NFPA 12
Standard on Carbon Dioxide Extinguishing Systems

2000 edition

National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
An International Codes and Standards Organization

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NFPA 12

Standard on

Carbon Dioxide Extinguishing Systems

2000 Edition

This edition of NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems,* was prepared by the Technical Committee on Carbon Dioxide and acted on by the National Fire Protection Association, Inc., at its November Meeting held November 14–17, 1999, in New Orleans, LA. It was issued by the Standards Council on January 14, 2000, with an effective date of February 11, 2000, and supersedes all previous editions.

This edition of NFPA 12 was approved as an American National Standard on February 11, 2000.

Origin and Development of NFPA 12

Work on this standard was initiated in 1928 by the Committee on Manufacturing Risks and Special Hazards. The standard was first adopted in 1929 and was revised in 1933, 1939, 1940, 1941, 1942 (January and May), 1945, 1946, 1948, 1949, 1956, 1957, 1961, 1962, 1963, 1964, 1966, 1968, 1972, 1973, 1977, and 1980. Revisions adopted between 1945 and 1949 were proposed by the Committee on Special Extinguishing Systems, and those in 1956 and subsequent revisions were proposed by the Committee on Carbon Dioxide. The standard was revised in 1985 and 1989.

The standard was completely rewritten for the 1993 revision to more clearly state the requirements and to separate the mandatory requirements from the advisory text in an effort to make the document more usable, enforceable, and adoptable.

The standard was revised for the 1998 edition and again in 2000 in order to add a new chapter for marine systems.

Technical Committee on Carbon Dioxide

Gregory G. Wilks, *Chair*
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S. Douglas Ross, Automated Fire Suppression, NC [IM]
Rep. Nat'l Assn. of Fire Equipment Distributors Inc.
Klaus Wahle, U.S. Coast Guard Headquarters (G-MSE-4), DC [E]
Thomas J. Wysocki, Guardian Services, Inc., IL [SE]

Alternates

Ronald C. Adcock, Marsh Inc., IL [I]
(Alt. to R. K. Andrews)
William M. Carey, Underwriters Laboratories Inc., IL [RT]
(Alt. to K. M. Bell)
Randall S. Chaney, Wausau HPR Engr, CA [I]
(Alt. to R. Bisterfeldt)
David M. Gough, HSB Industrial Risk Insurers, CT [I]
(Alt. to S. A. Chines)
Donald W. Hering, Ansul Preferred CO_2 Systems/Tyco, OH [M]
(Alt. to D. R. Edlbeck)
Robert Kasiski, Factory Mutual Research Corp., MA [I]
(Alt. to R. C. Merritt)
James L. Kidd, Hiller New England Fire Protection, Inc., MA [IM]
(Vot Alt. to FSSA Rep.)
Norbert W. Makowka, Nat'l Assn. of Fire Equipment Distributors (NAFED), IL [IM]
(Alt. to S. D. Ross)
Bernard R. Planer, Fike Protection Systems, MO [M]
(Alt. to E. D. Neargarth)
Bruce G. Scheiman, Chemetron Fire Systems/Williams Holdings, IL [M]
(Alt. to R. Downey)

Nonvoting

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

Committee Scope: This Committee shall have primary responsibility for documents on the installation, maintenance and use of carbon dioxide systems for fire protection.

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

Information on referenced publications can be found in Chapter 7 and Appendix C.

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition.

Chapter 1 General

1-1* Scope. This standard contains minimum requirements for carbon dioxide fire extinguishing systems. It includes only the necessary essentials to make the standard workable in the hands of those skilled in this field.

1-2 Purpose.

1-2.1 This standard is prepared for the use and guidance of those charged with the purchasing, designing, installing, testing, inspecting, approving, listing, operating, or maintaining of carbon dioxide fire extinguishing systems, in order that such equipment will function as intended throughout its life. Nothing in this standard is intended to restrict new technologies or alternate arrangements, provided the level of safety prescribed by the standard is not lowered.

1-2.2 Only those with the proper training and experience shall design, install, inspect, and maintain this equipment.

1-3 Definitions. For purposes of clarification, general terms used with special technical meanings in this standard are defined as follows.

1-3.1 Alarms and Indicators. Any device capable of providing audible, visual, or olfactory indication.

1-3.2* Approved. Acceptable to the authority having jurisdiction.

1-3.3* Authority Having Jurisdiction. The organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.

1-3.4 Inspection. A visual examination of a system or portion thereof to verify that it appears to be in operating condition and is free of physical damage.

1-3.5 Labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

1-3.6* Listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

1-3.7 Lock-Out. A manually operated valve in the discharge pipe between the nozzles and the supply, which can be locked in the closed position to prevent flow of carbon dioxide to the protected area.

1-3.8 Maintenance. A "thorough check" of the system, intended to give maximum assurance that the system will operate effectively and safely. It includes a thorough examination and any necessary repair or replacement of components. *(See Section 1-11.)*

1-3.9 Pressure, High. Indicates that the carbon dioxide is stored in pressure containers at ambient temperatures. At 70°F (21°C), the pressure in this type of storage is 850 psi (5860 kPa).

1-3.10 Pressure, Low. Indicates that the carbon dioxide is stored in pressure containers at a controlled low temperature of 0°F (–18°C). At this temperature the pressure in this type of storage is 300 psi (2068 kPa).

1-3.11 Shall. Indicates a mandatory requirement.

1-3.12 Should. Indicates a recommendation or that which is advised but not required.

1-3.13 Standpipe System and Mobile Supply. A system consisting of a mobile supply of carbon dioxide, designed to be quickly moved into position and connected to a system of fixed piping, supplying fixed nozzles or hose lines or both that are designed for either total flooding or local application.

1-3.14 System, Hand Hose Line. A hose and nozzle assembly connected by fixed piping or connected directly to a supply of extinguishing agent.

1-3.15 System, Local Application. A system consisting of a supply of extinguishing agent arranged to discharge directly on the burning material.

1-3.16* System, Pre-Engineered. A system that has predetermined flow rates, nozzle placement, and quantities of carbon dioxide and that incorporates specific nozzles and methods of application that can differ from those detailed elsewhere in this standard and those that are listed by a testing laboratory. The hazards protected by these systems are specifically limited as to type and size. Limitations on hazards that can be protected by these systems are contained in the manufacturer's installation manual, which is referenced as part of the listing.

1-3.17 System, Total Flooding. A system consisting of a supply of carbon dioxide arranged to discharge into, and fill to the proper concentration, an enclosed space or enclosure around the hazard.

1-4 Units. Metric units of measurement in this standard are in accordance with the modernized metric system known as the International System of Units (SI). *(See Table 1-4.)*

1-4.1 If a value for measurement as given in this standard is followed by an equivalent value in other units, the first value stated is to be regarded as the requirement. A given equivalent value can be approximate.

Table 1-4 Units

Name of Unit	Unit Symbol	Conversion Factor
pascal	Pa	1 psi = 6894.757 Pa
kilogram	kg	1 lb = 2.205 kg
meter	m	1 ft = 0.3048 m
millimeter	mm	1 in. = 25.4 mm

Note: For additional conversions and information, see ASTM SI 10, *Standard for Use of the International System of Units (SI): The Modern Metric System.*

1-4.2 The conversion procedure for the SI units has been to multiply the quantity by the conversion factor and then round the result to the appropriate number of significant digits.

1-5 General Information.

1-5.1* Carbon Dioxide. Carbon dioxide is a colorless, odorless, electrically nonconductive inert gas that is a suitable medium for extinguishing fires. Liquid carbon dioxide forms solid dry ice ("snow") when released directly into the atmosphere. Carbon dioxide gas is 1.5 times heavier than air. Carbon dioxide extinguishes fire by reducing the concentrations of oxygen, the vapor phase of the fuel, or both in the air to the point where combustion stops. *(See Section 1-6, Personnel Safety.)*

1-5.2 Use and Limitations. Carbon dioxide fire-extinguishing systems are useful within the limits of this standard in extinguishing fires involving specific hazards or equipment in the following occupancies:

(1) Where an inert electrically nonconductive medium is essential or desirable
(2) Where cleanup of other media presents a problem
(3) Where they are more economical to install than systems using other media

1-5.2.1 Some of the types of hazards and equipment that carbon dioxide systems can satisfactorily protect include the following:

(1) Flammable liquid materials *(see 1-8.3.8)*
(2) Electrical hazards such as transformers, switches, circuit breakers, rotating equipment, and electronic equipment
(3) Engines utilizing gasoline and other flammable liquid fuels
(4) Ordinary combustibles such as paper, wood, and textiles
(5) Hazardous solids

1-5.2.2* Carbon dioxide fire-extinguishing systems protecting areas where explosive atmospheres could exist shall utilize metal nozzles, and the entire system shall be properly grounded. In addition, objects exposed to discharge from carbon dioxide nozzles shall be grounded to dissipate possible electrostatic charges.

1-5.2.3* Carbon dioxide will not extinguish fires where the following materials are actively involved in the combustion process:

(1) Chemicals containing their own oxygen supply, such as cellulose nitrate
(2) Reactive metals such as sodium, potassium, magnesium, titanium, and zirconium
(3) Metal hydrides

1-6* Personnel Safety.

1-6.1 Hazards to Personnel. The discharge of carbon dioxide in fire-extinguishing concentration creates serious hazards to personnel, such as suffocation and reduced visibility during and after the discharge period. Consideration shall be given to the possibility of carbon dioxide drifting and settling into adjacent places outside of the protected space *(see 1-6.1.1)*. Consideration shall also be given to where the carbon dioxide can migrate or collect in the event of a discharge from a safety relief device of a storage container.

1-6.1.1* In any use of carbon dioxide, consideration shall be given to the possibility that personnel could be trapped in or enter into an atmosphere made hazardous by a carbon dioxide discharge. Suitable safeguards shall be provided to ensure prompt evacuation, to prevent entry into such atmospheres, and to provide means for prompt rescue of any trapped personnel. Personnel training shall be provided. Predischarge alarms shall be provided except as noted in 1-8.1(c) and 1-8.3.5.

1-6.1.2 The following represent typical signs.

1-6.1.2.1 Appropriate warning signs shall be affixed in a conspicuous location.

(1) Typical sign in every protected space

WARNING

CARBON DIOXIDE GAS

WHEN ALARM OPERATES VACATE IMMEDIATELY

(2) Typical sign at every entrance to protected space

WARNING

CARBON DIOXIDE GAS

WHEN ALARM OPERATES DO NOT ENTER UNTIL VENTILATED

(3) Typical sign in every nearby space where carbon dioxide can accumulate to hazardous levels

CAUTION
CARBON DIOXIDE DISCHARGE INTO A NEARBY SPACE CAN COLLECT HERE. WHEN ALARM OPERATES VACATE IMMEDIATELY

(4) Typical sign outside each entrance to carbon dioxide storage rooms

CAUTION
CARBON DIOXIDE GAS

VENTILATE THE AREA BEFORE ENTERING. A HIGH CARBON DIOXIDE GAS CONCENTRATION CAN OCCUR IN THIS AREA AND CAN CAUSE SUFFOCATION

1-6.1.2.2 Appropriate warning signs shall be placed at every location where manual operation of the system can occur. A typical sign at each manual actuation station is as follows:

WARNING

ACTUATION OF THIS DEVICE WILL CAUSE CARBON DIOXIDE TO DISCHARGE. BEFORE

ACTUATING, BE SURE PERSONNEL ARE CLEAR OF THE AREA

1-6.1.3 All persons that can at any time enter a space protected by carbon dioxide shall be warned of the hazards involved, given an alarm signal, and provided with safe evacuation procedures. *(See 1-8.5.)*

1-6.1.4 The predischarge warning signal shall provide a time delay of sufficient duration to allow for evacuation under worst-case conditions, except as noted in 1-8.1(c) and 1-8.3.5. Dry runs shall be made to determine the minimum time needed for persons to evacuate the hazard area, allowing time to identify the warning signal.

1-6.1.5 Audible and visual predischarge signals shall be provided, except as noted in 1-8.1(c) and 1-8.3.5.

1-6.1.6 All personnel shall be informed that discharge of carbon dioxide gas from either high- or low-pressure systems directly at a person will endanger the person's safety by causing eye injury, ear injury, or even falls due to loss of balance upon the impingement of the high velocity discharging gas. Contact with carbon dioxide in the form of dry ice can cause frostbite.

1-6.1.7* To prevent accidental or deliberate discharge, a "lock-out" shall be provided when persons not familiar with the systems and their operation are present in a protected space. Local application systems shall be locked out when persons are present in locations where discharge of the system will endanger them, and they will be unable to proceed to a safe location within the time-delay period for the system. When protection is to be maintained during the lock-out period, a person(s) shall be assigned as a "fire watch" with suitable portable or semiportable fire-fighting equipment or means to restore protection. The fire watch shall have a communication link to a constantly monitored location. Authorities responsible for continuity of fire protection shall be notified of lock-out and subsequent restoration of the system.

1-6.1.8* Safe handling procedures shall be followed when transporting system cylinders.

1-6.2 Electrical Clearances. All system components shall be located so as to maintain minimum clearances from live parts as shown in Table 1-6.2 and Figure 1-6.2.

As used in this standard, clearance is the air distance between equipment, including piping and nozzles, and unenclosed or uninsulated live electrical components at other than ground potential. The minimum clearances listed in Table 1-6.2 are for the purpose of electrical clearance under normal conditions; they are not intended for use as "safe" distances during fixed system operation.

The clearances given in Table 1-6.2 and Figure 1-6.2 are for altitudes of 3300 ft (1000 m) or less. At altitudes in excess of 3300 ft (1000 m) the clearance shall be increased at the rate of 1 percent for each 330-ft (100-m) increase in altitude above 3300 ft (1000 m).

The clearances are based on minimum general practices related to design basic insulation level (BIL) values. To coordinate the required clearance with the electrical design, the design BIL of the equipment being protected shall be used as a basis, although this is not material at nominal line voltages of 161 kV or less.

Up to electrical system voltages of 161 kV, the design BIL kilovolts and corresponding minimum clearances, phase to ground, have been established through long usage.

At voltages higher than 161 kV, uniformity in the relationship between design BIL kilovolts and the various electrical system voltages has not been established in practice. For these higher system voltages it has become common practice to use BIL levels dependent on the degree of protection that is to be obtained. For example, in 230-kV systems, BILs of 1050, 900, 825, 750, and 650 kV have been utilized.

Required clearance to ground can also be affected by switching surge duty, a power system design factor that along with BIL must correlate with selected minimum clearances. Electrical design engineers can furnish clearances dictated by switching surge duty. Table 1-6.2 and Figure 1-6.2 deal only with clearances required by design BIL. The selected clearance to ground shall satisfy the greater of switching surge or BIL duty, rather than be based on nominal voltage.

Possible design variations in the clearance required at higher voltages are evident in Table 1-6.2, where a range of BIL values is indicated opposite the various voltages in the high-voltage portion of the table. However, the clearance between uninsulated energized parts of the electrical system equipment and any portion of the carbon dioxide system shall be not less than the minimum clearance provided elsewhere for electrical system insulations on any individual component.

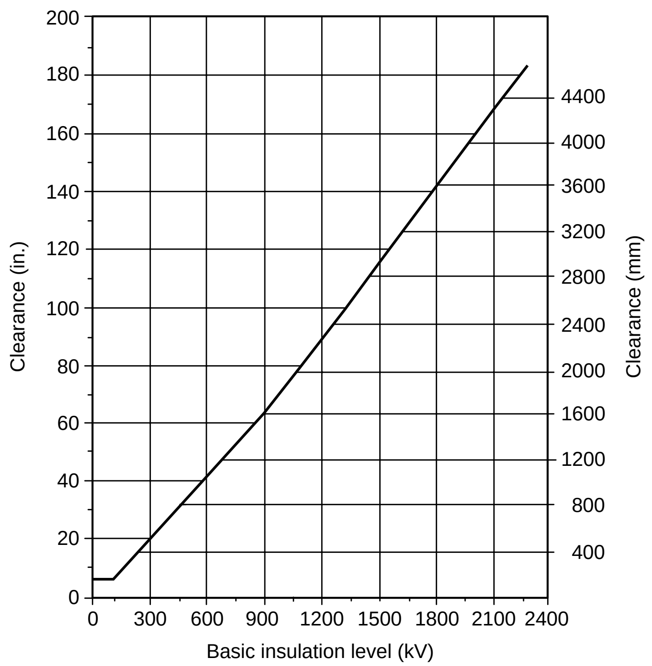
Table 1-6.2 Clearance from Carbon Dioxide Equipment to Live Uninsulated Electrical Components

Nominal System Voltage (kV)	Maximum System Voltage (kV)	Design BIL (kV)	Minimum* Clearance in.	Minimum* Clearance mm
To ≤13.8	14.5	110	7	178
≤23.0	24.3	150	10	254
≤34.5	36.5	200	13	330
≤46.0	48.3	250	17	432
≤69.0	72.5	350	25	635
≤115.0	121.0	550	42	1067
≤138.0	145.0	650	50	1270
≤161.0	169.0	750	58	1473
≤230.0	242.0	900	76	1930
		1050	84	2134
≤345.0	362.0	1050	84	2134
		1300	104	2642
≤500.0	550.0	1500	124	3150
		1800	144	3658
≤765.0	800.0	2050	167	4242

Note: BIL values are expressed as kilovolts (kV), the number being the crest value of the full wave impulse test that the electrical equipment is designed to withstand. For BIL values that are not listed in the table, clearances can be found by interpolation.

*For voltages up to 161 kV, the clearances are taken from NFPA 70, *National Electrical Code*®. For voltages 230 kV and above, the clearances are taken from Table 124 of ANSI/IEEE C 2, *National Electrical Safety Code*. In Canada, refer to CSA C22.1, *Canadian Electrical Code*, Part I.

FIGURE 1-6.2 Clearance from carbon dioxide equipment to live uninsulated electrical components.



1-6.2.1 When the design BIL is not available, and when nominal voltage is used for the design criteria, the highest minimum clearance listed for this group shall be used.

1-7 Specifications, Plans, and Approvals.

1-7.1 Specifications. Specifications for carbon dioxide fire-extinguishing systems shall be prepared under the supervision of a person fully experienced and qualified in the design of carbon dioxide extinguishing systems and with the advice of the authority having jurisdiction. The specifications shall include all pertinent items necessary for the proper design of the system such as the designation of the authority having jurisdiction, variances from the standard to be permitted by the authority having jurisdiction, and the type and extent of the approval testing to be performed after installation of the system.

1-7.2 Plans. Plans and calculations shall be submitted for approval to the authority having jurisdiction before the installation begins. Plans and calculations shall be prepared by persons fully qualified in the design of carbon dioxide fire-extinguishing systems.

1-7.2.1 These plans shall be drawn to an indicated scale or be suitably dimensioned. The plans shall be made so that they can be easily reproduced.

1-7.2.2 These plans shall contain sufficient detail to enable the authority having jurisdiction to evaluate the hazard or hazards and to evaluate the effectiveness of the system. The details shall include the following:

(1) Materials involved in the protected hazards
(2) Location of the hazards
(3) Enclosure or limits and isolation of the hazards
(4) Surrounding area that could affect the protected hazards

1-7.2.3 The detail on the system shall include the following:

(1) Information and calculations on the amount of carbon dioxide
(2) Location and flow rate of each nozzle including equivalent orifice area
(3) Location, size, and equivalent lengths of pipe, fittings, and hose
(4) Location and size of the carbon dioxide storage facility

Details of pipe size reduction method (reducing couplings or bushings) and orientation of tees shall be clearly indicated. Information shall be submitted pertaining to the location and function of the detection devices, operating devices, auxiliary equipment, and electrical circuitry, if used. Sufficient information shall be indicated to identify properly the apparatus and devices used. Any special features shall be adequately explained.

1-7.2.4 When field conditions necessitate any substantial change from approved plans, the change shall be submitted to the authority having jurisdiction for approval.

1-7.2.5 When such changes from approved plans are made, corrected "as-installed" plans shall be supplied to the owner and the authority having jurisdiction.

1-7.2.6 The system owner shall maintain an instruction and maintenance manual that includes a full sequence of operation, and a full set of system drawings and calculations shall be maintained in a protective enclosure.

1-7.3* Approval of Installations. The completed system shall be inspected and tested by qualified personnel to meet the approval of the authority having jurisdiction. Only listed or approved equipment and devices shall be used in the system. To determine that the system has been properly installed and will function as specified, the following shall be performed.

(a) A thorough visual inspection of the installed system and hazard area. The piping, operational equipment, and discharge nozzles shall be inspected for proper size and location. The locations of alarms and manual emergency releases shall be confirmed. The configuration of the hazard shall be compared to the original hazard specification. The hazard shall be inspected closely for unclosable openings and sources of agent loss that could have been overlooked in the original specification.

(b) A check of labeling of devices for proper designations and instructions. Nameplate data on the storage containers shall be compared to specifications.

(c) Nondestructive operational tests on all devices necessary for proper functioning of the system, including detection and actuation devices.

(d) A full discharge test shall be performed on all systems. Where multiple hazards are protected from a common supply, then a full discharge test shall be performed for each hazard.

Prior to testing, proper safety procedures shall be reviewed. *(See Section 1-6.)*

1-7.4 Testing of Systems. Systems shall be tested as follows.

