ENGINEERING STANDARD

FOR

CO_2 GAS FIRE EXTINGUISHING SYSTEMS

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0. INTRODUCTION

"Fire Fighting and Fire Protection System" are broad and contain variable subjects of paramount importance therefore, a group of engineering standards are prepared to cover the subject.

This group includes the following standards:

STANDARD CODE	STANDARD TITLE
IPS-E-SF-120	"Off-Shore Installations Fire Fighting & Fire Protection"
IPS-E-SF-140	"Foam Generating and Proportionating Systems"
IPS-E-SF-160	"CO_2 Gas Fire Extinguishing Systems"
IPS-E-SF-180	"Dry Chemical Fire Extinguishing Systems"
IPS-E-SF-200	"Fire Fighting Sprinkler Systems"
IPS-E-SF-220	"Fire Water Distribution and Storage Facilities"
IPS-E-SF-240	"Fire Water Pump Systems"
IPS-E-SF-260	"Automatic Detectors and Fire Alarm Systems"
IPS-E-SF-280	"Telecommunication for Fire Fighting Systems"
IPS-E-SF-300	"Application of Breathing Apparatus in Safety and Fire Fighting"
IPS-E-SF-320	"Tugs, Fire-Fighters and other Off-Shore Harbour Vessels"
IPS-E-SF-340	"Fire Fighting Hose Box and or Shelter"

This Standard covers:

CO_2 Gas Fire Extinguishing Systems

1. SCOPE

This Standard covers the minimum requirements for carbon dioxide systems, with which this section is concerned, and are designed to provide a piped supply of Carbon dioxide for the extinction of fire.

Several different methods of piping supplies of carbon dioxide and applying the gas at the required points of discharge for fire extinction have been developed in recent years, and there is a need for dissemination of information on established systems and methods. This Standard has been prepared to meet this need.

2. SOURCES

In preparation of this Standard, in addition to the Referenced Codes and Standards mentioned in 2.2, the following standards and publications have also been considered:

BS 5306 Part 4-1986	"Fire Extinguishing Installations and Equipment on Premises; Specification for Carbon Dioxide Systems"
NATIONAL FIRE CODES (NFPA) - 12	"Carbon Dioxide Extinguishing Systems"

3. DEFINITIONS AND TERMINOLOGY

Automatic / Manual or Manual Only Change - Over Device

A device that can be operated before a person enters a space protected by a fire extinguishing system preventing the fire detection system from activating the automatic release of carbon dioxide.

Closed Section of Pipe

That section between two valves which may be intentionally closed, or between valves and carbon dioxide storage containers including filling and gas balance lines.

Deep - seated Fire

A fire involving solids subject to smouldering.

Filling Density

The ratio of mass of carbon dioxide charged in a container to the container volume.

High Pressure Storage

Storage of carbon dioxide at ambient temperature.

Note:

A change in ambient temperature from 10°C to 21°C will raise the pressure from 44 bar to 59 bar.

Local Application System

An automatic or manual fire extinguishing system in which a fixed supply or carbon dioxide is permanently connected to fixed piping with nozzles arranged to discharge the carbon dioxide to a fire occurring in a defined area that has no enclosure surrounding it, or is only partially enclosed and that does not produce an extinguishing concentration throughout the entire volume containing the protected hazard.

Low Pressure Storage

Storage of carbon dioxide in pressure containers at a controlled low temperature of -18°C.

Note:

The pressure in this type of storage is approximately 21 bar.

Manual

Pertaining to a fire extinguishing system, that under specified conditions, functions by means of intervention of a human operator.

Manual Hose Reel System

A manual fire extinguishing system consisting of a hose, stowed on a reel or a rack, with a manually operated discharge nozzle assembly, all connected by a fixed pipe to a supply of carbon dioxide.

Material Conversion Factor (MCF)

A numerical factor that should be used when the minimum design concentration of carbon dioxide for the material at risk exceeds 34% to increase the basic quantity of carbon dioxide as obtained by application of the volume factor required for protection against surface fires.

Open - ended Pipework

Pipework between a valve (including a relief valve) and open nozzle which cannot be under a continuous pressure.

Surface Fire

A fire involving flammable liquids, gases or solids not subject to smoldering.

Total Flooding System

An automatic or manual fire extinguishing system in which a fixed supply of carbon dioxide is permanently connected to fixed piping with nozzles arranged to discharge the carbon dioxide into an enclosed space in order to produce a concentration sufficient to extinguish fire throughout the entire volume of the enclosed space.

Volume Factor

A numerical factor that, when applied to the volume of an enclosure, indicates the basic quantity of carbon dioxide (subject to a minimum appropriate to the volume of the enclosure) required for protection against surface fires.

4. UNITS

International System of Units (SI) in accordance with IPS-E-GN-100 shall be used.

5. CHARACTERISTICS AND USES OF CARBON DIOXIDE

5.1 General Information

Carbon dioxide for use in fire extinguishing system shall comply with the requirements of Table 1 when tested by the appropriate method of test.

Carbon dioxide at atmospheric pressure is a colorless, odorless and electrically non-conducting inert gas which is almost 1.5 times as dense as air. It is stored as a liquid under pressure, and 1 kg of liquid carbon dioxide expanded to atmospheric pressure will produce about 0.56 m^3 of free gas at a temperature of 30°C.

Carbon dioxide extinguishes fire by reducing the oxygen content of the atmosphere to a point where it will not support combustion. Reducing the oxygen content from the normal 21 % in air to 15 % will extinguish most surface fires, though for some materials a greater reduction as low as 5% is necessary. In some applications the cooling effect of carbon dioxide assists extinction.

Carbon dioxide should be used to fight fires of classes A and B. Class C fires can also be extinguished by carbon dioxide but in these cases the risk of explosion after extinction should be carefully considered.

Carbon dioxide is ineffective on fires involving materials such as metal hydrides, reactive metals such as sodium, potassium, magnesium, titanium and, zirconium, and chemicals containing oxygen available for combustion, such as cellulose nitrate.

Carbon dioxide is suitable for use on fires involving live electrical apparatus.

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.

TABLE 1 - CARBON DIOXIDE REQUIREMENTS

PROPERTY	REQUIREMENT
PURITY, % (V/V) Min.	99.5
WATER CONTENT, % (m/m) Max.	0.015
OIL CONTENT, PPM BY MASS, Max.	5
TOTAL SULPHUR COMPOUNDS CONTENT, EXPRESSED AS SULPHUR, PPM BY MASS, Max.	1.0

Carbon dioxide obtained by converting dry ice to liquid will not usually comply with these requirements unless it has been processed to remove excess oil and waste.

5.2 Use and Limitations

Carbon dioxide fire extinguishing systems are useful within limits of this standard in extinguishing fires in specific hazards or equipment, and in occupancies where an inert electrically nonconductive medium is essential or desirable, where cleanup of other media presents a problem, or where they are more economical to install than systems using other media.

5.2.1 All areas or parts of a hazard to which or from which a fire will spread shall be simultaneously protected.

5.2.2 Some of the more important types of hazards and equipment that carbon dioxide systems will satisfactorily protect include:

a) flammable liquid materials;

Caution: Gas fire should normally be extinguished by shutting off the gas flow. Extinguishing the gas flame with carbon dioxide is desirable where necessary to permit immediate access to valves to shut off the gas supply. Extinguishment of gas fires indoors with carbon dioxide will create an explosion hazard and should not be used.

b) electrical hazards, such as transformers, oil switches and circuit breakers, rotating equipment, and electronic equipment;

c) engines utilizing gasoline and other flammable liquid fuels;

d) ordinary combustibles such as paper, wood, and textiles;

e) hazardous solids.

5.2.3 The discharge of liquid carbon dioxide is known to produce electrostatic charges which, under certain conditions, could create a spark. Carbon dioxide fire extinguishing systems protecting areas where explosive atmospheres could exist shall utilize metal nozzles and shall be properly grounded.

In addition, objects exposed to discharge from carbon dioxide nozzle shall be grounded to dissipate possible electrostatic charges.

5.2.4 Carbon dioxide will not extinguish fires where the following materials are actively involved in the combustion process:

a) chemicals containing their own oxygen supply, such as cellulose nitrate;
b) reactive metals such as sodium, potassium, magnesium, titanium, and zirconium;
c) metal hydrides.

