NFPA 2001

Standard on Clean Agent Fire Extinguishing Systems

2000 Edition

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

IMPORTANT NOTICE ABOUT THIS DOCUMENT

NFPA codes, standards, recommended practices, and guides, of which the document contained herein is one, are developed through a consensus standards development process approved by the American National Standards Institute. This process brings together volunteers representing varied viewpoints and interests to achieve consensus on fire and other safety issues. While the NFPA administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate, or verify the accuracy of any information or the soundness of any judgments contained in its codes and standards.

The NFPA disclaims liability for any personal injury, property or other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this document. The NFPA also makes no guaranty or warranty as to the accuracy or completeness of any information published herein.

In issuing and making this document available, the NFPA is not undertaking to render professional or other services for or on behalf of any person or entity. Nor is the NFPA undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

The NFPA has no power, nor does it undertake, to police or enforce compliance with the contents of this document. Nor does the NFPA list, certify, test or inspect products, designs, or installations for compliance with this document. Any certification or other statement of compliance with the requirements of this document shall not be attributable to the NFPA and is solely the responsibility of the certifier or maker of the statement.

NOTICES

All questions or other communications relating to this document and all requests for information on NFPA procedures governing its codes and standards development process, including information on the procedures for requesting Formal Interpretations, for proposing Tentative Interim Amendments, and for proposing revisions to NFPA documents during regular revision cycles, should be sent to NFPA headquarters, addressed to the attention of the Secretary, Standards Council, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

Users of this document should be aware that this document may be amended from time to time through the issuance of Tentative Interim Amendments, and that an official NFPA document at any point in time consists of the current edition of the document together with any Tentative Interim Amendments then in effect. In order to determine whether this document is the current edition and whether it has been amended through the issuance of Tentative Interim Amendments, consult appropriate NFPA publications such as the *National Fire Codes*® Subscription Service, visit the NFPA website at www.nfpa.org, or contact the NFPA at the address listed above.

A statement, written or oral, that is not processed in accordance with Section 5 of the Regulations Governing Committee Projects shall not be considered the official position of NFPA or any of its Committees and shall not be considered to be, nor be relied upon as, a Formal Interpretation.

The NFPA does not take any position with respect to the validity of any patent rights asserted in connection with any items which are mentioned in or are the subject of this document, and the NFPA disclaims liability for the infringement of any patent resulting from the use of or reliance on this document. Users of this document are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Users of this document should consult applicable federal, state, and local laws and regulations. NFPA does not, by the publication of this document, intend to urge action that is not in compliance with applicable laws, and this document may not be construed as doing so.

Licensing Policy

This document is copyrighted by the National Fire Protection Association (NFPA). By making this document available for use and adoption by public authorities and others, the NFPA does not waive any rights in copyright to this document.

1. Adoption by Reference—Public authorities and others are urged to reference this document in laws, ordinances, regulations, administrative orders, or similar instruments. Any deletions, additions, and changes desired by the adopting authority must be noted separately. Those using this method are requested to notify the NFPA (Attention: Secretary, Standards Council) in writing of such use. The term "adoption by reference" means the citing of title and publishing information only.

2. Adoption by Transcription—A. Public authorities with lawmaking or rule-making powers only, upon written notice to the NFPA (Attention: Secretary, Standards Council), will be granted a royalty-free license to print and republish this document in whole or in part, with changes and additions, if any, noted separately, in laws, ordinances, regulations, administrative orders, or similar instruments having the force of law, provided that: (1) due notice of NFPA's copyright is contained in each law and in each copy thereof; and (2) that such printing and republication is limited to numbers sufficient to satisfy the jurisdiction's lawmaking or rule-making process. **B.** Once this NFPA Code or Standard has been adopted into law, all printings of this document by public authorities with lawmaking or rule-making powers or any other persons desiring to reproduce this document or its contents as adopted by the jurisdiction in whole or in part, in any form, upon written request to NFPA (Attention: Secretary, Standards Council), will be granted a nonexclusive license to print, republish, and vend this document in whole or in part, with changes and additions, if any, noted separately, provided that due notice of NFPA's copyright is contained in each copy. Such license shall be granted only upon agreement to pay NFPA a royalty. This royalty is required to provide funds for the research and development necessary to continue the work of NFPA and its volunteers in continually updating and revising NFPA standards. Under certain circumstances, public authorities with lawmaking or rule-making powers may apply for and may receive a special royalty where the public interest will be served thereby.

3. Scope of License Grant—The terms and conditions set forth above do not extend to the index of this document.

(For further explanation, see the Policy Concerning the Adoption, Printing, and Publication of NFPA Documents, which is available upon request from the NFPA.)

NFPA 2001

Standard on

Clean Agent Fire Extinguishing Systems

2000 Edition

This edition of NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*, was prepared by the Technical Committee on Halon Alternative Protection Options 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 2001 was approved as an American National Standard on February 11, 2000.

Origin and Development of NFPA 2001

The Technical Committee on Alternative Protection Options to Halon was organized in 1991 and immediately started work to address the new total flooding clean agents that were being developed to replace Halon 1301. A need existed on how to design, install, maintain, and operate systems using these new clean agents, and NFPA 2001 was established to address these needs. The 1994 edition was the first edition of NFPA 2001. This standard was revised in 1996 and again in 2000.

Technical Committee on Halon Alternative Protection Options

Philip J. DiNenno, *Chair*
Hughes Assoc., Inc., MD [SE]

Jeff L. Harrington, *Secretary*
Harrington Group, Inc., GA [SE]

W. C. (Chuck) Boyte, Royal & Sun Alliance, TN [I]
Rep. American Insurance Services Group
Michael P. Broadribb, BP Amoco Toledo Refinery, OH [U]
Jon S. Casler, Fike Corp., MO [M]
Salvatore A. Chines, HSB Industrial Risk Insurers, CT [I]
Michelle Collins, Nat'l Aeronautics & Space Admin, FL [E]
William J. Fries, Liberty Mutual Insurance Co., MA [I]
Rep. The Alliance of American Insurers
William A. Froh, U.S. Dept. of Energy, MD [U]
William L. Grosshandler, Nat'l Inst. of Standards & Technology, MD [RT]
Elio Guglielmi, North American Fire Guardian Technology Inc., Canada [M]
Alankar Gupta, Boeing Commercial Airplane Group, WA [U]
Howard S. Hammel, E. I. DuPont, DE [M]
David H. Kay, U.S. Dept. of the Navy, VA [U]
George A. Krabbe, Automatic Suppression Systems Inc., IL [IM]
Rep. Fire Suppression Systems Assn.
Robert L. Langer, Ansul Inc./Tyco, WI [M]
Robert C. Merritt, Factory Mutual Research Corp., MA [I]
W. Douglas Register, Great Lakes Chemical Corp., IN [M]
Paul E. Rivers, 3M Co., MN [M]
Samuel L. Rogers, Kemper Nat'l Insurance Cos., CO [I]
Reva Rubenstein, U.S. Environmental Protection Agency, DC [E]
Joseph A. Senecal, Kidde-Fenwal, Inc./Williams Holdings, MA [M]
Clifford R. Sinopoli II, Baltimore Gas & Electric, MD [U]
Rep. Edison Electric Inst.
Louise C. Speitel, Federal Aviation Administration Technical Center, NJ [E]
Tim N. Testerman, Procter & Gamble, OH [U]
Klaus Wahle, U.S. Coast Guard Headquarters (G-MSE-4), DC [E]
Stephen B. Waters, Fireline Corp., MD [IM]
Rep. Nat'l Assn. of Fire Equipment Distributors Inc.
Kenneth W. Zastrow, Underwriters Laboratories Inc., IL [RT]

Alternates

Charles Bauroth, Liberty Mutual Insurance Co., TX [I]
(Alt. to W. J. Fries)
William M. Carey, Underwriters Laboratories Inc., IL [RT]
(Alt. to K. W. Zastrow)
Christina F. Francis, Procter & Gamble, OH [U]
(Alt. to T. N. Testerman)
Christopher P. Hanauska, Hughes Assoc., Inc., MD [SE]
(Alt. to P. J. DiNenno)
Richard L. Hansen, U.S. Coast Guard, CT [E]
(Alt. to K. Wahle)
Paul William Lain, U.S. Dept. of Energy, DC [U]
(Alt. to W. A. Froh)
Lorne MacGregor, North American Fire Guardian Technology Inc., Canada [M]
(Alt. to E. Guglielmi)
J. Douglas Mather, New Mexico Engr Research Inst., NM [RT]
(Vot. Alt. to NMERI Rep.)
Jonathan S. Meltzer, Kidde-Fenwal, Inc./Williams Holdings, MA [M]
(Alt. to J. A. Senecal)
Earl D. Neargarth, Fike Corp., MO [M]
(Alt. to J. S. Casler)
David A. Pelton, Ansul Inc./Tyco, IL [M]
(Alt. to R. L. Langer)
John A. Pignato, Jr., 3M Co., MN [M]
(Alt. to P. E. Rivers)
Todd E. Schumann, HSB Industrial Risk Insurers, IL [I]
(Alt. to S. A. Chines)
David C. Smith, Factory Mutual Research Corp., MA [I]
(Alt. to R. C. Merritt)
Al Thornton, Great Lakes Chemical Corp., TX [M]
(Alt. to W. D. Register)
Charles F. Willms, Fire Suppression Systems Assn., NC [IM]
(Alt. to G. A. Krabbe)
Joseph A. Wright, Federal Aviation Administration Technical Center, NJ [E]
(Alt. to L. C. Speitel)
Robert E. Yellin, CalProtection, CA [IM]
(Alt. to S. B. Waters)

Nonvoting

Anatoly Baratov, All-Russian Inst. of Fire Protection, Russia
Ole Bjarnsholt, Unitor Denmark A/S, Denmark [M]
Michael John Holmes, Preussag Fire Protection Ltd, England
Douglas J. Pickersgill, Fire and Safety Systems, Australia
Ingeborg Schlosser, VdS Schadenverhutung, Germany [I]
Robert E. Tapscott, Globe Tech Inc., NM
(Member Emeritus)
Fernando Vigara, Vimpex - Security Devices, SA, Spain

Mark T. Conroy, NFPA Staff Liaison

This list represents the membership at the time the Committee was balloted on the final text of this edition. Since that time, changes in the membership may have occurred. A key to classifications is found at the back of the document.

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 alternative protection options to Halon 1301 and 1211 fire extinguishing systems. It shall not deal with design, installation, operation, testing, and maintenance of systems employing carbon dioxide, dry chemical, wet chemical, foam, Halon 1301, Halon 1211, Halon 2402, or water as the primary extinguishing media.

Contents

Chapter 1 General 2001– 4
1-1 Scope 2001– 4
1-2 Purpose 2001– 4
1-3 Definitions 2001– 4
1-4 Units 2001– 5
1-5 General Information 2001– 5
1-6 Safety 2001– 6
1-7 Environmental Factors 2001– 8
1-8 Retrofitability 2001– 8
1-9 Compatibility with Other Agents 2001– 8

Chapter 2 Components 2001– 8
2-1 Agent Supply 2001– 8
2-2 Distribution 2001– 9
2-3 Detection, Actuation, Alarm, and Control Systems 2001–11

Chapter 3 System Design 2001–12
3-1 Specifications, Plans, and Approvals 2001–12
3-2 System Flow Calculations 2001–13
3-3 Enclosure 2001–13
3-4 Design Concentration Requirements 2001–14
3-5 Total Flooding Quantity 2001–14
3-6 Duration of Protection 2001–15
3-7 Distribution System 2001–15
3-8 Nozzle Choice and Location 2001–16

Chapter 4 Inspection, Maintenance, Testing, and Training 2001–16
4-1 Inspection and Tests 2001–16
4-2 Container Test 2001–16
4-3 Hose Test 2001–16
4-4 Enclosure Inspection 2001–17
4-5 Maintenance 2001–17
4-6 Training 2001–17
4-7 Approval of Installations 2001–17
4-8 Safety 2001–19

Chapter 5 Marine Systems 2001–19
5-1 General 2001–19
5-2 Use and Limitations 2001–19
5-3 Hazards to Personnel 2001–19
5-4 Agent Supply 2001–19
5-5 Detection, Actuation, and Control Systems 2001–20
5-6 Additional Requirements for Systems Protecting Class B Hazards Greater than 6000 ft^3 (170 m^3) with Stored Cylinders within the Protected Space 2001–20
5-7 Enclosure 2001–20
5-8 Design Concentration Requirements 2001–21
5-9 Distribution System 2001–21
5-10 Nozzle Choice and Location 2001–21
5-11 Inspection and Tests 2001–21
5-12 Approval of Installations 2001–21
5-13 Periodic Puff Testing 2001–21
5-14 Compliance 2001–21

Chapter 6 Referenced Publications 2001–21

Appendix A Explanatory Material 2001–22

Appendix B Cup Burner Test Procedure 2001–90

Appendix C Enclosure Integrity Procedure 2001–92

Appendix D Referenced Publications 2001–100

Index 2001–103

NFPA 2001

Standard on

Clean Agent Fire Extinguishing Systems

2000 Edition

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 6 and Appendix D.

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 total flooding clean agent fire extinguishing systems. It does not cover fire extinguishing systems that use carbon dioxide or water as the primary extinguishing media, which are addressed by other NFPA documents.

1-2 Purpose.

1-2.1 The agents in this standard were introduced in response to international restrictions on the production of certain halon fire extinguishing agents under the Montreal Protocol signed September 16, 1987, as amended. This standard is prepared for the use and guidance of those charged with purchasing, designing, installing, testing, inspecting, approving, listing, operating, and maintaining engineered or pre-engineered clean agent extinguishing systems, so 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 this standard is not lowered.

1-2.2 No standard can be promulgated that will provide all the necessary criteria for the implementation of a total flooding clean agent fire extinguishing system. Technology in this area is under constant development, and this will be reflected in revisions to this standard. The user of this standard must recognize the complexity of clean agent fire extinguishing systems. Therefore, the designer is cautioned that the standard is not a design handbook. The standard does not do away with the need for the engineer or for competent engineering judgment. It is intended that a designer capable of applying a more complete and rigorous analysis to special or unusual problems shall have latitude in the development of such designs. In such cases, the designer is responsible for demonstrating the validity of the approach.

1-3 Definitions. For purpose of clarification, the following general terms used with special technical meanings in this standard are defined.

1-3.1 Adjusted Minimum Design Quantity (AMDQ). The minimum design quantity of agent that has been adjusted in consideration of design factors.

1-3.2 Agent Concentration. The portion of agent in an agent-air mixture expressed in volume percent.

1-3.3* Approved. Acceptable to the authority having jurisdiction.

1-3.4* Authority Having Jurisdiction. The organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.

1-3.5 Class A Fire. Fire in ordinary combustible materials, such as wood, cloth, paper, rubber, and many plastics.

1-3.6 Class B Fire. Fire in flammable liquids, oils, greases, tars, oil-base paints, lacquers, and flammable gases.

1-3.7 Class C Fire. Fire that involves energized electrical equipment where the electrical resistivity of the extinguishing media is of importance.

1-3.8 Clean Agent. Electrically nonconducting, volatile, or gaseous fire extinguishant that does not leave a residue upon evaporation. The word *agent* as used in this document shall mean clean agent unless otherwise indicated.

1-3.9 Clearance. The air distance between extinguishing system equipment, including piping and nozzles, and unenclosed or uninsulated live electrical components not at ground potential.

1-3.10 Design Factor (DF). A fraction of the agent minimum design quantity (MDQ) added thereto deemed appropriate due to a specific feature of the protection application or design of the suppression system.

1-3.11 Engineered System. A system requiring individual calculation and design to determine the flow rates, nozzle pressures, pipe size, area or volume protected by each nozzle, quantity of agent, and the number and types of nozzles and their placement in a specific system.

1-3.12 Fill Density. Mass of agent per unit of container volume (the customary units are lb/ft^3 or kg/m^3).

1-3.13 Final Design Quantity (FDQ). The quantity of agent determined from the agent minimum design quantity as adjusted to account for design factors and pressure adjustment.

1-3.14* Halocarbon Agent. An agent that contains as primary components one or more organic compounds containing one or more of the elements fluorine, chlorine, bromine, or iodine.

1-3.15 Inert Gas Agent. An agent that contains as primary components one or more of the gases helium, neon, argon, or nitrogen. Inert gas agents that are blends of gases can also contain carbon dioxide as a secondary component.

1-3.16* 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.

1-3.17 Lowest Observable Adverse Effect Level (LOAEL). The lowest concentration at which an adverse physiological or toxicological effect has been observed.

1-3.18 Minimum Design Quantity (MDQ). The quantity of agent required to achieve the minimum design concentration as calculated using the method in 3-5.1 or 3-5.2, as appropriate.

1-3.19 No Observed Adverse Effect Level (NOAEL). The highest concentration at which no adverse toxicological or physiological effect has been observed.

1-3.20* Normally Occupied Area. One that is intended for occupancy.

1-3.21 Pre-Engineered System. A system having predetermined flow rates, nozzle pressures, and quantities of agent. These systems have the specific pipe size, maximum and minimum pipe lengths, flexible hose specifications, number of fittings, and number and types of nozzles prescribed by a testing laboratory. The hazards protected by these systems are specifically limited as to type and size by a testing laboratory based upon actual fire tests. 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.

1-3.22 Safety Factor (SF). A multiplier of the agent flame extinguishing or inerting concentration to determine the agent minimum design concentration.

1-3.23 Sea Level Equivalent of Agent. The agent concentration (volume percent) at sea level for which the partial pressure of agent matches the ambient partial pressure of agent at a given altitude.

1-3.24 Sea Level Equivalent of Oxygen. The oxygen concentration (volume percent) at sea level for which the partial pressure of oxygen matches the ambient partial pressure of oxygen at a given altitude.

1-3.25 Shall. Indicates a mandatory requirement.

1-3.26 Should. Indicates a recommendation or that which is advised but not required.

1-3.27 Superpressurization. The addition of gas to a fire extinguishing agent container to achieve a specified pressure therein.

1-3.28 Total Flooding. The act and manner of discharging an agent for the purpose of achieving a specified minimum agent concentration throughout a hazard volume.

1-3.29 Total Flooding System. A system consisting of an agent supply and distribution network designed to achieve a total flooding condition in a hazard volume.

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). Two units (liter and bar), outside of but recognized by SI, are commonly used in international fire protection. These units are listed in Table 1-4 with conversion factors.

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

Table 1-4 Metric Conversion Factors

Name of Unit	Unit Symbol	Conversion Factor
millimeter	mm	1 in. = 25.4 mm
liter	L	1 gal = 3.785 L
cubic meter	m^3	1 ft^3 = 0.028317 m^3
kilogram	kg	1 lb = 0.4536 kg
kilograms per cubic meter	kg/m^3	1 lb/ft^3 = 16.0185 kg/m^3
pascal	Pa	1 psi = 6895 Pa
bar	bar	1 psi = 0.0689 bar
bar	bar	1 bar = 10^5 Pa

Notes:
1. For additional conversions and information, see ASTM SI 10, *Standard Practice for Use of the International System of Units (SI): The Modern Metric System.*
2. In Canada refer to CAN/CSA-Z234.1, *Canadian Metric Practice Guide.*

1-5 General Information.

1-5.1* Applicability of Agents.

1-5.1.1 The fire extinguishing agents addressed in this standard are electrically nonconducting and leave no residue upon evaporation.

1-5.1.2* Agents that meet the criteria of 1-5.1.1 and are discussed in this standard are shown in Table 1-5.1.2.

Table 1-5.1.2 Agents Addressed in NFPA 2001

FC-2-1-8	Perfluoropropane	C_3F_8
FC-3-1-10	Perfluorobutane	C_4F_{10}
HCFC Blend A	Dichlorotrifluoroethane HCFC-123 (4.75%)	$CHCl_2CF_3$
	Chlorodifluoromethane HCFC-22 (82%)	$CHClF_2$
	Chlorotetrafluoroethane HCFC-124 (9.5%)	$CHClFCF_3$
	Isopropenyl-1-methylcyclohexene (3.75%)	
HCFC-124	Chlorotetrafluoroethane	$CHClFCF_3$
HFC-125	Pentafluoroethane	CHF_2CF_3
HFC-227ea	Heptafluoropropane	CF_3CHFCF_3
HFC-23	Trifluoromethane	CHF_3
HFC-236fa	Hexafluoropropane	$CF_3CH_2CF_3$
FIC-13I1	Trifluoroiodide	CF_3I
IG-01	Argon	Ar
IG-100	Nitrogen	N_2
IG-541	Nitrogen (52%)	N_2
	Argon (40%)	Ar
	Carbon dioxide (8%)	CO_2
IG-55	Nitrogen (50%)	N_2
	Argon (50%)	Ar

Notes:
1. Other agents could become available at later dates. They could be added via the NFPA process in future editions or amendments of the standard.
2. Composition of inert gas agents are given in percent by volume. Composition of HCFC Blend A is given in percent by weight.

1-5.1.3 The design, installation, service, and maintenance of clean agent systems shall be performed by those skilled in clean agent fire extinguishing system technology.

1-5.2 Use and Limitations.

1-5.2.1 Pre-engineered systems consist of system components designed to be installed according to pretested limitations as listed by a testing laboratory. Pre-engineered systems could incorporate special nozzles, flow rates, methods of application, nozzle placement, and pressurization levels that could differ from those detailed elsewhere in this standard. All other requirements of the standard apply. Pre-engineered systems shall be installed to protect hazards within the limitations that have been established by the testing laboratories where listed.

1-5.2.2 Clean agent fire extinguishing systems are useful within the limits of this standard in extinguishing fires in specific hazards or equipment and in occupancies where an electrically nonconductive medium is essential or desirable, or where cleanup of other media presents a problem.

1-5.2.3* Total flooding clean agent fire extinguishing systems are used primarily to protect hazards that are in enclosures or equipment that, in itself, includes an enclosure to contain the agent. Some typical hazards that could be suitable include, but are not limited to, the following:

(1) Electrical and electronic hazards
(2) Subfloors and other concealed spaces
(3) Flammable and combustible liquids and gases
(4) Other high-value assets
(5) Telecommunications facilities

1-5.2.4* Clean agent systems could also be used for explosion prevention and suppression where flammable materials could collect in confined areas.

1-5.2.5 Clean agents shall not be used on fires involving the following materials unless they have been tested to the satisfaction of the authority having jurisdiction:

(1) Certain chemicals or mixtures of chemicals, such as cellulose nitrate and gunpowder, that are capable of rapid oxidation in the absence of air
(2) Reactive metals such as lithium, sodium, potassium, magnesium, titanium, zirconium, uranium, and plutonium
(3) Metal hydrides
(4) Chemicals capable of undergoing autothermal decomposition, such as certain organic peroxides and hydrazine

1-5.2.6* Electrostatic charging of ungrounded conductors could occur during the discharge of liquefied gases. These conductors could discharge to other objects, causing an electric arc of sufficient energy to initiate an explosion.

1-5.2.7 Where a total flooding system is used, a fixed enclosure shall be provided about the hazard that allows a specified agent concentration to be achieved and maintained for a specified period of time.

1-5.2.8* The effects of agent decomposition on fire protection effectiveness and equipment shall be considered where using clean agents in hazards with high ambient temperatures (e.g., furnaces and ovens).

1-6 Safety.

1-6.1* Hazards to Personnel.

1-6.1.1* Any agent that is to be recognized by this standard or proposed for inclusion in this standard shall first be evaluated in a manner equivalent to the process used by the U.S. Environmental Protection Agency's (EPA) SNAP Program.

1-6.1.2* Halocarbon Agents.

1-6.1.2.1 Any unnecessary exposure to halocarbon clean agents, even at NOAEL concentrations, and halocarbon decomposition products shall be avoided. The requirement for pre-discharge alarms and time delays are intended to prevent human exposure to agents. The following additional provisions shall apply in order to account for failure of these safeguards:

(a) Halocarbon systems for spaces that are normally occupied and designed to concentrations up to the NOAEL *[see Table 1-6.1.2.1(a)]* shall be permitted.

(b) Halocarbon systems for spaces that are normally occupied and designed to concentrations above the NOAEL and up to the LOAEL *[see Table 1-6.1.2.1(a)],* shall be permitted, given that means be provided to limit exposure to no longer than the time specified in Tables 1-6.1.2.1(b) through 1-6.1.2.1(e) corresponding to the given design concentration.