(a) *Local Application.* Full discharge of design quantity carbon dioxide through system piping to ensure carbon dioxide effectively covers the hazard for the full period of time required by the design specifications, and all pressure-operated devices function as intended.

(b) *Total Flooding.* Full discharge of entire design quantity of carbon dioxide through system piping to ensure that carbon dioxide is discharged into the hazard and the concentration is achieved and maintained in the period of time required by the design specifications, and all pressure-operated devices function as intended.

(c) *Hand-Held Hose Lines.* Full discharge test of hand-held hose line systems. Requires evidence of liquid flow from each nozzle with an adequate pattern of coverage.

1-8 Detection, Actuation, and Control.

1-8.1 Systems shall be classified as automatic or manual in accordance with the following methods of actuation.

(a) *Automatic Operation.* Operation that does not require any human action.

(b) *Normal Manual Operation.* Operation of the system requiring human action where the location of the device used to cause operation makes it easily accessible at all times to the hazard *(see 1-8.3.4).* Operation of one control shall be all that is required to bring about the full operation of the system.

(c) **Emergency Manual Operation.* Operation of the system by human means where the device used to cause operation is fully mechanical in nature and is located at or near the device being controlled. A fully mechanical device can incorporate the use of system pressure to complete operation of the device. *(See 1-8.3.5.)*

1-8.1.1 Automatic detection and automatic actuation shall be used.

Exception No. 1: Manual-only actuation can be used if acceptable to the authority having jurisdiction where automatic release could result in an increased risk.

Exception No. 2: This does not apply to hand hose line and standpipe systems.

Exception No. 3: This does not apply to marine systems (see Chapter 6).

1-8.2* Automatic Detection. Automatic detection shall be by any listed or approved method or device that is capable of detecting and indicating heat, flame, smoke, combustible vapors, or an abnormal condition in the hazard such as process trouble that is likely to produce fire.

1-8.3 Operating Devices. Operating devices shall include carbon dioxide releasing devices or valves, discharge controls, and equipment shutdown devices, all of which are necessary for successful performance of the system.

1-8.3.1 Operation shall be by listed or approved mechanical, electrical, or pneumatic means. The control equipment shall be specifically listed or approved for the number and type of actuating devices utilized, and their compatibility shall have been listed or approved.

1-8.3.2 All devices shall be designed for the service they will encounter and shall not be readily rendered inoperative or susceptible to accidental operation. Devices shall be normally designed to function properly from –20°F to 150°F (–29°C to 66°C) or marked to indicate temperature limitations.

1-8.3.3 All devices shall be located, installed, or suitably protected so that they are not subject to mechanical, chemical, or other damage that would render them inoperative.

1-8.3.4* The normal manual controls for actuation shall be located for easy accessibility at all times including the time of fire. The manual control(s) shall be of distinct appearance and clearly recognizable for the purpose intended. This control shall cause the complete system to operate in its normal fashion. Operation of this device shall not cause the time delay to recycle. *(See 1-6.1.4.)*

1-8.3.5* All valves controlling the release and distribution of carbon dioxide shall be provided with an emergency manual control. This shall not apply to slave high-pressure cylinders.

The emergency means shall be easily accessible and located close to the valves controlled.

Determination shall be made as to whether a time delay and predischarge alarm for emergency manual control are required based on the nature of the hazard and safety requirements. Where there is no time delay or predischarge alarm with emergency manual method of actuation, it shall be ascertained that the hazard area and adjoining areas where carbon dioxide can accumulate are clear of all personnel prior to operation of this device. These devices shall be clearly marked to indicate this concept with a warning placard.

1-8.3.6* Where gas pressure from pilot cylinders fed through the system discharge manifold (i.e., using back pressure rather than a separate pilot line) is used to release remaining slave cylinders and the supply consists of less than three cylinders, one cylinder shall be used for such operation. Where the supply consists of three cylinders or more, there shall be one pilot cylinder more than the minimum required to actuate the system. During the full discharge acceptance test, the extra pilot cylinder shall be arranged to operate as a slave cylinder.

1-8.3.7 Manual controls shall not require a pull of more than 40 lb (force) (178 N) nor a movement of more than 14 in. (356 mm) to secure operation. At least one manual control for activation shall be positioned not more than 4 ft (1.2 m) above the floor.

1-8.3.8 Where the continuing operation of equipment associated with a hazard being protected could contribute to sustaining the fire in that hazard, the source of power or fuel shall be automatically shut off. All shutdown devices shall be considered integral parts of the system and shall function with the system operation.

Exception: This requirement shall not apply to lubricating oil systems associated with large rotating equipment, where an extended discharge system is provided that is designed to operate for the deceleration/cool down period.

1-8.3.9 All manual operating devices shall be identified as to the hazard they protect, the function they perform, and their method of operation.

1-8.3.10 Abort switches shall not be used on carbon dioxide systems.

1-8.4 Supervision and Lock-Out Valves. Supervision of automatic systems and manual lock-out valves shall be provided unless specifically waived by the authority having jurisdiction. Supervision of automatic systems shall be provided and the lock-out required by 1-6.1.7 shall be supervised for both automatic and manual systems unless specifically waived by the authority having jurisdiction. Interconnections between the components that are necessary for the control of the system and life safety (e.g., detection, actuation, alarms, power sources, main tank shutoff valve, pilot vapor supply valve, lock-out devices, etc.) shall be supervised. An open circuit, ground-fault condition, or loss of integrity in the pneumatic control lines that would impair full system operation shall result in a trouble signal. The alarm and trouble signals shall be transmitted by one of the methods described in NFPA 72, *National Fire Alarm Code®*.

Exception: High-pressure pneumatic-operated slave cylinder connections immediately adjacent to pilot cylinders need not be supervised.

1-8.5* Predischarge Alarms. Predischarge alarms shall be provided to give positive warning of a discharge where hazard to personnel could exist, except as noted in 1-8.1(c) and 1-8.3.5. Such alarms shall function to warn personnel against entry into hazardous areas as long as such hazards exist or until such hazards are properly recognized. *(See Section 1-6.)*

Audible predischarge alarms shall be at least 15 dB above ambient noise level or 5 dB above the maximum sound level, whichever is greater, measured 5 ft (1.5 m) above the floor of the occupiable area. Audible signal appliances shall have a sound level not more than 120 dB at the minimum hearing distance from the audible appliance. The predischarge alarm shall have a minimum decibel rating of 90 dBa at 10 ft (3 m).

1-8.5.1 An alarm or indicator shall be provided to show that the system has operated and needs recharging.

1-8.5.2* An alarm shall be provided to indicate the operation of automatic systems and that immediate personnel response is desired.

1-8.5.3 Alarms indicating failure of supervised devices or equipment shall give prompt and positive indication of any failure and shall be distinctive from alarms indicating operation or hazardous conditions.

1-8.6 Power Sources. The primary source of energy for the operation and control of the system shall have the capacity for intended service and shall be reliable. Where failure of the primary source of energy will jeopardize protection provided for the hazard, the life safety, or both, an independent secondary (standby) power supply shall supply energy to the system in the event of total failure or low voltage (less than 85 percent of the nameplate voltages) of the primary (main) power supply. The secondary (standby) supply shall be capable of operating the system under maximum normal load for 24 hours and then be capable of operating the system continuously for the full design discharge period. The secondary (standby) power supply shall automatically transfer to operate the system within 30 seconds of the loss of the primary (main) power supply.

1-8.6.1 All electrical devices shall be operable between 85 percent and 105 percent of rated voltage.

1-9 Carbon Dioxide Supply.

1-9.1* Quantities. The amount of the main supply of carbon dioxide in the system shall be at least sufficient for the largest single hazard protected or group of hazards that are to be protected simultaneously.

1-9.1.1 Where hand hose lines are provided for use on a hazard protected by a fixed system, separate supplies shall be provided unless sufficient carbon dioxide is provided to ensure that the fixed protection for the largest single hazard upon which the hose lines can be used will not be jeopardized. *(See Section 4-4 and A-4-1.1.)*

1-9.1.2 Where the authority having jurisdiction determines that continuous protection is required, the quantity of reserve supply shall be as many multiples of the quantities required in 1-9.1 and 1-9.1.1 as the authority having jurisdiction considers necessary.

1-9.1.3 Both main and reserve supplies for fixed storage systems shall be permanently connected to the piping and arranged for easy changeover, except where the authority having jurisdiction permits an unconnected reserve.

1-9.2 Replenishment. The time needed to obtain carbon dioxide for replenishment to restore systems to operating condition shall be considered as a major factor in determining the reserve supply needed.

1-9.3* Quality. Carbon dioxide shall have the following minimum properties:

(1) The vapor phase shall be not less than 99.5 percent carbon dioxide with no detectable off-taste or odor.
(2) The water content of the liquid phase shall comply with CGA G6.2, *Commodity Specification for Carbon Dioxide.*
(3) Oil content shall be not more than 10 ppm by weight.

1-9.4 Storage Containers. Storage containers and accessories shall be so located and arranged to facilitate inspection, maintenance, and recharging. Interruption to protection shall be held to a minimum.

1-9.4.1 Storage containers shall be located as near as possible to the hazard or hazards they protect, but they shall not be located where they will be exposed to a fire or explosion in these hazards.

1-9.4.2 Storage containers shall not be located where they will be subject to severe weather conditions or to mechanical, chemical, or other damage.

1-9.4.3 Where excessive climatic or mechanical exposures are expected, suitable guards or enclosures shall be provided.

1-9.5* High-Pressure Cylinders. The carbon dioxide supply shall be stored in rechargeable cylinders designed to hold carbon dioxide in liquid form at ambient temperatures. *(See 1-3.1.)*

1-9.5.1* High-pressure cylinders used in fire-extinguishing systems shall not be recharged without a hydrostatic test (and remarking) if more than 5 years have elapsed from the date of the last test. Cylinders continuously in service without discharging shall be permitted to be retained in service for a maximum of 12 years from the date of the last hydrostatic test. At the end of 12 years, they shall be discharged and retested before being returned to service.

1-9.5.2 Each cylinder shall be provided with a pressure relief device of the rupture disc type. The pressure relief device shall be sized and fitted in accordance with the requirements specified in Department of Transportation (DOT) 49 *CFR* 173.34(d).

1-9.5.3 When manifolded, cylinders shall be adequately mounted and suitably supported in a rack provided for the purpose, including facilities for convenient individual servicing and content weighing. Automatic means shall be provided to prevent the loss of carbon dioxide from the manifold if the system is operated when any cylinder is removed for maintenance.

1-9.5.4 Individual cylinders shall be used having a standard weight capacity of 5, 10, 15, 20, 25, 35, 50, 75, 100, or 120 lb (2.3, 4.5, 6.8, 9.1, 11.4, 15.9, 22.7, 34.1, 45.4, or 54.4 kg) of carbon dioxide contents except for special temperature charges *(see 1-9.5.5)*. In a multiple cylinder system, all cylinders supplying the same manifold outlet for distribution of agent shall be interchangeable and of one select size.

1-9.5.5 The ambient storage temperatures for local application systems shall not exceed 120°F (49°C) nor be less than 32°F (0°C). For total flooding systems, they shall not exceed 130°F (54°C) nor be less than 0°F (–18°C) unless the system is designed for proper operation with storage temperatures outside of this range. External heating or cooling shall be permitted to be used to keep the temperature within this range. Where special cylinder charges are used to compensate for storage temperatures outside of the ranges stated in this paragraph, the cylinders shall be appropriately marked in a permanent manner.

1-9.6* Low-Pressure Storage Containers. Low-pressure storage containers shall be designed to maintain the carbon dioxide supply at a nominal pressure of 300 psi (2068 kPa) corresponding to a temperature of approximately 0°F (–18°C).

1-9.6.1 The pressure container shall be made, tested, approved, equipped, and marked in accordance with the current specifications of the American Society of Mechanical Engineers (ASME) *Code for Unfired Pressure Vessels for Petroleum Liquids and Gases* or, in the case of mobile supply containers, if applicable, the requirements of DOT 49 *CFR* 171–190, or both. The design pressure shall be at least 325 psi (2241 kPa).

1-9.6.2* In addition to the ASME and DOT code requirements, each pressure container shall be equipped with a liquid level gauge, a pressure gauge, and a high-low pressure supervisory alarm set to alarm at no more than 90 percent of the pressure vessel's design maximum allowable working pressure (MAWP) and no less than 250 psi (1724 kPa).

1-9.6.3 The pressure container shall be insulated and equipped with automatically controlled refrigeration or heating, or both if necessary.

1-9.6.4 The refrigeration system shall be capable of maintaining 300 psi (2068 kPa) in the pressure container under the highest expected ambient temperature.

1-9.6.5 The heating system, where required, shall be capable of maintaining 0°F (–18°C) in the pressure container under the lowest expected ambient temperature. Heating need not be provided unless known meteorological data indicate the likely occurrence of ambient temperatures that will cool the contents of the tank sufficiently to reduce the pressure below 250 psi (1724 kPa) [approximately –10°F (–23°C)].

1-10 Distribution Systems.

1-10.1* Piping shall be of metallic noncombustible material having physical and chemical characteristics such that its deterioration under stress can be predicted with reliability. Where piping is installed in severely corrosive atmospheres, special corrosion-resistant materials or coatings shall be used. The following are examples of materials for piping and the standards covering these materials.

Black or galvanized steel pipe shall be either ASTM A 53 seamless or electric welded, Grade A or B; or ASTM A 106, Grade A, B, or C. ASTM A 120 and ordinary cast-iron pipe shall not be used. Stainless steel shall be TP304 or TP316 for threaded connections or TP304, TP316, TP304L, or TP316L for welded connections.

In systems using high-pressure supply, $^3/_4$-in. and smaller pipe shall be permitted to be Schedule 40. Pipe that is 1 in. through 4 in. shall be a minimum of Schedule 80. Furnace butt weld ASTM 53 pipe shall not be used.

In systems using low-pressure supply, pipe shall be a minimum of Schedule 40. Furnace butt weld ASTM 53 pipe shall be permitted to be used. A dirt trap consisting of a tee with a capped nipple, at least 2 in. (51 mm) long, shall be installed at the end of each pipe run.

Exception: Piping sections not normally opened to atmosphere need not have corrosion-resistant finish on the inside.

1-10.1.1* Flexible piping system components not specifically covered in this standard shall have a minimum burst pressure of 5000 psi (34,474 kPa) for high-pressure systems or 1800 psi (12,411 kPa) for low-pressure systems.

1-10.1.2 Class 150 and cast-iron fittings shall not be used. The following provides criteria for fittings for high- and low-pressure systems.

(a) *High-Pressure Systems.* Class 300 malleable or ductile iron fittings shall be used through 2-in. internal pipe size (IPS) and forged steel fittings in all larger sizes. Flanged joints upstream of any stop valves shall be Class 600. Flanged joints downstream of stop valves or in systems with no stop valves shall be permitted to be Class 300. Stainless steel fittings shall be type 304 or 316, wrought/forged (per ASTM A 182, *Standard Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service)*, Class 3000, threaded or socket weld, for all sizes, $^1/_8$ in. through 4 in.

(b) *Low-Pressure Systems.* Class 300 malleable or ductile iron fittings shall be used through 3-in. IPS and 1000-lb ductile iron or forged steel fittings in all larger sizes. Flanged joints shall be Class 300. Stainless steel fittings shall be type 304 or 316 for threaded connections or type 304, 316, 304L, or 316L for welded connections, wrought/forged (per ASTM A 182, *Standard Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service*), Class 2000, threaded or socket weld, for all sizes, $^1/_8$ in. through 4 in.

1-10.1.3 Welded joints and screwed or flanged fittings (malleable iron or ductile iron) shall be permitted to be used. Mechanical grooved couplings and fittings shall be permitted to be used if they are specifically listed for carbon dioxide service. Flush bushings shall not be used. Where hex bushings are used for one pipe size reduction, a 3000-lb steel bushing shall be provided to maintain adequate strength. Where hex bushings are used for more than one pipe size reduction, see 1-10.1.2. Suitable flared, compression-type, or brazed fittings shall be used with compatible tubing. Where brazed joints are used, the brazing alloy shall have a melting point of 1000°F (538°C) or higher.

1-10.1.4 In systems using high-pressure supply with pipe other than that specified in 1-10.1, the thickness of the pipe shall be calculated in accordance with ANSI B31.1, *Power Piping Code*. The internal pressure for this calculation shall be 2800 psi (19,306 kPa).

1-10.1.5 In systems using low-pressure supply with pipe other than that specified in 1-10.1, the thickness of the pipe shall be calculated in accordance with ANSI B31.1, *Power Piping Code*. The internal pressure for this calculation shall be 450 psi (3103 kPa).

1-10.2* The piping system shall be securely supported with due allowance for agent thrust forces and thermal expansion and contraction, and shall not be subject to mechanical, chemical, or other damage. Where explosions are possible, the piping system shall be hung from supports that are least likely to be displaced.

1-10.2.1 Pipe shall be reamed and cleaned before assembly, and after assembly the entire piping system shall be blown out before nozzles or discharge devices are installed.

1-10.2.2 In systems where valve arrangement introduces sections of closed piping, such sections shall be equipped with pressure relief devices or the valves shall be designed to prevent entrapment of liquid carbon dioxide. The pressure relief devices shall operate at between 2400 psi and 3000 psi (16,547 kPa and 20,684 kPa) on systems supplied with high-pressure storage and at 450 psi (3103 kPa) on systems supplied by low-pressure storage. Where pressure-operated cylinder valves are used, a means shall be provided to vent any cylinder gas leakage from the manifold, but the means shall also prevent loss of gas when the system operates.

1-10.2.3 All pressure relief devices shall be of such design and so located that the discharge of carbon dioxide therefrom will not injure personnel.

1-10.3 Valves. All valves shall be suitable for the intended use, particularly regarding flow capacity and operation. They shall be used only under temperatures and other conditions for which they are listed or approved.

1-10.3.1 Valves used in systems with high-pressure storage and constantly under pressure shall have a minimum bursting pressure of 6000 psi (41,369 kPa) whereas those not under constant pressure shall have a minimum bursting pressure of at least 5000 psi (34,474 kPa).

1-10.3.2 Valves used in systems using low-pressure storage shall withstand a hydrostatic test to 1800 psi (12,411 kPa) without permanent distortion.

1-10.3.3 Valves shall be located, installed, or suitably protected so that they are not subject to mechanical, chemical, or other damage that would render them inoperative.

1-10.3.4 Valves shall be rated for equivalent length in terms of the pipe or tubing sizes with which they will be used. The equivalent length of cylinder valves shall include siphon tube, valve, discharge head, and flexible connector.

1-10.4 Discharge Nozzles. Discharge nozzles shall be suitable for the use intended and shall be listed or approved for discharge characteristics. The discharge nozzle consists of the orifice and any associated horn, shield, or baffle.

1-10.4.1 Discharge nozzles shall be of adequate strength for use with the expected working pressures, shall be able to resist nominal mechanical abuse, and shall be constructed to withstand expected temperatures without deformation.

1-10.4.2 Discharge orifices shall be of corrosion-resistant metal.

1-10.4.3 Discharge nozzles used in local application systems shall be connected and supported so that they cannot readily be put out of adjustment.

1-10.4.4* Discharge nozzles shall be permanently marked to identify the nozzle and to show the equivalent single-orifice diameter regardless of shape and number of orifices. This equivalent diameter shall refer to the orifice diameter of the "standard" single-orifice-type nozzle having the same flow rate as the nozzle in question. The marking shall be readily discernible after installation. The standard orifice is an orifice having a rounded entry with a coefficient of discharge not less than 0.98 and flow characteristics as given in Tables 1-10.5.2 and 1-10.5.3.

For examples of equivalent orifice diameters see Table 1-10.4.4. The orifice code numbers indicate the equivalent single-orifice diameter in $^1/_{32}$-in. (0.8-mm) increments. Orifice sizes other than those shown in Table 1-10.4.4 shall be permitted to be used and can be marked as decimal orifice equipment.

1-10.4.5 Discharge nozzles shall be provided with frangible discs or blow-out caps where clogging by foreign materials is likely. These devices shall provide an unobstructed opening upon system operation.