Such as : HNa - H_3Al

5.3 System Components

Principal components shall comply with the appropriate clauses of this Standard and be installed in accordance with the requirements of the standard.

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 normally be designed to function properly from -30°C to 55°C or shall be marked to indicate their temperature limitations.

Where the pressure of a permanent gas from pilot containers is used as a means of releasing the remaining containers, the supply and discharge rate shall be designed for releasing all of the remaining containers. The pilot supply shall be continuously monitored and a fault alarm given in the event of excessive pressure loss.

Where the pressure of a liquefied gas is used as a means of releasing the remaining containers, duplicate containers, each of which is capable of operating the system, shall be used.

Various operating devices are necessary to control the flow of the extinguishing agent to operate the associated equipment. These include container valves, distribution valves, automatic and manual controls, delay devices, pressure trips and switches and discharge nozzles.

All devices, especially those having external moving parts, should be so located, installed or suitably protected that they are not subject to mechanical, chemical or other damage that would render them inoperable.

5.4 Types of Systems

There are four types of systems recognized in this Standard:

- Total Flooding Systems.
- Local Application Systems.
- Manual Hose Reel Systems.
- Standpipe System and Mobile Supply.

5.4.1 A Total Flooding System consists of a fixed supply of carbon dioxide normally connected to fixed piping with nozzles arranged to discharge carbon dioxide into an enclosed space or enclosure around the hazard.

5.4.2 A Local Application System consists of a fixed supply of carbon dioxide normally connected to fixed piping with nozzles arranged to discharge carbon dioxide directly on the burning material.

5.4.3 A Manual Hose Reel System consists of a fixed supply of carbon dioxide supplying hose reel.

5.4.4 A Standpipe System and Mobile Supply consists of a mobile supply of carbon dioxide capable of being quickly moved into position and connected to a system of fixed piping supplying fixed nozzle or hose reels or both that are used for either total flooding or local application.

5.4.5 In the selection of carton dioxide extinguishing system account should be taken of:

a) the field of usefulness of the four systems;
b) operating requirements dictating either manual or automatic operation;
c) the nature of the hazard;
d) the location and degree of enclosure of the hazard;
e) the degree of hazard to personnel arising from the CO_2 discharge:
f) other factors discussed in Clauses 6, 10, and 11.

5.4.6 A carbon dioxide system shall be used to protect one or more hazards or groups of hazards by means of directional valves. Where two or more hazards are simultaneously involved in fire by reason of their proximity, each hazard shall be either,

a) protected with an individual system, with the combination arranged to operate simultaneously, or,
b) protected with a single system that shall be sized and arranged to discharge on all potentially involved hazards simultaneously.

5.5 Package Systems (KITS)

Package systems consist of system components designed to be installed according to pretested limitations as approved or listed by a testing laboratory.

5.5.1 Package systems should incorporate special nozzles, flow rates, methods of application, nozzle placement, and quantities of carbon dioxide which differ from those detailed elsewhere in this standard since they are designed for very specific hazards. All other requirements of the standard apply.

5.5.2 Package systems shall be installed to protect hazards within the limitations which have been established by the testing laboratories where listed.

6. TOTAL FLOODING SYSTEMS

6.1 General Information

6.1.1 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.

6.1.2 Uses

This type of system shall be used where there is a permanent enclosure about the hazard that is adequate to enable the required concentration to be built up, and to be maintained for the required period of time to ensure the complete and permanent extinguishment of the fire in the specific combustible material or materials involved.

a) examples of hazards that are successfully protected by total flooding systems include rooms, vaults, enclosed machines, ducts, ovens, containers, and the contents thereof;

b) fires that can be extinguished or controlled by total flooding methods are:

1) surface fires involving flammable liquids, gases and solids;
2) deep-seated fires involving solids subject to smoldering.

6.2 General Design

6.2.1 The quantity of carbon dioxide, which will vary according to the hazard and permitted openings, shall be sufficient to reduce the oxygen content of the atmosphere within the enclosure to a point where combustion can no longer be sustained. The rate of application and the time necessary to maintain the extinguishing concentration shall be determined according to the hazard, and as specified in clauses 7, 8 and 9.

The distribution of the carbon dioxide should be so arranged that it is evenly and thoroughly mixed with the existing atmosphere. Special venting may be required to avoid excessive pressure build-up resulting from the volume of carbon dioxide discharged into the hazard area (see 6.3.2.).

6.2.2 The system shall be designed for either:

a) automatic and manual operation;
b) manual operation only.

Note:

This may be dependent upon the requirements of the authorities concerned.

6.3 Enclosure

6.3.1 General

6.3.1.1 The protected volume shall be enclosed by elements of construction having a fire resistance of not less than 30 min. and classified as non-combustible. Where opening can be closed, these shall be arranged to close before or at the start of CO_2 gas discharge. Where carbon dioxide can flow freely between two or more interconnected volumes, the quantity of carbon dioxide shall be the sum of quantities calculated for each volume using respective volume and material conversion factors. If one volume requires higher than normal concentration, the higher concentration shall be used in all interconnected volume.

The volume of the enclosure shall be the gross volume. The only permitted reductions shall be permanent, impermeable building elements within the enclosure.

A well enclosed space is required to maintain the extinguishing concentration of carbon dioxide.

6.3.2 Area of opening required for venting

6.3.2.1 The venting of flammable vapors and release of pressure caused by the discharge of quantities of carbon dioxide into closed spaces shall be considered, and provision shall be made for venting where necessary.

6.3.2.2 The pressure venting consideration involves such variables as enclosure strength and injection rate.

Leakage around doors, windows, ducts and dampers, though not apparent or easily determined, shall provide sufficient venting relief for normal carbon dioxide systems without special provisions being made.

For otherwise airtight enclosures, the area necessary for free venting, X, (in mm^2) may be calculated from the following equation:

$$X = 23.9\frac{Q}{\sqrt{P}}$$

(BS 5306)
(Pt. 4)

Where:

- ***Q*** is the calculated carbon dioxide flow rate (in kg/min.);
- ***P*** is the permissible strength (internal pressure) of enclosure (in bar).

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.

6.3.2.3 To prevent fire from spreading through openings to adjacent hazards or work areas which are 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 10.4.3.6). When neither method is practical, protection shall be extended to include these adjacent hazards or work areas.

6.3.2.4 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 10.4.3.6 are required.

6.3.2.5 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.

6.3.2.6 For ventilating systems which 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 Fig. 1) when the design concentration is greater than 34 percent.

6.3.2.7 For applications where the normal temperature of the enclosure is above 93°C, a 1-percent increase in the calculated total quantity of carbon dioxide shall be provided for each additional -15°C above 93°C.

6.3.2.8 For applications where the normal temperature of the enclosure is below -18°C, a 1-percent increase in the calculated total quantity of carbon dioxide shall be provided for each degree below -18°C.

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.

6.3.2.9 A flooding factor of 0.48 m^3/kg shall be used in ducts and covered trenches. If the combustibles represent a deep-seated fire, it shall be treated as described in Section 8.

7. CARBON DIOXIDE FOR SURFACE FIRES

7.1 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 is 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.

7.1.1 Table 2 gives the theoretical minimum carbon dioxide concentration and the suggested minimum design carbon dioxide concentration to prevent ignition of some common liquids and gases.

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

$$\%CO_2 = \frac{(21 - O_2)}{21} \times 100 \quad \text{(NFPA-12-15 chapter 2)}$$

TABLE 2 - MINIMUM CARBON DIOXIDE CONCENTRATION FOR EXTINGUISHMENT

MATERIAL	THEORETICAL Min. CO_2 % CONCENTRATION	MINIMUM DESIGN CO_2 % CONCENTRATION
ACETYLENE	55	66
ACETONE	27*	34
AVIATION GAS GRADES 11 5/ 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 Cn H_{2m} + 2 m - 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 above material were obtained from a compilation of U.S. Bureau of Mines Limits of Flammability of Gases and Vapors (Bulletins 503 and 627). Those marked with *were calculated from accepted residual oxygen values.

7.2 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 Table 3.