(c) In spaces that are not normally occupied and protected by a halocarbon system designed to concentrations above the LOAEL *[see Table 1-6.1.2.1(a)],* and where personnel could possibly be exposed, means shall be provided to limit exposure times using Tables 1-6.1.2.1(b) through 1-6.1.2.1(e).

(d) In the absence of the information needed to fulfill the conditions listed in 1-6.1.2.1(a) through 1-6.1.2.1(c), the following provisions shall apply:

(1) Where egress takes longer than 30 seconds but less than 1 minute, the halocarbon agent shall not be used in a concentration exceeding its LOAEL.
(2) Concentrations exceeding the LOAEL are permitted only in areas not normally occupied by personnel provided that any personnel in the area can escape within 30 seconds. No unprotected personnel shall enter the area during agent discharge.

Table 1-6.1.2.1(a) Information for Halocarbon Clean Agents

Agent	NOAEL (%)	LOAEL (%)
FC-3-1-10	40	>40
HCFC Blend A	10.0	>10.0
HCFC-124	1.0	2.5
HFC-125	7.5	10.0
HFC-227ea	9.0	>10.5
HFC-23	50	>50
HFC-236fa	10	15

Table 1-6.1.2.1(b) Time for Safe Human Exposure at Stated Concentrations for HFC-125

HFC-125 Concentration		
% v/v	ppm	Human Exposure Time (minutes)
7.5	75,000	5.00
8.0	80,000	5.00
8.5	85,000	5.00
9.0	90,000	5.00
9.5	95,000	5.00
10.0	100,000	5.00
10.5	105,000	5.00
11.0	110,000	5.00
11.5	115,000	5.00
12.0	120,000	1.67
12.5	125,000	0.59
13.0	130,000	0.54
13.5	135,000	0.49

Notes:
1. Data derived from the EPA-approved and peer-reviewed physiologically based pharmacokinetic (PBPK) model or its equivalent.
2. Based on LOAEL of 10.0 percent in dogs.

Table 1-6.1.2.1(c) Time for Safe Human Exposure at Stated Concentrations for HFC-227ea

HFC-227ea Concentration		
% v/v	ppm	Human Exposure Time (minutes)
9.0	90,000	5.00
9.5	95,000	5.00
10.0	100,000	5.00
10.5	105,000	5.00
11.0	110,000	1.13
11.5	115,000	0.60
12.0	120,000	0.49

Notes:
1. Data derived from the EPA-approved and peer-reviewed PBPK model or its equivalent.
2. Based on LOAEL of 10.5 percent in dogs.

Table 1-6.1.2.1(d) Time for Safe Human Exposure at Stated Concentrations for HFC-236fa

HFC-236fa Concentration		
% v/v	ppm	Human Exposure Time (minutes)
10.0	100,000	5.00
10.5	105,000	5.00
11.0	110,000	5.00
11.5	115,000	5.00
12.0	120,000	5.00
12.5	125,000	5.00
13.0	130,000	1.65
13.5	135,000	0.92
14.0	140,000	0.79
14.5	145,000	0.64
15.0	150,000	0.49

Notes:
1. Data derived from the EPA-approved and peer-reviewed PBPK model or its equivalent.
2. Based on LOAEL of 15.0 percent in dogs.

Table 1-6.1.2.1(e) Time for Safe Human Exposure at Stated Concentrations for FIC-13I1

FIC-13I1 Concentration		
% v/v	ppm	Human Exposure Time (minutes)
0.2	2000	5.00
0.25	2500	5.00
0.30	3000	5.00
0.35	3500	4.30
0.40	4000	0.85
0.45	4500	0.49
0.50	5000	0.35

Notes:
1. Data derived from the EPA-approved and peer-reviewed PBPK model or its equivalent.
2. Based on LOAEL of 0.4 percent in dogs.

1-6.1.2.2 To maintain oxygen concentrations above 16 percent (sea level equivalent), the point at which onset of impaired personnel function occurs, no halocarbon fire extinguishing agents of concentration greater than 24 percent addressed in this standard shall be used in a normally occupied area.

1-6.1.3* Inert Gas Clean Agents. Unnecessary exposure to inert gas agent systems resulting in low oxygen atmospheres shall be avoided. The requirement for pre-discharge alarms and time delays is intended to prevent human exposure to agents. The following additional provisions shall apply in order to account for failure of these safeguards:

(a) Inert gas systems designed to concentrations below 43 percent (corresponding to an oxygen concentration of 12 percent, sea level equivalent of oxygen) shall be permitted, given the following:

(1) The space is normally occupied.
(2) Means are provided to limit exposure to no longer than 5 minutes.

(b) Inert gas systems designed to concentrations between 43 and 52 percent (corresponding to between 12 and 10 percent oxygen, sea level equivalent of oxygen) shall be permitted, given the following:

(1) The space is normally occupied.
(2) Means are provided to limit exposure to no longer than 3 minutes.

(c) Inert gas systems designed to concentrations between 52 and 62 (corresponding to between 10 and 8 percent oxygen, sea level equivalent of oxygen) shall be permitted given the following:

(1) The space is normally unoccupied.
(2) Where personnel could possibly be exposed, means are provided to limit the exposure to less than 30 seconds.

(d) Inert gas systems designed to concentrations above 62 percent (corresponding to 8 percent oxygen or below, sea level equivalent of oxygen), shall only be used in unoccupied areas where personnel are not exposed to such oxygen depletion. *(See 3-5.3.3 for atmospheric correction factors.)*

1-6.1.4 Safety Requirements.

1-6.1.4.1* Suitable safeguards shall be provided to ensure prompt evacuation of and prevent entry into hazardous atmospheres and also to provide means for prompt rescue of any trapped personnel. Safety items such as personnel training, warning signs, discharge alarms, self-contained breathing apparatus (SCBA), evacuation plans, and fire drills shall be considered.

1-6.1.4.2* Consideration shall be given to the possibility of a clean agent migrating to adjacent areas outside of the protected space.

1-6.2 Electrical Clearances.

1-6.2.1 All system components shall be located to maintain no less than minimum clearances from energized electrical parts. The following references shall be considered as the minimum electrical clearance requirements for the installation of clean agent systems:

(1) ANSI C2, *National Electrical Safety Code*
(2) NFPA 70, *National Electrical Code*®
(3) 29 *CFR* 1910, Subpart S

1-6.2.2 Where the design basic insulation level (BIL) is not available, and where nominal voltage is used for the design criteria, the highest minimum clearance listed for this group shall be used.

1-6.2.3 The selected clearance to ground shall satisfy the greater of the switching surge or BIL duty, rather than being based on nominal voltage.

1-6.2.4 The clearance between uninsulated, energized parts of the electrical system equipment and any portion of the clean agent system shall not be less than the minimum clearance provided elsewhere for electrical system insulations on any individual component.

1-6.2.5 Where BIL is not available and where nominal voltage is used for the design criteria, the highest minimum clearance listed for this group shall be used.

1-7* Environmental Factors. When an agent is being selected to protect a hazard area, the effects of the agent on the environment shall be considered. Selection of the appropriate fire suppression agent shall include consideration of the following items:

(1) Potential environmental effect of a fire in the protected area
(2) Potential environmental effect of the various agents that could be used

1-8 Retrofitability. Retrofitting of any clean agent into an existing fire extinguishing system shall result in a system that is listed or approved.

1-9 Compatibility with Other Agents.

1-9.1* Mixing of agents in the same container shall be permitted only if the system is listed.

1-9.2 Systems employing the simultaneous discharge of different agents to protect the same enclosed space shall not be permitted.

Chapter 2 Components

2-1 Agent Supply.

2-1.1 Quantity.

2-1.1.1 Primary Agent Supply. The amount of agent in the system primary agent supply shall be at least sufficient for the largest single hazard protected or group of hazards to be protected simultaneously.

2-1.1.2* Reserve Agent Supply. Where required, a reserve agent supply shall consist of as many multiples of the primary agent supply as the authority having jurisdiction considers necessary.

2-1.1.3 Uninterrupted Protection. Where uninterrupted protection is required, both the primary and the reserve agent supplies shall be permanently connected to the distribution piping and arranged for easy changeover.

2-1.2* Quality. Agent properties shall meet the standards of quality given in Tables 2-1.2(a), 2-1.2(b), and 2-1.2(c). Each batch of agent manufactured shall be tested and certified to the specifications given in the tables. Agent blends shall remain homogeneous in storage and use within the listed temperature range and conditions of service that they will encounter.

Table 2-1.2(a) Halogenated Agent Quality Requirements

Property	Specification
Agent purity, mole %, minimum	99.0
Acidity, ppm (by weight HCl equivalent), maximum	3.0
Water content, % by weight, maximum	0.001
Nonvolatile residues, grams/100 mL maximum	0.05

Table 2-1.2(b) Inert Gas Agent Quality Requirements

		IG-01	IG-100	IG-541	IG-55
Composition, % by volume	N$_2$		Minimum 99.9%	52% ± 4%	50% ± 5%
	Ar	Minimum 99.9%		40% ± 4%	50% ± 5%
	CO$_2$			8% + 1% – 0.0%	
Water content, % by weight		Maximum 0.005%	Maximum 0.005%	Maximum 0.005%	Maximum 0.005%

Table 2-1.2(c) HCFC Blend A Quality Requirements

Component	Amount, weight %
HCFC-22	82% ± 0.8%
HCFC-124	9.50% ± 0.9%
HCFC-123	4.75% ± 0.5%
Isopropenyl-1-methylcyclohexene	3.75% ± 0.5%

2-1.3 Storage Container Arrangement.

2-1.3.1 Storage containers and accessories shall be located and arranged so that inspection, testing, recharging, and other maintenance activities are facilitated and interruption of protection is held to a minimum.

2-1.3.2* Storage containers shall be located as close as possible to or within the hazard or hazards they protect.

2-1.3.3 Agent storage containers shall not be located where they can be rendered inoperable or unreliable due to mechanical damage or exposure to chemicals or harsh weather conditions or by any other foreseeable cause. Where container exposure to such conditions is unavoidable then suitable enclosures or protective measures shall be employed.

2-1.3.4 Storage containers shall be securely installed and secured according to the manufacturer's listed installation manual and in a manner that provides for convenient individual servicing or content weighing.

2-1.3.5 Where storage containers are connected to a manifold, automatic means, such as a check valve, shall be provided to prevent agent loss and to ensure personnel safety if the system is operated when any containers are removed for maintenance.

2-1.4 Agent Storage Containers.

2-1.4.1* Storage Containers. Agent shall be stored in containers designed to hold that specific agent at ambient temperatures. Containers shall be charged to a fill density or superpressurization level within the range specified in the manufacturer's listed manual.

2-1.4.2* Each agent container shall have a permanent nameplate or other permanent marking that indicates the following:

(1) For halocarbon agent containers, the agent, tare and gross weights, and superpressurization level (where applicable) of the container

(2) For inert gas agent containers, the agent, pressurization level of the container, and nominal agent volume

2-1.4.3 The containers used in these systems shall be designed to meet the requirements of the U.S. Department of Transportation or the Canadian Transport Commission, if used as shipping containers. If not shipping containers, they shall be designed, fabricated, inspected, certified, and stamped in accordance with Section VIII of the ASME *Boiler and Pressure Vessel Code;* independent inspection and certification is recommended. The design pressure shall be suitable for the maximum pressure developed at 130°F (55°C) or at the maximum controlled temperature limit.

2-1.4.4 A reliable means of indication shall be provided to determine the pressure in refillable superpressurized containers.

2-1.4.5 The containers connected to a manifold shall be as follows:

(a) For halocarbon clean agents in a multiple container system, all containers supplying the same manifold outlet for distribution of the same agent shall be interchangeable and of one select size and charge.

(b) *Inert gas agents shall be permitted to utilize multiple storage container sizes connected to a common manifold.

2-1.4.6 Storage temperatures shall not exceed or be less than the manufacturer's listed limits. External heating or cooling shall be used to keep the temperature of the storage container within desired ranges.

2-2 Distribution.

2-2.1* Pipe.

2-2.1.1* Pipe shall be noncombustible material having physical and chemical characteristics such that its integrity under stress can be predicted with reliability. Special corrosion-resistant materials or coatings shall be required in severely corrosive atmospheres. The thickness of the piping shall be calculated in accordance with the ASME B31.1, *Power Piping Code.* The internal pressure used for this calculation shall not be less than the greater of either of the following values:

(1) The normal charging pressure in the agent container at 70°F (21°C)

(2) Eighty percent of the maximum pressure in the agent container at the maximum storage temperature of not less than 130°F (55°C), using the equipment manufacturer's maximum allowable fill density, if applicable

In no case shall the value used, for the minimum piping design pressure, be less than that specified in Table 2-2.1.1(a) or Table 2-2.1.1(b), for the conditions shown.

For inert gas clean agents Table 2-2.1.1(a) shall be used. The pressure-reducing device shall be readily identifiable. For halocarbon clean agents Table 2-2.1.1(b) shall be used.

If different fill densities, pressurization levels, or higher storage temperatures, other than those shown in Table 2-2.1.1(a) or Table 2-2.1.1(b), are approved for a given system, the minimum design pressure for the piping shall be adjusted to the maximum pressure in the agent container at maximum temperature, using the basic design criteria specified in 2-2.1.1(1) and 2-2.1.1(2).

Table 2-2.1.1(a) Minimum Design Working Pressure for Inert Gas Clean Agent System Piping

					Minimum Design Pressure at 70°F (21°C)			
	Agent Container Charging Pressure at 70°F (21°C)		Agent Container Charging Pressure at 130°F (55°C)		Piping Upstream of Pressure Reducer		Piping Downstream of Pressure Reducer	
Agent	**psig**	**kPa**	**psig**	**kPa**	**psig**	**kPa**	**psig**	**kPa**
IG-01	2,371	16,347	2,650	18,271	2,371	16,347	975	6,723
	2,964	20,436	3,306	22,778	2,964	20,436	975	6,728
IG-541	2,175	14,997	2,575	17,755	2,175	14,997	1,000	6,895
	2,900	19,996	3,433	23,671	2,900	19,996	1,000	6,895
IG-55	2,222	15,320	2,475	17,065	2,222	15,320	950	6,550
	2,962	20,424	3,300	22,753	2,962	20,424	950	6,550
	4,443	30,633	4,950	34,130	4,443	30,635	950	6,550
IG-100	2,404	16,575	2,799	19,300	2,404	16,575	1,000	6,895
	3,236	22,311	3,773	26,014	3,236	22,311	1,000	6,895

Table 2-2.1.1(b) Minimum Design Working Pressure for Halocarbon Clean Agent System Piping

Agent	Agent Container Maximum Fill Density (lb/ft^3)	Agent Container Charging Pressure at 70°F (21°C) (psig)	Agent Container Pressure at 130°F (55°C) (psig)	Minimum Piping Design Pressure at 70°F (21°C) (psig)
HFC-227ea	62	150*	247	198
	72	360*	520	416
	72	600*	1025	820
FC-3-1-10	80	360*	450	360
HCFC Blend A	56.2	600*	850	680
	56.2	360*	540	432
HFC 23	54	608.9**	2182	1746
	49	608.9**	1765	1412
HCFC-124	74	240*	354	283
HCFC-124	74	360*	580	464
HFC-125	54	360*	615	492
HFC 125	56	600*	1045	836
HFC-236fa	74	240*	360	280
HFC-236fa	75	360*	600	480
HFC-236fa	74	600*	1100	880

*Superpressurized with nitrogen.
**Not superpressurized with nitrogen.

2-2.1.2 Cast-iron pipe, steel pipe conforming to ASTM A 120, *Specifications for Pipe, Steel, Black, and Hot-Dipped Zinc Coated, Welded and Seamless for Ordinary Uses*, or nonmetallic pipe shall not be used.

2-2.1.3 Stenciled pipe identification shall not be painted over, concealed, or removed prior to approval by the authority having jurisdiction.

2-2.1.4 Where used, flexible pipe, tubing, or hoses, including connections, shall be of approved materials and pressure ratings.

2-2.1.5 Each pipe section shall be cleaned internally after preparation and before assembly by means of swabbing, utilizing a suitable nonflammable cleaner. The pipe network shall be free of particulate matter and oil residue before installation of nozzles or discharge devices.

2-2.1.6 In sections 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. In systems using pressure-operated container valves, means shall be provided to vent any container leakage that could build up pressure in the pilot system and cause unwanted opening of the container valve. The means of pressure venting shall be arranged so as not to prevent reliable operation of the container valve.

2-2.1.7 All pressure relief devices shall be designed and located so that the discharge from the device will not injure personnel or pose a hazard.

2-2.2 Pipe Joints. Pipe joints other than threaded, welded, brazed, flared, compression, or flanged type shall be listed or approved.

2-2.3 Fittings.

2-2.3.1* Fittings shall have a minimum rated working pressure equal to or greater than the minimum design working pressure specified in 2-2.1.1, for the clean agent being used, or as otherwise listed or approved. For systems that employ the use of a pressure-reducing device in the distribution piping, the fittings downstream of the device shall have a minimum rated working pressure equal to or greater than the maximum anticipated pressure in the downstream piping.

2-2.3.2 Cast-iron fittings shall not be used. Class 150-lb fittings shall not be used unless it can be demonstrated that they comply with the appropriate Amercian National Standards Institute, Inc. (ANSI) stress calculations.

2-2.3.3 All threads used in joints and fittings shall conform to ANSI B1.20.1, *Standard for Pipe Threads, General Purpose,* or ISO/IEC Guide 7, *Requirements for Standards Suitable for Use for Conformity Assessment.* Joint compound, tape, or thread lubricant shall be applied only to the male threads of the joint.

2-2.3.4 Welding and brazing alloys shall have a melting point above 1000°F (538°C).

2-2.3.5 Welding shall be performed in accordance with Section IX, "Qualification Standard for Welding and Brazing Procedures, Welders, Brazers and Welding and Brazing Operators," of the ASME *Boiler and Pressure Vessel Code.*

2-2.3.6 Where copper, stainless steel, or other suitable tubing is jointed with compression-type fittings, the manufacturer's pressure and temperature ratings of the fitting shall not be exceeded.

2-2.4 Valves.

2-2.4.1 All valves shall be listed or approved for the intended use.

2-2.4.2* All gaskets, o-rings, sealants, and other valve components shall be constructed of materials that are compatible with the agent. Valves shall be protected against mechanical, chemical, or other damage.

2-2.4.3 Special corrosion-resistant materials or coatings shall be used in severely corrosive atmospheres.

2-2.5 Discharge Nozzles.

2-2.5.1 Discharge nozzles shall be listed for the intended use. Listing criteria shall include flow characteristics, area coverage, height limits, and minimum pressures. Discharge orifices and discharge orifice plates and inserts shall be of a material that is corrosion resistant to the agent used and the atmosphere in the intended application.

2-2.5.2 Special corrosion-resistant materials or coatings shall be required in severely corrosive atmospheres.

2-2.5.3 Discharge nozzles shall be permanently marked to identify the manufacturer as well as the type and size of the orifice.

2-2.5.4 Where clogging by external foreign materials is likely, discharge nozzles shall be provided with frangible discs, blow-off caps, or other suitable devices. These devices shall provide an unobstructed opening upon system operation and shall be located so they will not injure personnel.

2-3 Detection, Actuation, Alarm, and Control Systems.

2-3.1 General.

2-3.1.1 Detection, actuation, alarm, and control systems shall be installed, tested, and maintained in accordance with appropriate NFPA protective signaling systems standards. *(See NFPA 70, National Electrical Code, and NFPA 72, National Fire Alarm Code®. In Canada refer to ULC S524-M91, Standard for the Installation of Fire Alarm Systems, and ULC S529-M87, Smoke Detectors for Fire Alarm Systems.)*

2-3.1.2 Automatic detection and automatic actuation shall be used.

Exception: Manual-only actuation shall be permitted if acceptable to the authority having jurisdiction.

2-3.1.3 Initiating and releasing circuits shall be installed in raceways. Alternating current (ac) and direct current (dc) wiring shall not be combined in a common conduit or raceway.

Exception: Ac and dc wiring shall be permitted to be combined in a common conduit or raceway where shielded and grounded.

2-3.2 Automatic Detection.

2-3.2.1* Automatic detection shall be by any listed method or device 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.

2-3.2.2 Adequate and reliable primary and 24-hour minimum standby sources of energy shall be used to provide for operation of the detection, signaling, control, and actuation requirements of the system.

2-3.2.3 When a new agent system is being installed in a space that has an existing detection system, an analysis shall be made of the detection devices to assure that the detection system is in good operating condition and will respond promptly to a fire situation. This analysis shall be done to assist in limiting the decomposition products from a suppression event.

2-3.3 Operating Devices.

2-3.3.1 Operating devices shall include agent releasing devices or valves, discharge controls, and shutdown equipment necessary for successful performance of the system.

2-3.3.2 Operation shall be by listed mechanical, electrical, or pneumatic means. An adequate and reliable source of energy shall be used.

2-3.3.3 All devices shall be designed for the service they will encounter and shall not readily be rendered inoperative or susceptible to accidental operation. Devices normally shall be designed to function properly from −20°F to 130°F (−29°C to 54°C) or marked to indicate temperature limitations.

2-3.3.4 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.

2-3.3.5 A means of manual release of the system shall be provided. Manual release shall be accomplished by a mechanical manual release or by an electrical manual release when the control equipment monitors the battery voltage level of the standby battery supply and will provide a low battery signal. The release shall cause simultaneous operation of automatically operated valves controlling agent release and distribution.

2-3.3.6 The normal manual control(s) for actuation shall be located for easy accessibility at all times, including at the time of a fire. The manual control(s) shall be of distinct appearance and clearly recognizable for the purpose intended. Operation of any control shall cause the complete system to operate in its normal fashion.

2-3.3.7 Manual controls shall not require a pull of more than 40 lb (178 N) nor a movement of more than 14 in. (356 mm) to secure operation. At least one manual control for activation shall be located not more than 4 ft (1.2 m) above the floor.

2-3.3.8 Where gas pressure from the system or pilot containers is used as a means for releasing the remaining containers, the supply and discharge rate shall be designed for releasing all of the remaining containers.

2-3.3.9 All devices for shutting down supplementary equipment shall be considered integral parts of the system and shall function with the system operation.

2-3.3.10 All manual operating devices shall be identified as to the hazard they protect.

2-3.4 Control Equipment.

2-3.4.1 Electric Control Equipment. The control equipment shall supervise the actuating devices and associated wiring and, as required, cause actuation. The control equipment shall be specifically listed for the number and type of actuating devices utilized, and their compatibility shall have been listed.

2-3.4.2 Pneumatic Control Equipment. Where pneumatic control equipment is used, the lines shall be protected against crimping and mechanical damage. Where installations could be exposed to conditions that could lead to loss of integrity of the pneumatic lines, special precautions shall be taken to ensure that no loss of integrity will occur. The control equipment shall be specifically listed for the number and type of actuating devices utilized, and their compatibility shall have been listed.

2-3.5 Operating Alarms and Indicators.

2-3.5.1 Alarms or indicators or both shall be used to indicate the operation of the system, hazards to personnel, or failure of any supervised device. The type (audible, visual, or olfactory), number, and location of the devices shall be such that their purpose is satisfactorily accomplished. The extent and type of alarms or indicator equipment or both shall be approved.

2-3.5.2 Audible and visual pre-discharge alarms shall be provided within the protected area to give positive warning of impending discharge. The operation of the warning devices shall be continued after agent discharge until positive action has been taken to acknowledge the alarm and proceed with appropriate action.

2-3.5.3* Abort switches generally are not recommended, however, where provided, the abort switches shall be located within the protected area and shall be located near the means of egress for the area. An abort switch shall not be operated unless the cause for the condition is known and corrective action can be taken. The abort switch shall be of a type that requires constant manual pressure to cause abort. The abort switch shall not be of a type that would allow the system to be left in an aborted mode without someone present. In all cases the normal and manual emergency control shall override the abort function. Operation of the abort function shall result in both audible and distinct visual indication of system impairment. The abort switch shall be clearly recognizable for the purpose intended.

2-3.5.4 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.

2-3.5.5 Warning and instruction signs at entrances to and inside protected areas shall be provided.

2-3.5.6 Time Delays.

2-3.5.6.1* For clean agent extinguishing systems, a pre-discharge alarm and time delay, sufficient to allow personnel evacuation prior to discharge, shall be provided. For hazard areas subject to fast growth fires, where the provision of a time delay would seriously increase the threat to life and property, a time delay shall be permitted to be eliminated.