Table 1-10.4.4 Equipment Orifice Sizes

Orifice Code No.	Equivalent Single-Orifice Diameter		Equivalent Single-Orifice Area	
	in.	mm	in.^{2}	mm^2
1	$^1/_{32}$	0.79	0.0008	0.49
1.5	$^3/_{64}$	1.19	0.0017	1.11
2	$^1/_{16}$	1.59	0.0031	1.98
2.5	$^5/_{64}$	1.98	0.0047	3.09
3	$^3/_{32}$	2.38	0.0069	4.45
3.5	$^7/_{64}$	2.78	0.0094	6.06
4	$^1/_8$	3.18	0.0123	7.94
4.5	$^9/_{64}$	3.57	0.0155	10.00
5	$^5/_{32}$	3.97	0.0192	12.39
5.5	$^{11}/_{64}$	4.37	0.0232	14.97
6	$^3/_{16}$	4.76	0.0276	17.81
6.5	$^{13}/_{64}$	5.16	0.0324	20.90
7	$^7/_{32}$	5.56	0.0376	24.26
7.5	$^{15}/_{64}$	5.95	0.0431	27.81
8	$^1/_4$	6.35	0.0491	31.68
8.5	$^{17}/_{64}$	6.75	0.0554	35.74
9	$^9/_{32}$	7.14	0.0621	40.06
9.5	$^{19}/_{64}$	7.54	0.0692	44.65
10	$^5/_{16}$	7.94	0.0767	49.48
11	$^{11}/_{32}$	8.73	0.0928	59.87
12	$^3/_8$	9.53	0.1105	71.29
13	$^{13}/_{32}$	10.32	0.1296	83.61
14	$^7/_{16}$	11.11	0.1503	96.97
15	$^{15}/_{32}$	11.91	0.1725	111.29
16	$^1/_2$	12.70	0.1964	126.71
18	$^9/_{16}$	14.29	0.2485	160.32
20	$^5/_8$	15.88	0.3068	197.94
22	$^{11}/_{16}$	17.46	0.3712	239.48
24	$^3/_4$	19.05	0.4418	285.03
32	1	25.40	0.785	506.45
48	$1^1/_2$	38.40	1.765	1138.71
64	2	50.80	3.14	2025.80

1-10.5* Pipe and Orifice Size Determination. Pipe sizes and orifice areas shall be selected on the basis of calculations to deliver the required rate of flow at each nozzle.

1-10.5.1* The following equation or curves developed therefrom shall be used to determine the pressure drop in the pipeline:

$$Q^2 = \frac{(3647)(D^{5.25}Y)}{L + 8.08(D^{1.25}Z)}$$

where:

Q = flow rate (lb/min)
D = actual inside pipe diameter (in.)
L = equivalent length of pipeline (ft)
Y and Z = factors depending on storage and line pressure

1-10.5.2 For systems with low-pressure storage, flow shall be calculated on the basis of an average storage pressure of 300 psia (2068 kPa) during discharge. The discharge rate for equivalent orifices shall be based on the values given in Table 1-10.5.2. Design nozzle pressures shall not be less than 150 psia (1034 kPa).

Table 1-10.5.2 Discharge Rate per Square Inch of Equivalent Orifice Area for Low-Pressure Storage [300 psia (2068 kPa)]

Orifice Pressure		Discharge Rate	
psia	**kPa**	**lb/min·in.²**	**kg/min·mm²**
300	2068	4220	2.970
290	1999	2900	2.041
280	1931	2375	1.671
270	1862	2050	1.443
260	1793	1825	1.284
250	1724	1655	1.165
240	1655	1525	1.073
230	1586	1410	0.992
220	1517	1305	0.918
210	1448	1210	0.851
200	1379	1125	0.792
190	1310	1048	0.737
180	1241	977	0.688
170	1172	912	0.642
160	1103	852	0.600
150	1034	795	0.559

1-10.5.3 For systems with high-pressure storage, flow shall be calculated on the basis of an average storage pressure of 750 psia (5171 kPa) during discharge for normal 70°F (21°C) storage. The discharge rate through equivalent orifices shall be based on the values given in Table 1-10.5.3. Design nozzle pressure at 70°F (21°C) storage shall be greater than or equal to 300 psia (2068 kPa).

1-11 Inspection, Maintenance, and Instruction.

1-11.1* Inspection. At least every 30 days, an inspection shall be conducted to assess the system's operational condition.

1-11.2 Hose Testing. All system hose, including those used as flexible connectors, shall be tested at 2500 psi (17,239 kPa) for high-pressure systems, and at 900 psi (6205 kPa) for low-pressure systems. Hose shall be tested as follows:

(1) The hose shall be removed from any attachment.
(2) Hose for hand lines shall be checked for electrical continuity between couplings.
(3) The hose assembly shall then be placed in a protective enclosure designed to permit visual observation of the test.
(4) The hose shall be completely filled with water before testing.
(5) Pressure shall then be applied at a rate-of-pressure rise to reach the test pressure within 1 minute. The test pressure shall be maintained for 1 full minute. Observations shall then be made to note any distortion or leakage.
(6) If the test pressure has not dropped and if the couplings have not moved, the pressure shall be released. The hose assembly shall then be considered to have passed the hydrostatic test if no permanent distortion has taken place.
(7) Hose assembly passing the test shall be completely dried internally. If heat is used for drying, the temperature shall not exceed 150°F (66°C).
(8) Hose assemblies failing this test shall be marked and destroyed. They shall be replaced with new assemblies.
(9) Hose assemblies passing this test shall be suitably marked with the date of the test on the hose.

Table 1-10.5.3 Discharge Rate per Square Inch of Equivalent Orifice Area for High-Pressure Storage [750 psia (5171 kPa)]

Orifice Pressure		Discharge Rate	
psia	**kPa**	**lb/min·in.²**	**kg/min·mm²**
750	5171	4630	3.258
725	4999	3845	2.706
700	4826	3415	2.403
675	4654	3090	2.174
650	4481	2835	1.995
625	4309	2615	1.840
600	4137	2425	1.706
575	3964	2260	1.590
550	3792	2115	1.488
525	3620	1985	1.397
500	3447	1860	1.309
475	3275	1740	1.224
450	3103	1620	1.140
425	2930	1510	1.063
400	2758	1400	0.985
375	2586	1290	0.908
350	2413	1180	0.830
325	2241	1080	0.760
300	2068	980	0.690

1-11.2.1 All system hose including those used as flexible connectors shall be tested every 5 years in accordance with 1-11.2.

1-11.3* Maintenance.

1-11.3.1 A manufacturer's test and maintenance procedure shall be provided to the owner for testing and maintenance of the system. This procedure shall provide for the initial testing of the equipment as well as for periodic test inspection and maintenance of the system.

1-11.3.2 The following shall be verified by competent personnel at least annually using available documentation required in 1-7.2.6.

(1) Check and test the carbon dioxide system for proper operation
(2) Check that there have been no changes to the size, type, and configuration of the hazard and system

1-11.3.2.1 The goal of this maintenance and testing shall be not only to ensure that the system is in full operating condition, but shall indicate the probable continuance of that condition until the next inspection.

1-11.3.2.2 Suitable discharge tests shall be made when any maintenance indicates their advisability.

Prior to testing, proper safety procedures shall be reviewed. *(See Section 1-6 and A-1-6.)*

1-11.3.3 A maintenance report with recommendations shall be filed with the owner.

1-11.3.4 Between the regular service contract maintenance or tests, the system shall be inspected visually or otherwise by approved or competent personnel who follow an approved schedule.

1-11.3.5 At least semiannually, all high-pressure cylinders shall be weighed and the date of the last hydrostatic test noted *(see 1-9.5.1)*. If, at any time, a container shows a loss in net content of more than 10 percent, it shall be refilled or replaced.

1-11.3.6 At least weekly, the liquid level gauges of low-pressure containers shall be observed. If at any time a container shows a loss of more than 10 percent, it shall be refilled, unless the minimum gas requirements are still provided.

1-11.3.7* Testing of heat, smoke, and flame detectors shall be in accordance with Chapter 7 of NFPA 72, *National Fire Alarm Code*.

1-11.3.8 These systems shall be kept in full operating condition at all times. Use, impairment, and restoration of this protection shall be reported promptly to the authority having jurisdiction. Any troubles or impairments shall be corrected at once by competent personnel.

1-11.4 Instruction. Persons who inspect, test, maintain, or operate carbon dioxide fire-extinguishing systems shall be thoroughly trained in the functions they perform.

Chapter 2 Total Flooding Systems

2-1* General Information.

2-1.1 Description. A total flooding system consists of a fixed supply of carbon dioxide permanently connected to fixed piping, with fixed nozzles arranged to discharge carbon dioxide into an enclosed space or enclosure about the hazard.

2-1.2 Uses. This type of system shall be used where there is a permanent enclosure around the hazard that adequately enables the required concentration of carbon dioxide to be built up and to be maintained for the required period of time. This ensures the complete and permanent extinguishment of the fire in the specific combustible material or materials involved.

2-1.3 General Requirements. Total flooding systems shall be designed, installed, tested, and maintained in accordance with the applicable requirements in the previous chapter and with the additional requirements set forth in this chapter.

2-1.4 Safety Requirements. See Section 1-6 and 1-8.5.

2-2 Hazard Specifications.

2-2.1 Enclosure. Under this class of protection, a reasonably well-enclosed space is assumed in order to minimize the loss of the extinguishing medium. The area of allowable unclosable openings depends upon the type of combustibles involved.

2-2.1.1* For flash- or surface-type fires, such as will be present with flammable liquids, any unclosable openings shall be compensated for by additional carbon dioxide as specified in 2-3.5.1. If the quantity of carbon dioxide required for compensation exceeds the basic quantities required for flooding without leakage, the system shall be permitted to be designed for local application in accordance with Chapter 3.

2-2.1.2* For deep-seated fires, such as will be involved with solids, unclosable openings shall be restricted to those bordering or actually in the ceiling, if the size of the openings exceeds the pressure relief venting requirements set forth in 2-6.2.1.

2-2.1.3 To prevent fire from spreading through openings to adjacent hazards or work areas that can be possible reignition sources, such openings shall be provided with automatic closures or local application nozzles. The gas required for such protection shall be in addition to the normal requirement for total flooding *(see 3-4.3.6)*. Where neither method is practical, protection shall be extended to include these adjacent hazards or work areas.

2-2.1.4 In the case of process and storage tanks where safe venting of flammable vapors and gases cannot be realized, the use of external local application systems outlined in 3-4.3.6 is required.

2-2.2 Leakage and Ventilation. Since the efficiency of carbon dioxide systems depends on the maintenance of an extinguishing concentration of carbon dioxide, leakage of gas from the space shall be kept to a minimum and compensated for by applying extra gas.

2-2.2.1 Where possible, openings such as doorways, windows, and so forth, shall be arranged to close automatically before or simultaneously with the start of the carbon dioxide discharge, or 2-3.5.1 and 2-4.4.1 shall be followed. *(For personnel safety, see Section 1-6.)*

2-2.2.2 Where forced-air ventilating systems are involved, they preferably shall be shut down or closed, or both, before or simultaneously with the start of the carbon dioxide discharge, or additional compensating gas shall be provided. *(See 2-3.5.2.)*

2-2.3* Types of Fires. Fires that can be extinguished by total flooding methods are divided into the following two categories:

(1) Surface fires involving flammable liquids, gases, and solids
(2) Deep-seated fires involving solids subject to smoldering

2-2.3.1 Surface fires are the most common hazard particularly adaptable to extinguishment by total flooding systems. They are subject to prompt extinguishment when carbon dioxide is quickly introduced into the enclosure in sufficient quantity to overcome leakage and provide an extinguishing concentration for the particular materials involved.

2-2.3.2 For deep-seated fires, the required extinguishing concentration shall be maintained for a sufficient period of time to allow the smoldering to be extinguished and the material to cool to a point at which reignition will not occur when the inert atmosphere is dissipated. In any event, it is necessary to inspect the hazard immediately thereafter to make certain that extinguishment is complete and to remove any material involved in the fire.

2-3* Carbon Dioxide Requirements for Surface Fires.

2-3.1 General. The quantity of carbon dioxide for surface-type fires shall be based on average conditions assuming fairly prompt extinguishment. Although a reasonable allowance for normal leakage is included in the basic volume factors, corrections shall be made for the type of material involved and any other special conditions.

2-3.2 Flammable Materials. Proper consideration shall be given to the determination of the design concentration of carbon dioxide required for the type of flammable material involved in the hazard. The design concentration shall be determined by adding a suitable factor (20 percent) to the minimum effective concentration. In no case shall a concentration less than 34 percent be used.

2-3.2.1 Table 2-3.2.1 shall be used to determine the minimum carbon dioxide concentrations for the following liquids and gases. The theoretical minimum carbon dioxide concentration and the minimum design carbon dioxide concentration to prevent ignition of some common liquids and gases are given in Table 2-3.2.1.

2-3.2.2 For materials not given in Table 2-3.2.1, the minimum theoretical carbon dioxide concentration shall be obtained from some recognized source or determined by test. If maximum residual oxygen values are available, the theoretical carbon dioxide concentration shall be calculated by using the following formula:

$$\% \, CO_2 = \left(\frac{21 - O_2}{21}\right)(100)$$

2-3.3 Volume Factor. The volume factor used to determine the basic quantity of carbon dioxide to protect an enclosure containing a material requiring a design concentration of 34 percent shall be in accordance with Tables 2-3.3(a) and 2-3.3(b).

2-3.3.1 In figuring the net cubic capacity to be protected, due allowance shall be permitted to be made for permanent nonremovable impermeable structures materially reducing the volume.

2-3.3.2 As the average small space has proportionately more boundary area per enclosed volume than a larger space, greater proportionate leakages are anticipated and accounted for by the graded volume factors in Tables 2-3.3(a) and 2-3.3(b).

2-3.3.3 The least gas quantities for the smallest volumes are tabulated in order to clarify the intent of Column B and thus avoid possible overlapping at borderline volumes.

2-3.3.4 In two or more interconnected volumes where "free flow" of carbon dioxide can take place, the carbon dioxide quantity shall be the sum of the quantities calculated for each volume, using its respective volume factor from Tables 2-3.3(a) or 2-3.3(b) (SI units). If one volume requires greater than normal concentration *(see 2-3.4)*, the higher concentration shall be used in all interconnected volumes.

Table 2-3.2.1 Minimum Carbon Dioxide Concentrations for Extinguishment

Material	Theoretical Minimum CO_2 Concentration (%)	Minimum Design CO_2 Concentration (%)
Acetylene	55	66
Acetone	27*	34
Aviation Gas Grades 115/145	30	36
Benzol, Benzene	31	37
Butadiene	34	41
Butane	28	34
Butane-I	31	37
Carbon Disulfide	60	72
Carbon Monoxide	53	64
Coal or Natural Gas	31*	37
Cyclopropane	31	37
Diethyl Ether	33	40
Dimethyl Ether	33	40
Dowtherm	38*	46
Ethane	33	40
Ethyl Alcohol	36	43
Ethyl Ether	38*	46
Ethylene	41	49
Ethylene Dichloride	21	34
Ethylene Oxide	44	53
Gasoline	28	34
Hexane	29	35
Higher Paraffin Hydrocarbons $C_n H_{2m} + 2m - 5$	28	34
Hydrogen	62	75
Hydrogen Sulfide	30	36
Isobutane	30*	36
Isobutylene	26	34
Isobutyl Formate	26	34
JP-4	30	36
Kerosene	28	34
Methane	25	34
Methyl Acetate	29	35
Methyl Alcohol	33	40
Methyl Butene-I	30	36
Methyl Ethyl Ketone	33	40
Methyl Formate	32	39
Pentane	29	35
Propane	30	36
Propylene	30	36
Quench, Lube Oils	28	34

Note: The theoretical minimum extinguishing concentrations in air for the materials in the table were obtained from a compilation of Bureau of Mines, *Limits of Flammability of Gases and Vapors* (Bulletins 503 and 627).
*Calculated from accepted residual oxygen values.

Table 2-3.3(a) Flooding Factors

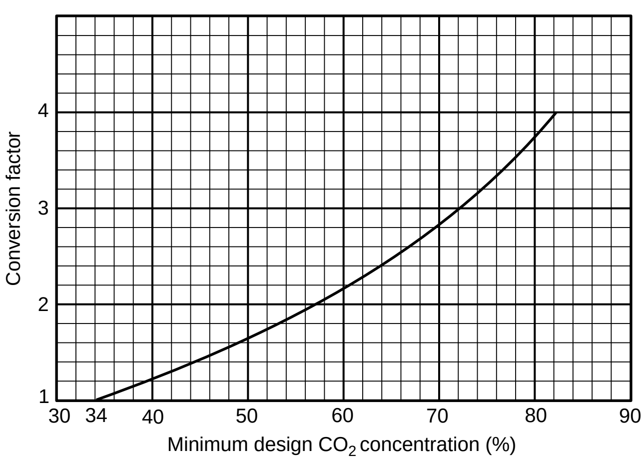
(A) Volume of Space (ft^3)	(B) Volume Factor		(C) Calculated Quantity (lb) (Not Less Than)
	$ft^3/lb\ CO_2$	$lb\ CO_2/ft^3$	
Up to 140	14	0.072	—
141–500	15	0.067	10
501–1600	16	0.063	35
1601–4500	18	0.056	100
4501–50,000	20	0.050	250
Over 50,000	22	0.046	2500

Table 2-3.3(b) Flooding Factors (SI Units)

(A) Volume of Space (m^3)	(B) Volume Factor		(C) Calculated Quantity (kg) (Not Less Than)
	$m^3/kg\ CO_2$	$kg\ CO_2/m^3$	
Up to 3.96	0.86	1.15	—
3.97–14.15	0.93	1.07	4.5
14.16–45.28	0.99	1.01	15.1
45.29–127.35	1.11	0.90	45.4
127.36–1415.0	1.25	0.80	113.5
Over 1415.0	1.38	0.77	1135.0

2-3.4 Material Conversion Factor. For materials requiring a design concentration over 34 percent, the basic quantity of carbon dioxide calculated from the volume factor given in Tables 2-3.3(a) and 2-3.3(b) shall be increased by multiplying this quantity by the appropriate conversion factor given in Figure 2-3.4.

FIGURE 2-3.4 Material conversion factor.



2-3.5 Special Conditions. Additional quantities of carbon dioxide shall be provided to compensate for any special condition that can adversely affect the extinguishing efficiency.

2-3.5.1* Any openings that cannot be closed at the time of extinguishment shall be compensated for by the addition of a quantity of carbon dioxide equal to the anticipated loss at the design concentration during a 1-minute period. This amount of carbon dioxide shall be applied through the regular distribution system. *(See 2-2.1.1 and A-2-5.2.)*

2-3.5.2 For ventilating systems that cannot be shut down, additional carbon dioxide shall be added to the space through the regular distribution system in an amount computed by dividing the volume moved during the liquid discharge period by the flooding factor. This shall be multiplied by the material conversion factor (determined in Figure 2-3.4) when the design concentration is greater than 34 percent.

2-3.5.3* For applications where the normal temperature of the enclosure is above 200°F (93°C), a 1-percent increase in the calculated total quantity of carbon dioxide shall be provided for each additional 5°F (–15°C) above 200°F (93°C).

2-3.5.4 For applications where the normal temperature of the enclosure is below 0°F (–18°C), a 1-percent increase in the calculated total quantity of carbon dioxide shall be provided for each degree Fahrenheit below 0°F (–18°C).

2-3.5.5 Under normal conditions, surface fires are usually extinguished during the discharge period. Except for unusual conditions, it will not be necessary to provide extra carbon dioxide to maintain the concentration.

2-3.5.6 If a hazard contains a liquid having an autoignition temperature below its boiling point, then the carbon dioxide concentration shall be maintained for a period sufficient for the liquid temperature to cool below its autoignition temperature. *(See 3-3.3.2.)*

2-3.5.7* A flooding factor of 8 ft^3/lb (0.22 m^3/kg) shall be used in ducts and covered trenches. If the combustibles represent a deep-seated fire, it then shall be treated as described in Section 2-4.

2-4 Carbon Dioxide Requirements for Deep-Seated Fires.

2-4.1* General. The quantity of carbon dioxide for deep-seated–type fires is based on fairly tight enclosures. After the design concentration is reached, the concentration shall be maintained for a substantial period of time, but not less than 20 minutes. Any possible leakage shall be given special consideration because no allowance is included in the basic flooding factors.

2-4.2 Combustible Materials. For combustible materials capable of producing deep-seated fires, the required carbon dioxide concentrations cannot be determined with the same accuracy possible with surface burning materials. The extinguishing concentration will vary with the mass of material present because of the thermal insulating effects. Flooding factors have therefore been determined on the basis of practical test conditions.

2-4.2.1* The design concentrations listed in Table 2-4.2.1 shall be achieved for the hazards listed. Generally, the flooding factors have been found to provide proper design concentrations for the rooms and enclosures listed.

Table 2-4.2.1 Flooding Factors for Specific Hazards

Design Concentration	Volume Factor				Specific Hazard
	$ft^3/lb\ CO_2$	$m^3/kg\ CO_2$	$lb\ CO_2/ft^3$	$kg\ CO_2/m^3$	
50	10	0.62	0.100	1.60	Dry electrical hazards in general [Spaces 0–2000 ft^3 (56.6 m^3)]
50	12	0.75	0.083 (200 lb) minimum	1.33 (91 kg) minimum	[Spaces greater than 2000 ft^3 (56.6 m^3)]
65	8	0.50	0.125	2.00	Record (bulk paper) storage, ducts, covered trenches
75	6	0.38	0.166	2.66	Fur storage vaults, dust collectors

2-4.2.2 Flooding factors for other deep-seated fires shall be justified to the satisfaction of the authority having jurisdiction before use. Proper consideration shall be given to the mass of material to be protected because the thermal insulating effects reduce the rate of cooling.

2-4.3 Volume Consideration. The volume of the space shall be determined in accordance with 2-3.3.1. The basic quantity of carbon dioxide required to protect an enclosure shall be obtained by treating the volume of the enclosure by the appropriate flooding factor given in 2-4.2.