TABLE 3 - FLOODING FACTORS

(A) VOLUME OF SPACE (m^3 Incl.)	(B) VOLUME FACTOR ($m^3/kg\ CO_2$)	($kg\ CO_2/m^2$)	(C) CALCULATED QUAN. (kg) NOT LESS THAN
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

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

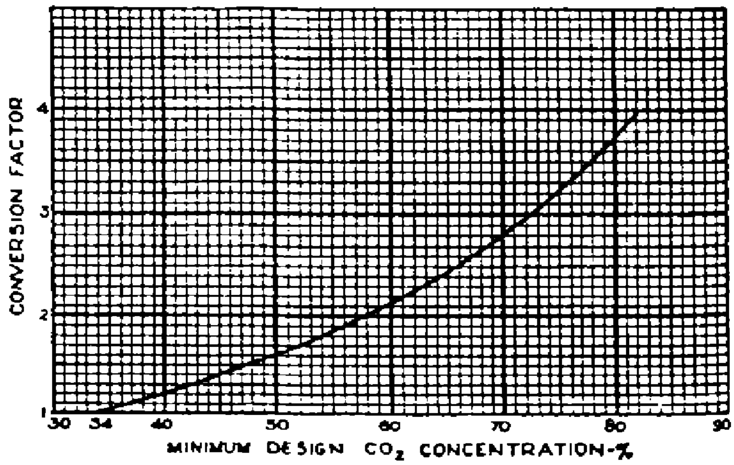
7.2.2 As the average small space has proportionately more boundary area per enclosed volume than a larger space, greater proportionate leakages are anticipated and accounted for by the graded volume factors in Table 3.

7.2.3 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.

7.2.4 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 Table 3. If one volume requires greater than normal concentration, the higher concentration shall be used in all interconnected volumes.

7.3 Material Conversion Factor

For materials (see Table 2) requiring a design concentration over 34 percent, the basic quantity of carbon dioxide calculated from the volume factor given in Table 3 shall be increased by multiplying this quantity by the appropriate conversion factor given in Fig. (1).



MATERIAL CONVERSION FACTORS
Fig. 1

7.3.1 Special conditions

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

7.4 Compensation for Abnormal Temperatures

Where there are abnormal temperatures, additional quantities of gas shall be provided as follows:

a) where the normal temperature of the enclosure is above 100°C, 2% carbon dioxide shall be added for each additional 5°C over 100°C,

b) where the normal temperature of the enclosure is below -20°C, 2 % carbon dioxide shall be added for each 1°C below -20°C.

8. CARBON DIOXIDE FOR DEEP - SEATED FIRES

8.1 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 since no allowance is included in the basic flooding factors.

8.2 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.

8.2.1 The design concentrations listed in Table 4 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.

8.2.2 Flooding factors for other deep-seated fires shall be justified to the satisfaction of the IPI Authorities before use. Proper consideration shall be given to the mass of material to be protected because the rate of cooling is reduced by the thermal insulating effects.

TABLE 4 - FLOODING FACTORS FOR SPECIAL HAZARDS

DESIGN CONCENTRATION %	FLOODING FACTOR m^3/kg	kg CO_2 / m^3	SPECIFIC HAZARD
50	0.62	1.60	DRY ELECTRICAL HAZARDS IN GENERAL(SPACES 0-57 m^3)
50	0.75	1.33 (91 Kg) MINIMUM	(SPACES GREATER THAN 57 m^3)
65	0.50	2.00	RECORD (BULK PAPER STORAGE, DUCTS, AND COVERED TRENCHES
75	0.38	2.66	FOR STORAGE VAULTS, DUST COLLECTORS

8.3 Volume Consideration

The volume of the space shall be determined in accordance with 7.2.1. 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 8.2.

8.4 Special Conditions

Additional quantities of carbon dioxide shall be provided to compensate for any special condition that shall adversely affect the extinguishing efficiency.

8.4.1 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 6.7.7.2.

8.4.2 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 openings exceeds the pressure relief venting requirements set forth in 2.6.2.1 of NFPA Volume 1 Section 12.

9. RATES OF APPLICATION

9.1 General

For surface fires, the design concentration shall be achieved within 1 min.

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

The times specified above are considered adequate for the usual surface or deep-seated fire. Where the materials involved are likely to give a higher spread of fire, rates higher than the minimum should be used. Where a hazard contains materials that will produce both surface and deep-seated fires, the rate of application should be at least the minimum required for surface fires.

9.2 Extended discharge

The minimum design concentration shall be achieved within the time limit specified in 9.1. The extended rate of discharge shall be sufficient to maintain the design concentration.

Where leakage is appreciable and the design concentration has to be obtained quickly and maintained for an extended period of time, carbon dioxide provided for leakage compensation shall be applied at a reduced rate. This method is particularly suited to enclosed rotating electrical apparatus, such as generators and alternators, but it can also be used on normal room flooding systems where suitable.

9.3 Rotating Electrical Machinery

For enclosed rotating electrical machinery, a minimum concentration of 30% shall be maintained for the deceleration period of the machine. This minimum concentration shall be held for the deceleration period or 20 min. whichever is the longer.

Table 5 should be used as a guide to estimate the quantity of gas needed for the extended discharge to maintain the minimum concentration. The quantities are based on the internal volume of the machine and the deceleration time assuming average leakage. For dampered, non-recirculating type machines, 35 % should be added to the quantities given in Table 5.

TABLE 5 - EXTENDED DISCHARGE GAS QUANTITIES FOR ENCLOSED RECIRCULATION: ROTATING ELECTRICAL MACHINES

Carbon dioxide required	Deceleration time							
	5 min	10 min	15 min	20 min	30 min	40 min	50 min	60 min
	Volume onclosect by the machins							
kg	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3
45	34	28	23	17	14	11	9	6
68	51	43	34	28	21	17	14	11
91	68	55	45	37	28	24	18	14
113	93	69	57	47	37	30	23	17
136	130	88	68	57	47	37	28	20
159	173	116	85	71	57	47	34	26
181	218	153	108	89	71	57	45	34
204	262	193	139	113	88	74	60	45
227	306	229	173	142	110	93	79	62
250	348	269	210	173	139	119	102	88
272	394	309	244	204	170	147	127	110
295	436	348	279	235	200	176	156	136
319	479	385	314	266	230	204	181	159
340	524	425	350	297	259	232	207	184
363	566	464	385	329	289	261	232	207
386	609	503	421	360	320	289	258	229
408	651	541	456	391	350	317	285	255
431	697	581	491	422	379	346	312	278
454	739	620	527	453	411	374	337	303
476	782	666	564	484	442	402	364	326
499	824	697	596	515	470	430	389	351
522	867	736	632	547	501	459	416	374
544	912	773	667	578	532	487	442	399
567	954	813	702	609	562	515	467	422
590	1000	852	738	641	592	544	494	447
612	1042	889	773	673	623	572	521	472
635	1087	929	809	705	654	600	548	496
658	1130	968	844	736	685	629	575	520
680	1172	1008	879	767	715	657	600	544

9.4 Distribution Systems

9.4.1 Design

Piping for total flooding systems shall be designed to deliver the required rate of application at each nozzle.

High pressure storage temperatures has the range from -18°C to 55°C without requiring special methods of compensating for changing flow rates. Storage temperatures outside those limits require special design considerations to ensure proper flow rates.

9.4.2 Nozzle selection and distribution

Rooms with ceiling heights above 7.5 m shall have discharge nozzles at two or more levels, depending upon the height. Nozzles used in total flooding systems should be of the type most suitable for the intended purpose, and they should be properly located to achieve the best results. The lower ring of nozzles should be located approximately one-third of the height from the floor but no higher than 2.5 m.

The nozzles should be arranged in the protected space in a manner that will ensure adequate, prompt and equal distribution of the carbon dioxide. Special consideration should be given to areas within the space that are of particular danger.

The type of nozzle selected and the disposition of the individual nozzles should be such that the discharge will not splash flammable liquids, dislodge ceiling tiles or create dust clouds that can extend the fire, create an explosion or otherwise adversely affect the contents of the enclosure. Nozzles vary in design and discharge characteristics and should be selected on the basis of their adequacy for the use intended.

10. LOCAL APPLICATION SYSTEMS

10.1 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.

10.2 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.