2-3.5.6.2 Time delays shall be used only for personnel evacuation or to prepare the hazard area for discharge.

2-3.5.6.3 Time delays shall not be used as a means of confirming operation of a detection device before automatic actuation occurs.

2-3.6* Unwanted System Operation. Care shall be taken to thoroughly evaluate and correct any factors that could result in unwanted discharges.

Chapter 3 System Design

3-1 Specifications, Plans, and Approvals.

3-1.1 Specifications. Specifications for total flooding clean agent fire extinguishing systems shall be prepared under the supervision of a person fully experienced and qualified in the design of such 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, design criteria, system sequence of operations, the type and extent of the approval testing to be performed after installation of the system, and owner training requirements.

3-1.2 Working Plans.

3-1.2.1 Working plans and calculations shall be submitted for approval to the authority having jurisdiction before system installation or remodeling begins. These documents shall be prepared only by persons fully experienced and qualified in the design of total flooding clean agent fire extinguishing systems. Deviation from these documents shall require permission of the authority having jurisdiction.

3-1.2.2 Working plans shall be drawn to an indicated scale and shall show the following items that pertain to the design of the system:

(a) Name of owner and occupant.

(b) Location, including street address.

(c) Point of compass and symbol legend.

(d) Location and construction of protected enclosure walls and partitions.

(e) Location of fire walls.

(f) Enclosure cross section, full height or schematic diagram, including location and construction of building floor/ceiling assemblies above and below, raised access floor and suspended ceiling.

(g) Agent being used.

(h) Design extinguishing or inerting concentration.

(i) Description of occupancies and hazards being protected, designating whether or not the enclosure is normally occupied.

(j) Description of exposures surrounding the enclosure.

(k) Description of the agent storage containers used including internal volume, storage pressure, and nominal capacity expressed in units of agent mass or volume at standard conditions of temperature and pressure.

(l) Description of nozzle(s) used including size, orifice port configuration, and equivalent orifice area.

(m) Description of pipe and fittings used including material specifications, grade, and pressure rating.

(n) Description of wire or cable used including classification, gauge [American Wire Gauge (AWG)], shielding, number of strands in conductor, conductor material, and color coding schedule. Segregation requirements of various system conductors shall be clearly indicated. The required method of making wire terminations shall be detailed.

(o) Description of the method of detector mounting.

(p) Equipment schedule or bill of materials for each piece of equipment or device showing device name, manufacturer, model or part number, quantity, and description.

(q) Plan view of protected area showing enclosure partitions (full and partial height); agent distribution system including agent storage containers, piping, and nozzles; type of pipe hangers and rigid pipe supports; detection, alarm, and control system including all devices and schematic of wiring interconnection between them; end-of-line device locations; location of controlled devices such as dampers and shutters; and location of instructional signage.

(r) Isometric view of agent distribution system showing the length and diameter of each pipe segment; node reference numbers relating to the flow calculations; fittings including reducers and strainers; and orientation of tees, nozzles including size, orifice port configuration, flow rate, and equivalent orifice area.

(s) Scale drawing showing the layout of the annunciator panel graphics if required by the authority having jurisdiction.

(t) Details of each unique rigid pipe support configuration showing method of securement to the pipe and to the building structure.

(u) Details of the method of container securement showing method of securement to the container and to the building structure.

(v) Complete step-by-step description of the system sequence of operations including functioning of abort and maintenance switches, delay timers, and emergency power shutdown.

(w) Point-to-point wiring schematic diagrams showing all circuit connections to the system control panel and graphic annunciator panel.

(x) Point-to-point wiring schematic diagrams showing all circuit connections to external or add-on relays.

(y) Complete calculations to determine enclosure volume, quantity of clean agent, and size of backup batteries and method used to determine number and location of audible and visual indicating devices, and number and location of detectors.

(z) Details of any special features.

3-1.2.3 The detail on the system shall include information and calculations on the amount of agent; container storage pressure; internal volume of the container; the location, type, 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 storage facility. Pipe size reduction 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. Apparatus and devices used shall be identified. Any special features shall be adequately explained.

Exception: Pre-engineered systems do not require specifying internal volume of the container, nozzle flow rates, equivalent lengths of pipe and fitting and hose, or flow calculations, when used within their listed limitations. The information required by the listed system design manual, however, shall be made available to the authority having jurisdiction for verification that the system is within its listed limitations.

3-1.2.4 An as-built instruction and maintenance manual that includes a full sequence of operations and a full set of drawings and calculations shall be maintained on site.

3-1.2.5 Flow Calculations.

3-1.2.5.1 Flow calculations along with the working plans shall be submitted to the authority having jurisdiction for approval. The version of the flow calculation program shall be identified on the computer calculation printout.

3-1.2.5.2 Where field conditions necessitate any material change from approved plans, the change shall be submitted for approval.

3-1.2.5.3 When such material changes from approved plans are made, corrected "as installed" plans shall be provided.

3-1.3 Approval of Plans.

3-1.3.1 Plans and calculations shall be approved prior to installation.

3-1.3.2 Where field conditions necessitate any significant change from approved plans, the change shall be approved prior to implementation.

3-1.3.3 When such significant changes from approved plans are made, the working plans shall be updated to accurately represent the system as installed.

3-2* System Flow Calculations.

3-2.1* System flow calculations shall be performed using a calculation method listed or approved by the authority having jurisdiction. The system design shall be within the manufacturer's listed limitations.

Exception: Pre-engineered systems do not require a flow calculation where used within their listed limitations.

3-2.2 Valves and fittings shall be rated for equivalent length in terms of pipe or tubing sizes with which they will be used. The equivalent length of the container valve shall be listed and shall include siphon tube, valve, discharge head, and flexible connector.

3-2.3 Piping lengths and orientation of fittings and nozzles shall be in accordance with the manufacturer's listed limitations.

3-2.4 If the final installation varies from the prepared drawings and calculations, new drawings and calculations representing the "as built" installation shall be prepared.

3-3 Enclosure.

3-3.1 In the design of a total flooding system, the characteristics of the protected enclosure shall be considered.

3-3.2 The area of unclosable openings in the protected enclosure shall be kept to a minimum.

3-3.3 The authority having jurisdiction shall be permitted to require pressurization/depressurization of the protected enclosure or other tests to assure performance meeting the requirements of this standard. *(See Appendix C.)*

3-3.4 To prevent loss of agent through openings to adjacent hazards or work areas, openings shall be permanently sealed or equipped with automatic closures. Where reasonable confinement of agent is not practicable, protection shall be expanded to include the adjacent connected hazards or work areas or additional agent shall be introduced into the protected enclosure using an extended discharge configuration.

3-3.5* Forced-air ventilating systems shall be shut down or closed automatically where their continued operation would adversely affect the performance of the fire extinguishing system or result in propagation of the fire. Completely self-contained recirculating ventilation systems shall not be required to be shut down. The volume of the ventilation system and associated ductwork shall be considered as part of the total hazard volume when determining the quantity of agent.

Exception: Ventilation systems necessary to ensure safety are not required to be shut down upon activation of the fire suppression system. An extended agent discharge shall be provided to maintain the design concentration for the required duration of protection.

3-3.6* The protected enclosure shall have the structural strength and integrity necessary to contain the agent discharge. If the developed pressures present a threat to the structural strength of the enclosure, venting shall be provided to prevent excessive pressures. Designers shall consult system manufacturer's recommended procedures relative to enclosure venting.

3-4 Design Concentration Requirements.

3-4.1 The flame extinguishing or inerting concentrations shall be used in determining the agent design concentration for a particular fuel. For combinations of fuels, the flame extinguishment or inerting value for the fuel requiring the greatest concentration shall be used unless tests are made on the actual mixture.

3-4.2* Flame Extinguishment.

3-4.2.1 The flame extinguishing concentration for Class B fuels shall be determined by the cup burner method described in Appendix B.

CAUTION

> Under certain conditions, it can be dangerous to extinguish a burning gas jet. As a first measure, the gas supply shall be shut off.

3-4.2.2* The flame extinguishing concentration for Class A fuels shall be determined by test as part of a listing program. As a minimum, the listing program shall conform to UL 2127, *Standard for Inert Gas Clean Agent Extinguishing System Units,* or UL 2166, *Standard for Halocarbon Clean Agent Extinguishing System Units,* or equivalent.

3-4.2.3 The minimum design concentration for a Class B fuel hazard or an only manually actuated system shall be the extinguishing concentration, as determined in 3-4.2.1, times a safety factor of 1.3.

3-4.2.4* The minimum design concentration for a Class A surface fire hazard shall be the extinguishing concentration, as determined in 3-4.2.2, times a safety factor of 1.2.

3-4.2.5 Minimum design concentration for Class C hazards shall be at least that for Class A surface fire.

3-4.3* Inerting.

3-4.3.1 The inerting concentration shall be determined by test.

3-4.3.2* The inerting concentration shall be used in determining the agent design concentration where conditions for subsequent reflash or explosion could exist.

3-4.3.3 The minimum design concentration used to inert the atmosphere of an enclosure where the hazard is a flammable liquid or gas shall be the inerting concentration times a safety factor of 1.1.

3-5 Total Flooding Quantity.

3-5.1* The amount of halocarbon agent required to achieve the design concentration shall be calculated from the following formula:

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right) \tag{3.1}$$

where:

W = weight of clean agent [lb (kg)]

V = net volume of hazard, calculated as the gross volume minus the volume of fixed structures impervious to clean agent vapor [ft^3 (m^3)]

s = specific volume of the superheated agent vapor at 1 atmosphere and the temperature, t [ft^3/lb (m^3/kg)]

C = agent design concentration [volume percent]

t = minimum anticipated temperature of the protected volume [°F (°C)]

This calculation includes an allowance for the normal leakage from a "tight" enclosure due to agent expansion.

Total flooding quantities based on Equation 3.1 are given in Tables A-3-5.1(a) through A-3-5.1(r).

3-5.2* The amount of inert gas agent required to achieve the design concentration shall be calculated using Equation 3.2, 3.3, or 3.4:

$$X = 2.303\left(\frac{V_S}{s}\right)\mathrm{Log}_{10}\left(\frac{100}{100 - C}\right) \tag{3.2}$$

where:

X = volume of inert gas added at standard conditions of 14.7 psia, 70°F (1.013 bar, 21°C) per volume of hazard space [ft^3/ft^3 (m^3/m^3)]

V_S = specific volume of inert gas agent at 70°F (21°C) and 14.7 psia (1.013 bar)

s = specific volume of inert gas at 1 atmosphere and temperature, t [ft^3/lb (m^3/kg)]

t = minimum anticipated temperature of the protected volume [°F (°C)]

C = inert gas design concentration [volume percent]

This calculation includes an allowance for the leakage of agent from a "tight" enclosure.

An alternative equation for calculating the inert gas clean agent concentrations is as follows:

$$X = 2.303\left(\frac{530}{460 + t}\right)\mathrm{Log}_{10}\left(\frac{100}{100 - C}\right) \text{ where } t \text{ is in °F} \tag{3.3}$$

$$X = 2.303\left(\frac{294.4}{273 + t}\right)\mathrm{Log}_{10}\left(\frac{100}{100 - C}\right) \text{ where } t \text{ is in °C} \tag{3.4}$$

Total flooding quantities based on Equations 3.3 and 3.4 are given in Tables A-3-5.2(a) through A-3-5.2(h).

3-5.3* Design Factors. In addition to the concentration requirements, additional quantities of agent are required through the use of design factors to compensate for any special conditions that would affect the extinguishing efficiency.

3-5.3.1* Tee Design Factor. Where a single agent supply is used to protect multiple hazards, a design factor from Table 3-5.3.1 shall be applied.

For the application of Table 3-5.3.1, the design factor tee count shall be determined for each hazard the system protects as follows:

(1) Starting from the point where the pipe system enters the hazard, the number of tees in the flow path returning to the agent supply shall be included (do not include tees used in a manifold) in the design factor tee count for the hazard.

(2) Any tee within the hazard that supplies agent to another hazard shall be included in the design factor tee count for the hazard.

The hazard with the greatest design factor tee count shall be used in Table 3-5.3.1 to determine the design factor.

Exception: For systems that pass a discharge test, this design factor does not need to apply.

Table 3-5.3.1 Design Factors for Piping Tees

Design Factor Tee Count	Halocarbon Design Factor	Inert Gas Design Factor
0–4	0.00	0.00
5	0.01	0.00
6	0.02	0.00
7	0.03	0.00
8	0.04	0.00
9	0.05	0.01
10	0.06	0.01
11	0.07	0.02
12	0.07	0.02
13	0.08	0.03
14	0.09	0.03
15	0.09	0.04
16	0.10	0.04
17	0.11	0.05
18	0.11	0.05
19	0.12	0.06

3-5.3.2* Additional Design Factors. The designer shall assign and document additional design factors for each of the following:

(1) Unclosable openings and their effects on distribution and concentration *(see also 3-8.2)*

(2) Control of acid gases

(3) Re-ignition from heated surfaces

(4) Fuel type, configurations, scenarios not fully accounted for in the extinguishing concentration, enclosure geometry, and obstructions and their effects on distribution.

3-5.3.3* Design Factor for Enclosure Pressure. The design quantity of the clean agent shall be adjusted to compensate for ambient pressures that vary more than 11 percent [equivalent to approximately 3000 ft (915 m) of elevation change] from standard sea level pressures [29.92 in. Hg at 70°F (760 mm Hg at 0°C)]. *(See Table 3-5.3.3.)*

Table 3-5.3.3 Atmospheric Correction Factors

Equivalent Altitude		Enclosure Pressure		Atmospheric Correction Factor
ft	km	psia	mm Hg	
–3,000	–0.92	16.25	840	1.11
–2,000	–0.61	15.71	812	1.07
–1,000	–0.30	15.23	787	1.04
0	0.00	14.71	760	1.00
1,000	0.30	14.18	733	0.96
2,000	0.61	13.64	705	0.93
3,000	0.91	13.12	6,789	0.89
4,000	1.22	12.58	650	0.86
5,000	1.52	12.04	622	0.82
6,000	1.83	11.53	596	0.78
7,000	2.13	11.03	570	0.75
8,000	2.45	10.64	550	0.72
9,000	2.74	10.22	528	0.69
10,000	3.05	9.77	505	0.66

3-6* Duration of Protection. It is important that the agent design concentration not only shall be achieved, but also shall be maintained for the specified period of time to allow effective emergency action by trained personnel. This is equally important in all classes of fires since a persistent ignition source (e.g., an arc, heat source, oxyacetylene torch, or “deep-seated” fire) can lead to resurgence of the initial event once the clean agent has dissipated.

3-7 Distribution System.

3-7.1 Rate of Application.

3-7.1.1 The minimum design rate of application shall be based on the quantity of agent required for the desired concentration and the time allotted to achieve the desired concentration.

3-7.1.2* Discharge Time.

3-7.1.2.1* For halocarbon agents, the discharge time required to achieve 95 percent of the minimum design concentration for flame extinguishment based on a 20-percent safety factor shall not exceed 10 seconds, or as otherwise required by the authority having jurisdiction.

3-7.1.2.2* For inert gas agents, the discharge time required to achieve 95 percent of the minimum design concentration for flame extinguishment based on a 20-percent safety factor shall not exceed 60 seconds, or as otherwise required by the authority having jurisdiction.

3-7.1.2.3* The discharge time period is defined as the time required to discharge from the nozzles 95 percent of the agent mass, at 70°F (21°C), necessary to achieve the minimum design concentration based on 20-percent safety factor for flame extinguishment.

3-7.1.2.4 Flow calculations performed in accordance with Section 3-2, or in accordance with the listed pre-engineered systems instruction manuals, shall be used to demonstrate compliance with 3-7.1.2.

3-7.1.2.5 For explosion prevention systems, the discharge time for agents shall ensure that the minimum inerting design concentration is achieved before concentration of flammable vapors reach the flammable range.

3-7.2* Extended Discharge. When an extended discharge is necessary to maintain the design concentration for the specified period of time, additional agent quantities can be applied at a reduced rate. The initial discharge shall be completed within the limits specified in 3-7.1.2. The performance of the extended discharge system shall be confirmed by test.

3-8 Nozzle Choice and Location.

3-8.1 Nozzles shall be of the type listed for the intended purpose and shall be placed within the protected enclosure in compliance with listed limitations with regard to spacing, floor coverage, and alignment.

3-8.2 The type of nozzles selected, their number, and their placement shall be such that the design concentration will be established in all parts of the hazard enclosure and 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 or integrity of the enclosure.

Chapter 4 Inspection, Maintenance, Testing, and Training

4-1 Inspection and Tests.

4-1.1 At least annually, all systems shall be thoroughly inspected and tested for proper operation by competent personnel. Discharge tests are not required.

4-1.2 The inspection report with recommendations shall be filed with the owner.

4-1.3 At least semiannually, the agent quantity and pressure of refillable containers shall be checked.

4-1.3.1 For halocarbon clean agents, if a container shows a loss in agent quantity of more than 5 percent or a loss in pressure (adjusted for temperature) of more than 10 percent, it shall be refilled or replaced.

4-1.3.2 For inert gas clean agents that are not liquefied, pressure is an indication of agent quantity. If an inert gas clean agent container shows a loss in pressure (adjusted for temperature) of more than 5 percent, it shall be refilled or replaced. Where container pressure gauges are used for this purpose, they shall be compared to a separate calibrated device at least annually.

4-1.3.3 Where the amount of agent in the container is determined by special measuring devices, these devices shall be listed.

4-1.4* All halocarbon clean agent removed from refillable containers during service or maintenance procedures shall be collected and recycled or disposed of in an environmentally sound manner and in accordance with existing laws and regulations.

4-1.5 Factory-charged, nonrefillable containers that do not have a means of pressure indication shall have the agent quantity checked at least semiannually. If a container shows a loss in agent quantity of more than 5 percent, it shall be replaced. All factory-charged, nonrefillable containers removed from useful service shall be returned for recycling of the agent or disposed of in an environmentally sound manner and in accordance with existing laws and regulations.

4-1.6 For halocarbon clean agents, the date of inspection, gross weight of cylinder plus agent or net weight of agent, type of agent, person performing the inspection, and, where applicable, the pressure at a recorded temperature shall be recorded on a tag attached to the container. For inert gas clean agents, the date of inspection, type of agent, person performing the inspection, and the pressure at a recorded temperature shall be recorded on a tag attached to the container.

4-2 Container Test.

4-2.1 U.S. Department of Transportation (DOT), Canadian Transport Commission (CTC), or similar design clean agent containers shall not be recharged without retesting if more than 5 years have elapsed since the date of the last test and inspection. For halocarbon agent storage containers, the retest shall be permitted to consist of a complete visual inspection as described in 49 *CFR* 173.34(e)(10).

Transporting charged containers that have not been tested within 5 years could be illegal. Federal and local regulations should be consulted.

4-2.2 Cylinders continuously in service without discharging shall be given a complete external visual inspection every 5 years or more frequently if required. The visual inspection shall be in accordance with Section 3 of CGA C-6, *Standard for Visual Inspection of Steel Compressed Gas Cylinders*, except that the cylinders need not be emptied or stamped while under pressure. Inspections shall be made only by competent personnel and the results recorded on both of the following:

(1) A record tag permanently attached to each cylinder
(2) A suitable inspection report

A completed copy of the inspection report shall be furnished to the owner of the system or an authorized representative. These records shall be retained by the owner for the life of the system.

4-2.3 Where external visual inspection indicates that the container has been damaged, additional strength tests shall be required.

4-3 Hose Test.

4-3.1 General. All system hose shall be examined annually for damage. If visual examination shows any deficiency, the hose shall be immediately replaced or tested as specified in 4-3.2.

4-3.2 Testing.

4-3.2.1 All hose shall be tested every 5 years.

4-3.2.2 All hose shall be tested at $1^1/_2$ times the maximum container pressure at 130°F (54.4°C). The testing procedure shall be as follows:

(a) The hose is removed from any attachment.

(b) The hose assembly is then placed in a protective enclosure designed to permit visual observation of the test.

(c) The hose must be completely filled with water before testing.

(d) Pressure then is applied at a rate-of-pressure rise to reach the test pressure within a minimum of 1 minute. The test pressure is maintained for 1 full minute. Observations are then made to note any distortion or leakage.

(e) If the test pressure has not dropped or if the couplings have not moved, the pressure is released. The hose assembly is then considered to have passed the hydrostatic test if no permanent distortion has taken place.

(f) Hose assembly passing the test must be completely dried internally. If heat is used for drying, the temperature must not exceed the manufacturer's specifications.

(g) Hose assemblies failing a hydrostatic test must be marked and destroyed and be replaced with new assemblies.

(h) Each hose assembly passing the hydrostatic test is marked to show the date of test.

4-4 Enclosure Inspection. At least every 12 months, the enclosure protected by the clean agent shall be thoroughly inspected to determine if penetrations or other changes have occurred that could adversely affect agent leakage or change volume of hazard or both. Where the inspection indicates conditions that could result in inability to maintain the clean agent concentration, they shall be corrected. If uncertainty still exists, the enclosures shall be retested for integrity in accordance with 4-7.2.3.

Exception: An enclosure inspection is not required every 12 months if a documented administrative control program exists that addresses barrier integrity.

4-5 Maintenance.

4-5.1 These systems shall be maintained in full operating condition at all times. Actuation, impairment, and restoration of this protection shall be reported promptly to the authority having jurisdiction.

4-5.2 Any troubles or impairments shall be corrected in a timely manner consistent with the hazard protected.

4-5.3* Any penetrations made through the enclosure protected by the clean agent shall be sealed immediately. The method of sealing shall restore the original fire resistance rating of the enclosure.

4-6 Training.

4-6.1 All persons who could be expected to inspect, test, maintain, or operate fire extinguishing systems shall be thoroughly trained and kept thoroughly trained in the functions they are expected to perform.

4-6.2* Personnel working in an enclosure protected by a clean agent shall receive training regarding agent safety issues.

4-7 Approval of Installations.

4-7.1 General. The completed system shall be reviewed and tested by qualified personnel to meet the approval of the authority having jurisdiction. Only listed equipment and devices shall be used in the systems. To determine that the system has been properly installed and will function as specified, the following tests shall be performed.

4-7.2 Installation Acceptance.

4-7.2.1 General. It shall be determined that the protected enclosure is in general conformance with the construction documents.

4-7.2.2 Review Mechanical Components.

4-7.2.2.1 The piping distribution system shall be inspected to determine that it is in compliance with the design and installation documents.

4-7.2.2.2 Nozzles and pipe size shall be in accordance with system drawings. Means of pipe size reduction and attitudes of tees shall be checked for conformance to the design.

4-7.2.2.3 Piping joints, discharge nozzles, and piping supports shall be securely fastened to prevent unacceptable vertical or lateral movement during discharge. Discharge nozzles shall be installed in such a manner that piping cannot become detached during discharge.

4-7.2.2.4 During assembly, the piping distribution system shall be inspected internally to detect the possibility of any oil or particulate matter soiling the hazard area or affecting the agent distribution due to a reduction in the effective nozzle orifice area.

4-7.2.2.5 The discharge nozzle shall be oriented in such a manner that optimum agent dispersal can be effected.

4-7.2.2.6 If nozzle deflectors are installed, they shall be positioned to obtain maximum benefit.

4-7.2.2.7 The discharge nozzles, piping, and mounting brackets shall be installed in such a manner that they will not potentially cause injury to personnel. Agent shall not directly impinge on areas where personnel could be found in the normal work area. Agent shall not directly impinge on any loose objects or shelves, cabinet tops, or similar surfaces where loose objects could be present and become missiles.

4-7.2.2.8 All agent storage containers shall be properly located in accordance with an approved set of system drawings.

4-7.2.2.9 All containers and mounting brackets shall be fastened securely in accordance with the manufacturer's requirements.

4-7.2.2.10* If a discharge test is to be conducted, containers for the agent to be used shall be weighed before and after discharge. Fill weight of container shall be verified by weighing or other approved methods. For inert gas clean agents, container pressure shall be recorded before and after discharge.

4-7.2.2.11 Adequate quantity of agent to produce the desired specified concentration shall be provided. The actual room volumes shall be checked against those indicated on the system drawings to ensure the proper quantity of agent. Fan coastdown and damper closure time shall be taken into consideration.

4-7.2.2.12 The piping shall be pneumatically tested in a closed circuit for a period of 10 minutes at 40 psig (276 kPa). At the end of 10 minutes, the pressure drop shall not exceed 20 percent of the test pressure.