2-4.4 Special Conditions. Additional quantities of carbon dioxide shall be provided to compensate for any special condition that can adversely affect the extinguishing efficiency. *(See 2-3.5.2, 2-3.5.3, and 2-3.5.4.)*

2-4.4.1 Any openings that cannot be closed at the time of extinguishment shall be compensated for by the addition of carbon dioxide equal in volume to the expected leakage volume during the extinguishing period. If leakage is appreciable, consideration shall be given to an extended discharge system as covered in 2-5.3. *(Also see 2-2.1.2.)*

2-5 Distribution System.

2-5.1 General. The distribution system for applying carbon dioxide to enclosed hazards shall be designed with due consideration for the materials involved and the nature of the enclosure, because these items can require various discharge times and rates of application.

2-5.2* Rate of Application. The minimum design rate of application shall be based on the quantity of carbon dioxide and the maximum time to achieve design concentration.

2-5.2.1* For surface fires, the design concentration shall be achieved within 1 minute from start of discharge.

2-5.2.2 For high-pressure systems, if a part of the hazard is to be protected by total flooding, the discharge rate for the total flooding portion shall be computed as specified in 3-3.2.3.

2-5.2.3 For deep-seated fires, the design concentration shall be achieved within 7 minutes, but the rate shall be not less than that required to develop a concentration of 30 percent in 2 minutes.

2-5.3* Enclosed Rotating Electrical Equipment. For enclosed rotating electrical equipment, a minimum concentration of 30 percent shall be maintained for the deceleration period, but not less than 20 minutes.

2-5.4 Piping Systems. Piping shall be designed in accordance with 1-10.5 to deliver the required rate of application at each nozzle.

2-5.4.1* High-pressure storage temperatures shall be permitted to range from 0°F (–18°C) to 130°F (54°C) without requiring special methods of compensating for changing flow rates. *(See 1-9.5.5.)*

2-5.5 Nozzle Sizing and Distribution. Nozzles used in connection with total flooding systems with either high- or low-pressure supply shall be of a type suitable for the intended purpose and shall be located to achieve the best results.

2-5.5.1 The types of nozzles selected and their placement shall be such that the discharge will not unduly splash flammable liquids or create dust clouds that could extend the fire, create an explosion, or otherwise adversely affect the contents of the enclosure. Nozzles vary in design and discharge characteristics and shall be selected on the basis of their adequacy for the use intended.

2-5.5.2 Spacing and sizing of nozzles in ductwork is dependent on many factors such as velocity in duct, location and effectiveness of dampers, possible loading of duct walls with combustible deposits, duct length, and cross-sectional dimensions. The nozzle locations and sizing shall be selected to assure distribution of the carbon dioxide throughout the entire length of the ductwork. Automatic dampers shall be provided to close on system operation. No allowance is needed for inlet and outlet duct openings that have surface hazards only. *(See Table 2-4.2.1 and 2-3.5.7.)*

2-6 Venting Consideration.

2-6.1 General. The venting of flammable vapors and pressure buildup from the discharge of quantities of carbon dioxide into closed spaces shall be considered *(see 2-2.1.4)*. The pressure venting consideration involves such variables as enclosure strength and injection rate.

2-6.2 Pressure Relief Venting. Porosity and leakages such as at doors, windows, and dampers, though not readily apparent or easily calculated, have been found to provide sufficient relief for the normal carbon dioxide flooding systems without need for additional venting. Record storage rooms, refrigerated spaces, and ductwork have also been found to need no additional venting when tested under their average system conditions.

2-6.2.1 For very tight enclosures, the necessary area of free venting shall be calculated from the following equation. Satisfactory results will be achieved by assuming the expansion of carbon dioxide to be 9 ft^3/lb (0.56 m^3/kg).

$$X = \frac{Q}{1.3\sqrt{P}}$$

where:

X = free venting area (in.^{2})
Q = calculated carbon dioxide flow rate (lb/min)
P = allowable strength of enclosure (lb/ft^2)

For SI units, the following equation applies:

$$X = \frac{239Q}{\sqrt{P}}$$

where:

X = free venting area (mm^2)
Q = calculated carbon dioxide flow rate (kg/min)
P = allowable strength of enclosure (kPa gauge)

2-6.2.2 In many instances, particularly when hazardous materials are involved, relief openings are already provided for explosion venting. These and other available openings often provide adequate venting.

2-6.2.3 General construction practices provide the guide in Table 2-6.2.3 for considering the normal strength and allowable pressures of average enclosures.

Table 2-6.2.3 Strength and Allowable Pressures for Average Enclosures

Type Construction	Windage (mph)	Pressure (lb/ft^2)	In. Water	psi	kPa Gauge
Light building	100	25*	5	0.175	1.2
Normal building	140	50**	10	0.35	2.4
Vault building	200	100	20	0.70	4.8

*Venting sash remains closed.
**Venting sash designed to open freely.

Chapter 3 Local Application Systems

3-1* General Information.

3-1.1 Description. A local application system consists of a fixed supply of carbon dioxide permanently connected to a system of fixed piping with nozzles arranged to discharge directly into the fire.

3-1.2* Uses. Local application systems shall be used for the extinguishment of surface fires in flammable liquids, gases, and shallow solids where the hazard is not enclosed or where the enclosure does not conform to the requirements for total flooding.

3-1.3 General Requirements. Local application systems shall be designed, installed, tested, and maintained in accordance with the applicable requirements in previous chapters and with the additional requirements set forth in this chapter.

3-1.4 Safety Requirements. Reference is made to Section 1-6, 1-8.5, and A-1-6 regarding hazards to personnel due to obscuration of vision and reduction of oxygen concentration below that which will support life, not only in the immediate area of discharge, but in adjacent areas to which gas can migrate.

3-2 Hazard Specifications.

3-2.1 Extent of Hazard. The hazard shall be so isolated from other hazards or combustibles that fire will not spread outside the protected area. The entire hazard shall be protected. The hazard shall include all areas that are, or can become, coated by combustible liquids or shallow solid coatings, such as areas subject to spillage, leakage, dripping, splashing, or condensation. The hazard also includes all associated materials or equipment, such as freshly coated stock, drain boards, hoods, ducts, and so forth, that could extend fire outside or lead fire into the protected area.

3-2.1.1 A series of interexposed hazards shall be permitted to be subdivided into smaller groups or sections with the approval of the authority having jurisdiction. Systems for such hazards shall be designed to give immediate independent protection to adjacent groups or sections as needed.

3-2.2 Location of Hazard. The hazard can be indoors, partly sheltered, or completely out of doors; it is essential that the carbon dioxide discharge shall be such that winds or strong air currents do not impair the protection.

3-3 Carbon Dioxide Requirements.

3-3.1* General. The quantity of carbon dioxide required for local application systems shall be based on the total rate of discharge needed to blanket the area or volume protected, and the time that the discharge must be maintained to assure complete extinguishment.

3-3.1.1* For systems with high-pressure storage, the computed quantity of carbon dioxide shall be increased by 40 percent to determine nominal cylinder storage capacity because only the liquid portion of the discharge is effective. This increase in cylinder storage capacity is not required for the total flooding portion of combined local application–total flooding systems.

3-3.1.2* The quantity of carbon dioxide in storage shall be increased by an amount sufficient to compensate for liquid vaporized in cooling the piping.

3-3.2 Rate of Discharge. Nozzle discharge rates shall be determined by either the surface method or the volume method as covered in Sections 3-4 and 3-5.

3-3.2.1 The total rate of discharge for the system shall be the sum of the individual rates of all the nozzles or discharge devices used on the system.

3-3.2.2 For low-pressure systems, if a part of the hazard is to be protected by total flooding, the discharge rate for the total flooding part shall be sufficient to develop the required concentration in not more than the discharge time used for the local application part of the system.

3-3.2.3 For high-pressure systems, if a part of the hazard is to be protected by total flooding, the discharge rate for the total flooding part shall be computed by dividing the quantity required for total flooding by the factor 1.4, and by the time of the local application discharge in minutes.

$$Q_F = \frac{W_F}{1.4\,T_L}$$

where:

Q_F = rate of flow for the total flooding portion [lb/min (kg/min)]

W_F = total quantity of carbon dioxide for the total flooding portion [lb (kg)]

T_L = liquid discharge time for the local application portion (min)

3-3.3* Duration of Discharge. The minimum effective discharge time for computing quantity shall be 30 seconds. The minimum time shall be increased to compensate for any hazard condition that would require a longer cooling period to assure complete extinguishment.

3-3.3.1 Where there is a possibility that metal or other material can become heated above the ignition temperature of the fuel, the effective discharge time shall be increased to allow adequate cooling time.

3-3.3.2* Where the fuel has an autoignition point below its boiling point, such as paraffin wax and cooking oils, the effective discharge time shall be increased to permit cooling of the fuel to prevent reignition. The minimum liquid discharge time shall be 3 minutes.

3-4 Rate-by-Area Method.

3-4.1 General. The area method of system design shall be used where the fire hazard consists primarily of flat surfaces or low-level objects associated with horizontal surfaces.

3-4.1.1 System design shall be based on listing or approval data for individual nozzles. Extrapolation of such data above or below the upper or lower limits shall not be permitted.

3-4.2 Nozzle Discharge Rates. The design discharge rate through individual nozzles shall be determined on the basis of location or projection distance in accordance with specific approvals or listings.

3-4.2.1* The discharge rate for overhead-type nozzles shall be determined solely on the basis of distance from the surface each nozzle protects.

3-4.2.2* The discharge rate for tankside nozzles shall be determined solely on the basis of the throw or projection required to cover the surface each nozzle protects.

3-4.3 Area per Nozzle. The maximum area protected by each nozzle shall be determined on the basis of location or projection distance and the design discharge rate in accordance with specific approvals or listings.

3-4.3.1 The same factors used to determine the design discharge rate shall be used to determine the maximum area to be protected by each nozzle.

3-4.3.2 The portion of the hazard protected by individual overhead-type nozzles shall be considered as a square area.

3-4.3.3 The portion of the hazard protected by individual tankside or linear nozzles is either a rectangular or a square area in accordance with spacing and discharge limitations stated in specific approvals or listings.

3-4.3.4* Where coated rollers or other similar irregular shapes are to be protected, the projected wetted area shall be used to determine nozzle coverage.

3-4.3.5 Where coated surfaces are to be protected, the area per nozzle shall be permitted to be increased to a maximum of 40 percent over the areas given in specific approvals or listings. Coated surfaces are defined as those designed for drainage that are constructed and maintained so that no pools of liquid will accumulate over a total area exceeding 10 percent of the protected surface. This subsection shall not apply where there is a heavy buildup of residue. *(See 3-1.2.)*

3-4.3.6 Where local application nozzles are used for protection across openings as defined in 2-2.1.3 and 2-2.1.4, the area per nozzle given by specific approval or listing shall be permitted to be increased to a maximum of 20 percent.

3-4.3.7 Where deep-layer flammable liquid fires are to be protected, a minimum freeboard of 6 in. (152 mm) shall be provided unless otherwise noted in approvals or listings of nozzles.

3-4.4 Location and Number of Nozzles. A sufficient number of nozzles shall be used to adequately cover the entire hazard area on the basis of the unit areas protected by each nozzle.

3-4.4.1 Tankside or linear nozzles shall be located in accordance with spacing and discharge rate limitations stated in specific approvals or listings.

3-4.4.2 Overhead-type nozzles shall be installed perpendicular to the hazard and centered over the area protected by the nozzle. They shall also be permitted to be installed at angles between 45 degrees and 90 degrees from the plane of the hazard surface as prescribed in 3-4.4.3. The height used in determining the necessary flow rate and area coverage shall be the distance from the aiming point on the protected surface to the face of the nozzle measured along the axis of the nozzle.

3-4.4.3 When nozzles are installed at an angle, they shall be aimed at a point measured from the near side of the area protected by the nozzle. This location is calculated by multiplying the fractional aiming factor in Table 3-4.4.3 by the width of the area protected by the nozzle.

Table 3-4.4.3 Aiming Factors for Angular Placement of Nozzles, Based on 6-in. (152-mm) Freeboard

Discharge Angle[1]	Aiming Factors[2]
45–60	$^1/_4$
60–75	$^1/_4$–$^3/_8$
75–90	$^3/_8$–$^1/_2$
90 (perpendicular)	$^1/_2$ (center)

[1]Degrees from plane of hazard surface.
[2]Fractional amount of nozzle coverage area.

3-4.4.4 Nozzles shall be located so as to be free of possible obstructions that could interfere with the proper projection of the discharged carbon dioxide.

3-4.4.5 Nozzles shall be located so as to develop an extinguishing atmosphere over coated stock extending above a protected surface. Additional nozzles can be required for this specific purpose, particularly if stock extends more than 2 ft (0.6 m) above a protected surface.

3-4.4.6 The possible effects of air currents, winds, and forced drafts shall be compensated for by properly locating nozzles or by providing additional nozzles to adequately protect the outside areas of the hazard.

3-5 Rate-by-Volume Method.

3-5.1 General. The volume method of system design shall be used where the fire hazard consists of three-dimensional irregular objects that cannot be easily reduced to equivalent surface areas.

3-5.2 Assumed Enclosure. The total discharge rate of the system shall be based on the volume of an assumed enclosure entirely surrounding the hazard.

3-5.2.1 The assumed enclosure shall be based on an actual closed floor unless special provisions are made to take care of bottom conditions.

3-5.2.2 The assumed walls and ceiling of this enclosure shall be at least 2 ft (0.6 m) from the main hazard unless actual walls are involved, and they shall enclose all areas of possible leakage, splashing, or spillage.

3-5.2.3 No deductions shall be made for solid objects within this volume.

3-5.2.4 A minimum dimension of 4 ft (1.2 m) shall be used in calculating the volume of the assumed enclosure.

3-5.2.5 If the hazard can be subjected to winds or forced drafts, the assumed volume shall be increased to compensate for losses on the windward sides.

3-5.3 System Discharge Rate. The total discharge rate for the basic system shall be equal to 1 lb/min·ft^3 (16 kg/min·m^3) of assumed volume.

3-5.3.1* If the assumed enclosure has a closed floor and is partly defined by permanent continuous walls extending at least 2 ft (0.6 m) above the hazard (where the walls are not normally a part of the hazard), the discharge rate shall be permitted to be proportionately reduced to not less than 0.25 lb/min·ft^3 (4 kg/min·m^3) for actual walls completely surrounding the enclosure.

3-5.4 Location and Number of Nozzles. A sufficient number of nozzles shall be used to adequately cover the entire hazard volume on the basis of the system discharge rate as determined by the assumed volume.

3-5.4.1 Nozzles shall be located and directed so as to retain the discharged carbon dioxide in the hazard volume by suitable cooperation between nozzles and objects in the hazard volume.

3-5.4.2 Nozzles shall be located so as to compensate for any possible effects of air currents, winds, or forced drafts.

3-5.4.3 The design discharge rates through individual nozzles shall be determined on the basis of location or projection distance in accordance with specific approvals or listings for surface fires.

3-6 Distribution System.

3-6.1 General. The system shall be designed to provide an effective discharge of carbon dioxide promptly before excessive amounts of heat can be absorbed by materials within the hazard.

3-6.1.1 The carbon dioxide supply shall be located as near to the hazard as practicable and yet not exposed to the fire, and the pipeline shall be as direct as practicable with a minimum number of turns in order to get carbon dioxide to the fire promptly.

3-6.1.2 The system shall be designed for automatic operation except where the authorities having jurisdiction permit manual operation.

3-6.2 Piping Systems. Piping shall be designed in accordance with 1-10.5 to deliver the required rate of application at each nozzle.

3-6.2.1* High-pressure storage temperatures ranging from 32°F to 120°F (0°C to 49°C) do not require special methods of compensating for changing flow rates.

3-6.3 Discharge Nozzles. The nozzles used shall be listed or approved for rate of discharge, effective range, and pattern or area coverage.

3-6.3.1 The equivalent orifice size used in each nozzle shall be determined in accordance with 1-10.5 to match the design discharge rate.

3-6.3.2 Nozzles shall be accurately located and directed in accordance with the system design requirements as covered in Sections 3-4 and 3-5.

Chapter 4 Hand Hose Line Systems

4-1 General Information.

4-1.1* Description. Hand hose line systems consist of a hose reel or rack, hose, and discharge nozzle assembly connected by fixed piping to a supply of carbon dioxide.

4-1.2 Uses. Hand hose line systems shall be permitted to be used to supplement fixed fire protection systems or to supplement first aid fire extinguishers for the protection of specific hazards for which carbon dioxide is a suitable extinguishing agent. These systems shall not be used as a substitute for other fixed carbon dioxide fire-extinguishing systems equipped with fixed nozzles, except where the hazard cannot adequately or economically be provided with fixed protection. The decision as to whether hose lines are applicable to the particular hazard shall rest with the authority having jurisdiction.

4-1.3 General Requirements. Hand hose line systems shall be installed and maintained in accordance with the applicable requirements of Chapters 1, 2, and 3, except as outlined in Sections 4-2 through 4-6.

4-1.4 Safety Requirements. Reference is made to 1-6.1 and A-1-6 regarding hazards to personnel due to obscuration of vision and reduction of oxygen concentration below that which will support life, not only in the immediate area of discharge but in adjacent areas to which gas can migrate.

4-2 Hazard Specifications. Hand hose line systems can be used to combat fires in all hazards covered under Chapter 1, except those that are inaccessible and beyond the scope of manual fire fighting.

4-3 Location and Spacing.

4-3.1 Location. Hand hose line stations shall be placed such that they are easily accessible and within reach of the most distant hazard that they are expected to protect. In general, they shall not be located such that they are exposed to the hazard nor shall they be located inside any hazard area protected by a total flooding system.

4-3.2 Spacing. If multiple-hose stations are used, they shall be spaced so that any area within the hazard can be covered by one or more hose lines.

4-4 Carbon Dioxide Requirements.

4-4.1 Rate and Duration of Discharge. The rate and duration of discharge and consequently the amount of carbon dioxide shall be determined by the type and potential size of the hazard. A hand hose line shall have a sufficient quantity of carbon dioxide to permit its use for at least 1 minute.

4-4.2 Provision for Use by Inexperienced Personnel. The possibility of these hose lines being used by inexperienced personnel shall be considered, and adequate provision shall be made so that there will be a sufficient supply of carbon dioxide to enable personnel to effect extinguishment of the hazards that they are likely to encounter.

4-4.3 Simultaneous Use. Where simultaneous use of two or more hose lines is possible, a sufficient quantity of carbon dioxide shall be available to support the maximum number of nozzles that are likely to be used at any one time for at least 1 minute. All supply piping shall be sized for the simultaneous operation of the number of nozzles that are likely to be used.

4-5 Equipment Specifications.

4-5.1 Hose. Hose lines on systems with high-pressure supply shall have a minimum bursting pressure of 5000 psi (34,474 kPa), and hose lines of systems with low-pressure supply shall have a minimum bursting pressure of 1800 psi (12,411 kPa). *(See 1-11.2.)*

4-5.2 Discharge Nozzle Assembly. Hose lines shall be equipped with a discharge nozzle assembly that can be easily handled by one operator and that contains a quick-opening shutoff valve to control the flow of carbon dioxide through the nozzle and a suitable handle for directing the discharge. The attachment of the discharge nozzle assembly to the hose by means of a swivel connection is desirable for providing more ease of manipulation.

4-5.3 Hose Line Storage. The hose shall be coiled on a hose reel or rack such that it will be ready for immediate use without the necessity of coupling, and such that it can be uncoiled with a minimum of delay. If installed outdoors, it shall be protected against the weather.

4-5.4 Charging the Hose Line. Operation of hand hose line systems depends upon manual actuation and manual manipulation of a discharge nozzle. Speed and simplicity of operation are therefore essential for successful extinguishment.

4-5.4.1 All controls for actuating the system shall be located in the immediate vicinity of the hose reel.

4-5.4.2* The carbon dioxide supply shall be located as close to the hose reel as possible so that liquid carbon dioxide will be supplied to the hose line with a minimum of delay after actuation.

4-5.4.3 Except when in actual use, pressure shall not be permitted to remain in the hose line.

4-6 Training. Successful extinguishment of fire with hand hose lines is greatly dependent upon the individual ability and technique of the operator. All personnel who are likely to use this equipment at the time of a fire shall be properly trained in its operation and in the fire-fighting techniques applicable to this equipment.

Chapter 5 Standpipe Systems and Mobile Supply

5-1 General Information.

5-1.1 Description. A standpipe system is a fixed total flooding, local application, or hand hose line system without a permanently connected carbon dioxide supply. The carbon dioxide supply is mounted on a mobile vehicle that can be towed or driven to the scene of a fire and quickly coupled to the standpipe system protecting the involved hazard. Mobile supply is primarily fire brigade or fire department equipment requiring trained personnel for effective use.

5-1.2* Uses. Standpipe systems shall be installed only with the approval of the authority having jurisdiction.

5-1.3 General Requirements. Standpipe systems and mobile supply shall be installed and maintained in accordance with the requirements in Chapters 1, 2, 3, and 4, in addition to those outlined in Sections 5-2 through 5-5. Piping shall be installed in accordance with the requirements applicable for the system if a permanently connected supply is used. Appreciable lengths of piping on the portable supply shall be taken into account.

5-2 Hazard Specifications. Standpipe systems and mobile supply shall be permitted to be used to protect hazards described in Chapters 1, 2, 3, and 4, where extinguishment will not be adversely affected by the delay in obtaining effective discharge of carbon dioxide while the mobile supply is being brought to the scene and coupled to the standpipe system.