10.2.1 Examples of hazards that are successfully protected by local application systems include:

- **a)** coating machines;
- **b)** dip tanks:
- **c)** quench tanks;
- **d)** printing presses;
- **e)** spray booths;
- **f)** fume ducts;
- **g)** process machinery;
- **h)** oil-filled electric transformers and switchgear.

Open cable or pipe trenches (covered perhaps with chequer plate or similar) crossing, or adjacent to, a hazardous area should also be considered.

10.3 Carbon Dioxide Requirements

10.3.1 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.

10.3.1.1 For system with high pressure storage, the computed quantity of carbon dioxide shall be increased by 40 percent to determine nominal cylinder storage capacity since 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.

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

10.3.2 Rate of discharge

Nozzle discharge rates shall be determined by either the surface method or the volume method, depending upon the type of risk.

10.3.2.1 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.

10.3.2.2 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.

10.3.2.3 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.

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

(BS 5306 pt.4)
(Section Five)

Where:

Q_F = Rate of flow for the total flooding portion in (kg/min.).
W_F = Total quantity of carbon dioxide for the total flooding portion in (kg).
T_L = Liquid discharge time for the local application portion in minutes.

10.3.3 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 required a longer cooling period to assure complete extinguishment.

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

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

10.4 Rate by Area Method

10.4.1 General

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

10.4.1.1 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.

10.4.2 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.

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

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

10.4.3 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.

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

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

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

10.4.3.4 When coated rollers or other similar irregular shapes are to be protected, the projected wetted area shall be used to determine nozzle coverage.

10.4.3.5 Where coated surfaces are to be protected, the area per nozzle should be increased by 40 percent over the areas given in specific approvals or listings. Coated surfaces are defined as those designed for drainage which 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 does not apply where there is a heavy build-up of residue. (see 10.2)

10.4.3.6 Where local application nozzles are used for protection across openings as defined in 6.3.2.3 and 6.3.2.4, the area per nozzle given by specific approval or listing should be increased by 20 percent.

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

10.4.4 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.

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

10.4.4.2 Overhead type nozzles shall be installed perpendicular to the hazard and centered over the protected area by the nozzle. They should also be installed at angles between 45 degrees and 90 degrees from the plane of the hazard surface as prescribed in 10.4.5 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.

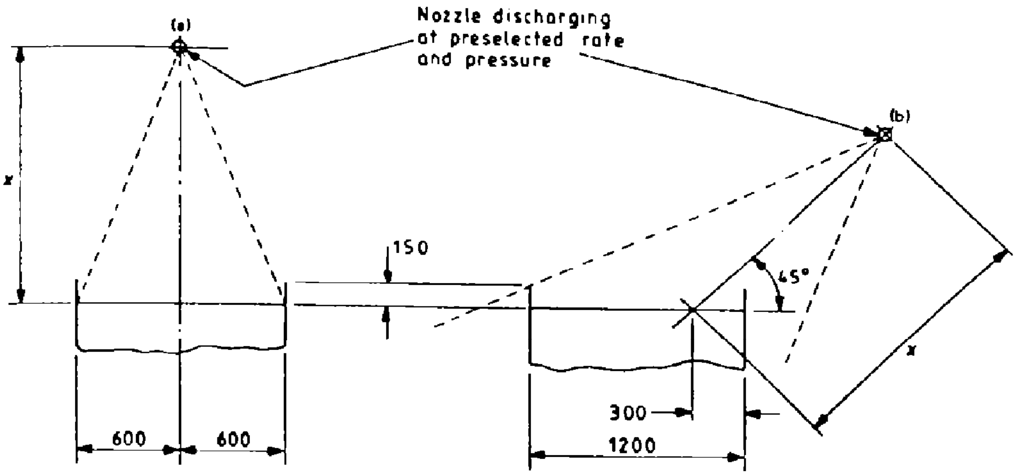
10.4.5 Nozzles installed at an angle

When installed at an angle, nozzles shall be aimed at a point measured from the near side of the area protected by the nozzle, the location of which is calculated by multiplying the fractional aiming factor in table 6 by the width of the area protected by the nozzle (see Fig. 2).

TABLE 6 - AIMING FACTOR FOR NOZZLES INSTALLED AT AN ANGLE (BASED ON 150 mm FREEBOARD)

DISCHARGE ANGLE *	AIMING FACTOR
45° TO 60°	0.25
60° TO 75°	0.25 to 0.375
75° TO 90°	0.375 to 0.5
90° (PERPENDICULAR)	0.5 (CENTER)

***Degrees from plane of hazard surface.**



AIMING POSITION FOR ANGLED DISCHARGE NOZZLES
Fig. 2

Notes:

1) The diagram shows nozzles discharging at (a) 90° with the aiming point at the center of the protected surface, and at (b) 45° with the aiming point at 0.25 of the width of the protected surface, into a tray containing liquid fuel with a freeboard of 150 mm.

2) X is the preselected height used to determine the flow rate required.

10.4.6 Rate by volume method

10.4.6.1 General

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

10.4.6.2 Assumed enclosure

The total discharge rate of the system shall be based on the volume of an assumed enclosure entirely surrounding the hazard.

a) the assumed enclosure shall be based on an actual closed floor unless special provisions are made to take care of bottom conditions;

b) the assumed walls and ceiling of this enclosure shall be at least (0.6 m) from the main hazard unless actual walls are involved and shall enclose all areas of possible leakage, splashing or spillage;

c) no deductions shall be made for solid objects within this volume;

d) a minimum dimension of (1.2 m) shall be used in calculating the volume of the assumed enclosure;

e) if the hazard is subjected to winds or forced drafts, the assumed volume shall be increased to compensate for losses on the windward sides.

10.4.6.3 System discharge rate

The total discharge rate for the basic system shall be equal to (16 kg/min./m^3) of assumed volume.

11. MANUAL HOSE REEL SYSTEMS

11.1 Description

Manual hose reel systems consist of a hose reel or rack, hose, and discharge nozzle assembly connected by fixed piping to a supply of carbon dioxide.

A separate carbon dioxide supply can be provided for hand hose reel use or carbon dioxide can be piped from a central storage unit which should be supplying several hose reels or fixed manual or automatic systems.

11.2 Uses

Manual hose reel systems shall 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 reels are applicable to the particular hazard shall rest with the authorities concerned.

11.3 Location and Spacing

11.3.1 Manual hose reel stations shall be placed such that they are easily accessible and within reach of the most distant hazard which 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.

11.3.2 Spacing

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

11.4 Rate and Duration of Discharge

11.4.1 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 manual hose reel system shall have sufficient quantity of carbon dioxide to permit its effective (liquid phase) use for at least 1 min.

11.4.2 Simultaneous use of hose reels

Where simultaneous use of two or more hose reels is possible, a sufficient quantity of carbon dioxide shall be available to supply the maximum number of nozzles that are likely to be used at any one time for at least 1 min.

12. STANDPIPE SYSTEMS AND MOBILE SUPPLY

12.1 General Information

12.1.1 Description

A standpipe is a fixed total flooding, local application, or manual hose reel system without a permanently connected carbon dioxide supply. The carbon dioxide supply is mounted on a mobile vehicle which 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.

12.1.2 Uses

Standpipe system and mobile supply shall be used to supplement complete fixed fire protection systems or should be used alone for the protection of the specific hazards. Mobile supply shall be used as a reserve to supplement a fixed supply. Mobile supply shall also be outfitted with manual hose reel for the protection of scattered hazards. These systems shall be installed only with the approval of the authorities concerned.

12.2 Capacity

The mobile supply shall have a capacity in accordance with the provisions of clauses 5,6,10 and 11. Extra quantities are required to compensate for delay in getting the mobile supply to the hazard.

13. STORAGE CONTAINERS

13.1 The requirements of 13.2 shall apply to rooms or spaces housing storage containers.

Storage containers and accessories should be so located and arranged that inspection, testing recharging and other maintenance is facilitated and interruption to protection is held to a minimum.

Storage containers should be located as near as possible to the hazard or hazards they protect, but should not be exposed to fire in a manner that is likely to impair system performance.

Storage containers should not be located so as to be subject to severe weather conditions or be subject to mechanical, chemical, or other damage. Where excessive climatic or mechanical exposures are expected, suitable guards or enclosures should be provided.

Containers should also be protected from direct sunlight through windows and from interference by unauthorized persons. The area selected should be dry and ventilated.