Exception: The pressure test shall be permitted to be omitted if the total piping contains no more than one change in direction fitting between the storage container and the discharge nozzle, and where all piping is physically checked for tightness.

4-7.2.2.13* A flow test using nitrogen or an inert gas shall be performed on the piping network to verify that flow is continuous and that the piping and nozzles are unobstructed.

4-7.2.3* Review Enclosure Integrity. All total flooding systems shall have the enclosure examined and tested to locate and then effectively seal any significant air leaks that could result in a failure of the enclosure to hold the specified agent concentration level for the specified holding period. The currently preferred method is using a blower door fan unit and smoke pencil. Quantitative results shall be obtained and recorded to indicate that the specified agent concentration for the specified duration of protection is in compliance with Section 3-6, using an approved blower fan unit or other means as approved by the authority having jurisdiction. *(For guidance, see Appendix B.)*

4-7.2.4 Review Electrical Components.

4-7.2.4.1 All wiring systems shall be properly installed in compliance with local codes and the system drawings. Alternating current (ac) and direct current (dc) wiring shall not be combined in a common conduit or raceway unless properly shielded and grounded.

4-7.2.4.2 All field circuits shall be free of ground faults and short circuits. Where field circuitry is being measured, all electronic components, such as smoke and flame detectors or special electronic equipment for other detectors or their mounting bases, shall be removed and jumpers shall be properly installed to prevent the possibility of damage within these devices. Components shall be replaced after measuring.

4-7.2.4.3 Power shall be supplied to the control unit from a separate dedicated source that will not be shut down on system operation.

4-7.2.4.4 Adequate and reliable primary and 24-hour minimum standby sources of energy shall be used to provide for operation of the detection, signaling, control, and actuation requirements of the system.

4-7.2.4.5 All auxiliary functions such as alarm-sounding or displaying devices, remote annunciators, air-handling shutdown, and power shutdown shall be checked for proper operation in accordance with system requirements and design specifications. If possible, all air-handling and power-cutoff controls shall be of the type that, once interrupted, require manual restart to restore power.

4-7.2.4.6 Silencing of alarms, if desirable, shall not affect other auxiliary functions such as air handling or power cutoff if required in the design specification.

4-7.2.4.7 The detection devices shall be checked for proper type and location as specified on the system drawings.

4-7.2.4.8 Detectors shall not be located near obstructions or air ventilation and cooling equipment that would appreciably affect their response characteristics. Where applicable, air changes for the protected area shall be taken into consideration. *(Refer to NFPA 72, National Fire Alarm Code, and the manufacturer's recommended guidelines.)*

4-7.2.4.9 The detectors shall be installed in a professional manner and in accordance with technical data regarding their installation.

4-7.2.4.10 Manual pull stations shall be properly installed, readily accessible, accurately identified, and properly protected to prevent damage.

4-7.2.4.11 All manual stations used to release agents shall require two separate and distinct actions for operation. They shall be properly identified. Particular care shall be taken where manual release devices for more than one system are in close proximity and could be confused or the wrong system actuated. Manual stations in this instance shall be clearly identified as to which zone or suppression area they affect.

4-7.2.4.12 For systems with a main/reserve capability, the main/reserve switch shall be properly installed, readily accessible, and clearly identified.

4-7.2.4.13 For systems using abort switches, the switches shall be of the deadman type requiring constant manual pressure, properly installed, readily accessible within the hazard area, and clearly identified. Switches that remain in the abort position when released shall not be used for this purpose. Manual pull stations shall always override abort switches.

4-7.2.4.14 The control unit shall be properly installed and readily accessible.

4-7.2.5 Functional Testing.

4-7.2.5.1 Preliminary Functional Tests. The following preliminary functional tests shall be provided:

(a) If the system is connected to an alarm receiving office, notify the alarm receiving office that the fire system test is to be conducted and that an emergency response by the fire department or alarm station personnel is not desired. Notify all concerned personnel at the end-user's facility that a test is to be conducted and instruct personnel as to the sequence of operation.

(b) Disable each agent storage container release mechanism so that activation of the release circuit will not release agent. Reconnect the release circuit with a functional device in lieu of each agent storage container release mechanism. For electrically actuated release mechanisms, these devices can include 24-V lamps, flashbulbs, or circuit breakers. Pneumatically actuated release mechanisms can include pressure gauges. Refer to the manufacturer's recommendations in all cases.

(c) Check each detector for proper response.

(d) Check that polarity has been observed on all polarized alarm devices and auxiliary relays.

(e) Check that all end-of-line resistors have been installed across the detection and alarm bell circuits where required.

(f) Check all supervised circuits for proper trouble response.

4-7.2.5.2 System Functional Operational Test. The following system functional operational tests shall be performed:

(a) Operate detection initiating circuit(s). Verify that all alarm functions occur according to design specification.

(b) Operate the necessary circuit to initiate a second alarm circuit if present. Verify that all second alarm functions occur according to design specifications.

(c) Operate manual release. Verify that manual release functions occur according to design specifications.

(d) Operate abort switch circuit if supplied. Verify that abort functions occur according to design specifications. Confirm that visual and audible supervisory signals are received at the control panel.

(e) Test all automatic valves unless testing the valve will release agent or damage the valve (destructive testing).

(f) Check pneumatic equipment, where required, for integrity to ensure proper operation.

4-7.2.5.3 Remote Monitoring Operations. The following testing of remote monitoring operations, if applicable, shall be performed:

(a) Operate one of each type of input device while on standby power. Verify that an alarm signal is received at remote panel after device is operated. Reconnect primary power supply.

(b) Operate each type of alarm condition on each signal circuit and verify receipt of trouble condition at the remote station.

4-7.2.5.4 Control Panel Primary Power Source. The following testing of the control panel primary power source shall be performed:

(a) Verify that the control panel is connected to a dedicated circuit and labeled properly. This panel shall be readily accessible, yet restricted from unauthorized personnel.

(b) Test a primary power failure in accordance with the manufacturer's specification with the system fully operated on standby power.

4-7.2.5.5 Return of System to Operational Condition. When all predischarge work is completed, each agent storage container shall be reconnected so that activation of the release circuit will release the agent. The system shall be returned to its fully operational design condition. The alarm-receiving office and all concerned personnel at the end-user's facility shall be notified that the fire system test is complete and that the system has been returned to full service condition.

4-8* Safety. Safe procedures shall be observed during installation, servicing, maintenance, testing, handling, and recharging of clean agent systems and agent containers.

Chapter 5 Marine Systems

5-1 General. This chapter outlines the deletions, modifications, and additions that are necessary for marine applications. All other requirements of NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems,* shall apply to shipboard systems except as modified by this chapter. Where the provisions of Chapter 5 conflict with the provisions of Chapters 1 through 4, the provisions of Chapter 5 shall take precedence.

5-1.1 Scope. This chapter is limited to marine applications of clean agent fire extinguishing systems on commercial and government vessels. Explosion inerting systems were not considered during development of this chapter.

5-1.2 Special Definitions.

5-1.2.1 Control Room and Electronic Equipment Space. A space containing electronic or electrical equipment, such as that found in control rooms or electronic equipment rooms, where only Class A surfaces fires or Class C electrical hazards are present.

5-1.2.2 Marine Systems. Systems installed on ships, barges, offshore platforms, motorboats, and pleasure craft.

5-1.2.3 Machinery Space. A space containing the main and auxiliary propulsion machinery.

5-1.2.4 Pump Room. A space that contains mechanical equipment for handling, pumping, or transferring flammable or combustible liquids as a fuel.

5-2 Use and Limitations.

5-2.1* Total flooding clean agent fire extinguishing systems shall be used primarily to protect hazards that are in enclosures or equipment that, in itself, includes an enclosure to contain the agent.

5-2.2* In addition to the limitations given in 1-5.2.5, clean agent fire extinguishing systems shall not be used to protect the following:

(1) Dry cargo holds
(2) Bulk cargo

5-2.3 The effects of agent decomposition products and combustion products on fire protection effectiveness and equipment shall be considered where using clean agents in hazards with high ambient temperatures (e.g., incinerator rooms, hot machinery and piping.)

5-3 Hazards to Personnel.

5-3.1 All main machinery spaces are considered normally occupied spaces.

Exception: Engine rooms of 6000 ft^3 (170 m^3) or less that are accessed for maintenance only.

5-3.2* For marine systems, electrical clearances shall be in accordance with 46 *CFR*, Subchapter J, "Electrical Engineering."

5-4 Agent Supply.

5-4.1 Reserve quantities of agent are not required by this standard.

5-4.2* Storage container arrangement shall be in accordance with 2-1.3.1, 2-1.3.3, 2-1.3.4, and 2-1.3.5. Where equipment is subject to extreme weather conditions, the system shall be installed in accordance with the manufacturer's design and installation instructions.

5-4.2.1 Except in the case of systems with storage cylinders located within the protected space, pressure containers required for the storage of the agent shall be in accordance with 5-4.2.2.

5-4.2.2 When the agent 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 in excess of 130°F (55°C). Common bulkheads and decks located between clean agent container storage rooms and protected spaces shall be protected with A-60 class structural insulation as defined by 46 *CFR* 72. Agent container storage rooms shall be accessible without having to pass through the space being protected. Access doors shall open outwards, and bulkheads and decks including doors and other means of closing any opening therein, which form the boundaries between such rooms and adjoining spaces, shall be gastight.

5-4.3 Where agent containers are stored in a dedicated space, doors at exits shall be outward-swinging.

5-4.4 Where subject to moisture, containers shall be installed such that a space of at least 2 in. (51 mm) between the deck and the bottom of the container is provided.

5-4.5 In addition to the requirements of 2-1.3.4, containers shall be secured with a minimum of two brackets to prevent movement from vessel motion and vibration.

5-4.6* For marine applications, all piping, valves, and fittings of ferrous materials shall be protected inside and out against corrosion. Prior to acceptance testing, the inside of the piping shall be cleaned without compromising its corrosion resistance.

Exception: Closed sections of pipe and valves and fittings within closed sections of pipe need only be protected against corrosion on the outside.

5-4.7* Pipes, fittings, nozzles, and hangers, including welding filling materials, within the protected space shall have a melting temperature greater than 1600°F (871°C). Aluminum components shall not be used.

5-4.8 Piping shall extend at least 2 in. (51 mm) beyond the last nozzle in each branch line to prevent clogging.

5-5 Detection, Actuation, and Control Systems.

5-5.1 General.

5-5.1.1 Detection, actuation, alarm, and control systems shall be installed, tested, and maintained in accordance with the requirements of the authority having jurisdiction.

5-5.1.2* Automatic release of the fire extinguishing agent shall not be permitted where actuation of the system can interfere with the safe navigation of the vessel. Automatic release of the fire extinguishing agent shall be permitted for any space where actuation of the system will not interfere with the safe navigation of the vessel.

Exception: Automatic release is permitted for any space of 6000 ft^3 *(170* m^3*) or less.*

5-5.2 Automatic Detection.

5-5.2.1 Electrical detection, signaling, control, and actuation system(s) shall have at least two sources of power. The primary source shall be from the vessel's emergency bus. The back-up source shall either be the vessel's general alarm battery or an internal battery within the system. Internal batteries shall be capable of operating the system for a minimum of 24 hours. All power sources shall be supervised.

Exception: For vessels without an emergency bus or battery, the primary source can be the main electrical supply.

5-5.2.2 In addition to the requirements set forth in 2-3.3.5, actuation circuits shall not be routed through the protected space where manual electrical actuation is used in marine systems.

Exception: Systems complying with 5-5.2.4.

5-5.2.3* Manual actuation for systems shall not be capable of being put into operation by any single action. Manual actuation stations shall be housed in an enclosure.

Exception: Local manual actuation at the cylinder(s) location.

5-5.2.4 Every system shall have a manual actuation station located in the main egress route outside the protected space. In addition, systems having cylinders within the protected space and systems protecting unattended main machinery spaces shall have an actuation station in a continuously monitored control station outside the protected space.

Exception: Systems protecting spaces of 6000 ft^3 *(170* m^3*) or less shall be permitted to have a single actuation station at either of the locations described in 5-5.2.4.*

5-5.2.5 Emergency lighting shall be provided for remote actuation stations serving systems protecting main machinery spaces. All manual operating devices shall be labeled to identify the hazards they protect. In addition, the following information shall be provided:

(1) Operating instructions
(2) Length of time delay
(3) Actions to take if system fails to operate
(4) Other actions to take such as closing vents and taking a head count

For systems having cylinders within the protected space, a means of indicating system discharge shall be provided at the remote actuation station.

5-6 Additional Requirements for Systems Protecting Class B Hazards Greater than 6000 ft^3 (170 m^3) with Stored Cylinders within the Protected Space.

5-6.1* An automatic fire detection system shall be installed in the protected space to provide early warning of fire to minimize potential damage to the fire extinguishing system before it can be manually actuated. The detection system shall initiate audible and visual alarms in the protected space and on the navigating bridge upon detection of fire. All detection and alarm devices shall be electrically supervised for continuity, and trouble indication shall be annunciated on the navigating bridge.

5-6.2* Electrical power circuits connecting the containers shall be monitored for fault conditions and loss of power. Visual and audible alarms shall be provided to indicate this, and these shall be annunciated on the navigating bridge.

5-6.3* Within the protected space, electrical circuits essential for the release of the system shall be heat resistant, such as mineral-insulated cable compliant with Article 330 of NFPA 70, *National Electrical Code*, or equivalent. Piping systems essential for the release of systems designed to be operated hydraulically or pneumatically shall be of steel or other equivalent heat-resisting material.

5-6.4* The arrangements of containers and the electrical circuits and piping essential for the release of any system shall be such that in the event of damage to any one power release line through fire or explosion in a protected space, that is, a single fault concept, the entire fire extinguishing charge required for that space can still be discharged.

5-6.5* The containers shall be monitored for decrease in pressure due to leakage and discharge. Visual and audible signals in the protected area and either on the navigating bridge or in the space where the fire control equipment is centralized shall be provided to indicate a low-pressure condition.

5-6.6* Within the protected space, electrical circuits essential for the release of the system shall be Class A rated in accordance with NFPA 72, *National Fire Alarm Code.*

5-7 Enclosure.

5-7.1* To prevent loss of agent through openings to adjacent hazards or work areas, openings shall be one of the following designs:

(1) Permanently sealed
(2) Equipped with automatic closures
(3) Equipped with manual closures outfitted with an alarm circuit to indicate when these closures are not sealed upon activation of the system

Where confinement of agent is not practical, or if the fuel can drain from one compartment to another, such as via a bilge, protection shall be extended to include the adjacent connected compartment or work areas.

5-7.2* Prior to agent discharge, all ventilating systems shall be closed and isolated to preclude passage of agent to other compartments or the vessel exterior. Automatic shutdowns or manual shutdowns capable of being closed by one person from a position co-located with the agent discharge station shall be used.

5-8 Design Concentration Requirements.

5-8.1 Combinations of Fuels. For combinations of fuels, the design concentration shall be derived from the flame extinguishment value for the fuel requiring the greatest concentration.

5-8.2 Design Concentration. For a particular fuel, the design concentration referred to in 5-8.3 shall be used.

5-8.3 Flame Extinguishment. The minimum design concentration for Class B flammable and combustible liquids shall be as determined following the procedures described in IMO MSC/Circular 848.

5-8.4* Total Flooding Quantity. The quantity of agent shall be based on the net volume of the space and shall be in accordance with the requirements of paragraph five of IMO MSC/Circular 848 "Annex."

5-8.5* Duration of Protection. It is important that the agent design concentration not only shall be achieved, but also shall be maintained for a sufficient period of time to allow effective emergency action by trained ship's personnel. In no case shall the hold time be less than 15 minutes.

5-9 Distribution System.

5-9.1 Rate of Application. The minimum design rate of application shall be based on the quantity of agent required for the desired concentration and the time allowed to achieve the desired concentration.

5-9.2 Discharge Time.

5-9.2.1 The discharge time for halocarbon agents shall not exceed 10 seconds or as otherwise required by the authority having jurisdiction.

5-9.2.2 For halocarbon agents, the discharge time period shall be defined as the time required to discharge from the nozzles 95 percent of the agent mass [at 70°F (21°C)] necessary to achieve the minimum design concentration.

5-9.2.3 The discharge time for inert gas agents shall not exceed 120 seconds for 85 percent of the design concentration or as otherwise required by the authority having jurisdiction.

5-10 Nozzle Choice and Location. Nozzles shall be of the type listed for the intended purpose. Limitations shall be determined based on testing in accordance with IMO MSC/Circular 848. Nozzle spacing, area coverage, height, and alignment shall not exceed the limitations.

Exception: For spaces having only Class A fuels, nozzle placement shall be in accordance with the nozzles' listed limitations.

5-11 Inspection and Tests. At least annually, all systems shall be thoroughly inspected and tested for proper operation by competent personnel. Discharge tests are not required.

5-11.1 An inspection report with recommendations shall be filed with the vessel's master and the owner's agent. The report shall be available for inspection by the authority having jurisdiction.

5-11.2 At least annually, the agent quantity of refillable containers shall be checked by competent personnel. The container pressure shall be verified and logged at least monthly by the vessel's crew.

5-11.3* For halocarbon clean agents, if a container shows a loss in agent of more than 5 percent or a loss in pressure, adjusted for temperature, of more than 10 percent, it shall be refilled or replaced.

5-11.3.1 For inert gas clean agents that are not liquefied, pressure is an indication of agent quantity. If an inert gas clean agent container shows a loss in pressure, adjusted for temperature, of more than 5 percent, it shall be refilled or replaced. Where container pressure gauges are used for this purpose, they shall be compared to a separate calibrated device at least annually.

5-11.4 The installing contractor shall provide instructions for the operational features and inspection procedures specific to the clean agent system installed on the vessel.

5-12 Approval of Installations. Prior to acceptance of the system, technical documentation such as the system design manual, test reports, or listing report shall be presented to the authority having jurisdiction. This documentation shall show that the system and its individual components are compatible, employed within tested limitations, and suitable for marine use.

The listing organization shall perform the following functions:

(1) Verify fire tests conducted in accordance with predetermined standard
(2) Verify component tests conducted in accordance with predetermined standard
(3) Review component quality assurance program
(4) Review design and installation manual
(5) Identify system and component limitations
(6) Verify flow calculations
(7) Verify integrity and reliability of system as a whole
(8) Have a follow-up program
(9) Publish a list of equipment

5-13 Periodic Puff Testing. A test in accordance with 4-7.2.2.13 shall be performed at 24-month intervals. The periodic test program shall include a functional test of all alarms, controls, and time delays.

5-14 Compliance. Electrical systems shall be in accordance with 46 *CFR*, Subchapter J, "Electrical Engineering." For Canadian vessels, electrical installations shall be in accordance with TP 127.

Chapter 6 Referenced Publications

6-1 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 D.

6-1.1 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.

6-1.2 Other Publications.

6-1.2.1 ANSI Publications. American National Standards Institute, Inc., 11 West 42nd Street, 13 floor, New York, NY 10036.

ANSI B1.20.1, *Standard for Pipe Threads, General Purpose,* 1992.

ANSI C2, *National Electrical Safety Code*, 1997.

6-1.2.2 ASME Publications. American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990.

ASME *Boiler and Pressure Vessel Code*, 1998.

ASME B31.1, *Power Piping Code*, 1998.

6-1.2.3 ASTM Publications. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM A 120, *Specification for Seamless Carbon Steel Pipe for High Temperature Service,* 1988.

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

6-1.2.4 CGA Publication. Compressed Gas Association, 1725 Jefferson Davis Highway, Arlington, VA 22202-4100.

CGA C-6, *Standard for Visual Inspection of Steel Compressed Gas Cylinders*, 1993.

6-1.2.5 CSA Publication. Canadian Standards Association, 178 Rexdale Boulevard, Rexdale, Ontario M9W 1R3.

CAN/CSA-Z234.1, *Canadian Metric Practice Guide*, 1989.

6-1.2.6 IMO Publication. International Maritime Organization, 4 Albert Embankment, London, England, SE1 TSR.

IMO MSC/Circular 848.

6-1.2.7 ISO Publication. International Standards Organization, 1 rue de Varembé, Case Postale 56, CH-1211 Geneve 20, Switzerland.

ISO/IEC Guide 7, *Requirements for Standards Suitable for Use for Conformity Assessment*, 1994.

6-1.2.8 UL Publications. Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062.

UL 2127, *Standard for Inert Gas Clean Agent Extinguishing System Units*, 1999.

UL 2166, *Standard for Halocarbon Clean Agent Extinguishing System Units*, 1999.

6-1.2.9 ULC Publications. Underwriters Laboratories of Canada, 7 Crouse Road, Scarborough, Ontario M1R 3A9.

ULC S524-M91, *Standard for the Installation of Fire Alarm Systems*, 1991.

ULC S529-M87, *Smoke Detectors for Fire Alarm Systems*, 1987.

6-1.2.10 U.S. Government Publications. U.S. Government Printing Office, Washington, DC 20402.

OSHA, Title 29, *Code of Federal Regulations*, Part 1910, Subpart S.

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

Title 46, *Code of Federal Regulations,* Subchapter J, "Electrical Engineering."

Title 49, *Code of Federal Regulations*, Parts 170–190, "Transportation."

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-1-3.3 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-1-3.4 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-1-3.14 Halocarbon Agent. Examples are hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs or FCs), and fluoroiodocarbons (FICs).

A-1-3.16 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-1-3.20 Normally Occupied Area. Spaces occasionally visited by personnel, such as transformer bays, switch-houses, pump rooms, vaults, engine test stands, cable trays, tunnels, microwave relay stations, flammable liquid storage areas, and enclosed energy systems are examples of areas considered not normally occupied.

A-1-5.1 The agents currently listed possess the physical properties as detailed in Tables A-1-5.1(a) through A-1-5.1(d). This data will be revised from time to time as new information becomes available. Additional background information and data on these agents can be found in several references: Fernandez (1991), Hanauska (1991), Robin (1991), and Sheinson (1991).

A-1-5.1.2 The designations for perfluorocarbons (FCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and fluoroiodocarbons (FICs) are an extension of halocarbon designations in ANSI/ASHRAE 34, *Number Designation and*

Safety Classification of Refrigerants, prepared by the American National Standards Institute, Inc. (ANSI) and the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). HCFC Blend A is a designation for a blend of HCFCs and a hydrocarbon. The designation IG-541 is used in this standard for a blend of three inert gases — nitrogen, argon, and carbon dioxide (52 percent, 40 percent, and 8 percent, respectively). The designation IG-01 is used in this standard for argon, an unblended inert gas. The designation IG-100 is used in this standard for nitrogen, an unblended inert gas. The designation IG-55 is used in this standard for a blend of two inert gases — nitrogen and argon (50 percent and 50 percent, respectively).

Table A-1-5.1(a) Physical Properties of Clean Halocarbon Agents (SI Units)

	Units	FC-2-1-8	FC-3-1-10	HCFC Blend A	HCFC-124	HFC-125	HFC-227ea	HFC-23	HFC-236fa	FIC-13I1
Molecular weight	N/A	188	238.03	92.90	136.5	120	170.03	70.01	152	195.91
Boiling point at 760 mm Hg	°C	–37.0	–2.0	–38.3	–12.1	–48.5	–16.4	–82.1	–1.4	–22.5
Freezing point	°C	–183.0	–128.2	<107.2	–198.9	–102.8	–131	–155.2	–103*	–110
Critical temperature	°C	71.9	113.2	124.4	122.6	66	101.7	25.9	124.9	122
Critical pressure	kPa	2680	2323	6647	3620	3595	2912	4836	3200	4041
Critical volume	cc/mole	300.8	371	162	243	210	274	133	274*	225
Critical density	kg/m^3	629	629	577	560.72	572	621	525	555.3*	871
Specific heat, liquid at 25°C	kJ/kg °C	1.099	1.047	1.256	1.153	1.481	1.184	4.337 at 20°C	1.283	0.592
Specific heat, vapor at constant pressure (1 atm) and 25°C	kJ/kg °C	0.794	0.804	0.67	0.754	0.794	0.808	0.731 at 20°C	0.844	0.3618
Heat of vaporization at boiling point	kJ/kg	104.8	96.3	225.6	163.1	164.8	132.6	238.8	160.1	112.4
Thermal conductivity of liquid at 25°C	W/m °C	0.0138	0.0537	0.0900	0.0746	0.0634	0.069	0.0527	0.0745	0.07
Viscosity, liquid at 25°C	centipoise	0.297	0.324	0.21	0.305	0.143	0.184	0.083	0.306	0.196
Relative dielectric strength at 1 atm at 734 mm Hg, 25°C (N_2 = 1.0)	N/A	2.2	2.8	1.32	1.55	0.955 at 21°C	2.00	1.04	TBD	1.41
Solubility of water in agent at 21°C	ppm	<0.005% by weight	0.001% by weight	0.12% by weight	700 at 25°C	700 at 25°C	0.06% by weight	500 at 10°C	740 at 20°C	1.0062% by weight

*Dupont estimated values.