5-3 Standpipe Requirements. The supply piping of standpipe systems shall be equipped with quick-change couplings and shall terminate in an easily accessible and well-marked location for connection to the mobile supply. This location shall also be marked with the amount of carbon dioxide required and the required duration of discharge.

5-4 Mobile Supply Requirements.

5-4.1 Capacity. The mobile supply shall have a capacity in accordance with the provisions of Chapters 1, 2, 3, and 4. Extra quantities could be required to compensate for delay in getting the mobile supply to the hazard.

5-4.2 Coupling. The mobile supply shall be provided with suitable means for transferring carbon dioxide into the standpipe system. Quick-change couplings shall be provided to permit these connections to be made as rapidly as possible.

5-4.3 Mobility. The storage container or containers of carbon dioxide shall be mounted on a movable vehicle that can be brought to the scene of the fire by manual means, by a separate motor vehicle, or under its own power. The means of transporting the mobile supply shall be dependable and capable of getting to the fire with a minimum of delay.

5-4.4 Location. The mobile supply shall be kept close to the hazards that it is intended to protect so that fire extinguishment can be started as soon as possible after the fire breaks out.

5-4.5 Accessories. Mobile supply for standpipe systems can be provided with hand hose lines as accessory equipment for the protection of small scattered hazards or as a supplement to standpipe systems or other fixed protection.

5-5 Training. The effectiveness of fire protection provided by standpipe systems and mobile supply depends upon the efficiency and ability of the manpower that handles the mobile supply. It is imperative that those persons assigned to the units shall be properly trained in its use and maintenance. Generally, this equipment is in the category of fire brigade or fire department equipment requiring a regularly assigned crew.

Chapter 6 Marine Systems

6-1 General.

6-1.1* This chapter outlines the modifications necessary for marine systems. All other requirements of this standard shall apply to marine systems except as modified by this chapter.

6-1.2 Special Definitions.

6-1.2.1 Space, Cargo. A space for the carriage or storage of items or products that are transported by the vessel.

6-1.2.2* Space, Machinery. A space that contains mechanical equipment for handling, pumping, or transferring flammable or combustible liquids as a fuel.

6-1.2.3* Space, Vehicle. A space that is designed for the carriage of automobiles or other self-propelled vehicles.

6-1.2.4 Space, Electrical Equipment. A space containing electrical propulsion, power generating or power distribution equipment.

6-1.2.5 Systems, Marine. Systems installed on ships, barges, offshore platforms, motorboats, and pleasure craft.

6-2 System Requirements.

6-2.1 Components. System components shall be specifically listed or approved for carbon dioxide system marine applications.

6-2.2 Operating Instructions.

6-2.2.1 Instructions for the operation of the system shall be located in a conspicuous place at or near all manual controls, and in the carbon dioxide storage room.

6-2.2.2 For systems in which the carbon dioxide storage is not within the protected space, the operating instructions shall include a chart indicating the location of the emergency control to be used if the normal controls fail to operate.

6-2.3 System Actuation.

6-2.3.1 Two separate valves shall be provided for releasing carbon dioxide into any protected space. One valve shall control discharge from the carbon dioxide storage. The second valve shall control carbon dioxide discharge into the protected space(s). *(See 1-8.3.6.)*

Exception: For systems that contain 300 lb (136 kg) of carbon dioxide storage or less, only one valve need be used for the release of the system provided that the protected space is normally unoccupied and has horizontal egress.

6-2.3.2* A separate manually operated control shall be provided to operate each valve required by 6-2.3.1. A set of controls shall be located outside at least one of the main means of egress from each protected space.

6-2.3.3* In addition to the manually operated controls required by 6-2.3.2, each of the valves required by 6-2.3.1 shall be provided with its own emergency manual control.

6-2.3.4 Controls for the valves required by 6-2.3.2 shall be located inside a release box clearly identified for the protected space. If the box containing the controls is to be locked, a key to the box shall be provided in a break-glass-type enclosure conspicuously located adjacent to the box.

6-2.3.5* In addition to the requirements of 1-6.1.5, audible predischarge alarms shall be provided that depend on no source of power other than carbon dioxide pressure. The time delay required by 1-6.1.4 shall be a minimum of 20 seconds and shall depend on no source of power other than carbon dioxide pressure.

6-2.4 Carbon Dioxide Storage.

6-2.4.1 Carbon dioxide storage shall be permitted inside normally unoccupied protected spaces for systems that contain not more than 300 lb (136 kg) of carbon dioxide storage and are equipped for automatic actuation.

6-2.4.2 Low-pressure systems shall be provided with dual refrigeration units and shall be constructed in accordance with 46 *CFR* 58.20.

6-2.4.3 When the carbon dioxide containers are located outside a protected space, they shall be stored in a room that shall be situated in a safe and readily accessible location, and shall be effectively ventilated so that the agent containers are not exposed to ambient temperatures outlined in 1-9.5.5. Common bulkheads and decks located between agent container storage rooms and protected spaces shall be protected with A-60 class structural insulation as defined by 46 *CFR* 72. Doors and other means of closing any opening therein, which form the boundaries between such rooms and adjoining protected spaces, shall be gastight. Agent container storage rooms shall be accessible without having to pass through the space being protected. Access doors shall open outward. For systems that contain 300 lb (136 kg) of carbon dioxide storage or less, only one valve need be used for the release of the system provided that the protected space is normally unoccupied and has horizontal egress.

6-2.5 System Piping.

6-2.5.1* Where necessary, drains shall be provided for the removal of accumulated moisture.

6-2.5.2 Carbon dioxide piping shall not be fitted with drains or other openings within living quarters.

6-2.5.3 Carbon dioxide piping shall be used for no other purpose.

Exception: Carbon dioxide piping shall be permitted to be used in an air-sampling-type smoke detection system.

6-2.6 System Design. System design shall comply with Chapters 2, 3, and 4 except as follows:

(a) *Machinery Spaces.* Machinery spaces shall be designed to a 34-percent concentration based on the gross volume. Eighty-five percent of this concentration shall be achieved within 2 minutes from the start of discharge. Gross volume shall include the casing.

(b) **Cargo Spaces.* Cargo spaces other than vehicle spaces shall be supplied with carbon dioxide based on 1 lb/ 30 ft^3 based on the gross volume. The initial quantity of carbon dioxide discharged shall be based on the net volume of the space as determined by the amount of cargo in the cargo space. Additional carbon dioxide shall be released as needed to maintain control of the fire. Clear instructions shall be posted within the carbon dioxide storage room detailing the carbon dioxide release procedure.

(c) *Vehicle Spaces.* Vehicle spaces where the vehicles contain more than 5 gallons of fuel (gasoline or diesel) shall be designed to a 34-percent concentration based on the gross volume. Eighty-five percent of this concentration shall be achieved within 2 minutes from start of discharge.

(d) *Vehicle Spaces.* Vehicle spaces where the vehicles contain 5 gallons or less of fuel (gasoline or diesel) shall be designed to a 34-percent concentration based on the gross volume. Two-thirds of this concentration shall be achieved within 10 minutes from start of discharge.

6-2.6.1 Electrical Equipment Spaces. Electrical equipment spaces shall be treated as a dry electrical hazard in accordance with Chapter 2.

6-3 Inspection and Maintenance. Inspection and maintenance shall comply with 1-11.3 and this section.

6-3.1 General. Prior to testing or maintenance of a fixed carbon dioxide system, all personnel shall be evacuated from the protected space *(See Section 1-6).*

6-3.2 Approval of Installations. The following approval tests shall be conducted prior to the tests required by 1-7.3. Pressure tests of the piping shall be performed to meet the requirements of the following paragraphs. The test media shall be a dry, noncorrosive gas such as nitrogen or carbon dioxide. When pressurizing the piping, pressure shall be increased in 50-psi (3.5-bar) increments. Once the pressure in the pipe has reached the required test pressure, the pressure source shall be shut off and disconnected from the pipe.

CAUTION

Pneumatic pressure testing creates a potential risk of injury to personnel in the area, as a result of airborne projectiles, if rupture of the piping system occurs. Prior to conducting the pneumatic pressure test, the area in which the pipe is located shall be evacuated and appropriate safeguards shall be provided for test personnel.

6-3.2.1 High-Pressure Systems.

6-3.2.1.1 Systems with Stop Valves. All piping from the carbon dioxide supply to the stop valves shall be subjected to a minimum pressure of 1000 psig (6895 KPa). The leakage during a 2-minute period shall not exceed a pressure drop of 10 percent.

All piping between the stop valves and the nozzles shall be subjected to a minimum pressure of 600 psig (4137 KPa). The leakage during a 2-minute period shall not exceed a pressure drop of 10 percent.

6-3.2.1.2 Systems without Stop Valves. All piping from the carbon dioxide supply to the nozzles shall be subjected to a minimum pressure of 600 psig (4137 KPa). The leakage during a 2-minute period shall not exceed a pressure drop of 10 percent.

6-3.2.2 Low-Pressure Systems.

6-3.2.2.1 All piping that is normally pressurized shall be subjected to a pressure test of minimum 300 psig (2068 KPa). No leakage shall be permitted from the piping during a 2-minute test.

6-3.2.2.2 All piping between the tank shut-off valve and the nozzles shall be subjected to a minimum pressure test of 300 psig (2068 KPa). The leakage during a 2-minute period shall not exceed a pressure drop of 10 percent.

6-3.3 Predischarge Delays, Alarms, and Shutdowns. Predischarge delays and alarms and ventilation shutdowns shall be tested by flowing carbon dioxide into the system. Predischarge delays that are not accurate to within +20%/–0% at 70°F (21°C) of their rating shall be replaced.

6-3.4 Verification. Compliance with 6-2.2 shall be verified.

Chapter 7 Referenced Publications

7-1 The following documents or portions thereof are referenced within this standard as mandatory requirements and shall be considered part of the requirements of this standard. The edition indicated for each referenced mandatory document is the current edition as of the date of the NFPA issuance of this standard. Some of these mandatory documents might also be referenced in this standard for specific informational purposes and, therefore, are also listed in Appendix C.

7-1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 70, *National Electrical Code*®, 1999 edition.
NFPA 72, *National Fire Alarm Code*®, 1999 edition.

7-1.2 Other Publications.

7-1.2.1 ANSI Publications. American National Standards Institute, Inc., 11 West 42nd Street, 13th floor, New York, NY 10036.

ANSI B 31.1, *Power Piping Code,* 1989.
ANSI/IEEE C 2, *National Electrical Safety Code,* 1993.

7-1.2.2 API Publication. American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005.

API-ASME, *Code for Unfired Pressure Vessels for Petroleum Liquids and Gases,* Pre-July 1, 1961.

7-1.2.3 ASTM Publications. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM A 53, *Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless,* 1999.

ASTM A 106, *Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service,* 1999.

ASTM A 120, *Specification for Welded and Steel Pipe*, 1984.

ASTM A 182, *Standard Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service,* 1998.

ASTM SI 10, *Standard for Use of the International System of Units (SI): The Modern Metric System*, 1997.

7-1.2.4 CGA Publication. Compressed Gas Association, 1725 Jefferson Davis Highway, Arlington, VA 22202–4100.

CGA G6.2, *Commodity Specification for Carbon Dioxide*, 1994.

7-1.2.5 CSA Publication. Canadian Standards Association, 178 Rexdale Boulevard, Rexdale, Ontario, Canada M9W 1R3.

CSA C22.1, *Canadian Electrical Code*, 1986.

7-1.2.6 U.S. Government Publications. U.S. Government Printing Office, Washington, DC 20402.

Title 46, *Code of Federal Regulations*, Part 72.

Title 46, *Code of Federal Regulations*, Part 58.20.

DOT Title 49, *Code of Federal Regulations*, Parts 171–190.

(DOT) Bureau of Mines 503 and 627, *Limits of Flammability of Gases and Vapors,* 1962.

Appendix A Explanatory Material

Appendix A is not a part of the requirements of this NFPA document but is included for informational purposes only. This appendix contains explanatory material, numbered to correspond with the applicable text paragraphs.

A-1-1 Portable carbon dioxide equipment is covered in NFPA 10, *Standard for Portable Fire Extinguishers.* The use of carbon dioxide for inerting is covered in NFPA 69, *Standard on Explosion Prevention Systems.*

A-1-3.2 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluate testing laboratories. In determining the acceptability of installations, procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A-1-3.3 Authority Having Jurisdiction. The phrase "authority having jurisdiction" is used in NFPA documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A-1-3.6 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A-1-3.16 Pre-Engineered System. Pre-engineered systems can incorporate special nozzles, flow rates, methods of application, nozzle placement, and quantities of carbon dioxide that could differ from those detailed elsewhere in this standard because they are designed for very specific hazards. All other requirements of the standard apply. It is possible for the normal manual control to qualify as the emergency manual control if the provisions of 1-8.1 are satisfied.

A-1-5.1 Carbon dioxide is present in the atmosphere at an average concentration of about 0.03 percent by volume. It is also a normal end product of human and animal metabolism. Carbon dioxide influences certain vital functions in a number of important ways, including control of respiration, dilation, and constriction of the vascular system — particularly the cerebrum — and the pH of body fluids. The concentration of carbon dioxide in the air governs the rate at which carbon dioxide is released from the lungs and thus affects the concentration of carbon dioxide in the blood and tissues. An increasing concentration of carbon dioxide in air can, therefore, become dangerous due to a reduction in the rate of release of carbon dioxide from the lungs and decreased oxygen intake. [Further details of carbon dioxide exposure can be obtained from HEW (NIOSH) Publication No. 76-194.] Personnel safety considerations are covered in Section 1-6.

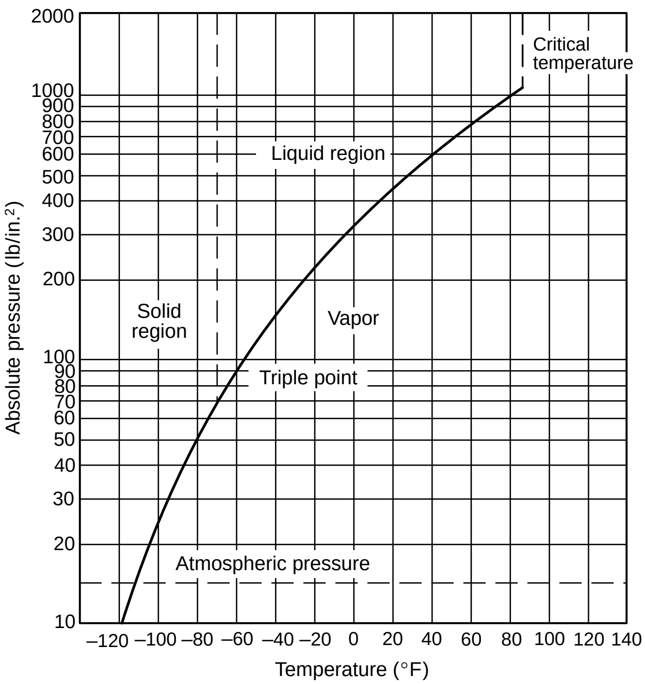
Carbon dioxide is a standard commercial product with many uses. It is perhaps most familiar as the gas that gives the "tingle" in soda pop and other carbonated beverages. In other industrial applications it can be used for its chemical properties, for its mechanical properties as a pressurizing agent, or for its refrigerating properties as dry ice.

For fire-extinguishing applications, carbon dioxide has a number of desirable properties. It is noncorrosive, nondamaging, and leaves no residue to clean up after the fire. It provides its own pressure for discharge through pipes and nozzles. Because it is a gas, it will penetrate and spread to all parts of a hazard. It will not conduct electricity and can therefore be used on live electrical hazards. It can effectively be used on practically all combustible materials except for a few active metals and metal hydrides, and materials such as cellulose nitrate, which contain available oxygen.

Under normal conditions carbon dioxide is an odorless, colorless gas with a density about 50 percent greater than the density of air. Many people insist they can detect an odor of carbon dioxide, but this could be due to impurities or chemical effects in the nostrils. Carbon dioxide is easily liquefied by compression and cooling. By further cooling and expansion, it can be converted to the solid state.

The relationship between the temperature and the pressure of liquid carbon dioxide is shown on the curve given in Figure A-1-5.1. It will be noted that, as the temperature of the liquid increases, the pressure also increases. As the pressure increases, the density of the vapor over the liquid increases. On the other hand, the liquid expands as the temperature goes up and its density decreases. At 87.8°F (31°C) the liquid and vapor have the same density, and of course the liquid phase disappears. This is called the critical temperature for carbon dioxide.

FIGURE A-1-5.1 Variation of pressure of carbon dioxide with change in temperature (constant volume). Below the critical temperature [87.8°F (31°C)], carbon dioxide in a closed container is part liquid and part gas. Above the critical temperature it is entirely gas.



For SI units, 1 psi = 6.89 kPa; °C = ⁵⁄₉ (°F – 32).

An unusual property of carbon dioxide is the fact that it cannot exist as a liquid at pressures below 60.4 psi [75 psi absolute (517 kPa)]. This is the triple point pressure where carbon dioxide could be present as a solid, liquid, or vapor. Below this pressure it must be either a solid or gas, depending on the temperature.

If the pressure in a storage container is reduced by bleeding off vapor, some of the liquid will vaporize and the remaining liquid will become colder. At 60.4 psi [75 psi absolute (517 kPa)] the remaining liquid will be converted to dry ice at a temperature of –69.9°F (–57°C). Further reduction in the pressure to atmospheric will lower the temperature of the dry ice to the normal –109.3°F (–79°C).

The same process takes place when discharging liquid carbon dioxide to the atmosphere. A large portion of the liquid flashes to vapor with a considerable increase in volume. The rest is converted to finely divided particles of dry ice at –109.3°F (–79°C). It is this dry ice or snow that gives the discharge its typical white cloudy appearance. The low temperature also causes the condensation of water from the entrained air so that ordinary water fog tends to persist for a while after the dry ice has sublimed.

A-1-5.2.2 The discharge of liquid carbon dioxide is known to produce electrostatic charges that, under certain conditions, could create a spark. *(See NFPA 77, Recommended Practice on Static Electricity.)*

A-1-5.2.3 While carbon dioxide will not extinguish these fires, it will not react dangerously with these materials or increase their burning rate. Carbon dioxide, if used in this type of situation in a total flooding system, will provide protection for adjacent combustibles or can be successfully used if the reactive metals or hydrides are first covered by another material. The following are examples of this latter condition:

(1) Sodium stored or used under kerosene
(2) Cellulose nitrate in solution of lacquer thinner
(3) Magnesium chips covered with heavy oil

Local application systems with attendant high velocity — directed discharge should not be used.

A-1-6 The steps and safeguards necessary to prevent injury or death to personnel in areas whose atmospheres will be made hazardous by the discharge of carbon dioxide can include the following provisions:

(1) Adequate aisleways and routes of exit and keeping them clear at all times
(2) Necessary additional or emergency lighting, or both, and directional signs to ensure quick, safe evacuation
(3) Alarms within such areas that will operate immediately upon activation of the system on detection of the fire, with the discharge of the carbon dioxide and the activation of automatic door closures delayed for sufficient time to evacuate the area before discharge begins
(4) Only outward swinging, self-closing doors at exits from hazardous areas, and, where such doors are latched, provision of panic hardware
(5) Continuous alarms at entrances to such areas until atmosphere has been restored to normal
(6) Odor, which is added to the carbon dioxide so that hazardous atmospheres in such areas can be recognized
(7) Warning and instruction signs at entrances to and inside such areas
(8) Prompt discovery and rescue of persons rendered unconscious in such areas (This can be accomplished by having such areas searched by trained personnel equipped with proper breathing equipment immediately after carbon dioxide discharge stops. Those persons rendered unconscious by carbon dioxide can be restored without permanent injury by artificial respiration, if removed quickly from the hazardous atmosphere. Self-contained breathing equipment and personnel trained in its use, and in rescue practices including artificial respiration, should be readily available.)
(9) Instruction and drills of all personnel within or in the vicinity of such areas, including maintenance or construction people who can be brought into the area, to ensure their correct action when carbon dioxide protective equipment operates
(10) Means for prompt ventilation of such areas (Forced ventilation will often be necessary. Care should be taken to really dissipate hazardous atmospheres and not merely move them to another location. Carbon dioxide is heavier than air.)

(11) Other steps and safeguards that are necessary to prevent injury or death as indicated by a careful study of each particular situation

A-1-6.1.1 It is recommended that self-contained breathing apparatus be provided for rescue purposes.

A-1-6.1.7 Examples of situations that could require lock-out of a total flooding system are when persons are present in the spaces on ladders or scaffolds or working so they are physically under or inside equipment. If the location of persons is where they cannot easily exit the protected space within the system's time delay period, the system should be locked out.

A-1-6.1.8 Cylinder outlets should be fitted with safety covers or anti-recoil devices whenever the cylinder is not connected to the system piping.

A-1-7.3 Where piping is not normally under pressure, it is possibly not bubbletight. However, where a slow discharge is involved, or if under continual pressure, bubbletightness should be a requirement. It is anticipated that full discharge tests will be waived by the authority having jurisdiction only under extremely unusual conditions. Factors such as extra cost and interruptions to production or business operations are not considered to be valid reasons for waiver of full discharge tests.