13.2 Exits

Adequate means of egress from a protected space shall be provided. Doors at exits shall open outwards and shall be self-closing. All exit doors shall open readily from the inside and any that have to be secured shall be fitted with panic bolts or latches.

The means of egress from a protected space should be kept clear at all times.

13.3 Temperatures

13.3.1 The general ambient storage temperatures shall not exceed the following limits unless the system is designed for proper operation with storage temperatures outside the appropriate range:

- **a)** For total flooding systems: not more than 46°C or less than -18°C.
- **b)** For local application systems: not more than 46°C or less than 0°C.

External heating or cooling may be used to keep the temperature within the range.

13.4 High Pressure Storage Containers

13.4.1 The carbon dioxide supply shall be stored in rechargeable containers designed to hold pressurized carbon dioxide in liquid form at atmospheric temperatures corresponding to a nominal pressure of (58.6 bars) at (21°C).

13.4.2 Manifolded cylinders shall be adequately mounted and suitably supported in a rack provided for the purpose, including facilities for convenient individual servicing or content weighings. 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.

13.5 Low Pressure Storage Containers

13.5.1 Low pressure storage container shall be designed to maintain the carbon dioxide supply at a nominal pressure of (20.7 bars) corresponding to a temperature of approximately (-18°C).

All containers in any one battery shall be of the same size and contain the same mass of carbon dioxide.

13.6 Flexible Hoses

13.6.1 The use of flexible piping or hoses 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 be made of materials that will be resistant to atmospheric corrosion.

13.6.2 A dirt trap consisting of a tee with a capped nipple, at least (51 mm) long, should be installed at the end of each pipe run.

14. 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.

14.1 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 8 and 9.

For examples of equivalent orifice diameters see Table 7. The orifice code numbers indicate the equivalent single orifice diameter in (0.8 mm) increments. Orifice sizes other than those shown in Table 7 can be used and shall be marked as decimal orifice equipment

TABLE 7 - EQUIVALENT ORIFICE SIZES

ORIFICE CODE No.	EQUIVALENT SINGLE ORIFICE DIAMETER mm	EQUIVALENT SINGLE ORIFICE AREA mm^2
1	0.79	0.49
1.5	1.19	1.11
2	1.59	1.98
2.5	1.98	3.09
3	2.38	4.45
3.5	2.78	6.06
4	3.18	7.94
4.5	3.57	10.00
5	3.97	12.39
5.5	4.37	14.97
6	4.76	17.81
6.5	5.16	20.90
7	5.56	24.26
7.5	5.95	27.81
8	6.35	31.68
8.5	6.75	35.74
9	7.14	40.06
9.5	7.54	44.65
10	7.94	49.48
11	8.73	59.87
12	9.53	71.29
13	10.32	83.61
14	11.11	96.97
15	11.91	111.29
16	12.70	126.71
18	14.29	160.32
20	15.88	197.94
22	17.46	239.48
24	19.05	285.03
32	25.40	506.45
48	38.40	1138.71
64	50.80	2025.80

TABLE 8 - DISCHARGE RATE PER SQUARE mm OF EQUIVALENT ORIFICE AREA FOR LOW PRESSURE STORAGE (20. 7 bars)

ORIFICE PRESSURE BARS	DISCHARGE RATES Kg /Min. / mm^2
20.7	2.970
20.0	2.041
19.3	1.671
18.6	1.443
17.9	1.284
17.2	1.165
16.5	1.073
15.9	0.992
15.2	0.918
14.5	0.851
13.8	0.792
13.1	0.737
12.4	0.688
11.7	0.642
11.0	0.600
10.3	0.559

TABLE 9 - DISCHARGE RATE PER SQUARE mm OF EQUIVALENT ORIFICE AREA FOR HIGH PRESSURE STORAGE (51 . 7 bars)

ORIFICE PRESSURE BARS	DISCHARGE RATE Kg / Min. / mm^2
51.7	3.258
50.0	2.706
48.3	2.403
46.5	2.174
44.8	1.995
43.1	1.840
41.4	1.706
39.6	1.590
37.9	1.488
36.2	1.397
34.5	1.309
32.8	1.224
31.0	1.140
29.3	1.063
27.6	0.985
25.9	0.908
24.1	0.830
22.4	0.760
20.7	0.690

15. DETERMINATION OF CARBON DIOXIDE PIPE AND ORIFICE SIZE

15.1 Pipe sizes and orifice areas shall be selected on the basis of calculations to deliver the required rate of flow at each nozzle.

15.2 Pressure Drop in the Pipe Line

The following equation or derived curves shall be used to determine the pressure drop in the pipe line:

$$Q^2 = \frac{10^{-5} \times 0.8725 (D^{5.25} Y)}{L + 0.04319 (D^{1.25} Z)}$$

(BS 5306 pt.4)
(Appendix B and C)

Where:

- ***Q*** is the flow rate (in kg/min.);
- ***D*** is the inside pipe diameter (actual) (in mm);
- ***L*** is the equivalent length of pipeline (in m);
- ***Y*** and Z are the factors depending on storage and line pressure.

These factors can be evaluated from the following equations;

$$Y = \int_{p1}^{p} \rho \, dp$$

(BS 5306 pt.4)
(Appendix C)

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

Where:

P_1 is the storage pressure (in bar);
P is the pressure at the end of pipe line (in bar);
ρ_i is the density at pressure P1 (in kg/m^3);
ρ is the density at pressure P (in kg/m^3);
ln: is the natural logarithm.

In the design of piping systems, pressure drop values can best be obtained from curves of pressure versus equivalent length for various flow rates and pipe size.

15.3 Values of Y and Z

The storage pressure is an important factor in carbon dioxide flow. In low pressure storage the starting pressure in the storage vessel will drop by an amount depending on whether all or only part of supply is discharged. Because of this, it will be about 19.7 bar. The flow equation is based on absolute pressure, therefore 20.7 bar is used for calculations necessary for low pressure systems. In high pressure systems the storage pressure depends on ambient temperature. Normal ambient temperature is assumed to be 21°C.

At this temperature, the average pressure in the cylinder during discharge of the liquid portion will be approximately 51.7 bar. This pressure is used for calculation involving high pressure systems. Using the above base pressures of 20.7 bar and 51.7 bar, values have been determined for the Y and Z factors in the flow equation. These are given in Tables 10 and 11.

TABLE 10 - VALUES OF Y AND Z FOR 20 . 7 bar STORAGE

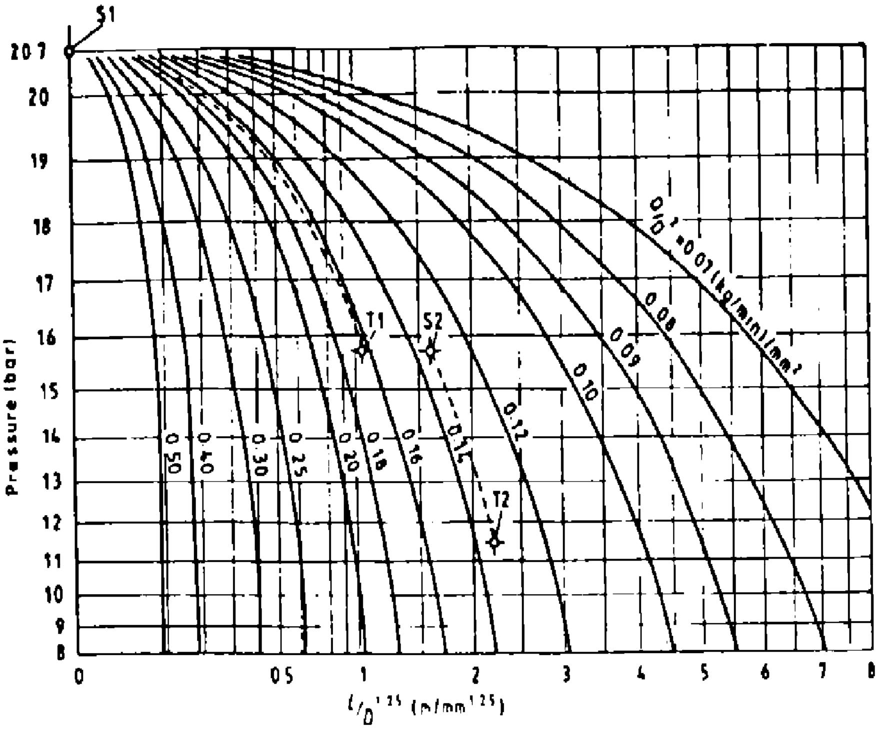
Y factor, in (bar. kg) / m3, for a pressure, in bar, of											Z
0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	
bar	(bar. kg) / m ^{3}										
20	652	562	470	377	282	185	86	0	0	0	0.134
19	1468	1393	1317	1239	1160	1079	997	913	828	741	0.319
18	2152	2088	2024	1959	1893	1825	1756	1686	1615	1542	0.493
17	2727	2674	2619	2564	2508	2451	2393	2334	2274	2214	0.659
16	3215	3169	3123	3076	3029	2981	2931	2882	2831	2779	0.819
15	3631	3592	3553	3513	3472	3431	3389	3346	3303	3259	0.976
14	3987	3954	3920	3886	3851	3816	3780	3743	3706	3669	1.132
13	4292	4264	4235	4205	4176	4145	4115	4083	4052	4020	1.290
12	4553	4529	4504	4479	4453	4428	4401	4375	4348	4320	1.451
11	4774	4754	4733	4712	4690	4668	4646	4623	4600	4577	1.618
10	4960	4943	4926	4908	4890	4871	4853	4834	4814	4794	1.792