Table A-1-5.1(b) Physical Properties of Inert Gas Agents (SI Units)

	Units	IG-01	IG-100	IG-541	IG-55
Molecular weight	N/A	39.9	28.0	34.0	33.95
Boiling point at 760 mm Hg	°C	–189.85	–195.8	–196	–190.1
Freezing point	°C	–189.35	–210.0	–78.5	–199.7
Critical temperature	°C	–122.3	–146.9	N/A	–134.7
Critical pressure	kPa	4,903	3,399	N/A	4,150
Specific heat, vapor at constant pressure (1 atm) and 25°C	kJ/kg °C	0.519	1.04	0.574	0.782
Heat of vaporization at boiling point	kJ/kg	163	199	220	181
Relative dielectric strength at 1 atm at 734 mm Hg, 25°C (N_2 = 1.0)	N/A	1.01	1.0	1.03	1.01
Solubility of water in agent at 25°C	N/A	0.006%	0.0013%	0.015%	0.006%

Table A-1-5.1(c) Physical Properties of Clean Halocarbon Agents (English Units)

	Units	FC-2-1-8	FC-3-1-10	HCFC Blend A	HCFC-124	HFC-125	HFC-227ea	HFC-23	HFC-236fa	FIC-13I1
Molecular weight	N/A	188	238.0	92.9	136.5	120.0	170.0	70.01	152	195.9
Boiling point at 14.7 psia	°F	–34.4	28	–37.0	10.3	–55.3	1.9	–115.8	29.5	–8.5
Freezing point	°F	–297.4	–199	≤161	–326	–153	–204	–247.4	–153.4	–166
Critical temperature	°F	161.4	235	256	252.5	150.8	214	78.6	256.8	252
Critical pressure	psia	388.7	337	964	527	521	422	701	464	586
Critical volume	ft^3/lb	0.026	0.0250	0.0280	0.0289	0.0281	0.0258	0.0305	0.0288*	0.0184
Critical density	lb/ft^3	39.3	39.30	36.00	34.58	35.68	38.76	32.78	34.67*	54.38
Specific heat, liquid at 77°F	Btu/lb-°F	0.26	0.241	0.30	0.276	0.354	0.282	1.037 at 68°F	0.307	0.141
Specific heat, vapor at constant pressure (1 atm) and 77°F	Btu/lb-°F	0.19	0.180	0.16	0.180	0.190	0.185	0.175 at 68°F	0.202	0.86
Heat of vaporization at boiling point	Btu/lb	45.1	41.4	97	70.2	70.8	56.7	103	68.8	48.1
Thermal conductivity of liquid at 77°F	Btu/h-ft-°F	0.008	0.0310	0.052	0.0417	0.0367	0.040	0.0305	0.0431	0.04
Viscosity, liquid at 77°F	lb/ft-hr	0.719	0.783	0.508	0.738	0.346	0.433	0.201	0.74	0.473
Relative dielectric strength at 1 atm at 734 mm Hg, 77°F (N_2 = 1)	N/A	2.2	2.8	1.32	1.55	0.955 at 70°F	2.00	1.04	TBD	1.41
Solubility, by weight, of water in agent at 70°F	ppm	<0.005%	0.001%	0.12%	770 at 77°F	770 at 77°F	0.06%	500 at 50°F	740 at 68°F	0.0062%

*Dupont estimated values.

Table A-1-5.1(d) Physical Properties of Inert Gases (English Units)

	Units	IG-01	IG-100	IG-541	IG-55
Molecular weight	N/A	39.9	28.0	34.0	33.95
Boiling point at 760 mm Hg	°F	–302.6	–320.4	–320	–310.2
Freezing point	°F	–308.9	–346.0	–109	–327.5
Critical temperature	°F	–188.1	–232.4	N/A	–210.5
Critical pressure	psia	711	492.9	N/A	602
Specific heat, vapor at constant pressure (1 atm) and 77°F	Btu/lb-°F	0.125	0.445	0.195	0.187
Heat of vaporization at boiling point	Btu/lb	70.1	85.6	94.7	77.8
Relative dielectric strength at 1 atm at 734 mm Hg, 77°F (N_2 = 1.0)	N/A	1.01	1.0	1.03	1.01
Solubility of water in agent at 70°F	N/A	0.006%	0.0013%	0.015%	0.006%

A-1-5.2.3 While an attractive feature of these agents is their suitability for use in environments containing energized electrical equipment without damaging that equipment, in some instances the electrical equipment could be the source of ignition. In such cases, the energized equipment should be de-energized prior to or during agent discharge.

A-1-5.2.4 The provision of an enclosure can create an unnecessary explosion hazard where otherwise only a fire hazard exists. A hazard analysis should be conducted to determine the relative merits of differing design concepts, for example, with and without enclosures, and the most relevant means of fire protection.

A-1-5.2.6 See NFPA 77, *Recommended Practice on Static Electricity.*

A-1-5.2.8 This provision provides consideration for using a clean agent in an environment that could result in an inordinate amount of products of decomposition (i.e., within an oven).

A-1-6.1 Potential hazards to be considered for individual systems are the following:

(a) *Noise.* Discharge of a system can cause noise loud enough to be startling but ordinarily insufficient to cause traumatic injury.

(b) *Turbulence.* High-velocity discharge from nozzles could be sufficient to dislodge substantial objects directly in the path. System discharge can cause enough general turbulence in the enclosures to move unsecured paper and light objects.

(c) *Cold Temperature.* Direct contact with the vaporizing liquid being discharged from a system will have a strong chilling effect on objects and can cause frostbite burns to the skin. The liquid phase vaporizes rapidly when mixed with air and thus limits the hazard to the immediate vicinity of the discharge point. In humid atmospheres, minor reduction in visibility can occur for a brief period due to the condensation of water vapor.

A-1-6.1.1 The discharge of clean agent systems to extinguish a fire could create a hazard to personnel from the natural form of the clean agent or from the products of decomposition that result from exposure of the agent to the fire or hot surfaces. Unnecessary exposure of personnel either to the natural agent or to the decomposition products should be avoided.

The SNAP Program was originally outlined in 59 *FR* 13044.

A-1-6.1.2 Table A-1-6.1.2(a) provides information on the toxicological effects of halocarbon agents covered by this standard. The NOAEL is the highest concentration at which no adverse physiological or toxicological effect has been observed. The LOAEL is the lowest concentration at which an adverse physiological or toxicological effect has been observed.

An appropriate protocol measures the effect in a stepwise manner such that the interval between the LOAEL and NOAEL is sufficiently small to be acceptable to the competent regulatory authority. The EPA includes in its SNAP evaluation this aspect (of the rigor) of the test protocol.

Table A-1-6.1.2(a) Toxicity Information for Halocarbon Clean Agents

Agent	LC_{50} or ALC (%)	NOAEL (%)	LOAEL (%)
FC-2-1-8	>81	30	>30
FC-3-1-10	>80	40	>40
FIC-13I1	>12.8	0.2	0.4
HCFC Blend A	64	10.0	>10.0
HCFC-124	23–29	1.0	2.5
HFC-125	>70	7.5	10.0
HFC-227ea	>80	9.0	10.5
HFC-23	>65	50	>50
HFC-236fa	>18.9	10	15

Notes:
1. LC_{50} is the concentration lethal to 50 percent of a rat population during a 4-hour exposure. The ALC is the approximate lethal concentration.
2. The cardiac sensitization levels are based on the observance or nonobservance of serious heart arrhythmias in a dog. The usual protocol is a 5-minute exposure followed by a challenge with epinephrine.
3. High concentration values are determined with the addition of oxygen to prevent asphyxiation.

For halocarbons covered in this standard, the NOAEL and LOAEL are based on the toxicological effect known as cardiac sensitization. Cardiac sensitization occurs when a chemical causes an increased sensitivity of the heart to adrenaline, a naturally occurring substance produced by the body during times of stress, leading to the sudden onset of irregular heart beats and possibly heart attack. Cardiac sensitization is measured in dogs after they have been exposed to a halocarbon agent for 5 minutes. At the 5-minute time period, an external dose of adrenaline (epinephrine) is administered and an effect is recorded, if the dog experiences cardiac sensitization. The cardiac sensitization potential as measured in dogs is a highly conservative indicator of the potential in humans. The conservative nature of the cardiac sensitization test stems from several factors, the two most pertinent are as follows:

1. Very high doses of adrenaline are given to the dogs during the testing procedure (doses are more than 10 times higher than the highest levels secreted by humans under maximum stress.
2. Four to ten times more halocarbon is required to cause cardiac sensitization in the absence of externally administered adrenaline, even in artificially created situations of stress or fright in the dog test.

Because the cardiac sensitization potential is measured in dogs, a means of providing human relevance to the concentration at which this cardiac sensitization occurs (LOAEL) has been established through the use of physiologically based pharmacokinetic (PBPK) modeling.

A PBPK model is a computerized tool that describes time-related aspects of a chemical's distribution in a biological system. The PBPK model mathematically describes the uptake of the halocarbon into the body and the subsequent distribution of the halocarbon to the areas of the body where adverse effects can occur. For example, the model describes the breathing rate and uptake of the halocarbon from the exposure atmosphere into the lungs. From there, the model uses the blood flow bathing the lungs to describe the movement of the halocarbon from the lung space into the arterial blood that directly feeds the heart and vital organs of the body.

It is the ability of the model to describe the halocarbon concentration in human arterial blood that provides it primary utility in relating the dog cardiac sensitization test results to a human who is unintentionally exposed to the halocarbon. The concentration of halocarbon in the dog arterial blood at the time the cardiac sensitization event occurs (5-minute exposure) is the critical arterial blood concentration, and this blood parameter is the link to the human system. Once this critical arterial blood concentration has been measured in dogs, the EPA-approved PBPK model simulates how long it will take the human arterial blood concentration to reach the critical arterial blood concentration (as determined in the dog test) during human inhalation of any particular concentration of the halocarbon agent. As long as the simulated human arterial concentration remains below the critical arterial blood concentration, the exposure is considered safe. Inhaled halocarbon concentrations that produce human arterial blood concentrations equal to or greater than the critical arterial blood concentration are considered unsafe because they represent inhaled concentration that potentially yield arterial blood concentrations where cardiac sensitization events occur in the dog test. Using these critical arterial blood concentrations of halocarbons as the ceiling for allowable human arterial concentrations, any number of halocarbon exposure scenarios can be evaluated using this modeling approach.

For example, in the dog cardiac sensitization test on Halon 1301, a measured dog arterial blood concentration of 25.7 mg/L is measured at the effect concentration (LOAEL) of 7.5 percent after a 5-minute exposure to Halon 1301 and an external intravenous adrenaline injection. The PBPK model predicts the time at which the human arterial blood concentration reaches 25.7 mg/L for given inhaled Halon 1301 concentrations. Using this approach the model also predicts that at some inhaled halocarbon concentrations, the critical arterial blood concentration is never reached, and thus, cardiac sensitization will not occur. Accordingly, in the tables in 1-6.1.2.1, the time is arbitrarily truncated at 5 minutes, because the dogs were exposed for 5 minutes in the original cardiac sensitization testing protocols.

The time value, estimated by the EPA-approved and peer-reviewed PBPK model or its equivalent, is that required for the human arterial blood level for a given halocarbon to equal the arterial blood level of a dog exposed to the LOAEL for 5 minutes.

For example, if a system is designed to achieve a maximum concentration of 12.0 percent HFC-125, then means should be provided such that personnel are exposed for no longer than 1.67 minutes. Examples of suitable exposure limiting mechanisms include self-contained breathing apparatuses and planned and rehearsed evacuation routes.

The requirement for predischarge alarms and time delays are intended to prevent human exposure to agents during fire fighting. However, in the unlikely circumstance that an accidental discharge occurs, restrictions on the use of certain halocarbon agents covered in this standard are based on the availability of PBPK-modeling information. For those halocarbon agents, in which modeling information is available, means should be provided to limit the exposure to those concentrations and times specified in the tables in 1-6.1.2.1. These concentrations and times are those that have been predicted to limit the human arterial blood concentration to below the critical arterial blood concentration associated with cardiac sensitization. For halocarbon agents, where the needed data are unavailable, the agents are restricted based on whether the protected space is normally occupied or unoccupied, and how quickly egress from the area can be effected. Normally occupied areas are those intended for human occupancy. Normally unoccupied areas are those in which personnel can be present from time to time. Therefore, a comparison of the cardiac sensitization values to the intended design concentration would determine the suitability of a halocarbon for use in normally occupied or unoccupied areas. [To keep oxygen concentrations above 16 percent (sea level equivalent), the point at which onset of impaired personnel function occurs, no halogenated fire extinguishing agents addressed in this standard should be used at a concentration greater than 24 percent in a normally occupied area.]

Clearly, longer exposure of the agent to high temperatures would produce greater concentrations of these gases. The type and sensitivity of detection, coupled with the rate of discharge, should be selected to minimize the exposure time of the agent to the elevated temperature if the concentration of the breakdown products must be minimized. In most cases the area would be untenable for human occupancy due to the heat and breakdown products of the fire itself.

These decomposition products have a sharp, acrid odor, even in minute concentrations of only a few parts per million. This characteristic provides a built-in warning system for the agent, but at the same time creates a noxious, irritating atmosphere for those who must enter the hazard following a fire.

Background and Toxicology of Hydrogen Fluoride.

Hydrogen fluoride (HF) vapor can be produced in fires as a breakdown product of fluorocarbon fire extinguishing agents and in the combustion of fluoropolymers.

The significant toxicological effects of HF exposure occur at the site of contact. By the inhalation route, significant deposition is predicted to occur in the most anterior (front part) region of the nose and extending back to the lower respiratory tract (airways and lungs) if sufficient exposure concentrations are achieved. The damage induced at the site of contact with HF is characterized by extensive tissue damage and cell death (necrosis) with inflammation. One day after a single, 1-hour exposure of rats to HF concentrations of 950 ppm to 2600 ppm, tissue injury was limited exclusively to the anterior section of the nose (DuPont, 1990). No effects were seen in the trachea or lungs.

At high concentrations of HF (about 200 ppm), human breathing pattern would be expected to change primarily from nose breathing to primarily mouth breathing. This change in breathing pattern will determine the deposition pattern of HF into the respiratory tract, either upper respiratory tract (nose breathing) or lower respiratory tract (mouth breathing). In studies conducted by Dalby (Dalby, 1996), rats were exposed by nose-only or mouth-only breathing. In the mouth-breathing only model, rats were exposed to various concentrations of HF through a tube placed in the trachea thereby bypassing the upper respiratory tract. This exposure method is considered to be a conservative approach for estimating a "worst case" exposure in which a person would not breath through the nose but inhale through the mouth thereby maximizing the deposition of HF into the lower respiratory tract.

In the nose-breathing model, 2- or 10-minute exposures of rats to about 6400 or 1700 ppm, respectively, produced similar effects; that is, no mortality but significant cell damage in the nose. In contrast, marked differences in toxicity were evident in the mouth-breathing model. Indeed, mortality was evident following a 10-minute exposure to a concentration of about 1800 ppm and a 2-minute exposure to about 8600 ppm. Significant inflammation of the lower respiratory tract was also evident. Similarly, a 2-minute exposure to about 4900 ppm produced mortality and significant nasal damage. However, at lower concentrations (950 ppm) following a 10-minute exposure or 1600 ppm following a 2-minute exposure, no mortality and only minimal irritation were observed.

Numerous other toxicology studies have been conducted in experimental animals for longer durations, for example, 15, 30, or 60 minutes. In nearly all of these studies, the effects of HF were generally similar across all species; that is, severe irritation of the respiratory tract as the concentration of HF was increased.

In humans, an irritation threshold appears to be at about 3 ppm where irritation of the upper airways and eyes occurs. In prolonged exposure at about 5 ppm, redness of the skin has also resulted. In controlled human exposure studies, humans are reported to have tolerated mild nasal irritation (subjective response) at 32 ppm for several minutes (Machle et al., 1934). Exposure of humans to about 3 ppm for an hour produced slight eye and upper respiratory tract irritation. Even with an increase in exposure concentration (up to 122 ppm) and a decrease in exposure duration to about 1 minute, skin, eye, and respiratory tract irritation occurs (Machle and Kitzmiller, 1935).

Meldrum (Meldrum, 1993) proposed the concept of the dangerous toxic load (DTL) as a means of predicting the effects of, for example, HF in humans. These authors developed the argument that the toxic effects of certain chemicals tend to follow Haber's law:

$$C \times t = k$$

where:

C = concentration

t = time

k = constant

The available data on the human response to inhalation of HF were considered insufficient to provide a basis for establishing a DTL. Therefore, it was necessary to use the available animal lethality data to establish a model for the response in humans. The DTL is based on an estimate of 1 percent lethality in an exposed population of animals. Based on the analysis of animal lethality data, the author determined that the DTL for HF is 12,000 ppm/min. Although this approach appears reasonable and consistent with mortality data in experimental animals, the predictive nature of this relationship for nonlethal effects in humans has not been demonstrated.

Potential Human Health Effects and Risk Analysis in Fire Scenarios.

It is important for a risk analysis to distinguish between normally healthy individuals, for example, fire fighters, and those with compromised health. Exposure to higher concentrations of HF would be expected to be tolerated more in healthy individuals, whereas, at equal concentrations, escape-impairing effects can occur in those with compromised health. Therefore, an assumption in the following discussion is that the effects described at the various concentrations and durations are for the healthy individual.

Inflammation (irritation) of tissues represents a continuum from "no irritation" to "severe, deep penetrating" irritation. Use of terms slight, mild, moderate, and severe in conjunction with irritation represents an attempt to quantify this effect. However, given the large variability and sensitivity of the human population, differences in the degree of irritation from exposure to HF are expected to occur. For example, some individuals can experience mild irritation to a concentration that results in moderate irritation in another individual.

At concentrations of <50 ppm for up to 10 minutes, irritation of upper respiratory tract and the eyes would be expected to occur. At these low concentrations, escape-impairing effects would not be expected in the healthy individual. As HF concentrations increase to 50 ppm to 100 ppm, an increase in irritation is expected. For short duration (10 to 30 minutes) irritation of the skin, eyes, and respiratory tract would occur. At 100 ppm for 30 to 60 minutes, escape-impairing effects would begin to occur, and continued exposure at 200 ppm and greater for an hour could be lethal in the absence of medical intervention. As the concentration of HF increases, the severity of irritation increases, and the potential for delayed systemic effects also increases. At about 100 to 200 ppm of HF, humans would also be expected to shift their breathing pattern to mouth breathing. Therefore, deeper lung irritation is expected. At greater concentrations (>200 ppm), respiratory discomfort, pulmonary (deep lung) irritation, and systemic effects are possible. Continued exposure at these higher concentrations can be lethal in the absence of medical treatment.

Generation of HF from fluorocarbon fire extinguishing agents represents a potential hazard. In the foregoing discussion, the duration of exposure was indicated for 10 to 60 minutes. In fire conditions in which HF would be generated, the actual exposure duration would be expected to be less than 10 minutes and in most cases less than 5 minutes. As Dalby (Dalby, 1996) showed, exposing mouth-breathing rats to HF concentrations of about 600 ppm for 2 minutes was without effect. Similarly, exposing mouth-breathing rats to a HF concentration of about 300 ppm for 10 minutes did not result in any mortality or respiratory effects. Therefore, one could surmise that humans exposed to similar concentrations for less than 10 minutes would be able to survive such concentrations. However, caution needs to be employed in over-interpreting these data. Although the toxicity data would suggest that humans could survive these large concentrations for less than 10 minutes, those individuals with compromised lung function or those with cardiopulmonary disease can be more susceptible to the effects of HF. Furthermore, even in the healthy individual, irritation of the upper respiratory tract and eyes would be expected, and escape could be impaired.

Table A-1-6.1.2(b) provides potential human health effects of hydrogen fluoride in healthy individuals.

Occupational exposure limits have been established for HF. The limit set by the American Conference of Governmental Industrial Hygienists (ACGIH), the Threshold Limit Value (TLV®), represents exposure of normally healthy workers for an 8-hour workday or 40-hour workweek. For HF, the limit established is 3 ppm, which represents a ceiling limit; that is, the airborne concentration that should not be exceeded at any time during the workday. This limit is intended to prevent irritation and possible systemic effects with repeated, long-term exposure. This and similar time-weighted average limits are not considered relevant for fire extinguishing use of fluorocarbons during emergency situations. However, these limits may need to be considered in clean-up procedures where high levels of HF were generated. For more information, contact the American Conference of Governmental Industrial Hygienists, 6500 Glenway Ave., Bldg. D-7, Cincinnati, OH 45211-4438, (513) 742-2020.

Table A-1-6.1.2(b) Potential Human Health Effects of Hydrogen Fluoride in Healthy Individuals

Exposure Time	Hydrogen Fluoride (ppm)	Reaction
2 minutes	<50	Slight eye and nasal irritation
	50–100	Mild eye and upper respiratory tract irritation
	100–200	Moderate eye and upper respiratory tract irritation; slight skin irritation
	>200	Moderate irritation of all body surfaces; increasing concentration may be escape impairing
5 minutes	<50	Mild eye and nasal irritation
	50–100	Increasing eye and nasal irritation; slight skin irritation
	100–200	Moderate irritation of skin, eyes, and respiratory tract
	>200	Definite irritation of tissue surfaces; will cause escape impairing at increasing concentrations
10 minutes	<50	Definite eye, skin, and upper respiratory tract irritation
	50–100	Moderate irritation of all body surfaces
	100–200	Moderate irritation of all body surfaces; escape-impairing effects likely
	>200	Escape-impairing effects will occur; increasing concentrations can be lethal without medical intervention

In contrast to the ACGIH TLV, the American Industrial Hygiene Association (AIHA) Emergency Response Planning Guideline (ERPG) represents limits established for emergency release of chemicals. These limits are established to also account for sensitive populations, for example, those with compromised health. The ERPG limits are designed to assist emergency response personnel in planning for catastrophic releases of chemicals. These limits are not developed to be used as "safe" limits for routine operations. However, in the case of fire extinguishing use and generation of HF, these limits are more relevant than time-weighted average limits such as the TLV. The ERPG limits consist of three levels for use in emergency planning and are typically 1-hour values; 10-minute values have also been established for HF. For the 1-hour limits, the ERPG 1 (2 ppm) is based on odor perception and is below the concentration at which mild sensory irritation has been reported (3 ppm). ERPG 2 (20 ppm) is the most important guideline value set and is the concentration at which mitigating steps should be taken, such as evacuation, sheltering, and donning masks. This level should not impede escape or cause irreversible health effects and is based mainly on the human irritation data obtained by Machle et al. (Machle et al., 1934) and Largent (Largent, 1960). ERPG 3 (50 ppm) is based on animal data and is the maximum nonlethal level for nearly all individuals. This level could be lethal to some susceptible people. The 10-minute values established for HF and used in emergency planning in fires where HF vapor is generated are ERPG 3 = 170 ppm, ERPG 2 = 50 ppm, and ERPG 1 = 2 ppm. For more information, contact the American Industrial Hygiene Association, 2700 Prosperity Ave., Suite 250, Fairfax, VA 22031, (703) 849-8888, fax (703) 207-3561.

A-1-6.1.3 Table A-1-6.1.3 provides information on physiological effects of inert gas agents covered by this standard. The health concern for inert gas clean agents is asphyxiation due to the lowered oxygen levels. With inert gas agents, an oxygen concentration of no less than 12 percent (sea level equivalent) is required for normally occupied areas. This corresponds to an agent concentration of no more than 43 percent.

Table A-1-6.1.3 Physiological Effects for Inert Gas Agents

Agent	No Effect Level* (%)	Low Effect Level* (%)
IG-01	43	52
IG-100	43	52
IG-55	43	52
IG-541	43	52

*Based on physiological effects in humans in hypoxic atmospheres. These values are the functional equivalents of NOAEL and LOAEL values and correspond to 12-percent minimum oxygen for the No Effect Level and 10-percent minimum oxygen for the Low Effect Level.