A-1-8.1(c) The emergency manual control is intended for use only in the event of failure of automatic or normal manual actuation.

A-1-8.2 Detectors installed at the maximum spacing as listed or approved for fire alarm use can result in excessive delay in agent release.

For additional information on detectors refer to NFPA 72, *National Fire Alarm Code®*.

A-1-8.3.4 It is intended that initial actuation of a system by means of a normal manual control will result in a complete time delay sequence prior to system discharge. If system actuation is initiated by automatic means, subsequent operation of a normal manual control should not restart the time delay sequence.

A-1-8.3.5 It is possible for the normal manual control to qualify as the emergency manual control if the provisions of 1-8.1 are satisfied. If possible, the system should be designed so that emergency actuation can be accomplished from one location.

A-1-8.3.6 It is not the intent of this standard to prohibit the use of more pilot cylinders than the minimum number required in this paragraph.

On systems using discharge pressure from pilot cylinders (discharge manifold back pressure) to activate the slave cylinders, one more pilot cylinder than the minimum required to actuate the system is installed. This requirement provides assurance that the system will completely discharge even if one of the pilot cylinders has leaked.

A-1-8.5 Refer to the NFPA 72, *National Fire Alarm Code,* chapter on visual signaling for guidance for installation of referenced visual alarms. The "public mode" for visual appliance operation should be used.

A-1-8.5.2 Alarm(s) should be connected to existing protective signaling (fire alarm) system(s) to aid life safety and property protection as outlined in NFPA 72, *National Fire Alarm Code*, and NFPA *101®*, *Life Safety Code®*.

A-1-9.1 Not all of the carbon dioxide in the low-pressure container can be rapidly discharged. As the storage container becomes empty, a quantity of cold carbon dioxide vapor will remain in the container. The quantity of this residual vapor will vary depending on the physical configuration of the container. This residual vapor should be considered in determining the storage capacity.

A-1-9.3 Carbon dioxide, as normally manufactured, is an extremely pure product. In general, the industry produces only one grade or quality. This grade is considered suitable for all applications, including food and medical uses.

Dry carbon dioxide gas or liquid is completely noncorrosive to the containers. Carbon dioxide containing excess water can cause some corrosion in high-pressure cylinders, particularly in the lightweight cylinders that are highly stressed. Excess water is present when the amount exceeds the normal solubility in liquid carbon dioxide, so that actual water can condense out on the walls of the container.

Carbon dioxide produced in modern low-pressure plants must necessarily have a very low water content to avoid operating difficulties. The normal practice is to maintain the water content below about 0.03 percent (32 ppm) by weight. If this dry product is stored and transported in clean bulk low-pressure equipment, the quality will be maintained until it is used.

Dry ice normally contains more water and oil than does liquid carbon dioxide. It also tends to freeze moisture and other impurities from the atmosphere, because of its very low temperature of −109.3°F (−79°C). When dry ice is placed in a converter and allowed to warm up so that it becomes liquid carbon dioxide, the liquid so produced will obviously contain an excess amount of water. This liquid should not be used to charge fire-extinguishing cylinders, unless it is further processed through a dehydrating unit to remove the excess water. It should also be noted that such dehydrating units can become ineffective unless the drying agent is renewed or reactivated as necessary to maintain its drying ability.

There are still a few high-pressure carbon dioxide production plants in service. The carbon dioxide produced in these plants can also contain excess water, unless the dehydrating equipment is kept in good condition. The only positive way to be assured of proper quality is periodically to analyze the carbon dioxide supply used for charging fire protection systems.

A-1-9.5 In high-pressure storage systems the temperature of the contained carbon dioxide will depend on the ambient temperature at the storage location. The containers must therefore be capable of withstanding the pressures developed at the highest expected temperature.

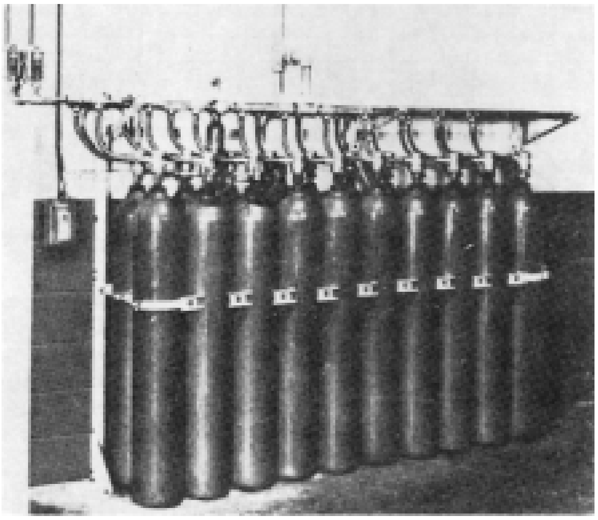
The maximum pressure in the cylinder is also affected by the filling density or percent filling. This is the ratio expressed in percent of the carbon dioxide weight to the water capacity in pounds. The filling density commonly used is between 60 and 68 percent, the latter being the maximum allowed by the U.S. Department of Transportation (DOT), Sections 178.36 and 178.37 of 49 *CFR* 171–190. Proper filling is determined by weight stamped on the valve body.

A-1-9.5.1 High-pressure cylinders can be constructed, tested, and marked in accordance with U.S. Department of Transportation specifications or Transport Canada specifications.

Transporting of a charged cylinder could be illegal where the cylinder has been damaged or exposed to fire. Federal and local regulations should be consulted.

A typical high-pressure storage facility using a number of cylinders is shown in Figure A-1-9.5.1. Flexible connectors are used between each cylinder and the common manifold. This is to facilitate the problem of check-weighing cylinders and replacing cylinders after use. Each cylinder is provided with its own valve with a dip tube extending to the bottom. Some older types of cylinders do not have dip tubes and are installed upside down to ensure discharge of liquid carbon dioxide.

FIGURE A-1-9.5.1 A typical high-pressure storage facility.



A-1-9.6 In low-pressure storage systems the temperature of the contained carbon dioxide is controlled at about 0°F (−18°C) by means of insulation and refrigeration. The normal pressure is thus maintained at about 300 psi (2068 kPa). Welded pressure vessels are used for this service, and there is no special limitation as far as size is concerned.

The filling density will have no effect on the pressure as long as there is sufficient vapor space to allow for expansion of the liquid at the maximum storage temperature and pressure. This would be determined by the setting or the pressure relief valves. In general, the filling density can range from 90 to 95 percent. The maximum liquid level is controlled, when filling, by means of a short dip tube that returns excess liquid to the delivery unit when the liquid reaches the maximum filling level in the storage unit. A liquid level gauge is also provided to indicate the quantity of carbon dioxide in storage.

A typical low-pressure storage facility is shown in Figure A-1-9.6. In this unit the insulated pressure vessel is covered with an outer metal housing that is sealed to keep out water moisture. A standard air-cooled refrigeration unit is mounted at one end, with its cooling coils mounted within the pressure vessel. This unit is electrically powered and automatically controlled by means of a pressure switch.

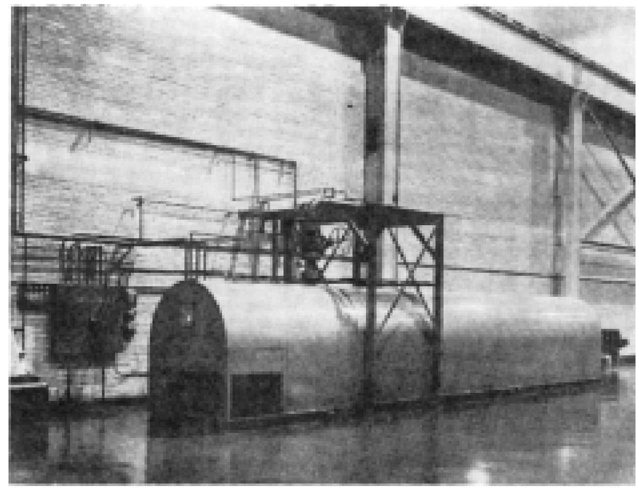
A-1-9.6.2 A special relief valve (in addition to code requirements) can be provided for controlled bleed-off at a pressure below the setting of the main safety valve.

A-1-10.1 Piping should be installed in accordance with good commercial practices and the equipment manufacturer's recommendations.

All piping should be laid out to reduce friction losses to a reasonable minimum and care should be taken to avoid possible restrictions due to foreign matter or faulty fabrication.

Examples are hot dipped galvanized inside and out or stainless steel.

FIGURE A-1-9.6 A typical low-pressure storage facility.



A-1-10.1.1 The use of flexible piping or hose in a carbon dioxide system introduces a number of things to be considered that do not affect rigid piping. One of these is the nature of any changes of direction. The minimum radius of curvature for any flexible hose to be used in a carbon dioxide system should not be less than indicated by the manufacturer's data, usually shown in the listing information for a particular system. Other areas of concern are resistance to the effects of vibration, flexure, tension, torsion, temperature, flame, compression, and bending. It is also necessary for the hose to have the strength to contain the carbon dioxide during discharge and to be made of materials that will be resistant to atmospheric corrosion.

A-1-10.2 ANSI B31.1, *Power Piping Code,* should be consulted for guidance on this matter.

A-1-10.4.4 Formerly, a plus sign following the orifice code number indicated equivalent diameters $^1/_{64}$ in. (0.4 mm) greater than that indicated by the numbering system [e.g., No. 4 indicated an equivalent diameter of $^4/_{32}$ in. (3.18 mm); a No. 4 +, $^9/_{64}$ in. (3.57 mm)].

A-1-10.5 The problem of computing pipe sizes for carbon dioxide systems is complicated by the fact that the pressure drop is nonlinear with respect to the pipeline. Carbon dioxide leaves the storage vessel as a liquid at saturation pressure. As the pressure drops because of pipeline friction, the liquid boils so as to produce a mixture of liquid and vapor. Because of this the volume of the flowing mixture increases and the velocity of flow must also increase. Thus, the pressure drop per unit length of pipe is greater near the end of the pipeline than it is at the beginning.

Pressure drop information for designing piping systems can best be obtained from curves of pressure versus equivalent length for various flow rates and pipe sizes. Such curves can be plotted using the theoretical equation given in 1-10.5.1. The *Y* and *Z* factors in the equation depend on storage pressure and line pressure. These can be evaluated from the following equations:

$$Y = -\int_{P_1}^{P} \rho \, dP$$

$$Z = -\int_{\rho_1}^{\rho} \frac{d\rho}{\rho} = \ln\frac{\rho_1}{\rho}$$

where:

P_1 = storage pressure (psia)
P = pressure at end of pipeline (psia)
ρ_1 = density at pressure P_1 (lb/ft^3)
ρ = density at pressure P (lb/ft^3)
ln = natural logarithm

For SI units, the following equation applies:

$$Y = -\int_{P_1}^{P} \rho\, dP$$

$$Z = -\int_{\rho_1}^{\rho} \frac{d\rho}{\rho} = \ln\frac{\rho_1}{\rho}$$

where:

P_1 = storage pressure (kPa)
P = pressure at end of pipeline (kPa)
ρ_1 = density at pressure P_1 (kg/m^3)
ρ = density at pressure P (kg/m^3)
ln = natural logarithm

In the preceding equations, Z is a dimensionless ratio. The Y factor has units of pressure times density and will therefore change the system of units.

The storage pressure is an important factor in carbon dioxide flow. In low-pressure storage the starting pressure in the storage vessel will recede to a lower level depending on whether all or only a part of the supply is discharged. Because of this, the average pressure during discharge will be about 285 psi (1965 kPa). The flow equation is based on absolute pressure; therefore, 300 psia (2068 kPa) is used for calculations involving low-pressure systems.

In high-pressure systems, the storage pressure depends on the ambient temperature. Normal ambient temperature is assumed to be 70°F (21°C). For this condition the average pressure in the cylinder during discharge of the liquid portion will be about 750 psia (5171 kPa). This pressure has therefore been selected for calculations involving high-pressure systems.

Using the base pressures of 300 psia (2068 kPa) and 750 psia (5171 kPa), values have been determined for the Y and Z factors in the flow equation. These are listed in Tables A-1-10.5(a) and A-1-10.5(b).

Table A-1-10.5(a) Values of *Y* and *Z* for 300-psia Initial Storage Pressure

Pressure		Y									
(psia)	Z	0	1	2	3	4	5	6	7	8	9
300	0.000	0	0	0	0	0	0	0	0	0	0
290	0.135	596	540	483	426	367	308	248	187	126	63
280	0.264	1119	1070	1020	969	918	866	814	760	706	652
270	0.387	1580	1536	1492	1448	1402	1357	1310	1263	1216	1168
260	0.505	1989	1950	1911	1871	1831	1790	1749	1708	1666	1623
250	0.620	2352	2318	2283	2248	2212	2176	2139	2102	2065	2027
240	0.732	2677	2646	2615	2583	2552	2519	2487	2454	2420	2386
230	0.841	2968	2940	2912	2884	2855	2826	2797	2768	2738	2708
220	0.950	3228	3204	3179	3153	3128	3102	3075	3049	3022	2995
210	1.057	3462	3440	3418	3395	3372	3349	3325	3301	3277	3253
200	1.165	3673	3653	3632	3612	3591	3570	3549	3528	3506	3485
190	1.274	3861	3843	3825	3807	3788	3769	3750	3731	3712	3692
180	1.384	4030	4014	3998	3981	3965	3948	3931	3914	3896	3879
170	1.497	4181	4167	4152	4138	4123	4108	4093	4077	4062	4046
160	1.612	4316	4303	4291	4277	4264	4251	4237	4223	4210	4196
150	1.731	4436	4425	4413	4402	4390	4378	4366	4354	4351	4329

Table A-1-10.5(b) Values of *Y* and *Z* for 750-psia Initial Storage Pressure

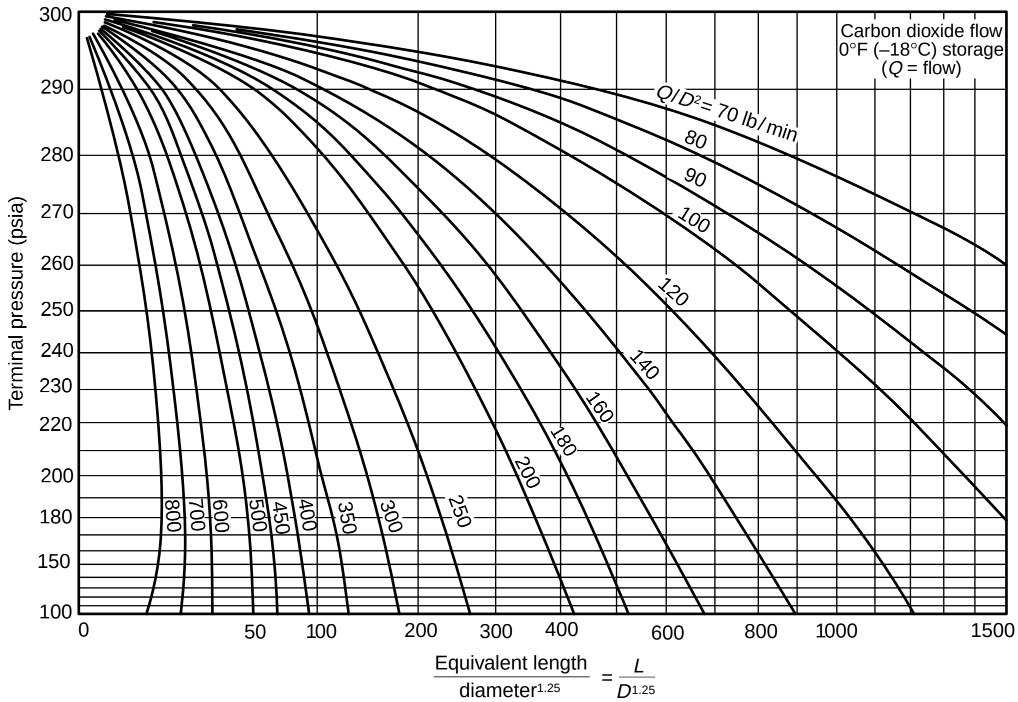
Pressure (psia)	*Z*	*Y*									
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
750	0.000	0	0	0	0	0	0	0	0	0	0
740	0.038	497	448	399	350	300	251	201	151	101	51
730	0.075	975	928	881	833	786	738	690	642	594	545
720	0.110	1436	1391	1345	1299	1254	1208	1161	1115	1068	1022
710	0.143	1882	1838	1794	1750	1706	1661	1616	1572	1527	1481
700	0.174	2314	2271	2229	2186	2143	2100	2057	2013	1970	1926
690	0.205	2733	2691	2650	2608	2567	2525	2483	2441	2399	2357
680	0.235	3139	3099	3059	3018	2978	2937	2897	2856	2815	2774
670	0.265	3533	3494	3455	3416	3377	3338	3298	3259	3219	3179
660	0.296	3916	3878	3840	3802	3764	3726	3688	3649	3611	3572
650	0.327	4286	4250	4213	4176	4139	4102	4065	4028	3991	3953
640	0.360	4645	4610	4575	4539	4503	4467	4431	4395	4359	4323
630	0.393	4993	4959	4924	4890	4855	4821	4786	4751	4716	4681
620	0.427	5329	5296	5263	5229	5196	5162	5129	5095	5061	5027
610	0.462	5653	5621	5589	5557	5525	5493	5460	5427	5395	5362
600	0.498	5967	5936	5905	5874	5843	5811	5780	5749	5717	5685
590	0.535	6268	6239	6209	6179	6149	6119	6089	6058	6028	5997
580	0.572	6560	6531	6502	6473	6444	6415	6386	6357	6328	6298
570	0.609	6840	6812	6785	6757	6729	6701	6673	6645	6616	6588
560	0.646	7110	7084	7057	7030	7003	6976	6949	6922	6895	6868
550	0.683	7371	7345	7320	7294	7268	7242	7216	7190	7163	7137
540	0.719	7622	7597	7572	7548	7523	7498	7472	7447	7422	7396
530	0.756	7864	7840	7816	7792	7768	7744	7720	7696	7671	7647
520	0.792	8098	8075	8052	8028	8005	7982	7958	7935	7911	7888
510	0.827	8323	8301	8278	8256	8234	8211	8189	8166	8143	8120
500	0.893	8540	8519	8497	8476	8454	8433	8411	8389	8367	8345
490	0.898	8750	8730	8709	8688	8667	8646	8625	8604	8583	8562
480	0.933	8953	8933	8913	8893	8873	8852	8832	8812	8791	8771
470	0.967	9149	9129	9110	9091	9071	9052	9032	9012	8993	8973
460	1.002	9338	9319	9301	9282	9263	9244	9225	9206	9187	9168
450	1.038	9520	9502	9484	9466	9448	9430	9412	9393	9375	9356
440	1.073	9697	9697	9662	9644	9627	9609	9592	9574	9556	9538
430	1.109	9866	9850	9833	9816	9799	9782	9765	9748	9731	9714
420	1.146	10030	10014	9998	9982	9966	9949	9933	9916	9900	9883
410	1.184	10188	10173	10157	10141	10126	10110	10094	10078	10062	10046
400	1.222	10340	10325	10310	10295	10280	10265	10250	10234	10219	10204
390	1.262	10486	10472	10458	10443	10429	10414	10399	10385	10370	10355
380	1.302	10627	10613	10599	10585	10571	10557	10543	10529	10515	10501
370	1.344	10762	10749	10735	10722	10708	10695	10681	10668	10654	10641
360	1.386	10891	10878	10866	10853	10840	10827	10814	10801	10788	10775
350	1.429	11015	11003	10991	10978	10966	10954	10941	10929	10916	10904
340	1.473	11134	11122	11110	11099	11087	11075	11063	11051	11039	11027
330	1.518	11247	11236	11225	11214	11202	11191	11180	11168	11157	11145
320	1.564	11356	11345	11334	11323	11313	11302	11291	11280	11269	11258
310	1.610	11459	11449	11439	11428	11418	11408	11398	11387	11377	11366
300	1.657	11558	11548	11539	11529	11519	11509	11499	11489	11469	11469

For practical application it is desirable to plot curves for each pipe size that can be used. However, it will be noted that the flow equation can be rearranged as shown in the following equation:

$$\frac{L}{D^{1.25}} = \frac{3647\,Y}{\left(\frac{Q}{D^2}\right)^2} - 8.08Z$$

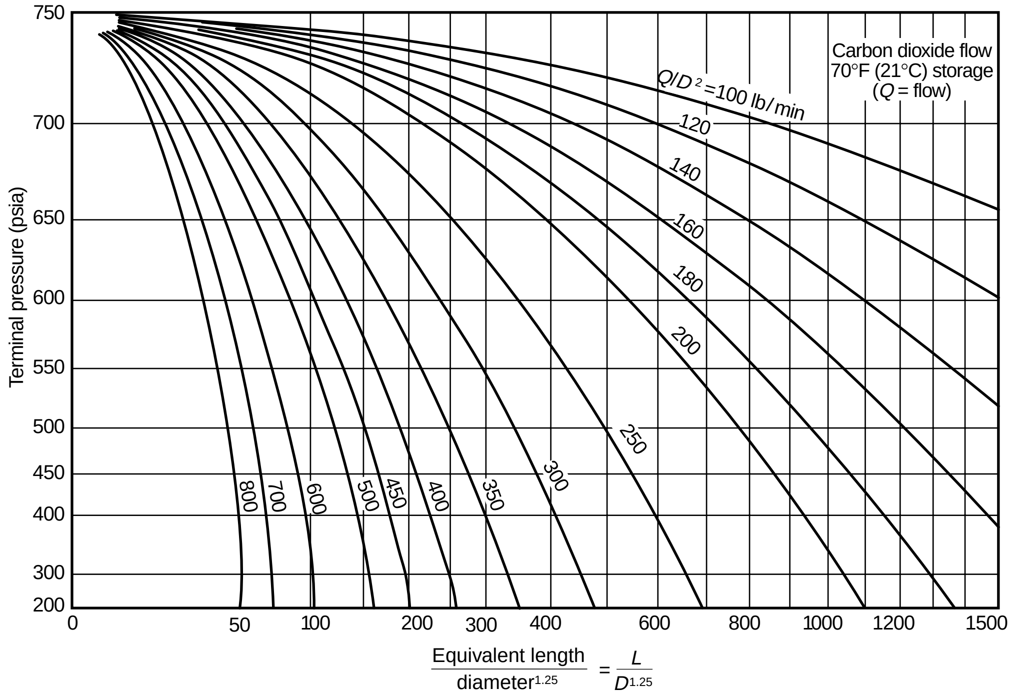
Thus by plotting values of $L/D^{1.25}$ and Q/D^2, it is possible to use one family of curves for any pipe size. Figure A-1-10.5(a) gives flow information for 0°F (–18°C) storage temperature on this basis. Figure A-1-10.5(b) gives similar information for high-pressure storage at 70°F (21°C). For an inside pipe diameter of exactly 1 in., D^2 and $D^{1.25}$ reduce to unity and cancel out. For other pipe sizes it is necessary to convert the flow rate and equivalent length by dividing or multiplying by these factors. Table A-1-10.5(c) gives values for D.