*** Example. The Y factor for a pressure of 20.5 bar is 185(bar. kg)/m3**

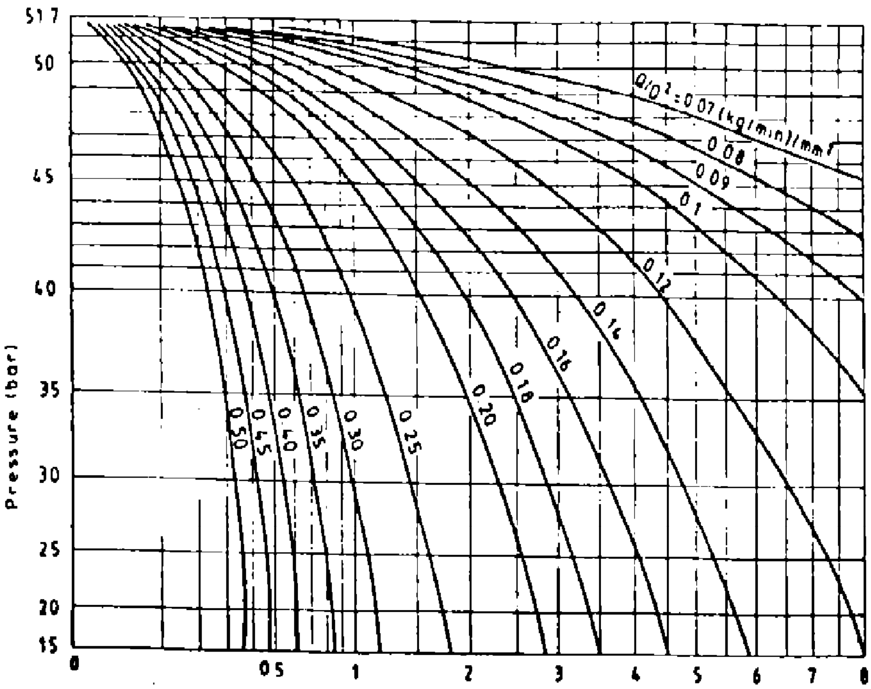
TABLE 11 - VALUES OF Y AND Z FOR 51. 7 bar STORAGE

Y factor, in (bar. kg) / m^3, for a pressure, in bar, of											Z
*	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	
bar	(bar. Kg) / m^3										
51	563	485	407	329	250	170	91	11	0	0	0.028
50	1321	1247	1172	1097	1022	946	871	794	718	640	0.085
49	2045	1974	1903	1831	1759	1687	1615	1542	1469	1395	0.133
48	2736	2669	2601	2532	2464	2325	2325	2256	2186	2115	0.179
47	3397	3332	3267	3202	3136	3004	3004	2938	2871	2804	0.223
46	4027	3966	3903	3841	3779	3652	3652	3589	3525	3461	0.267
45	4629	4570	4511	4452	4392	4271	4271	4211	4150	4089	0.313
44	5203	5147	5090	5034	4977	4862	4862	4804	4746	4688	0.361
43	5750	5696	5643	5589	5534	5425	5425	5370	5315	5259	0.411
42	6271	6220	6168	6117	6065	5961	5961	5909	5856	5803	0.462
41	6766	6717	6669	6620	6571	6472	6472	6422	6372	6321	0.515
40	7236	7190	7144	7098	7051	6957	6957	6909	6862	6814	0.568
39	7683	7639	7596	7552	7507	7418	7418	7373	7328	7282	0.622
38	8107	8066	8024	7982	7940	7855	7855	7813	7770	7727	0.676
37	8510	8470	8431	8391	8351	8271	8271	8230	8189	8148	0.729
36	8891	8854	8816	8779	8741	8665	8665	8626	8588	8549	0.782
35	9253	9218	9182	9146	9111	9038	9038	9002	8965	8928	0.834
34	9596	9563	9529	9495	9461	9392	9392	9358	9323	9288	0.885
33	9922	9890	9858	9826	9793	9728	9728	9696	9663	9629	0.936
32	10230	10200	10170	10139	10109	10047	10047	10016	9985	9953	0.987
31	10523	10495	10466	10437	10408	10349	10349	10320	10290	10260	1.038
30	10801	10774	10747	10720	10692	10636	10636	10608	10580	10552	1.090
29	11065	11040	11014	10988	10961	10909	10909	10882	10855	10828	1.143
28	11316	11291	11267	11242	11217	11167	11167	11142	11116	11091	1.198
27	11553	11530	11506	11483	11460	11412	11412	11388	11364	11340	1.255
26	11777	11756	11734	11711	11689	11644	11644	11622	11599	11576	1.313
25	11990	11969	11948	11927	11906	11864	11864	11842	11821	11799	1.374
24	12190	12170	12151	12131	12111	12071	12071	12051	12031	12010	1.436
23	12378	12360	12341	12323	12304	12267	12267	12248	12229	12209	1.501
22	12554	12537	12520	12503	12485	12450	12450	12432	12414	12396	1.568
21	12719	12703	12687	12671	12654	12621	12621	12605	12588	12751	1.635
20	12871	12857	12842	12827	12812	12781	12781	12766	12750	12734	1.705

*** Example. The Y factor for a pressure of 51.5 bar is 170 (bar. kg) / m^3**



PRESSURE DROP IN PIPELINE FOR 20 . 7 bar STORAGE PRESSURE
Fig . 3



PRESSURE DROP IN PIPELINE FOR 51.7 bar STORAGE PRESSURE
Fig. 4

15.4 Derivation of Figures 3 and 4

For practical applications curves for each pipe size shall be plotted and used. However, it will be noted that the flow equation can be rearranged as follows: (Appendix).

$$\frac{L}{D^{1.25}} = \frac{10^5 ¢\ 0.8725\ Y}{(Q=D^2)^2} \quad 0.04319\ Z$$

(BS 5304 pT. 4)
(Appendix C)

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. Fig. 3 gives flow information for -18°C storage temperature on these bases. Figure 4 gives similar information for high pressure storage at 21°C.

15.5 Use of Figures 3 and 4

These curves can be used for designing systems or for checking possible flow rates. Pressure conditions at any point in a pipeline can be determined by calculating Q/D^2 and $L/D^{1.25}$ values. Points shall then be plotted on the Q/D^2 curve to obtain starting and terminal pressures. For example, assume the problem is to determine the terminal pressure for a low pressure system consisting of a single 50 mm schedule 40 pipeline with an equivalent length of 152 m and a flow rate of 454 kg/min.

Q/D^2 and $L/D^{1.25}$ values are first calculated from the following equations:

$$\frac{Q}{D^2} = \frac{454}{2758} = 0.165\ (Kg = min) = m^2$$

$$\frac{L}{D^{1.25}} = \frac{152}{141.3} = 1.075\ m = m^{1.25}$$

(BS 5304 pT. 4
(Appendix C)

Starting pressure is 20.7 bar and $L/D^{1.25} = 0$, shown on figure 3 at S1. The terminal pressure is found to be about 15.7 bar at point T 1 where the Q/D^2 value of 0.165 intersects the $L/D^{1.25}$ value of 1.075.