IG-541 uses carbon dioxide to promote breathing characteristics intended to sustain life in the oxygen-deficient environment for protection of personnel. Care should be used not to design inert gas-type systems for normally occupied areas using design concentrations higher than that specified in the system manufacturer's listed design manual for the hazard being protected.

Inert gas agents do not decompose measurably in extinguishing a fire. As such, toxic or corrosive decomposition products are not found. However, heat and breakdown products of the fire itself can still be substantial and could make the area untenable for human occupancy.

A-1-6.1.4.1 The steps and safeguards necessary to prevent injury or death to personnel in areas whose atmospheres will be made hazardous by the discharge or thermal decomposition of clean agents can include the following:

(a) Provision of adequate aisleways and routes of exit, and procedures to keep them clear at all times.

(b) Provision of emergency lighting and directional signs as necessary to ensure quick, safe evacuation.

(c) Provision of alarms within such areas that will operate immediately upon detection of the fire.

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

(e) Provision of continuous alarms at entrances to such areas until the atmosphere has been restored to normal.

(f) Provision of warning and instruction signs at entrances to and inside such areas. These signs should inform persons in or entering the protected area that a clean agent system is installed and should contain additional instructions pertinent to the conditions of the hazard.

(g) Provision for the prompt discovery and rescue of persons rendered unconscious in such areas. This should be accomplished by having such areas searched immediately by trained personnel equipped with proper breathing equipment. Self-contained breathing equipment and personnel trained in its use and in rescue practices, including artificial respiration, should be readily available.

(h) Provision of instruction and drills for all personnel within or in the vicinity of such areas, including maintenance or construction people who could be brought into the area, to ensure their correct action when a clean agent system operates.

(i) Provision of means for prompt ventilation of such areas. Forced ventilation will often be necessary. Care should be taken to readily dissipate hazardous atmospheres and not merely move them to another location.

(j) Prohibition against smoking by persons until the atmosphere has been determined to be free of the clean agent.

(k) Provision of such other steps and safeguards that a careful study of each particular situation indicates is necessary to prevent injury or death.

A-1-6.1.4.2 A certain amount of leakage from a protected space to adjacent areas is anticipated during and following agent discharge. Consideration should be given to agent concentration (when above NOAEL), decomposition products, products of combustion, and relative size of adjacent spaces. Additional consideration should be given to exhaust paths when opening or venting the enclosure after a discharge.

A-1-7 Many factors impact the environmental acceptability of a fire suppression agent. Uncontrolled fires pose significant impact by themselves. All extinguishing agents should be used in ways that eliminate or minimize the potential environmental impact. General guidelines to be followed to minimize this impact include the following:

(1) Do not perform unnecessary discharge testing.
(2) Consider the ozone depletion and global warming impact of the agent under consideration and weigh these impacts against the fire safety concerns.
(3) Recycle all agents where possible.
(4) Consult the most recent environmental regulations on each agent.

The unnecessary emission of clean extinguishing agents with either the potential of ozone depletion or the potential of global warming, or the potential of both, should be avoided. All phases of design, installation, testing, and maintenance of systems using these agents should be performed with the goal of no emission to the environment.

A-1-9.1 It is generally believed that, because of the highly stable nature of the compounds that are derived from the families including halogenated hydrocarbons and inert gases, incompatibility will not be a problem. These materials tend to behave in a similar fashion and, as far as is known, the reactions that could occur as the result of mixing of these materials within the container is not thought to be a real consideration with regard to their application to a fire protection hazard.

It is clearly not the intent of this section to deal with compatibility of the agents with components of the extinguishing hardware. This particular consideration is addressed elsewhere in this document. It is also clearly not the intent of this section to deal with the subject of storability or storage life of individual agents or mixtures of those agents. This also is addressed in another section of this standard.

A-2-1.1.2 An extra-full complement of charged cylinders (connected reserve) manifolded and piped to feed into the automatic system should be considered on all installations. The reserve supply is normally actuated by manual operation of the main/reserve switch on either electrically operated or pneumatically operated systems. A connected reserve is desirable for the following reasons:

(1) Provides protection should a reflash occur
(2) Provides reliability should the main bank malfunction
(3) Provides protection during impaired protection when main tanks are being replaced
(4) Provides protection of other hazards if selector valves are involved and multiple hazards are protected by the same set of cylinders

If a full complement of charged cylinders cannot be obtained or if the empty cylinder cannot be recharged, delivered, and reinstalled within 24 hours, a third complement of fully charged, nonconnected spare cylinders should be considered and made available on the premises for emergency use. The need for spare cylinders could depend on whether or not the hazard is under the protection of automatic sprinklers.

A-2-1.2 The normal and accepted procedures for making these quality measurements will be provided by the chemical manufacturers in a future submittal. As each clean agent varies in its quality characteristics, a more comprehensive table than the one currently in the standard will be developed. It will be submitted through the public proposal process. Recovered or recycled agents are currently not available, and thus quality standards do not exist at this time. As data becomes available, this criteria will be developed.

A-2-1.3.2 Storage containers should not be exposed to a fire in a manner likely to impair system performance.

A-2-1.4.1 Containers used for agent storage should be fit for the purpose. Materials of construction of the container, closures, gaskets, and other components should be compatible with the agent and designed for the anticipated pressures. Each container is equipped with a pressure relief device to protect against excessive pressure conditions.

The variations in vapor pressure with temperature for the various clean agents are shown in Figures A-2-1.4.1(a) through A-2-1.4.1(hh).

FIGURE A-2-1.4.1(a) Isometric diagram of FC-2-1-8 for 360-psig containers.

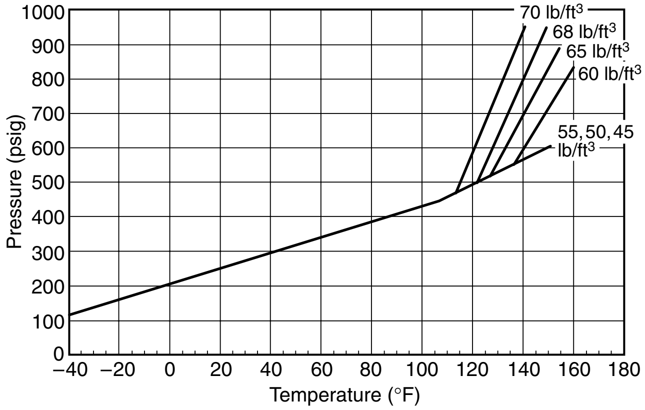


FIGURE A-2-1.4.1(b) Isometric diagram of FC-2-1-8 for 2.5-MPa containers.

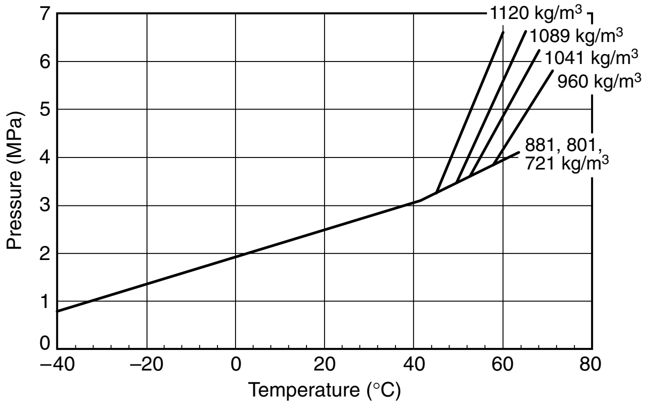


FIGURE A-2-1.4.1(c) Isometric diagram of HFC-125 pressurized with nitrogen to 360 psig at 72°F.

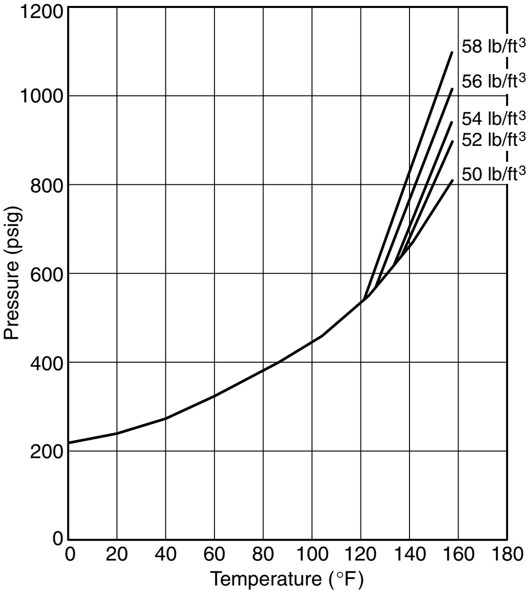


FIGURE A-2-1.4.1(d) Isometric diagram of HFC-125 pressurized with nitrogen to 24.82 bar, gauge at 22°C.

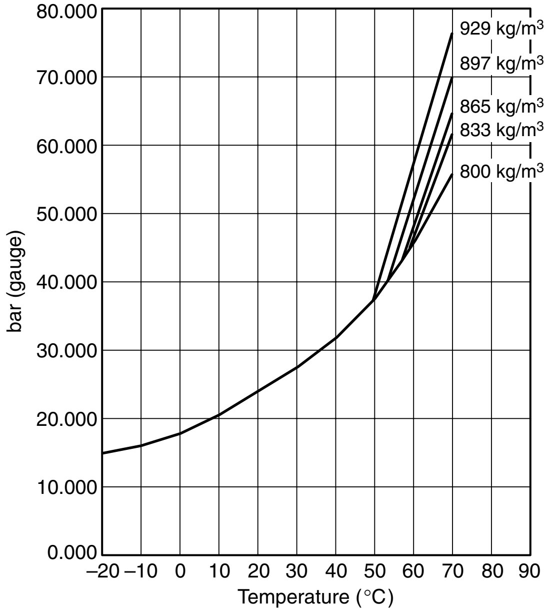


FIGURE A-2-1.4.1(e) Isometric diagram of HFC-125 pressurized with nitrogen to 600 psig at 72°F.

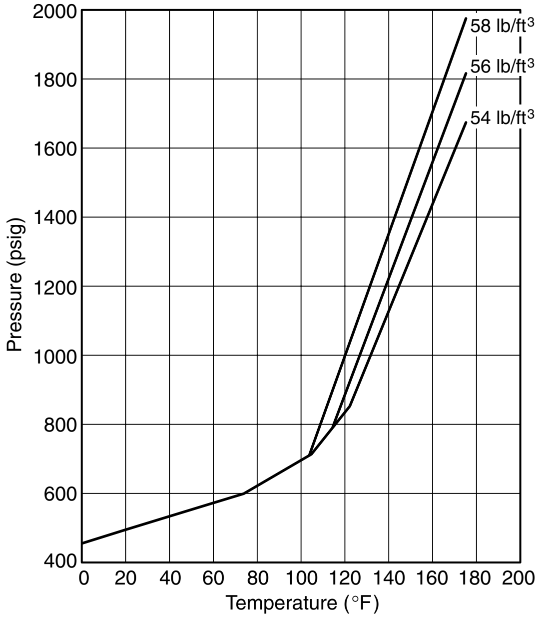


FIGURE A-2-1.4.1(f) Isometric diagram of HFC-125 pressurized with nitrogen to 41.4 bar, gauge at 22°C.

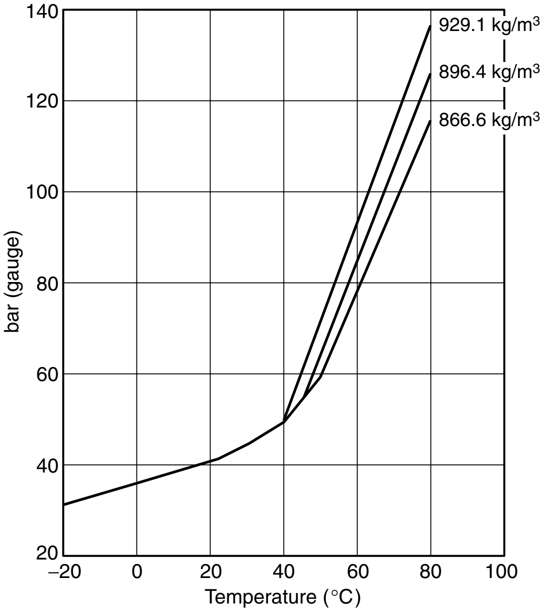


FIGURE A-2-1.4.1(g) Isometric diagram of HFC-125 pressurized with nitrogen to 750 psig at 72°F.

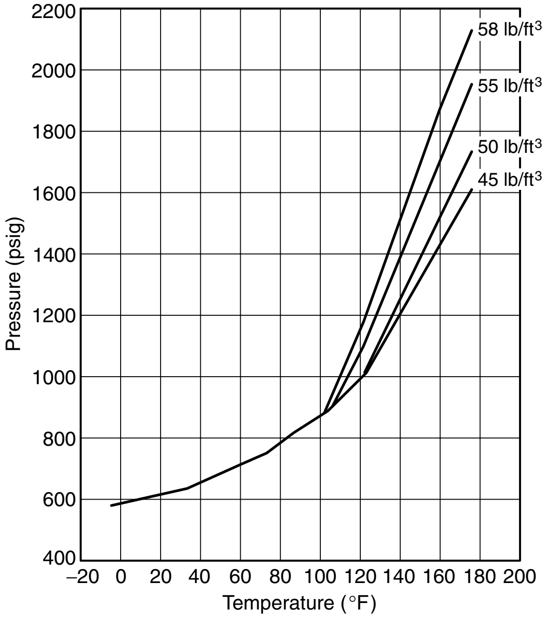


FIGURE A-2-1.4.1(h) Isometric diagram of HFC-125 pressurized with nitrogen to 51.7 bar, gauge at 22°C.

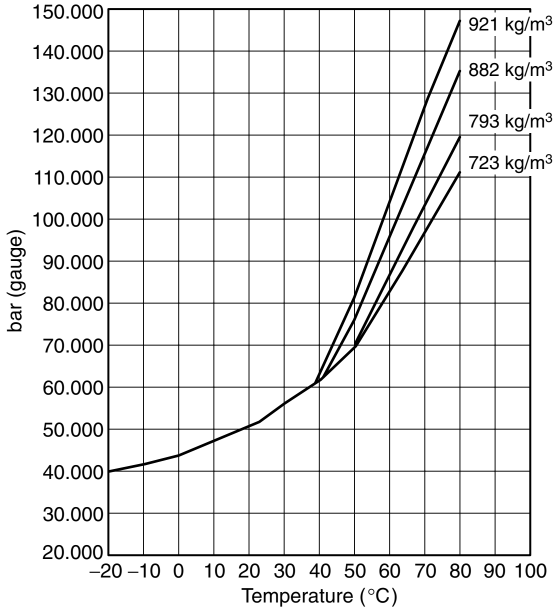


FIGURE A-2-1.4.1(i) Isometric diagram of FC-3-1-10 for 360-psig containers.

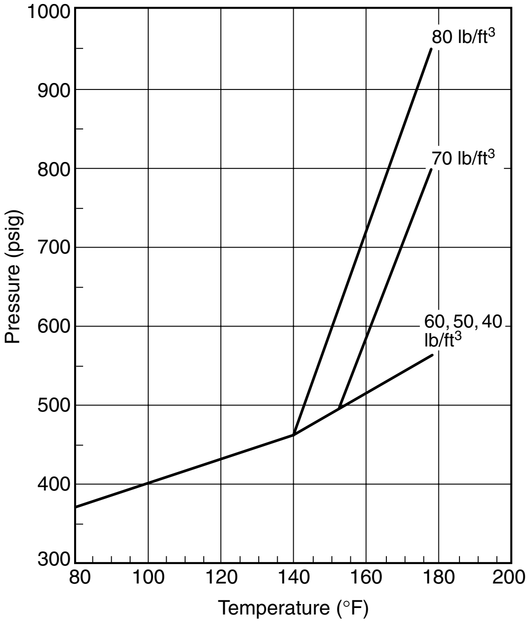


FIGURE A-2-1.4.1(j) Isometric diagram of FC-3-1-10 for 2.5 MPa containers.

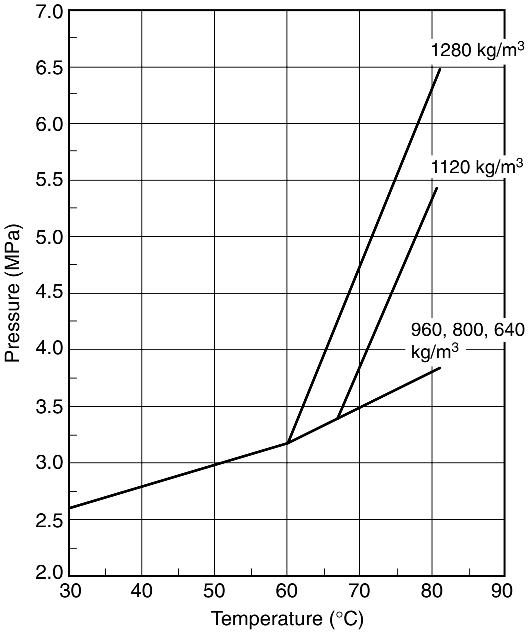


FIGURE A-2-1.4.1(k) Isometric diagram of HCFC Blend A, English.

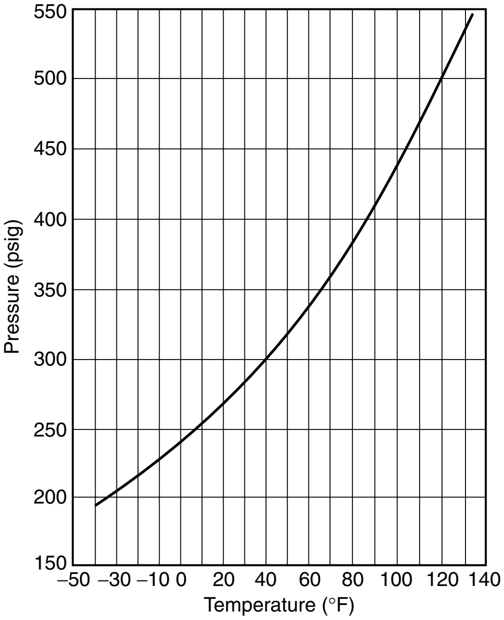


FIGURE A-2-1.4.1(l) Isometric diagram of HCFC Blend A, SI.

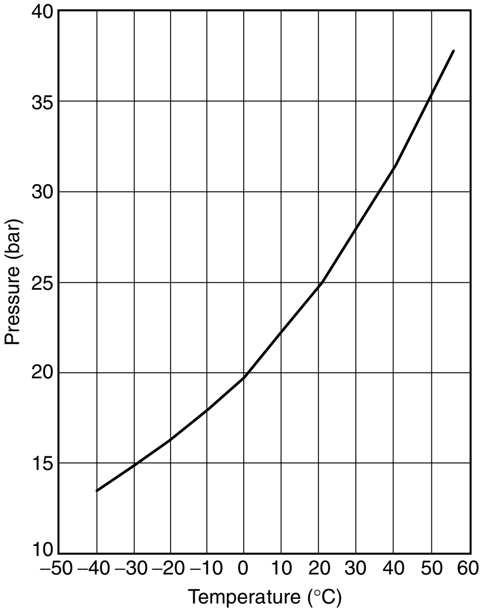


FIGURE A-2-1.4.1(m) Isometric diagram for HCFC Blend A pressurized with nitrogen to 600 psig at 70°F for fill densities of 31.2 to 56.2 lb/ft³.

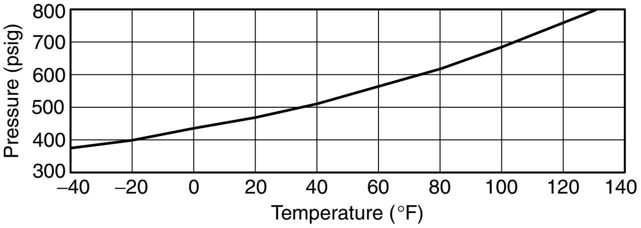


FIGURE A-2-1.4.1(n) Isometric diagram for HCFC Blend A pressurized with nitrogen to 40 bar at 20°C for fill densities of 0.5 to 0.9 kg/L.

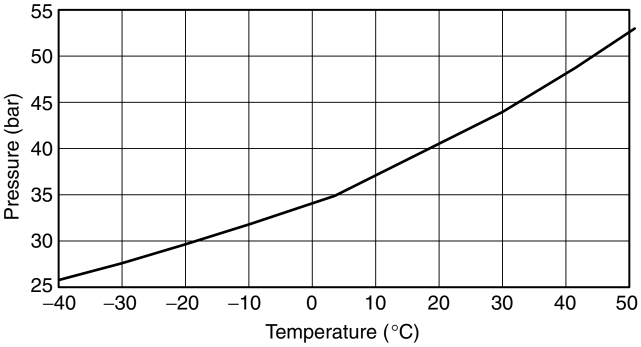


FIGURE A-2-1.4.1(o) Isometric diagram of HCFC-124 pressurized with nitrogen to 195 psig at 70°F and a loading density of 71.17 lb/ft^3.

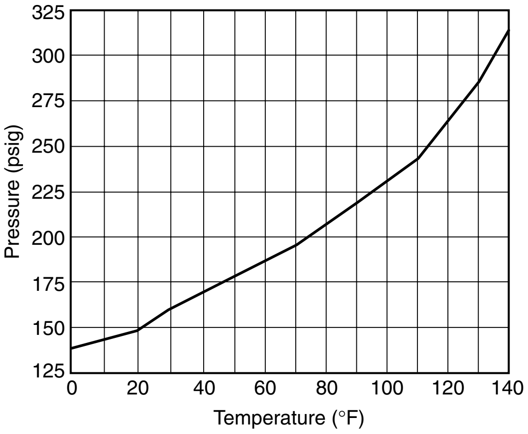


FIGURE A-2-1.4.1(p) Isometric diagram of HCFC-124 pressurized with nitrogen to 1340 kPa at 21°C and a loading density of 1140 kg/m^3.

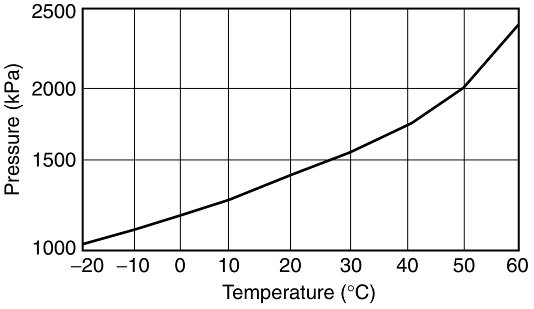


FIGURE A-2-1.4.1(q) Isometric diagram of HFC-227ea pressurized with nitrogen to 360 psig at 70°F.

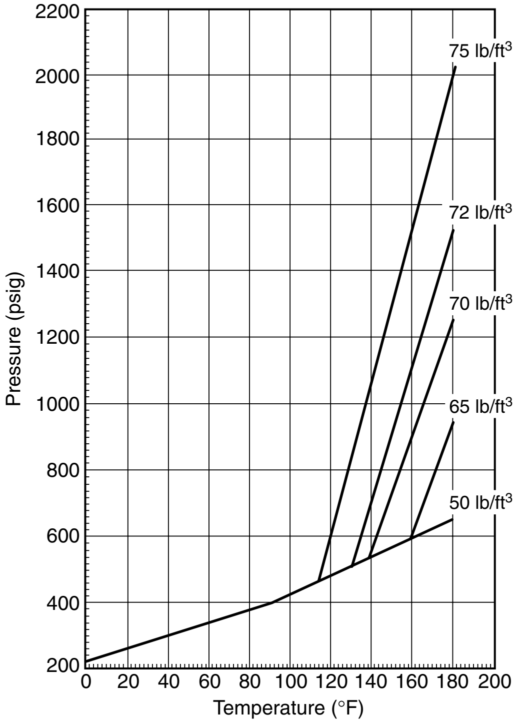


FIGURE A-2-1.4.1(r) Isometric diagram of HFC-227ea pressurized with nitrogen to 2.5 MPa at 21°C.