FIGURE A-1-10.5(a) Pressure drop in pipeline for 300-psia (2068-kPa) storage pressure.



For SI units, 1 psia = 6.89 kPa; 1 lb/min = 0.454 kg/min.

FIGURE A-1-10.5(b) Pressure drop in pipeline for 750-psia (5171-kPa) storage pressure.



For SI units, 1 psia = 6.89 kPa; 1 lb/min = 0.454 kg/min.

Table A-1-10.5(c) Values of $D^{1.25}$ and D^2 for Various Pipe Sizes

Pipe Size and Type	Inside Diameter (in.)	$D^{1.25}$	D^2
$^1/_2$ Std	0.622	0.5521	0.3869
$^1/_4$ Std.	0.824	0.785	0.679
1 Std.	1.049	1.0615	1.100
1 XH	0.957	0.9465	0.9158
$1^1/_4$ Std.	1.380	1.496	1.904
$1^1/_4$ XH	1.278	1.359	1.633
$1^1/_2$ Std.	1.610	1.813	2.592
$1^1/_2$ XH	1.500	1.660	2.250
2 Std.	2.067	2.475	4.272
2 XH	1.939	2.288	3.760
$2^1/_2$ Std.	2.469	3.09	6.096
$2^1/_2$ XH	2.323	2.865	5.396
3 Std.	3.068	4.06	9.413
3 XH	2.900	3.79	8.410
4 Std.	4.026	5.71	16.21
4 XH	3.826	5.34	14.64
5 Std.	5.047	7.54	25.47
5 XH	4.813	7.14	23.16
6 Std.	6.065	9.50	36.78
6 XH	5.761	8.92	33.19

These curves can be used for designing systems or for checking possible flow rates. For example, assume the problem is to determine the terminal pressure for a low-pressure system consisting of a single 2-in. Schedule 40 pipeline with an equivalent length of 500 ft and a flow rate of 1000 lb/min. The flow rate and the equivalent length must be converted to terms of Figure A-1-10.5(a) as follows:

$$\frac{Q}{D^2} = \frac{1000}{4.28} = 234 \text{ lb/min} \cdot D^2$$

$$\frac{L}{D^{1.25}} = \frac{500}{2.48} = 201 \text{ ft} \cdot D^{1.25}$$

From Figure A-1-10.5(a) the terminal pressure is found to be about 228 psia at the point where the interpolated flow rate of 234 lb/min intersects the equivalent length scale at 201 ft.

If this line terminates in a single nozzle, the equivalent orifice area must be matched to the terminal pressure in order to control the flow rate at the desired level of 1000 lb/min. Referring to Table 1-10.5.2, it will be noted that the discharge rate will be 1410 lb/min·in.^{2} of equivalent orifice area when the orifice pressure is 230 psia. The required equivalent orifice area of the nozzle is thus equal to the total flow rate divided by the rate per square inch.

$$\text{Equivalent orifice area} = \frac{1000 \text{ lb/min}}{1410 \text{ lb/min} \cdot \text{in}^2} = 0.709 \text{ in.}^2$$

From a practical viewpoint the designer would select a standard nozzle having an equivalent area nearest to the computed area. If the orifice area happened to be a little larger, the actual flow rate would be slightly higher and the terminal pressure would be somewhat lower than the estimated 228 psia (1572 kPa).

If, in the previous example, instead of terminating with one large nozzle, the pipeline branches into two smaller pipelines, it will be necessary to determine the pressure at the end of each branch line. To illustrate this procedure, assume that the branch lines are equal and consist of 1 ½-in. Schedule 40 pipe with equivalent lengths of 200 ft (61 m) and the flow in each branch line is to be 500 lb/min (227 kg/min). Converting to terms used in Figure A-1-10.5(a):

$$\frac{Q}{D^2} = \frac{500}{2.592} = 193\ \text{lb/min} \cdot D^2$$

$$\frac{L}{D^{1.25}} = \frac{200}{1.813} = 110\ \text{ft}/D^{1.25}$$

From Figure A-1-10.5(a) the starting pressure of 228 psia (1572 kPa) (terminal pressure of main line) intersects the flow rate line [193 lb/min (87.6 kg/min)] at an equivalent length of about 300 ft (91.4 m). In other words, if the branch line started at the storage vessel, the liquid carbon dioxide would have to flow through 300 ft (91.4 m) of pipeline before the pressure drops to 228 psia (1572 kPa). This length thus becomes the starting point for the equivalent length of the branch line. The terminal pressure of the branch line is then found to be 165 psia (1138 kPa) at the point where the 193 lb/min (87.6 kg/min) flow rate line intersects the total equivalent length line of 410 ft (125 m) (300 ft + 110 ft). With this new terminal pressure [165 psia (1138 kPa)] and flow rate [500 lb/min (227 kg/min)] the required equivalent nozzle area at the end of each branch line will be approximately 0.567 in.^{2} (366 mm^2). It will be noted that this is about the same as the single large nozzle example, except that the discharge rate is cut in half due to the reduced pressure.

The design of the piping distribution system is based on the flow rate desired at each nozzle. This in turn determines the required flow rate in the branch lines and the main pipeline. From practical experience it is possible to estimate the approximate pipe sizes required. The pressure at each nozzle can then be determined from suitable flow curves. The nozzle orifice sizes are then selected on the basis of nozzle pressure from the data given in 1-10.5.2.

In high-pressure systems the main header is supplied by a number of separate cylinders. The total flow is thus divided by the number of cylinders to obtain the flow rate from each cylinder. The flow capacity of the cylinder valve and the connector to the header will vary with each manufacturer, depending on design and size. For any particular valve, dip tube, and connector assembly, the equivalent length can be determined in terms of feet of standard pipe size. With this information the flow equation can be used to prepare a curve of flow rate versus pressure drop. This provides a convenient method of determining header pressure for a specific valve and connector combination.

Tables A-1-10.5(d) and A-1-10.5(e) list the equivalent lengths of pipe fittings for determining the equivalent length of piping systems. Table A-1-10.5(d) is for threaded joints, and Table A-1-10.5(e) is for welded joints. Both tables were computed for Schedule 40 pipe sizes; however, for all practical purposes the same figures can also be used for Schedule 80 pipe sizes.

Table A-1-10.5(d) Equivalent Length in Feet of Threaded Pipe Fitting

Pipe Size (in.)	Elbow Std. 45°	Elbow Std. 90°	Elbow 90° Long Radius & Tee Thru Flow	Tee Side	Union Coupling or Gate Valve
3/8	0.6	1.3	0.8	2.7	0.3
1/2	0.8	1.7	1.0	3.4	0.4
3/4	1.0	2.2	1.4	4.5	0.5
1	1.3	2.8	1.8	5.7	0.6
1 1/4	1.7	3.7	2.3	7.5	0.8
1 1/2	2.0	4.3	2.7	8.7	0.9
2	2.6	5.5	3.5	11.2	1.2
2 1/2	3.1	6.6	4.1	13.4	1.4
3	3.8	8.2	5.1	16.6	1.8
4	5.0	10.7	6.7	21.8	2.4
5	6.3	13.4	8.4	27.4	3.0
6	7.6	16.2	10.1	32.8	3.5

For SI units, 1 ft = 0.3048 m.

Table A-1-10.5(e) Equivalent Length in Feet of Welded Pipe Fitting

Pipe Size (in.)	Elbow Std. 45°	Elbow Std. 90°	Elbow 90° Long Radius & Tee Thru Flow	Tee Side	Gate Valve
3/8	0.2	0.7	0.5	1.6	0.3
1/2	0.3	0.8	0.7	2.1	0.4
3/4	0.4	1.1	0.9	2.8	0.5
1	0.5	1.4	1.1	3.5	0.6
1 1/4	0.7	1.8	1.5	4.6	0.8
1 1/2	0.8	2.1	1.7	5.4	0.9
2	1.0	2.8	2.2	6.9	1.2
2 1/2	1.2	3.3	2.7	8.2	1.4
3	3.8	4.1	3.3	10.2	1.8
4	2.0	5.4	4.4	13.4	2.4
5	2.5	6.7	5.5	16.8	3.0
6	3.0	8.1	6.6	20.2	3.5

For SI units, 1 ft = 0.3048 m.

For nominal changes in elevation of piping, the change in head pressure is negligible. However, if there is a substantial change in elevation, this factor should be taken into account. The head pressure correction per foot of elevation depends on the average line pressure where the elevation takes place because the density changes with pressure. Correction factors are given in Tables A-1-10.5(f) and A-1-10.5(g) for low-pressure and high-pressure systems respectively.

The correction is subtracted from the terminal pressure when the flow is upward and is added to the terminal pressure when the flow is downward.

Table A-1-10.5(f) Elevation Correction Factors for Low-Pressure System

Average Line Pressure		Elevation Correction	
psia	**kPa**	**psi/ft**	**kPa/m**
300	2068	0.443	10.00
280	1930	0.343	7.76
260	1792	0.265	5.99
240	1655	0.207	4.68
220	1517	0.167	3.78
200	1379	0.134	3.03
180	1241	0.107	2.42
160	1103	0.085	1.92
140	965	0.067	1.52

Table A-1-10.5(g) Elevation Correction Factors for High-Pressure System

Average Line Pressure		Elevation Correction	
psia	**kPa**	**psi/ft**	**kPa**
750	5171	0.352	7.96
700	4826	0.300	6.79
650	4482	0.255	5.77
600	4137	0.215	4.86
550	3792	0.177	4.00
500	3447	0.150	3.39
450	3103	0.125	2.83
400	2758	0.105	2.38
350	2413	0.085	1.92
300	2068	0.070	1.58

A-1-10.5.1 For further explanation see A-1-10.5.

A-1-11.1 An inspection is a "quick check" to give reasonable assurance that the extinguishing system is fully charged and operable is done by seeing that the system is in place, that it has not been activated or tampered with, and that there is no obvious physical damage or condition to prevent operation. As a minimum, the inspection should determine the following:

(1) High-pressure cylinders are in place and properly secured.
(2) For low-pressure storage unit, that pressure gauge shows normal pressure, that tank shutoff valve is open, and that pilot pressure supply valve is open. Liquid level gauge should be observed. If at any time a container shows a loss of more than 10 percent, it should be refilled, unless the minimum gas requirements are still provided.
(3) Carbon dioxide storage is connected to discharge piping and actuators.
(4) All manual actuators are in place and tamper seals are intact.
(5) Nozzles are connected, properly aligned, and free from obstructions and foreign matter.
(6) Detectors are in place and free from foreign matter and obstructions.
(7) System control panel is connected and showing "normal-ready" condition.

A-1-11.3 Manufacturer's maintenance procedure should be guided by the following outline.

(a) System

(1) Check overall physical appearance
(2) Disarm system prior to test

(b) Hazard

(1) Size
(2) Configuration
(3) Uncloseable openings
(4) Fuels
(5) Other aspects that could impact effectiveness of the extinguishing systems

(c) Supervised circuits

(1) Exercise all functions
(2) Check all electrical or pneumatic supervisory circuits for proper operation

(d) Control panel

(1) Exercise all functions
(2) Check supervision, if applicable, of each circuit (including releasing devices) as recommended by the manufacturer

(e) Power supply

(1) Check routing, circuit breakers, fuses, disconnects

(f) Emergency power

(1) Check battery condition
(2) Check charger operation; check fuse
(3) Check automatic changeover
(4) Check maintenance of generator (if one exists)

(g) Detectors

(1) Test each detector using heat or smoke or manufacturer's approved test device *(See NFPA 72, National Fire Alarm Code.)*
(2) Electric type
  a. Clean and adjust smoke detector and check sensitivity
  b. Check wiring condition
(3) Pneumatic type
  a. Check tightness of tubing and operation of mercury checks, using manometer

(h) Time delay

(1) Exercise functions
(2) Check time limit
(3) Check that timer will complete its cycle even though wiring between it and the detector circuit is interrupted

(i) Alarms

(1) Test for operation (audible and visual)
(2) Check to see that warning signs are properly displayed

(j) Selector (directional) valves

(1) Exercise functions
(2) Reset properly

(k) Release devices

(1) Check for complete closure of dampers
(2) Check doors; check for any doors blocked open

(l) Equipment shutdown

(1) Test shutdown function
(2) Check adequacy (all necessary equipment included)

(m) Manual releases

(1) Mechanical type

a. Check pull, force, and length of pull required
b. Operate and adjust all devices
c. Check tightness of connectors
d. Check condition of conduit
e. Check condition and operation of corner pulleys

(2) Electric type

a. Test manual release
b. Check that covers are in place

(3) Check pneumatic releases
(4) Check accessibility during fire
(5) Separate main and reserve manual pulls that require only one operation, to obtain discharge of either main or reserve supply of gas
(6) Clearly mark and identify all manual releases

(n) Piping

(1) Check security; check that piping is adequately supported
(2) Check condition; check for any corrosion

(o) Nozzles

(1) Check orientation and orifice size; make sure it is unchanged from original design
(2) Check cleanliness
(3) Check security
(4) Check seals where needed

(p) Containers

(1) Check physical condition; check for any sign of corrosion
(2) Check the contents for weight by acceptable methods for each cylinder or low-pressure tank (If the contents are more than 10 percent below the normal capacity, refilling is required. Proper operation of the liquid level gauge should be verified.)
(3) Check that cylinders are securely held in position
(4) Check hydrostatic test date
(5) Check cylinder connectors for integrity and condition
(6) Check weights and cables of mechanical release system
(7) Release devices; check for proper arrangement and security
(8) Check explosive release devices; check replacement date and check condition

(q) Test

(1) Perform recommended discharge tests when there is any question about the adequacy of the system
(2) Perform recommended full discharge test when cylinder hydrostatic test is required

(r) Return all parts of system to full service

(s) Give Certificate of Inspection to owner

Regular service contracts with the manufacturer or installing company are recommended. Work should be performed by personnel thoroughly trained and regularly engaged in providing such service.

A-1-11.3.7 Due to the nature of the hazard or environmental conditions, more frequent tests could be necessary.

A-2-1 From a performance viewpoint, a total flooding system is designed to develop a carbon dioxide concentration that will extinguish fires in combustible materials located in an enclosed space. It should also maintain an effective concentration until the maximum temperature has been reduced below the reignition point.

For many materials there can be a need to maintain a concentration of carbon dioxide to allow for cooling. Sheetmetal ducting that can be heated quickly and substantially is an example of where maintaining the concentration for cooling can be necessary.

The concentration of carbon dioxide required will depend on the type of combustible material involved. This has been accurately determined for most surface-type fires, particularly those involving liquids and gases. Most of this information has been obtained by the U.S. Bureau of Mines. For deep-seated fires the critical concentration required for extinguishment is less definite and has in general been established by practical test work.

The volume of carbon dioxide required to develop a given concentration will be greater than the final volume remaining in the enclosure. In most cases carbon dioxide should be applied in a manner that promotes progressive mixing of the atmosphere. The displaced atmosphere is exhausted freely from the enclosure through various small openings or through special vents, as carbon dioxide is injected. Some carbon dioxide is therefore lost with the vented atmosphere. This loss becomes greater at high concentrations. This method of application is called "free-efflux" flooding.

Under the above conditions the volume of carbon dioxide required to develop a given concentration in the atmosphere is expressed by the following equations:

$$e^{x} = \frac{100}{100 - \%\ CO_2}$$

or

$$X = 2.303 \log_{10}\frac{100}{100 - \%\ CO_2}$$

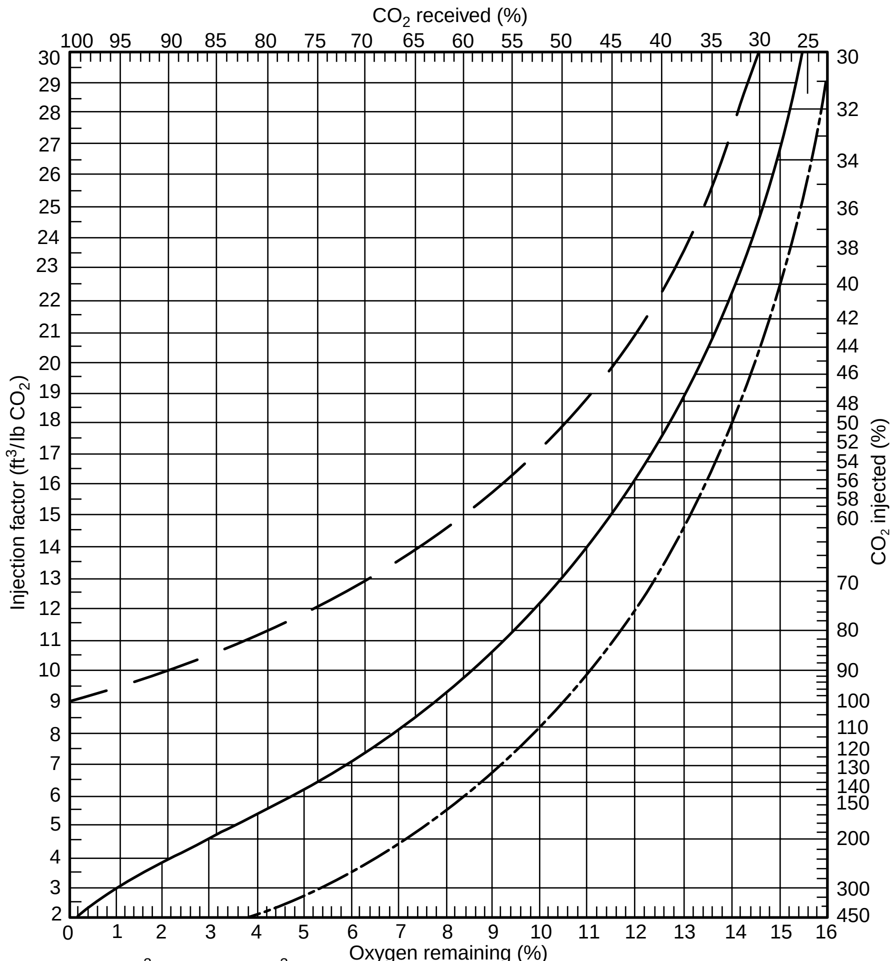
where:

X = volume of carbon dioxide added per volume of space
e = 2.718 (natural logarithm base)

From the preceding formula, the volume of carbon dioxide required to develop a given concentration can be calculated. This quantity of carbon dioxide can be expressed in terms of cubic feet of space protected per pound of carbon dioxide or pounds of carbon dioxide per 100 ft^3 (0.28 m^3). These results have been calculated and plotted for easy reference.

One such curve is shown on Figure A-2-1(a). On this curve it was assumed that the carbon dioxide would expand to a volume of 9 ft^3/lb (0.56 m^3/kg) at a temperature of 86°F (30°C). Similar information is also given on Figure A-2-1(b) in the form of a nomograph. In this case, it was assumed that the final temperature would be about 50°F (10°C), giving a volume of 8.35 ft^3/lb (0.52 m^3/kg) of carbon dioxide. The nomograph will therefore indicate somewhat greater quantities of carbon dioxide for the same concentration. The data in Chapters 1 through 5 are based on an expansion of 9 ft^3/lb (0.56 m^3/kg) of carbon dioxide. It should be noted that, in some well-insulated enclosures, such as freezers and anechoic test chambers, complete and rapid vaporization of the carbon dioxide discharge might not occur. For unusual cases like these, the manufacturer should be consulted.