If this line terminates in a single nozzle, the equivalent orifice area should be matched to the terminal pressure in order to control the flow rate at the desired level of 454 kg/min.

Referring to Table 12, it will be noted that the discharge rate will be 0.9913 (kg/min.)/mm² of equivalent orifice area when the orifice pressure is 15.9 bar. The required equivalent orifice area of the nozzle is thus equal to the total flow rate divided by the rate per square millimeter

$$\text{Equivalent orifice area} = \frac{454 Kg=min}{0.9913 (Kg=min) m^2} = 458 m^2$$

TABLE 12 - DISCHARGE RATE OF EQUIVALENT ORIFICE AREA* FOR LOW PRESSURE STORAGE (20 . 7 bar)

ORIFICE PRESSURE	DISCHARGE RATE/UNIT AREA
bar	(K g/ Min.)/ mm^2
20.7	2.967
20.0	2.039
19.3	1.670
18.6	1.441
17.9	1.283
17.2	1.164
16.5	1.072
15.9	0.9913
15.2	0.9175
14.5	0.8507
13.8	0.7910
13.1	0.7368
12.4	0.6869
11.7	0.6412
11.0	0.5990
10.3	0.5589
9.65	0.5210
8.96	0.4844
8.27	0.4486
7.58	0.4141
6.89	0.3811

*** Based upon a standard single orifice having a rounded entry with a coefficient of 0.98.**

TABLE 13 - DISCHARGE RATE OF EQUIVALENT ORIFICE AREA* FOR HIGH PRESSURE STORAGE (5 1. 7 bar)

ORIFICE PRESSURE	DISCHARGE RATE/UNIT AREA
bar	(Kg / Min.) / mm^2
51.7	3.255
50.0	2.703
48.3	2.401
46.5	2.172
44.8	1.993
43.1	1.839
41.4	1.705
39.6	1.589
37.9	1.487
36.2	1.396
34.5	1.308
32.8	1.223
31.0	1.139
29.3	1.062
27.6	0.9843
25.9	0.9070
24.1	0.8296
22.4	0.7593
20.7	0.6890
17.2	0.5484
13.8	0.4183

*** Based upon a standard orifice having a rounded entry with a coefficient of 0.98.**

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 15.7 bar.

If, in the above 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 40 mm schedule 40 pipe with equivalent lengths of 61 m and the flow in each branch line is to be 227 kg/min.

Q/D^2 and $L/D^{1.25}$ values are calculated for the branch pipe as follows:

$$\frac{Q}{D^2} = \frac{227}{1673} = 0.136 (Kg = min) = m^2$$

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$$\frac{L}{D^{1.25}} = \frac{61}{103.4} = 0.59 m = mm^{1.25}$$

From Figure 3, the starting pressure of 15.7 (terminal pressure of main line) intersects the Q/D^2 line 0.136 at point S2 giving an $L/D^{1.25}$ value of 1.6. The terminal pressure is found by moving down the Q/D^2 line a distance of 0.59 on the $L/D^{1.25}$ scale, i.e. $L/D^{1.25} = 1.60 + 0.59 = 2.19$, to the point T2 where terminal pressure is 11.4 bar. With this new terminal pressure and flow rate of 227 kg/min. the required nozzle area at the end of each branch line is obtained from Table 12 and is approximately 368 mm^2.

It will be noted that this is only slightly less than the single large nozzle example, but that the discharge rate is halved by the reduced pressure.

16. PLANS AND APPROVALS

Plans and calculations shall be submitted for approval to the relevant authorities before the work starts. Their preparation shall be entrusted to none but fully experienced and qualified persons.

16.1 These plans shall be drawn to an indicated scale or be suitably dimensioned and shall be made so that they can be easily reproduced.

16.2 These plans shall contain sufficient detail to enable the authorities concerned to evaluate the hazard or hazards and to evaluate the effectiveness of the system. The details shall include the materials involved in the protected hazards, location of the hazards, the enclosure or limits and isolation of the hazards, and the area surrounding which would affect the protected hazards.

16.3 The detail on the system shall include information and calculation on the amount of CO_2 ; the location and flow rate of each nozzle including equivalent orifice area; the location, size and equivalent lengths of pipe, fittings and hose; and the location and size of the CO_2 storage facility. 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.

16.4 When field conditions necessitate any material change from approved plans, the change shall be submitted to the authorities concerned for approval.

16.5 When such material changes from approved plans are made, corrected "as-installed" plans shall be supplied to the owner.

16.6 An instruction and maintenance manual which includes a full sequence of operation and a full set of system drawings and calculations shall be maintained in a protective enclosure.

17. ADDITIONAL REQUIREMENTS FOR ALL SYSTEMS

17.1 Manifold Venting

In systems using stop valves (accidental) release of the carbon dioxide from the storage containers shall activate a device which gives visual warning to indicate that carbon dioxide has been released and is trapped in the manifold.

In addition to the pressure relief device a manually operated vent valve shall be fitted to the manifold so that the trapped carbon dioxide can be safely vented to atmosphere. The vent valve shall normally be kept in the locked shut position.

17.2 Audible and Visual Alarms

Clear visual indication shall be provided at each entrance to a protected space to show whether the gas flooding system is on automatic or manual control.

An audible alarm, clearly distinguishable from the normal fire alarm, shall be provided within a protected space and any associated hazard areas, to sound in conjunction with the discharge of the gas. If a local application system is fitted with a time delay, the alarm shall sound during the time delay period before the gas is released.

A continuing visual alarm shall be given until the space has been ventilated and the atmosphere rendered safe.

The following lamps and wording should be used to identify system conditions:

Red lamp	:	CO_2 discharged
Amber lamp	:	automatic and manual control
Green lamp	:	manual control

Optional condition indicators shall be provided as follows:

Red (flashing)	:	fire
Amber	:	system disabled
Green	:	supply healthy

System condition indicators as described above are normally required only for total flooding systems but is necessary in local application systems. Duplication of the lamps will mitigate the effects of bulb failure.

17.3 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.

17.4 Confined Spaces

Entry into confined spaces poses additional hazards because of restrictions on freedom of movement, ventilation and on escape of rescue. Before entry into floor or ceiling voids, ducts, process vessels or similarly confined spaces that are protected by a gas flooding system, the automatic operation of the system shall be prevented.

Entry into confined spaces for any purpose should be controlled by a permit-to work system. Provision should be made for ensuring that the atmosphere within the space is safe for entry and will remain so for the duration of entry.

In cases where effective ventilation cannot be ensured, the permit should specify the respiratory protective equipment to be used and any other special precautions to be observed to ensure safe working conditions.

17.5 Warning Signs

Appropriate signs, shall be prominently displayed at each manual control point and at each entrance to the area protected by the system (see Clause 18-11-1).

17.6 Exits

Adequate means of egress from a protected space shall be provided. Doors at exits shall open outwards and shall be self-closing. All exit doors shall open readily from the inside and any that have to be secured shall be fitted with panic bolts or latches.

The means of egress from a protected space should be kept clear at all times.

17.7 Manual Hose Reels

A notice with the wording "Only for use by trained personnel" shall be mounted on or adjacent to manual hose reels.

The use of manual hose reels for the application of fire-smothering gas present a hazard to personnel. This method of fire control should be used only by trained personnel who have been adequately instructed and trained in the use of the equipment and in the safety precautions to be adopted.

All persons other than those fighting the fire should be evacuated prior to the use of manual hose reels. Particular precautions are required where ventilation is restricted, in order to guard against hazards that will arise from the fire or the extinguishing medium.

17.8 Area Ventilation after Discharge

A means of mechanically or naturally ventilating area after discharge of carbon dioxides shall be provided.

Consideration should be given to adding an odor to the carbon dioxide to assist in the detection of hazardous atmospheres and in their effective ventilation.

The means provided for ventilation should not form part of the normal building ventilation system, and should incorporate extraction arrangements at low level in the protected area.

Care should be taken to ensure that the post-fire atmosphere is not ventilated into other parts of the building. Provision should be made for the prompt discovery and rescue of persons rendered unconscious.