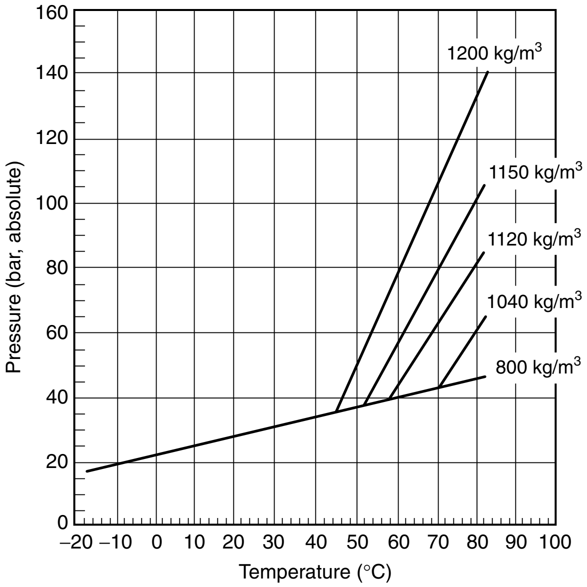


FIGURE A-2-1.4.1(s) Isometric diagram of HFC-227ea pressurized with nitrogen to 600 psig at 70°F.

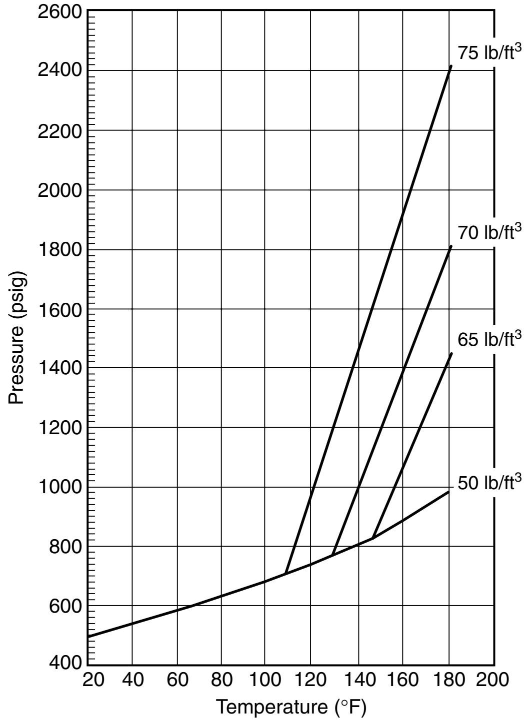


FIGURE A-2-1.4.1(t) Isometric diagram of HFC-227ea pressurized with nitrogen to 4.1 MPa at 21°C.

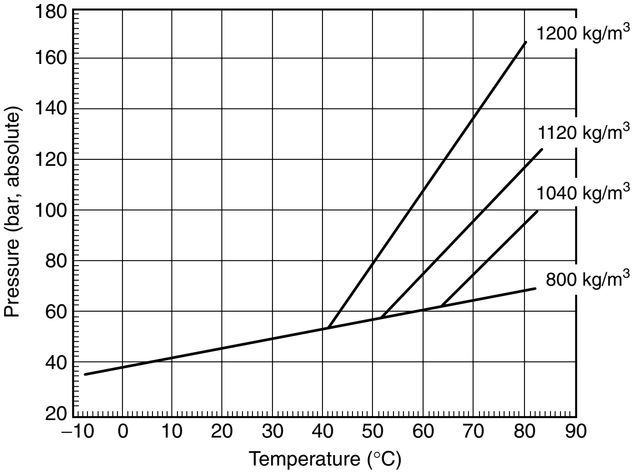


FIGURE A-2-1.4.1(u) Isometric diagram of HFC-23, English.

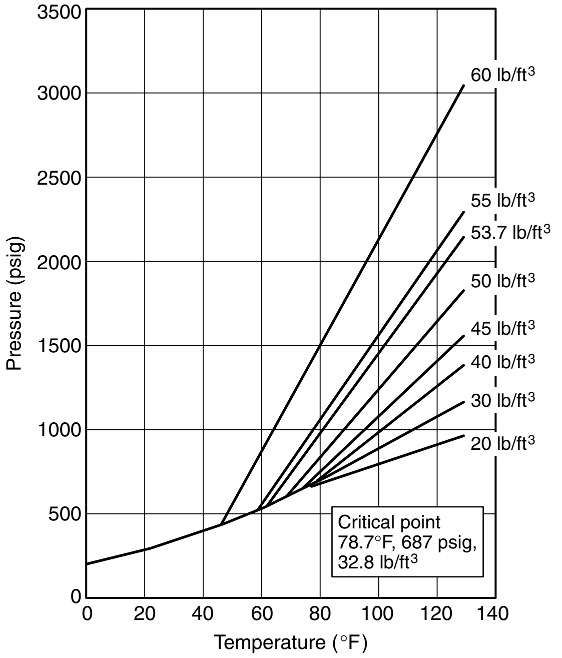


FIGURE A-2-1.4.1(v) Isometric diagram of HFC-23, SI.

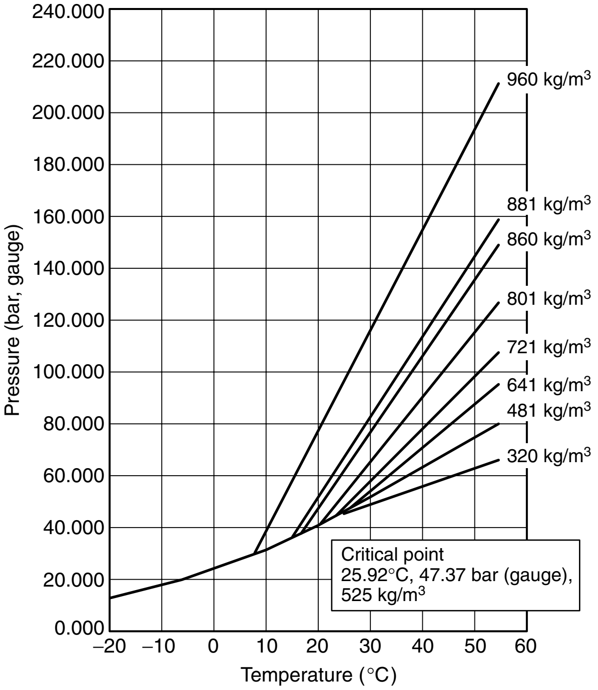
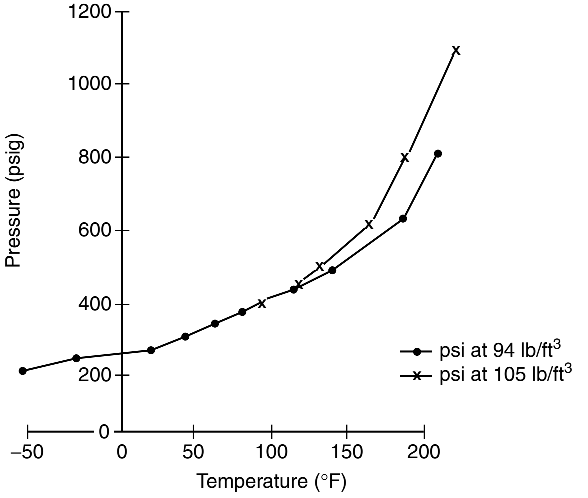
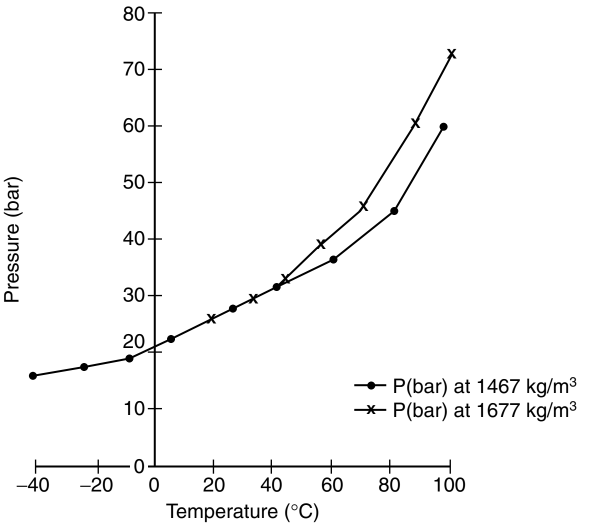


FIGURE A-2-1.4.1(w) Isometric diagram of FIC-13I1, English (°F).



Note: CF3I pressure versus temperature at 94 and 105 lb/ft^3.

FIGURE A-2-1.4.1(x) Isometric diagram of FIC-13I1, SI (°C).



Note: CF3I pressure versus temperature at 1467 and 1677 kg/m³.

FIGURE A-2-1.4.1(y) Isometric diagram of IG-01 (2370 psi at 70°F).

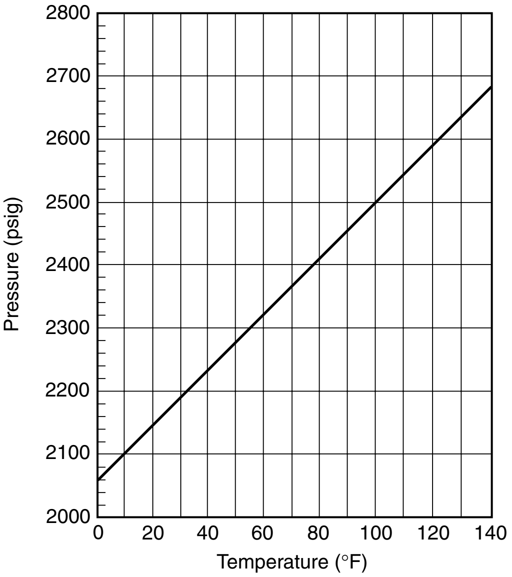


FIGURE A-2-1.4.1(z) Isometric diagram of IG-01 (160 bar at 15°C).

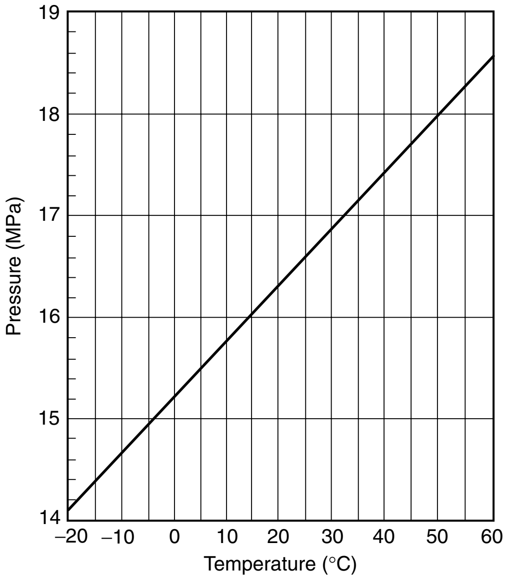


FIGURE A-2-1.4.1(aa) Isometric diagram of IG-100, English (°F).

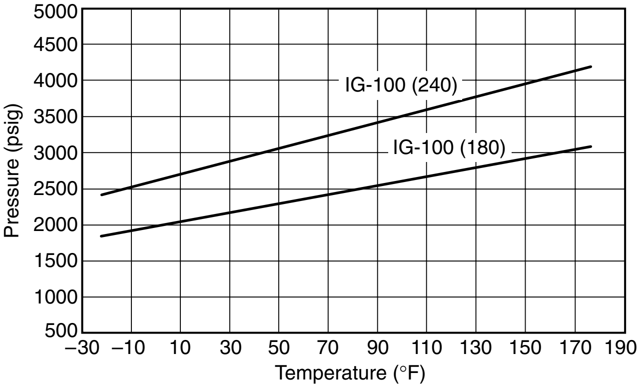


FIGURE A-2-1.4.1(bb) Isometric diagram of IG-100, SI (°C).

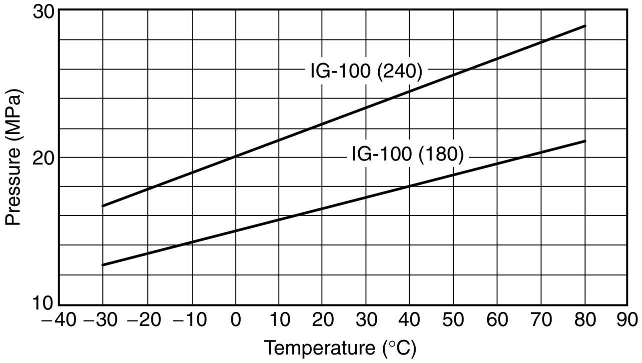


FIGURE A-2-1.4.1(cc) Isometric diagram of IG-541 (2175 psig at 70°F).

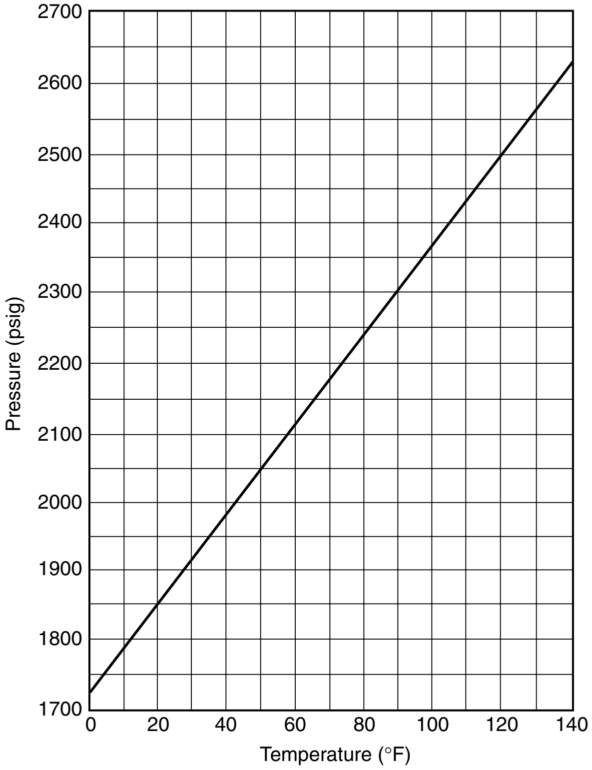


FIGURE A-2-1.4.1(dd) Isometric diagram of IG-541 (2900 psig at 59°F).

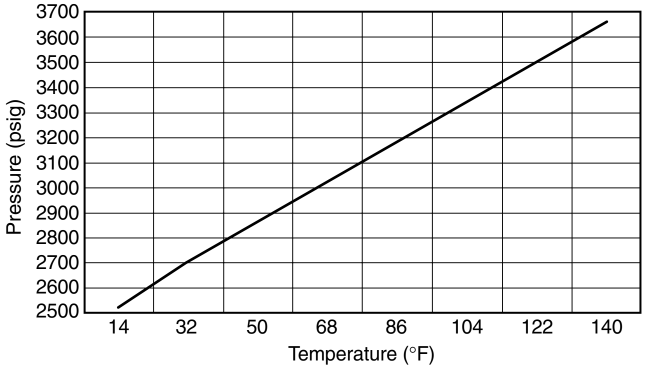


FIGURE A-2-1.4.1(ee) Isometric diagram of IG-541 (15 MPa at 21°C).

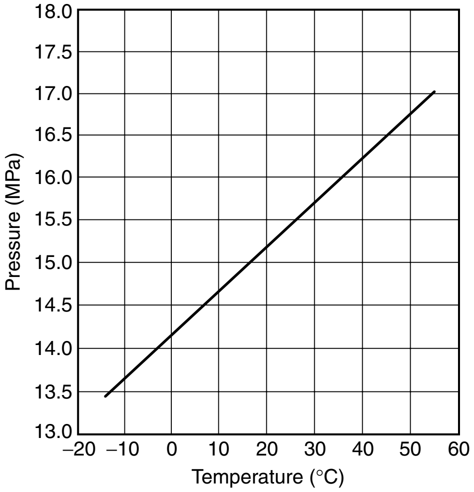


FIGURE A-2-1.4.1(ff) Isometric diagram of IG-541 (20 MPa at 15°C).

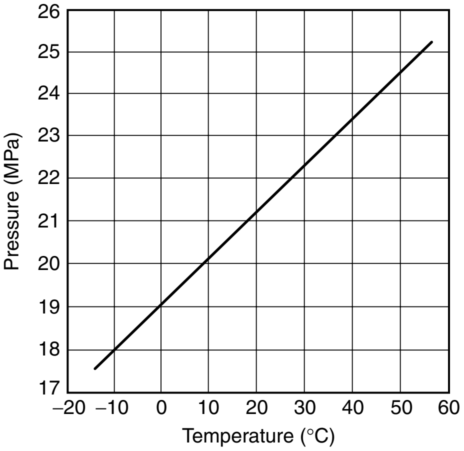


FIGURE A-2-1.4.1(gg) Isometric diagram of IG-55, English.

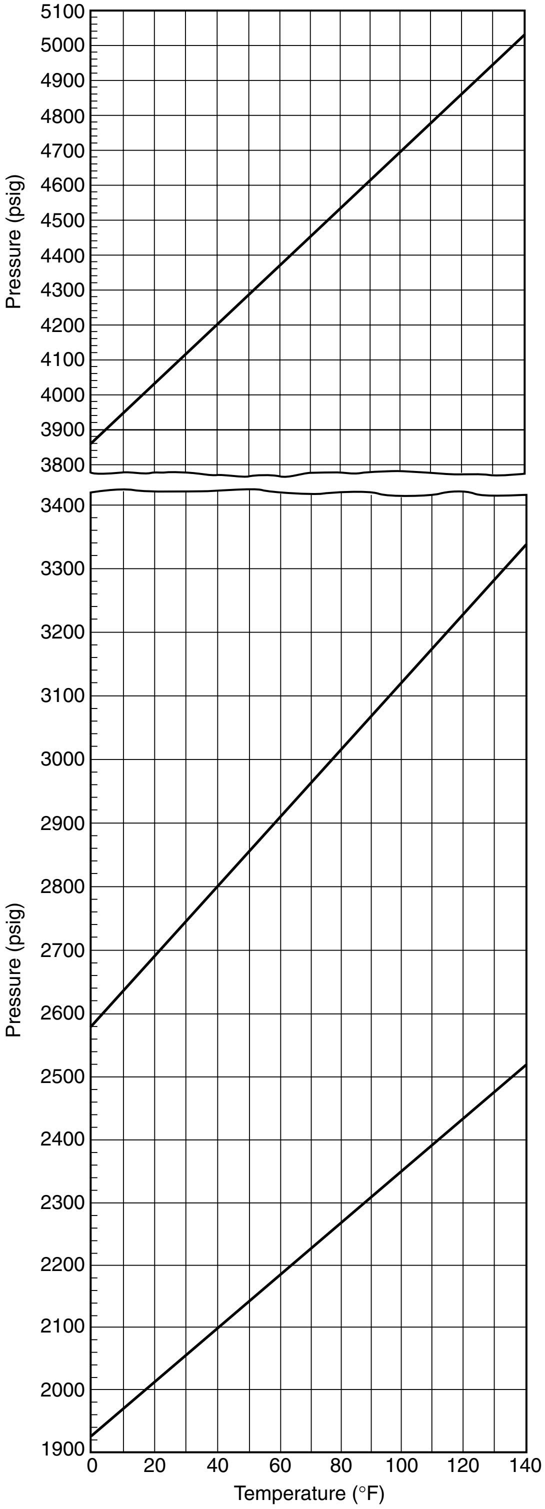


FIGURE A-2-1.4.1(hh) Isometric diagram of IG-55, SI.

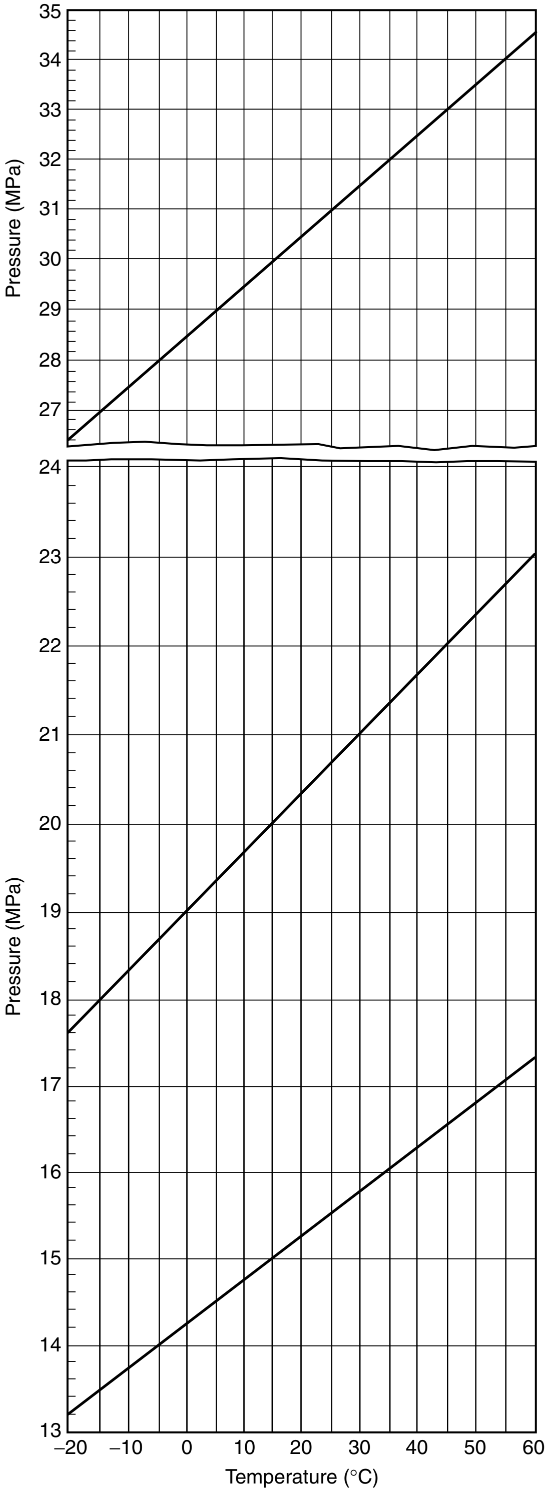


FIGURE A-2-1.4.1(ii) Isometric diagram of HFC 236fa pressurized with nitrogen to 360 psig at 72°F.

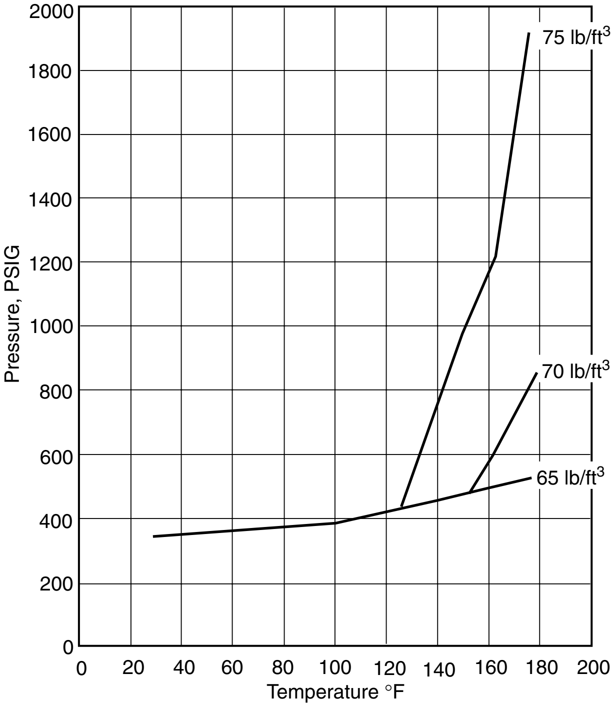


FIGURE A-2-1.4.1(jj) Isometric diagram of HFC 236fa pressurized with nitrogen to 24.82 bar, gauge at 22°C.

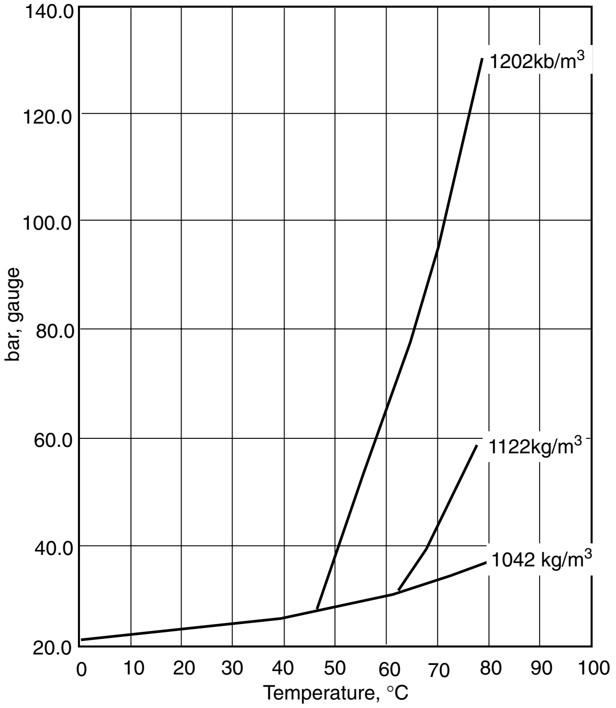


FIGURE A-2-1.4.1(kk) Isometric diagram of HFC236fa pressurized with nitrogen to 600 psig at 72°F.