FIGURE A-2-1(a) Carbon dioxide requirements for inert atmospheres [based on a carbon dioxide expansion of 9 ft^3/lb (0.56 m^3/kg)]. The top curve (complete displacement) and the bottom curve (no efflux) are theoretical extremes plotted for comparative purposes only. The middle curve (free efflux), the curve to be used, must be tempered by proper safety factors.



For SI units, 1 ft^3/lb = 0.0624 m^3/kg.

The time required for cooling below the reignition point depends on the type of fire and the insulating effect of the combustible material. For surface-type fires, it can be assumed that the fire will be extinguished almost as soon as the desired concentration is obtained. The enclosure should of course retain a reasonable concentration for some time after the carbon dioxide has been injected. This provides an additional factor of safety.

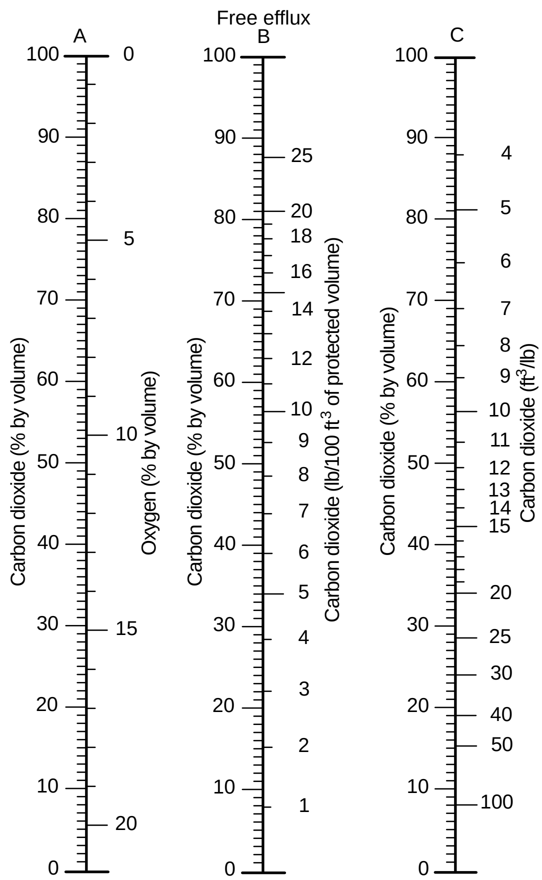
For deep-seated fires, the concentration should be maintained for a longer period of time because the hot material will cool off slowly. The cooling time will vary considerably, depending on the nature of the material. Because the cooling time will tend to be long, it is necessary to give considerable attention to the problem of maintaining the extinguishing concentration. Surface fires and deep-seated fires are therefore basically different and should be approached with somewhat different objectives in mind.

Examples of hazards protected by total flooding systems include rooms, vaults, enclosed machines, ducts, ovens, containers, and the contents thereof.

A-2-2.1.1 Where two or more hazards by reason of their proximity are expected to be simultaneously involved in fire, each hazard should be either protected with an individual system, with the combination arranged to operate simultaneously, or protected with a single system that should be sized and arranged to discharge on all potentially involved hazards simultaneously.

A-2-2.1.2 For deep-seated fires, low-level openings should be avoided regardless of the relief requirements in order to maintain a concentration for as long as necessary. Relief vents under these conditions should be as high within the enclosure as possible.

FIGURE A-2-1(b) Carbon dioxide requirement for inert atmospheres [based on a carbon dioxide expansion of 8.35 ft^3/lb (0.52 m^3/kg)]. Column A shows oxygen content of air–carbon dioxide mixtures; Column B shows weights of carbon dioxide in air–carbon dioxide mixtures; and Column C shows ft^3/lb of carbon dioxide in air–carbon dioxide mixtures.



For SI units, 1 lb/ft^3 = 16.018 kg/m^3; 1 ft^3/lb = 0.0624 m^3/kg.

A-2-2.3 Practically all hazards that contain materials that produce surface fires can contain varying amounts of materials that could produce deep-seated fires. Proper selection of the type of fire that the system should be designed to extinguish is important and, in many cases, will require sound judgment after careful consideration of all the various factors involved.

Basically, such a decision will be based on answers to the following questions:

(a) Will a deep-seated fire develop, considering the speed of detection and application of the contemplated system?

(b) If a deep-seated fire does develop, will it be of a minor nature, will the circumstances be such that it will not cause a reflash of the material that produced the surface fire, and can arrangements be set up to put it out manually after the carbon dioxide discharge before it causes trouble?

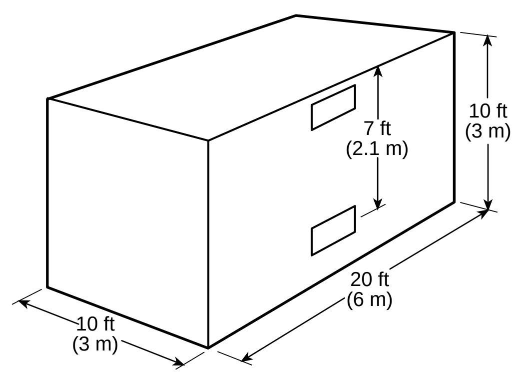
(c) Are the values involved, or the importance of equipment involved, such that the ultimate protection is justified regardless of the extra cost of providing a system that will extinguish deep-seated fires?

It will be seen that, with a remote possibility of a deep-seated fire causing trouble, there are many cases where taking this remote risk can be justified, and a system to extinguish surface fires can properly be selected. As an example, electrical transformers and other oil-filled electrical equipment have quite commonly been treated as producing surface fires, although there can be a chance that a heated core will produce a deep-seated fire in electrical insulation. On the other hand, the importance of some of the electrical equipment to production can be such that treating the hazard as a deep-seated fire will be justified.

Often a decision will involve consultation with the authority having jurisdiction and with the owner and the engineers of the company supplying the equipment. The cost comparison between a system that is designed to extinguish a surface fire and one designed to extinguish a deep-seated fire can be the deciding factor. In all cases, it is advisable that all interested parties are fully aware of any risks involved if the system is designed to extinguish only a surface fire and of the additional costs that are involved if a system is designed to extinguish a deep-seated fire.

A-2-3 The requirements given in Section 2-3 take into account the various factors that could affect the performance of the system. The question on limitation of unclosable openings is frequently encountered and is difficult to answer in precise terms. Because surface fires are normally of the type that can be extinguished with local application methods, a choice between total flooding or local application can be made on the basis of quantity of carbon dioxide required. This is illustrated in the following examples for the enclosure diagrammed in Figure A-2-3(a).

FIGURE A-2-3(a) Diagram of enclosure for Examples 1 and 2.



Example 1

Volume of space	2000 ft^3
Type of combustible	Gasoline
Ventilation openings	
Air outlet near ceiling	5 ft^2
Air inlet centered at 7 ft below ceiling	5 ft^2
Design concentration *(see Table 2-3.2.1)*	34% CO_2
Volume factor *[see Table 2-3.3(a)]*	18 ft^3/lb CO_2
Basic quantity of CO_2	$\frac{2000}{18} = 111$ lb

Material conversion factor *(see 2-3.4)*: Because the design concentration is not over 34 percent, no conversion is needed.

Special conditions *(see 2-3.5)*: Carbon dioxide will be lost through the bottom opening while air enters through the top opening. From Figure A-2-3(b) the loss rate will be 17 lb/min · ft^2 for a concentration of 34 percent at 7 ft.

Additional carbon dioxide for openings *(see 2-3.5.1):*

$$17 \times 5 = 85 \text{ lb}$$

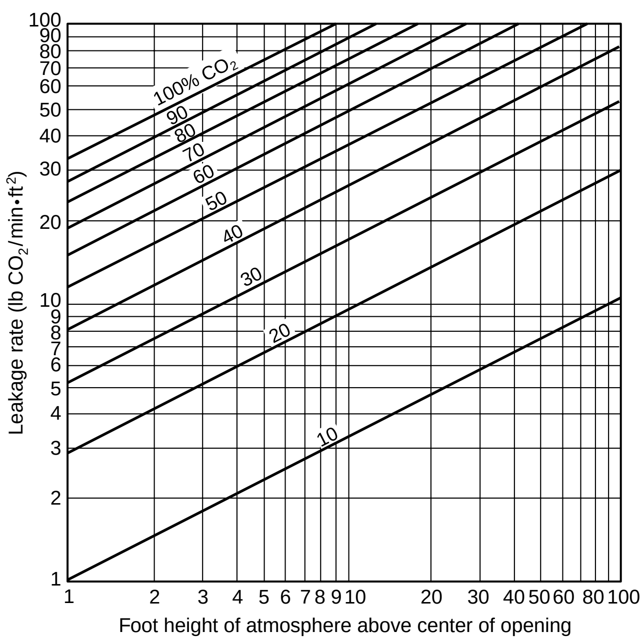
Total carbon dioxide required:

$$111 + 85 = 196 \text{ lb}$$

Example 1 (SI units)

Volume of space	54 m^3
Type of combustible	Gasoline
Ventilation openings	
Air outlet near ceiling	0.5 m^2
Air inlet centered at 2.1 m below ceiling	0.5 m^2
Design concentration *(see Table 2-3.2.1)*	34% CO_2
Volume factor *[see Table 2-3.3(a)]*	1.11 m^3/kg CO_2
Basic quantity of CO_2	$\frac{54}{1.11} = 48.6$ kg

FIGURE A-2-3(b) Calculated CO_2 loss rate based on an assumed 70°F (21°C) temperature within the enclosure and 70°F (21°C) ambient outside.



For SI units, 1 ft = 0.305 m; 1 lb/min•ft^2 = 4.89 kg/min•m^2.

Material conversion factor *(see 2-3.4)*: Because the design concentration is not over 34 percent no conversion is needed.

Special conditions *(see 2-3.5)*: Carbon dioxide will be lost through the bottom opening while air enters through the top opening. From Figure A-2-3(b), the loss rate will be 85 kg/min·m^2 for a concentration of 34 percent, at 2.1 m.

Additional carbon dioxide for openings *(see 2-3.5.1):*

$$85 \times 0.5 = 42.5 \text{ kg}$$

Total carbon dioxide required:

$$48.6 + 52.5 = 91.1 \text{ kg}$$

Example 2

Volume of space	2000 ft^3
Type of combustible	Gasoline
Ventilation openings	
Air outlet near ceiling	10 ft^2
Air inlet centered at 7 ft below ceiling	10 ft^2
Design concentration *(see Table 2-3.2.1)*	34% CO_2
Basic quantity of CO_2	$\frac{2000}{18} = 111$ lb

Additional carbon dioxide for openings *(see 2-3.5.1):*

$$17 \times 10 = 170 \text{ lb}$$

Total carbon dioxide required:

$$111 + 170 = 281 \text{ lb}$$

Because the compensation exceeds the basic flooding requirement *(see 2-2.1.1),* refer to Chapter 3. Using the rate-by-volume method, 3-5.3.1 states that the rate of discharge can be reduced to not less than 0.25 lb/min·ft^3 for actual walls completely surrounding the hazard enclosure. The openings can be calculated as a percent of wall enclosure to determine a proper discharge rate. The total opening area is 20 ft^2.

Total wall area:

$$(10 + 10 + 20 + 20) \times 10 = 600 \text{ ft}^2$$

Rate of discharge:

$$\frac{20}{600} \times (1 - 0.25) + 0.25 = 0.27 \text{ lb/min} \cdot \text{ft}^3$$

Total rate of discharge:

$$0.27 \times 2000 = 540 \text{ lb/min}$$

Quantity of carbon dioxide:

$$\frac{540}{2} = 270 \text{ lb}$$

Local application requires a liquid discharge for 30 seconds. In the case of high-pressure storage, the quantity of carbon dioxide must be increased by 40 percent *(see 3-3.1.1)* to assure a 30-second discharge of liquid. When the openings are increased to 20 ft^2 each, local application techniques will require less carbon dioxide than total flooding for both low-pressure and high-pressure storage.

Example 2 (SI units)

Volume of space	54 m^3
Type of combustible	Gasoline
Ventilation openings	
Air outlet near ceiling	1.0 m^2
Air inlet centered at 2.1 m below ceiling	1.0 m^2
Design concentration *(see Table 2-3.2.1)*	34% CO_2
Basic quantity of CO_2	$\frac{54}{1.11} = 48.6$ kg

Additional carbon dioxide for openings *(see 2-3.5.1):*

$$85 \times 1.0 = 85 \text{ kg}$$

Total carbon dioxide required:

$$48.6 + 85 = 133.6 \text{ kg}$$

Because the compensation exceeds the basic flooding requirement *(see 2-2.1.1),* refer to Chapter 3. Using the rate-by-volume method, 3-5.3.1 states that the rate of discharge can be reduced to not less than 4 kg/min · m^3 for actual walls completely surrounding the hazard enclosure. The openings can be calculated as a percent of wall enclosure to determine a proper discharge rate. The total opening area is 2.0 m^2.

Total wall area:

$$(3 + 3 + 6 + 6) \times 3 = 54 \text{ m}^2$$

Rate of discharge:

$$\frac{2.0}{54} \times (16 - 4) + 4 = 4.4 \text{ kg/min} \cdot \text{m}^3$$

Total rate of discharge:

$$4.4 \times 54 = 237.6 \text{ kg/min} \cdot \text{m}^3$$

Quantity of carbon dioxide:

$$\frac{237.6}{2} = 118.8 \text{ kg}$$

Local application requires a liquid discharge for 30 seconds. In the case of high-pressure storage, the quantity of carbon dioxide must be increased by 40 percent *(see 3-3.1.1)* to assure a 30-second discharge of liquid. When the openings are increased to 2.0 m^2 each, local application techniques will require less carbon dioxide than total flooding for both low-pressure and high-pressure storage.

A-2-3.5.1 Where forced ventilation is not a consideration, leakage of a carbon dioxide–air mixture from an enclosed space will depend upon one or more of the following parameters:

(a) *Temperature of Enclosure.* Carbon dioxide will not expand as much at a low temperature and will be more dense; thus, a greater amount will leak out if the openings are in the lower portion of the enclosure.

(b) *Volume of Enclosure.* The percent of total volume of carbon dioxide lost through any given opening in a small enclosure will be much greater than that from the same opening in a large enclosure.

(c) *Venting.* An opening at or near the ceiling is usually desirable to permit exhausting the lighter gases from the room during the discharge.

(d) *Location of Openings.* Because carbon dioxide is heavier than air, there could be little or no loss of carbon dioxide from openings near the ceiling, while the loss at the floor level could be substantial.

A-2-3.5.3 Hazards located in enclosures that are normally at temperatures above 200°F (93°C) can be more susceptible to reignition. Therefore, additional carbon dioxide is advisable to hold the extinguishing concentrations for a longer period of time, allowing the extinguished material to cool down and thereby reduce the chances of reignition when the gas dissipates.

A-2-3.5.7 Testing has shown that carbon dioxide applied directly to the liquid surface by local application–type nozzles can be necessary to provide the required cooling preventing reignition after the end of the carbon dioxide discharge.

A-2-4.1 Although specific test data is lacking, it is recognized that certain types of deep-seated fires can require holding times in excess of 20 minutes.

A-2-4.2.1 For further information, see A-2-1.

Depending on combustibility these hazards might not involve deep-seated fires *(see 2-3.5.6).*

A-2-5.2 The minimum rates established are considered adequate respectively for the usual surface or deep-seated fire. However, where the spread of fire can be faster than normal for the type of fire, or where high values or vital machinery or equipment are involved, rates higher than the minimums can, and in many cases should, be used, and where a hazard contains material that will produce both surface and deep-seated fires, the rate of application should be at least the minimum required for surface fires. Having selected a rate suitable to the hazard, the tables and information that follow in the standard should be used or such special engineering as is required should be carried out to obtain the proper combination of container releases, supply piping, and orifice sizes that will produce this desired rate.

The leakage rate from an enclosure in the absence of forced ventilation depends mainly on the difference in density between the atmosphere within the enclosure and the air surrounding the enclosure. The following equation can be used to calculate the rate of carbon dioxide loss, assuming that there is sufficient leakage in the upper part of the enclosure to allow free ingress of air:

$$R = 60 C \rho A \sqrt{\frac{2_g(\rho_1 - \rho_2)h}{\rho_1}}$$

where:

R = rate of CO_2 (lb/min)
C = CO_2 concentration fraction

ρ = density of CO_2 vapor (lb/ft^3)

A* = area of opening [ft^2 (flow coefficient included)]

g = gravitational constant (32.2 ft^2/sec)

ρ_1 = density of atmosphere (lb/ft^3)

ρ_2 = density of surrounding air (lb/ft^3)

h = static head between opening and top of enclosure (ft)

For SI units, the following equation applies:

$$R = 60 C\rho A\sqrt{\frac{2_g(\rho_1 - \rho_2)h}{\rho_1}}$$

where:

R = rate of CO_2 (kg/min)

C = CO_2 concentration fraction

ρ = density of CO_2 vapor (kg/m^3)

A* = area of opening [m^2 (flow coefficient included)]

g = gravitational constant (9.81 m/sec^2)

ρ_1 = density of atmosphere (kg/m^2)

ρ_2 = density of surrounding air (kg/m^3)

h = static head between opening and top of enclosure (m)

*If there are openings in the walls only, the area of the wall openings can be divided by 2 for calculations because it is presumed that fresh air can enter through one-half of the openings and protective gas will exit through the other half.

Figure A-2-3(b) can be used as a guide in estimating discharge rates for extended discharge systems. The curves were calculated using the preceding equation assuming a temperature of 70°F (21°C) inside and outside of the enclosure. In an actual system the inside temperature will normally be reduced by the discharge, thus increasing the rate of loss. Because of the many variables involved, a test of the installed system could be needed to ensure proper performance.

Extended Rate of Application. Where leakage is appreciable, the design concentration should be obtained quickly and maintained for an extended period of time. Carbon dioxide provided for leakage compensation should be applied at a reduced rate. The extended rate of discharge should be sufficient to maintain the minimum concentration.

A-2-5.2.1 Normally the measured discharge time is considered to be the time when the measuring device starts to record the presence of carbon dioxide until the design concentration is achieved.

A-2-5.3 For enclosed recirculating-type electrical equipment, the initial discharge quantity should not be less than 1 lb of gas for each 10 ft^3 (1.6 kg/m^3) of enclosed volume up to 2000 ft^3 (56.6 m^3). For larger volumes, 1 lb of gas for each 12 ft^3 (1.3 m^3) or a minimum of 200 lb (90.8 kg) should be used. Table A-2-5.3 can be used as a guide to estimate the quantity of gas needed for the extended discharge to maintain a minimum concentration of 30 percent for the deceleration time. The quantity is based on the internal volume of the machine and the deceleration time, assuming average leakage. For dampered, nonrecirculating-type machines, add 35 percent to the indicated quantities in Tables A-2-5.3(a) and A-2-5.3(b) for extended discharge protection.

A-2-5.4.1 Methods available to compensate for temperature exposures include reduced filling density for high temperatures and nitrogen super-pressurization combined with reduced filling density for low temperatures. Manufacturers should be consulted for advice.

A-3-1 A local application carbon dioxide system is designed to apply carbon dioxide directly to a fire that can occur in an area or space that essentially has no enclosure surrounding it. Such systems should be designed to deliver carbon dioxide to the hazard being protected in a manner that will cover or surround all burning or flaming surfaces with carbon dioxide during operation of the system.

The flow rate and time of application required will depend on the type of combustible material involved, the nature of the hazard (whether it is a liquid surface such as a dip tank or quench tank, or a complicated piece of machinery such as a printing press, etc.), and the location and spacing of the carbon dioxide nozzles with respect to the hazard.

The important factors to be considered in the design of a local application system are the rate of flow, the height and area limitations of the nozzles used, the amount of carbon dioxide needed, and the piping system. The following steps are necessary to lay out a system.

(a) Determine the area of the hazard to be protected. In determining this area, it is important to lay out to scale, the actual hazard showing all dimensions, and limitations as to placement of nozzles. The limits of the hazard should be carefully defined to include all combustibles that can be included in the hazard, and the possibility of stock or other obstructions that can be in or near the hazard should be carefully considered.

(b) For overhead-type nozzles, based on the height limitations of the hazard to be protected, lay out the nozzles to cover the hazard by using various nozzles within the height and area limitations that are expressed in the listings or approvals of these nozzles. The limits on area coverage of a nozzle for a particular height will be determined from listing information, which is presented in a form similar to that shown by Figure A-3-1(b). In considering the area that is covered by a particular nozzle, it is important to remember that all nozzle coverage is laid out on the basis of approximate squares. Omit this step for tankside or linear-type nozzles.

(c) Based on the height above the hazard of each nozzle, determine the optimum flow rate at which each nozzle should discharge to extinguish the hazard being protected. This will be determined from a curve such as the one shown by Figure A-3-1(c)(1), which will be given in the individual listings or approvals of nozzles.

Or for tankside or linear nozzles, based on the configuration of the hazard, lay out the nozzles to cover the hazard within the spacing limitations expressed in approvals or listings. Based on the spacing or area coverage, select an appropriate flow rate from an approval or listing curve such as the one shown by Figures A-3-1(c)(2) and A-3-1(c)(3). Omit this step for overhead-type nozzles.