Before re-entry to an area after discharge, the atmosphere therein should be tested by a responsible person as being safe for entry without breathing apparatus. This shall also apply to adjoining areas into which the agent have dispersed. Carbon dioxide will tend to collect in low-level spaces such as pits and ducts.

17.9 Electrostatic Discharge

Carbon dioxide systems shall not be designed, installed or used for inerting explosive atmospheres. Carbon dioxide systems shall not be test discharged into areas containing explosive atmospheres.

The discharge of carbon dioxide is known to produce electrostatic charges which, under certain conditions, could create a spark.

17.10 Electrical Clearances

All system components shall be so located as to maintain minimum clearances from live parts as shown in Table (14).

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 clearance listed in Table 14 are for purpose of electrical clearance under normal conditions; they are not intended for use as "safe" distances during fixed system operation.

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

The clearances are based upon 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 kV 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 kV 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 which 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 shall also be affected by switching surge duty, a power system design factor which along with BIL must correlate with selected minimum clearances. Electrical design engineers shall be able to furnish clearances dictated by switching surge duty. The selected clearance to ground shall satisfy the greater of switching surge or BIL duty, rather than be based upon nominal voltage.

TABLE 14 - CLEARANCE FROM CARBON DIOXIDE EQUIPMENT TO LIVE UNINSULATED ELECTRICAL COMPONENTS

NOMINAL SYSTEM VOLTAGE (kV)	MAXIMUM SYSTEM VOLTAGE (kV)	DESIGN BIL (kV)	MINIMUM* CLEARANCES (mm)
To 13.8	14.5	110	178
23	24.3	150	254
34.5	36.5	200	330
46	48.3	250	432
69	72.5	350	635
115	121	550	1067
138	145	650	1270
161	169	750	1473
230	242	900	1930
		1050	2134
345	362	1050	2134
		1300	2642
500	550	1500	3150
		1800	3658
765	800	2050	4242

*** For voltages up to 161 kV the clearances are taken from NFPA 70, National Electrical Code. For voltage 230 kV and above the clearances are taken from Table 124 of ANSI C-2. National Electrical Safety Code.**

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 which are not listed in the table, clearances may be found by interpolation.

Possible design variations in the clearance required at higher voltages are evident in the table, 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 clearances provided elsewhere for electrical system insulations on any individual component.

17.10.1 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.

18. SAFETY REQUIREMENT

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 should include the following.

18.1 Provision of adequate aisleways and routes of exit and keeping them clear at all times.

18.2 Provision of the necessary additional or emergency lighting, or both, and directional signs to ensure quick, safe evacuation.

18.3 Provision of 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 beings.

18.4 Provision of only outward swinging, self-closing doors at exits from hazardous areas, and where such doors are latched, provision of panic hardware.

18.5 Provision of continuous alarms at entrances to such areas until atmosphere has been restored to normal.

18.6 Provision of adding an odor to the carbon dioxide so that hazardous atmospheres in such areas can be recognized.

18.7 Provision of warning and instruction signs at entrances to and inside such areas.

18.8 Provision of such other steps and safeguards necessary to prevent injury or death as indicated by a careful study of each particular situation.

18.9 Total Flooding systems

18.9.1 Areas normally occupied

The automatic discharge of the system shall be prevented by means of an automatic/manual or manual only changeover device when persons are or will be present within the protected space or any adjacent area that could be rendered hazardous by discharge of the gas.

Provision shall be made for the manual operation of the fire extinguishing system by means of a control situated outside the protected space or adjacent to the main exit from the space.

While the connection between the fire detection system and the gas release is interrupted, the operation of the fire detector shall activate the fire alarm.

In order to guard against accidental release of the gas from the storage containers, the supply of carbon dioxide shall be isolated by means of a monitored, normally closed valve in the feed line, which will open on a signal from the detection system or manual release system.

The manual release push button or pull handle shall be housed in a box and protected by a glass front or other quick access front which can be broken manually to gain access to the button or handle.

Entry into a protected space should only be made when the total flooding system has been placed under manual control.

The system should be returned to fully automatic control only when all persons have left the space.

For greater protection the manual release could be keyoperated with the operating key being retained in an adjacent frangible glass or other quick access fronted box.

18.9.2 Areas not normally occupied but which will be entered. One of the following shall be provided to prevent the automatic release of carbon dioxide when the area has been entered by personnel:

a) an automatic/manual or manual only changeover device that rends the system capable of manual operation only; or;
b) a manual stop valve sited in the supply line from the storage vessel(s).

Note:

Option (a) is preferred.

During periods of entry, the automatic discharge of carbon dioxide however brief, should be prevented. The system should be returned to automatic control as soon as all persons have left the space.

18.10 Local Application Systems

When unusual circumstances make it impossible for personnel to leave the space protected by a system within the period of the predischarge alarm, e.g. during difficult maintenance work, the automatic operation of the system shall be prevented as in 18-9-1.

A local application system normally presents a lower risk to personnel than a total flooding system since the final developed concentration of extinguishant throughout the space will be lower. However, during the period of discharge it is necessary to produce an extinguishing concentration of gas around the protected area with a risk of high local concentrations. There is a further risk or higher concentrations of gas occurring in pits, wells, shaft bottoms and similar low areas.

The system shall normally be on automatic control if, after considering the geometry of the area in which a local application system is used, it can be established that there is not a foreseeable risk of a hazardous concentration of carbon dioxide being produced in any occupied part.

In assessing the degree of risk to personnel of automatically controlled systems, the need to approach close to the point of discharge or to work within the confines of the protected area should be considered. If it is necessary for personnel to work within an area that is likely to be quickly to be enveloped with CO_2 gas, consideration should be given to providing a pre-discharge alarm that gives sufficient warning to allow personnel to move away from the protected area before CO_2 is released.

18.11 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. Consideration shall also be given to where the carbon dioxide will migrate or collect in event of a discharge from a safety relief device of a storage container.

18.11.1 Warning signs

Appropriate warning signs shall be affixed outside of those spaces where concentrations of carbon dioxide gas can accumulate, not only in protected spaces but in adjacent areas where the carbon dioxide could migrate. Typical sings are shown below:

Typical sign in protected space:

WARNING!
CARBON DIOXIDE GAS
WHEN ALARM OPERATES
VACATE IMMEDIATELY

Typical sign at entrance to protected space:

WARNING!
CARBON DIOXIDE GAS
WHEN ALARM OPERATES DO NOT
ENTER UNTIL VENTILATED

Typical sign in nearby space:

CAUTION!
CARBON DIOXIDE DISCHARGE
INTO A NEARBY SPACE MAY COLLECT HERE
WHEN ALARM OPERATES
VACATE IMMEDIATELY

Appropriate warning signs shall be placed at every location where manual operation of the system should occur. A typical sign at each manual actuation station:

WARNING!
ACTUATION OF THIS DEVICE WILL CAUSE

CARBON DIOXIDE TO DISCHARGE
FORE ACTUATING, BE SURE PERSONNEL
ARE CLEAR OF THE AREA

18.11.2 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 carbon dioxide discharge. Suitable safeguards shall be provided to ensure prompt evacuation to prevent entry into such atmospheres and provide means for prompt rescue of any trapped personnel.

Personnel training shall be provided. Predischarge alarms shall be provided where-ever is necessary.

Self-contained breathing apparatus shall be provided for rescue purposes.

18.11.3 All persons that would at any time enter a space protected by carbon dioxide shall be warned of the hazards involved.

18.11.4 The predischarge warning signal shall provide a time delay of sufficient duration to allow for evacuation under "worst case" conditions. Dry runs shall be made to determine the minimum time that shall be allowed for persons to remove themselves from the hazard area after allowing time to identify the warning signal.

18.11.5 Audible predischarge signals shall be provided.

Visual signals shall be provided if the ambient noise level is high, or if persons with hearing impairment are involved.

18.11.6 All personnel must be acquainted with the fact that discharge of carbon dioxide gas from either high or low pressure systems directly at a person may endanger their safety by eye injury, ear injury, or even falls due to loss of balance on the impingement of the high velocity discharging gas. Contact with carbon dioxide in the form of dry ice can cause frostbite.

18.11.7 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. 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.