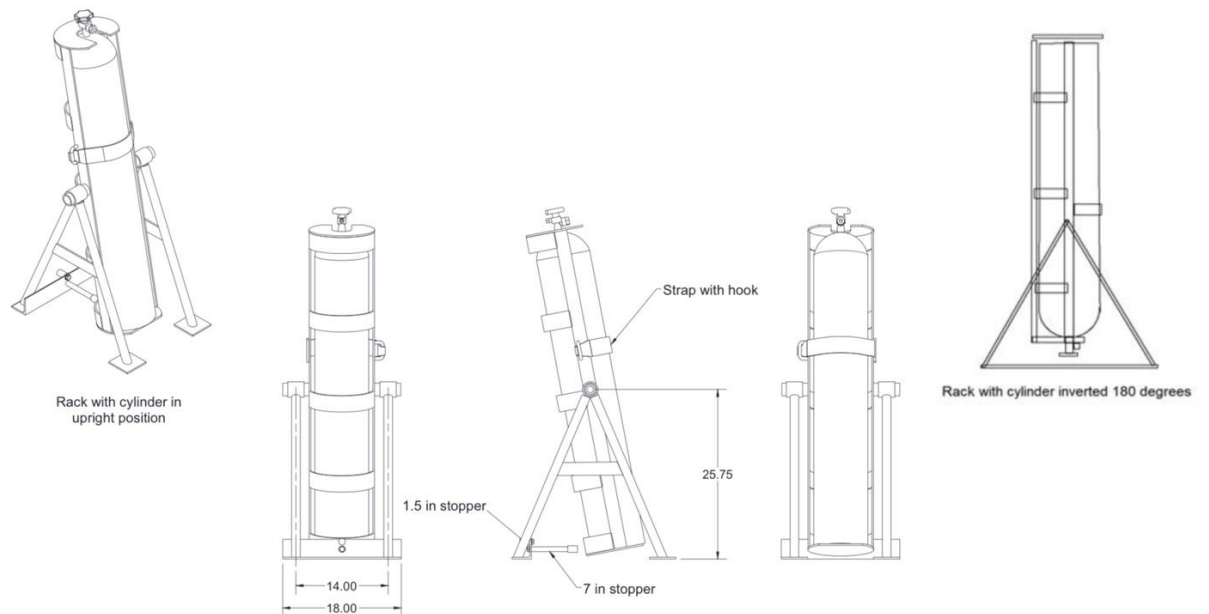


Figure 17: Typical carbon dioxide cylinder filling system schematic



NOTE: Do not use inverting racks with siphon-type cylinders.
Figure 18: Cylinder inverting

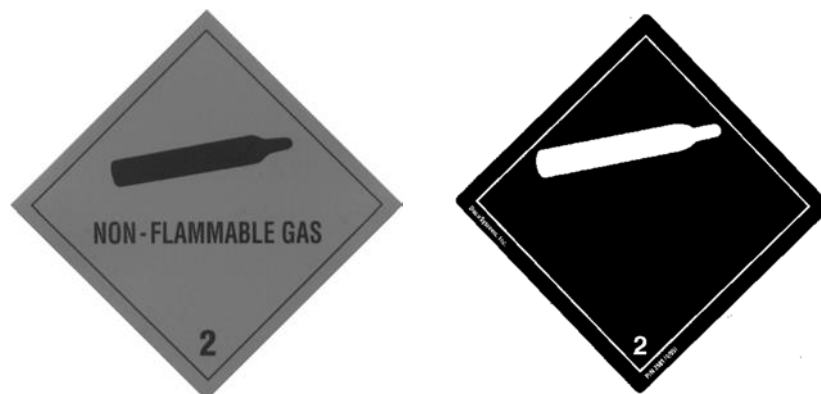


Figure 19: Nonflammable gas placards

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