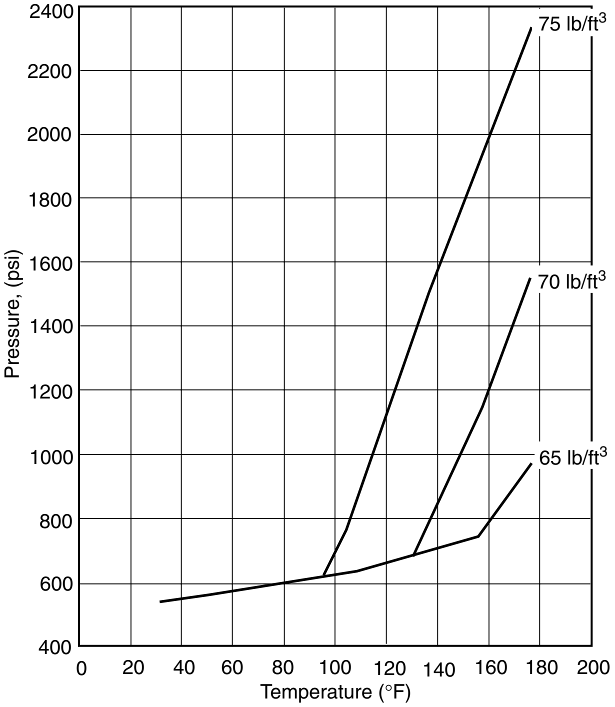
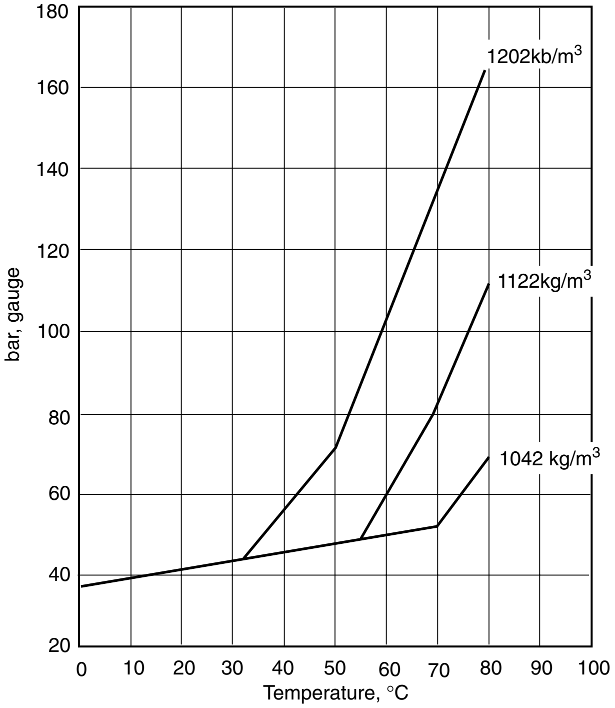


FIGURE A-2-1.4.1(ll) Isometric diagram of HFC-236fa pressurized with nitrogen to 41.4 bar, gauge at 22°C.



With the exception of inert gas–type systems, all of the other clean agents are classified as liquefied compressed gases at 70°F (21°C). For these agents, the pressure in the container is significantly affected by fill density and temperature. At elevated temperatures, the rate of increase in pressure is very sensitive to fill density. If the maximum fill density is exceeded, the pressure will increase rapidly with temperature increase so as to present a hazard to personnel and property. Therefore, it is very important that the maximum fill density limit specified for each liquefied clean agent not be exceeded. Adherence to the limits for fill density and pressurization levels specified in Table A-2-1.4.1 should prevent excessively high pressures from occurring if the agent container is exposed to elevated temperatures. Adherence to the limits will also minimize the possibility of an inadvertent discharge of agent through the pressure relief device. The manufacturer should be consulted for superpressurization levels other than those shown in Table A-2-1.4.1.

A-2-1.4.2 Although it is not a requirement of this particular paragraph, all new and existing halocarbon agent storage containers should be affixed with a label advising the user that the product in question can be returned for recovery and recycling to a qualified recycler when the halocarbon agent is no longer needed. The qualified recycler can be a halocarbon agent manufacturer, a fire equipment manufacturer, a fire equipment distributor or installer, or an independent commercial venture. It is not the intent to set down specific requirements but to indicate the factors that need to be taken into consideration with regard to recycling and reclamation of the halocarbon agent products, once facilities are available. As more information becomes available, more definitive requirements can be set forth in this section regarding quality, efficiency, recovery, and qualifications and certifications of facilities recycling halocarbon agents. At this point, no such facilities exist that would apply to the halocarbon agents covered by this document.

Inert gas agents need not be collected or recycled.

A-2-1.4.5(b) Inert gas agents are single-phase gases in storage and at all times during discharge.

A-2-2.1 Piping should be installed in accordance with good commercial practice. Care should be taken to avoid possible restrictions due to foreign matter, faulty fabrication, or improper installation.

The piping system should be securely supported with due allowance for agent thrust forces and thermal expansion and contraction and should not be subjected to mechanical, chemical, vibration, or other damage. ASME B31.1, *Power Piping Code*, should be consulted for guidance on this matter. Where explosions are likely, the piping should be attached to supports that are least likely to be displaced.

Although clean agent piping systems are not subjected to continuous pressurization, provisions should be made to ensure that the type of piping installed can withstand the maximum stress at maximum storage temperatures. Maximum allowable stress levels for this condition should be established at values of 67 percent of the minimum yield strength or 25 percent of the minimum tensile strength, whichever is less. All joint factors should be applied after this value is determined.

A-2-2.1.1 The following calculations provide minimum pipe schedules (wall thickness) for use with clean agent fire extinguishing systems in accordance with this standard. Paragraph 2-2.1.1 requires that "the thickness of the piping shall be calculated in accordance with ASME B31.1, *Power Piping Code*."

Table A-2-1.4.1 Storage Container Characteristics

	FC-3-1-10	**HCFC Blend A**	**HCFC-124**	**HFC-125**	**HFC-227ea**	**HFC-23**	**FIC-13I1**	**IG-01**	**IG-100 (240)**	**IG-100 (180)**	**IG-541**	**IG-541 (200)**	**IG-55 (222)**	**IG-55 (2962)**	**IG-55 (4443)**
Maximum fill density for conditions listed below (lb/ft^3)	80.0	56.2	71.0	58.0	72.0	54.0	104.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum container design level working pressure (psig)	500	500	240.0	320.0	500	1800	500	2120	2879	2161	2015+	2746	2057+	2743+	4114+
Total pressure level at 70°F (psig)	360	360	195.0	166.4[a]	360	608.9[a]	360	2370	3236	2404	2175	2900	2222[b]	2962[c]	4443[d]

For SI units, 1 lb/ft^3 = 16.018 kg/m^3; 1 psig = 6895 Pa; Temperature (°F) = [Temperature (°C)]$^{9}/_{5}$ + 32.

Notes:

1. The maximum fill density requirement is not applicable for IG-541. Cylinders for IG-541 are DOT 3A or 3AA, 2015+ stamped, or greater.

[a] Vapor pressure for HFC-23 and HFC-125.

[b] Cylinders for IG-55 are stamped 2060+.

[c] Cylinders for IG-55 are DOT 3A or 3AA stamped 2750+ or greater.

[d] Cylinders for IG-55 are DOT 3A or 3AA stamped 4120+ or greater.

2. Total pressure level at 70°F is calculated from filling conditions:

IG-100 (240): 3460 psig (23.9 MPa) and 95°F (35°C)
IG-100 (180): 2560 psig (17.7 MPa) and 95°F (35°C)
IG-55 (2222): 2175 psig (15 MPa) and 59°F (15°C)
IG-55 (2962): 2901 psig (20 MPa) and 59°F (15°C)
IG-55 (4443): 4352 psig (30 MPa) and 59°F (15°C)

The minimum piping requirements for clean agent systems can be determined as follows:

(a) Limitations on piping used for clean agent systems, or any pressurized fluid, are set by the following:

(1) Maximum pressure expected within the pipe
(2) Material of construction of the pipe, tensile strength, yield strength, and temperature limitations of the material
(3) End connection joining methods, for example, threaded, welded, and grooved
(4) Pipe construction method, for example, seamless, electric resistance welded (ERW), and furnace welded, etc.
(5) Pipe diameter
(6) Wall thickness of the pipe

(b) The calculations are based on the following:

(1) The calculations contained herein apply only to steel pipe conforming to ASTM A 53, *Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless*, or ASTM A 106, *Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service*.
(2) The calculations cover threaded, welded, and grooved joints for steel pipe.
(3) Other materials, such as stainless steel pipe or tubing, can be used provided that the appropriate *SE* values, wall thickness, and end connection factors are substituted.

(c) The basic equation to determine the minimum wall thickness for piping under internal pressure is as follows:

$$t = \frac{PD}{2SE} + A$$

where:

t = required wall thickness (in.)
D = outside pipe diameter (in.)
P = maximum allowable pressure (psig)
SE = maximum allowable stress, including joint efficiency (psi)
A = allowance for threading, grooving, and so forth (in.)

For these calculations, note the following:

A = depth of thread for threaded connections
A = depth of groove for cut groove connections
A = zero for welded or rolled groove connections
A = zero for joints in tubing using compression or flare fittings

The term *SE* is defined as one-quarter of the tensile strength of the piping material or two-thirds of the yield strength (whichever is lower) multiplied by a joint efficiency factor. Joint efficiency factors are 1.0 for seamless, 0.85 for ERW, 0.60 for furnace butt weld (continuous weld) (Class F).

(d) The basic equation can be rewritten to solve for *P* so as to determine the maximum allowable pressure for which a pipe having a nominal wall thickness, *t*, can be used.

$$P = 2SE\frac{t - A}{D}$$

(e) If higher storage temperatures are approved for a given system, the internal pressure should be adjusted to the maximum internal pressure at maximum temperature. In performing this calculation, all joint factors and threading, grooving, or welding allowances should be taken into account.

The requirements given in 2-2.1.1 provide guidance for determining the minimum piping design pressure for approved or listed systems having pressurization levels, fill densities, and/or temperature limitations different from those shown in Table 2-2.1.1(a) and Table 2-2.1.1(b).

The intent of 2-2.1.1 is illustrated in the following example given the following factors:

Clean agent: HFC-227ea

Fill density: 65 $\mathrm{lb/ft^3}$

Charging pressure at 70°F: 360 psig

Maximum operating temperature: 160°F

Using Figure A-2-1.4.1(q) for HFC-227ea, the pressure in the agent container at 160°F and 65 $\mathrm{lb/ft^3}$ fill density is found to be 600 psig. In this case, the governing criteria of 2-2.1.1(2) is 80 percent of the pressure in the agent container at 160°F. Therefore, the minimum design pressure for the piping is calculated as follows:

$$P_{\min} = 0.80 \times 600 \text{ psig} = 480 \text{ psig}$$

(f) Table A-2-2.1.1(f) gives values for *SE* as taken from Appendix A of the ASME B31.1, *Power Piping Code.*

Table A-2-2.1.1(f) *SE* Values from ASME B31.1, *Power Piping Code*

Type of Pipe	Standard	*SE* Value (psi)
Grade C seamless	ASTM A 106	17,500
Grade B seamless	ASTM A 53	15,000
Grade B seamless	ASTM A 106	15,000
Grade A seamless	ASTM A 53	12,000
Grade A seamless	ASTM A 106	12,000
Grade B ERW	ASTM A 53	12,800
Grade A ERW	ASTM A 53	10,200
Grade F furnace welded	ASTM A 53	6,800

For SI units, 1 psi = 6895 kPa.

(g) Paragraph 102.2.4(B) of ASME B31.1, *Power Piping Code,* allows the maximum allowable stress, *SE,* to be exceeded by 20 percent if the duration of the pressure (or temperature) increase is limited to less than 1 percent of any 24-hour period. Because the clean agent piping is normally unpressurized, the system discharge period satisfies this criteria. Therefore, the piping calculations set out in this paragraph are based on values of *SE* that are 20 percent greater than those outlined in A-2-2.1.1(f) (per Appendix A of ASME B31.1, *Power Piping Code*). The specific values for maximum allowable stress used in these calculations are as follows in Table A-2-2.1.1(g).

(h) The minimum piping requirements are as follows.

(1) *Inert agent systems.* For piping upstream and downstream of the pressure reducer, choose the proper piping where the pressure rating is equal to or greater than the minimum design pressure values specified in Table 2-2.1.1(a).

(2) *Halocarbon agent systems.* For halocarbon agent systems, choose the proper piping where the pressure rating is equal to or greater than the minimum design pressure values specified in Table 2-2.1.1(b).

For all other conditions, determine the minimum piping design pressure requirements as detailed in 2-2.1.1 and A-2-2.1.1(e).

Table A-2-2.1.1(g) *SE* Values for Maximum Allowable Stress Used in Calculations

Type of Pipe	Standard	*SE* Value (psi)
Grade C seamless	ASTM A 106	21,000
Grade B seamless	ASTM A 53	18,000
Grade B seamless	ASTM A 106	18,000
Grade A seamless	ASTM A 53	14,400
Grade A seamless	ASTM A 106	14,400
Grade B ERW	ASTM A 53	15,360
Grade A ERW	ASTM A 53	12,240
Grade F furnace welded	ASTM A 53	8,160

For SI units, 1 psi = 6895 kPa.

Notes:

1. When using rolled groove connections or welded connections with internal projections (backup rings, etc.), the hydraulic calculations should consider these factors.
2. Pipe supplied as dual stenciled A 120/A 53 Class F meets the requirements of Class F furnace-welded pipe ASTM A 53 as listed above. Ordinary cast-iron pipe, steel pipe conforming to ASTM A 120, *Specification for Welded and Seamless Steel Pipe,* or nonmetallic pipe should not be used.
3. All grooved couplings/fittings should be listed/approved for use with clean agent extinguishing systems.
4. The above calculations do not apply to extended discharge times exceeding 14.4 minutes.
5. For compression or flare-type tubing fittings, the maximum allowable working pressure specified by the fitting manufacturer should be used.

(i) Tables A-2-2.1.1(i)(1) and A-2-2.1.1(i)(2) provide data on the maximum allowable pressure for which the most common types of steel pipe can be used. The pressures have been calculated using the formula, *SE* values, and end connections shown in A-2-2.1.1(c), A-2-2.1.1.(d), and A-2-2.1.1(g).

Table A-2-2.1.1(i)(1) provides maximum allowable pressure ratings for NPS steel pipe with threaded end connections in Schedule 40, 80, 120, and 160 wall thicknesses.

Table A-2-2.1.1(i)(2) provides maximum allowable pressure ratings for NPS steel pipe with rolled groove (as applicable) or welded end connections in Schedule 40, 80, 120, and 160 wall thicknesses.

Table A-2-2.1.1(i)(1) Maximum Allowable Pressure (psig) for Steel Pipe with Threaded End Connections

				Grade:	**A-106C**	**A-53B** **A-106B**	**A-53B**	**A-53A** **A-106A**	**A-53A**	**A-53F**
				Type:	**Seamless**	**Seamless**	**ERW**	**Seamless**	**ERW**	**Furnace**
Schedule	**NPS Pipe Size**	**Wall Thickness (*t*)**	***A* Dimension**	***SE:***	**21,000**	**18,000**	**15,360**	**14,400**	**12,240**	**8,160**
40	$\frac{1}{2}$	.109	.057		2593	2222	1896	1778	1511	1008
	$\frac{3}{4}$	.113	.057		2234	1915	1634	1532	1302	868
	1	.133	.070		2026	1736	1482	1390	1181	787
	$1\frac{1}{4}$	.140	.070		1782	1528	1304	1222	1038	692
	$1\frac{1}{2}$	.145	.070		1667	1429	1220	1144	972	648
	2	.154	.070		1494	1280	1093	1025	871	581
	$2\frac{1}{2}$	.203	.100		1505	1290	1100	1032	877	584
	3	.216	.100		1392	1193	1018	954	811	541
	4	.237	.100		1278	1096	935	876	745	497
	5	.258	.100		1193	1022	872	818	693	463
	6	.280	.100		1141	978	834	782	664	443
	8	.322	.100		1081	926	790	740	630	420
80	$\frac{1}{2}$	.147	.057		4493	3851	3286	3080	2618	1746
	$\frac{3}{4}$	.154	.057		3874	3320	2833	2657	2258	1505
	1	.179	.070		3495	2996	2556	2397	2037	1358
	$1\frac{1}{4}$	.191	.070		3073	2634	2248	2107	1792	1194
	$1\frac{1}{2}$	.200	.070		2883	2472	2110	1978	1681	1121
	2	.218	.070		2625	2250	1920	1800	1530	1020
	$2\frac{1}{2}$	.276	.100		2571	2204	1882	1764	1499	1000
	3	.300	.100		2400	2057	1756	1645	1399	932
	4	.337	.100		2212	1896	1618	1517	1289	859
	5	.375	.100		2076	1780	1518	1423	1210	806
	6	.432	.100		2105	1804	1540	1442	1226	817
	8	.500	.100		1948	1669	1424	1336	1135	757
120	4	.437	.100		3145	2696	2301	2157	1833	1222
	5	.500	.100		3020	2589	2209	2071	1760	1173
	6	.562	.100		2929	2510	2142	2008	1707	1138
	8	.718	.100		3009	2579	2201	2064	1754	1169
160	$\frac{1}{2}$	.187	.057		6500	5571	4754	4457	3789	2526
	$\frac{3}{4}$	.218	.057		6440	5520	4710	4416	3754	2502
	1	.250	.070		5749	4928	4205	3942	3351	2234
	$1\frac{1}{4}$	.250	.070		4554	3904	3331	3123	2654	1770
	$1\frac{1}{2}$	.281	.070		4664	3998	3412	3198	2719	1812
	2	.343	.070		4828	4138	3531	3310	2814	1876
	$2\frac{1}{2}$	.375	.100		4017	3443	2938	2755	2342	1561
	3	.437	.100		4044	3466	2958	2773	2357	1571
	4	.531	.100		4023	3448	2942	2758	2345	1563
	5	.625	.100		3964	3397	2899	2718	2310	1540
	6	.718	.100		3918	3358	2866	2687	2284	1522
	8	.906	.100		3925	3364	2871	2691	2288	1525

Note: *A* = thread depth.

Table A-2-2.1.1(i)(2) Maximum Allowable Pressure (psig) for Steel Pipe with Rolled Groove or Welded End Connections

			Grade:	**A-106C**	**A-53B A-106B**	**A-53B**	**A-53A A-106A**	**A-53A**	**A-53F**
		Wall Thickness	**Type:**	**Seamless**	**Seamless**	**ERW**	**Seamless**	**ERW**	**Furnace**
Schedule	**NPS Pipe Size**	**(*t*)**	***SE:***	**21,000**	**18,000**	**15,360**	**14,400**	**12,240**	**8,160**
40	$^{1}/_{2}$	.109		5450	4672	3986	3737	3176	2118
	$^{3}/_{4}$	.113		4520	3875	3306	3100	2634	1757
	1	.133		4248	3641	3107	2912	2475	1650
	$1^{1}/_{4}$	.140		3542	3036	2591	2429	2064	1376
	$1^{1}/_{2}$	.145		3205	2747	2344	2197	1868	1246
	2	.154		2723	2334	1992	1867	1588	1058
	$2^{1}/_{2}$	.203		2965	2542	2168	2033	1728	1152
	3	.216		2592	2221	1896	1777	1511	1007
	4	.237		2212	1896	1618	1516	1289	859
	5	.258		1948	1669	1424	1336	1135	757
	6	.280		1775	1522	1298	1217	1034	690
	8	.322		1568	1344	1147	1075	914	609
80	$^{1}/_{2}$	.147		7350	6300	5376	5040	4284	2856
	$^{3}/_{4}$	.154		6160	5280	4506	4224	3590	2394
	1	.179		5717	4900	4182	3920	3332	2221
	$1^{1}/_{4}$	.191		4833	4142	3535	3314	2816	1878
	$1^{1}/_{2}$	.200		4421	3789	3234	3032	2576	1718
	2	.218		3855	3304	2820	2644	2248	1498
	$2^{1}/_{2}$	.276		4032	3456	2949	2765	2350	1567
	3	.300		3600	3086	2633	2469	2098	1339
	4	.337		3145	2696	2301	2157	1834	1223
	5	.375		3831	2427	2071	1941	1650	1100
	6	.432		2739	2347	2003	1878	1596	1064
	8	.500		2435	2087	1781	1670	1420	946
120	4	.437		4079	3496	2983	2797	2377	1585
	5	.500		3775	3236	2761	2589	2200	1467
	6	.562		3563	3054	2606	2443	2077	1384
	8	.718		3496	2997	2557	2397	2038	1359
160	$^{1}/_{2}$	.187		9350	8014	6839	6411	5450	3633
	$^{3}/_{4}$	.218		8720	7474	6378	5979	5083	3388
	1	.250		7985	6844	5840	5475	4654	3103
	$1^{1}/_{4}$	.250		6325	5422	4627	4337	3687	2458
	$1^{1}/_{2}$	.281		6212	5324	4543	4259	3620	2414
	2	.343		6066	5199	4437	4159	3535	2357
	$2^{1}/_{2}$	.375		5478	4696	4007	3757	3193	2129
	3	.437		5244	4495	3836	3596	3057	2038
	4	.531		4956	4248	3625	3398	2889	1926
	5	.625		4719	4045	3451	3236	2750	1834
	6	.718		4552	3902	3329	3121	2653	1769
	8	.906		4412	3782	3227	3025	2571	1714

Note: $A = 0$.

A-2-2.3.1 Fittings that are acceptable for use in clean agent systems can be found in Table A-2-2.3.1.

Table A-2-2.3.1 Piping System Fittings

	Initial Charging Pressure (up to and Including)			
Clean Agent	**psig**	**kPa**	**Acceptable Fittings**	**Maximum Pipe Size**
All halocarbon agents	360	2,482	Class 300 malleable or ductile iron fittings	3 in. NPS
			1,000-lb rated ductile iron or forged steel fittings	>3 in. NPS
			Class 300 flanged joints	All
	600	4,137	Class 300 malleable or ductile iron fittings	3 in. NPS
			1000-lb rated ductile iron or forged steel fittings	>3 in. NPS
			Class 600 flanged joints	All
HFC-23	609	4,199	Class 300 malleable or ductile iron fittings	2 in. NPS
			1000-lb rated ductile iron or forged steel fittings	>3 in. NPS
			Class 300 flanged joints	All — downstream of any stop valve or in systems with no stop valve
			Class 600 flanged joints	All — upstream of any stop valve
IG-541	2,175	14,997		
	Upstream of the pressure reducer		2,000-lb forged steel	All
	Downstream of the pressure reducer		Class 300 malleable iron or ductile iron	3 in. NPS
			1,000-lb rated ductile iron or forged steel	>3 in. NPS
			Class 600 flanged joints	All
	2,900	19,996	3,000-lb forged steel	All
	Upstream of the pressure reducer		Class 300 malleable iron or ductile iron	3 in. NPS
	Downstream of the pressure reducer		1,000-lb rated ductile iron or forged steel	>3 in. NPS
			Class 600 flanged joints	All
IG-01	2,370	16,341		
	Upstream of the pressure reducer		3000-lb forged steel	All
	Downstream of the pressure reducer		Class 300 malleable iron or ductile iron	3 in. NPS
			1000-lb rated ductile iron or forged steel	>3 in. NPS
			Class 600 flanged joints	All
IG-100	3,236	22,311	3,000-lb forged steel	1 in. NPS
	Upstream of the pressure reducer		6,000-lb forged steel	>1 in. NPS
	Downstream of the pressure reducer		Class 300 malleable iron or ductile iron	>3 in. NPS

(Sheet 1 of 2)

Table A-2-2.3.1 Piping System Fittings *(Continued)*

	Initial Charging Pressure (up to and Including)			
Clean Agent	**psig**	**kPa**	**Acceptable Fittings**	**Maximum Pipe Size**
			1,000-lb rated ductile iron or forged steel	>3 in. NPS
			Class 600 flanged joints	All
IG-100	2,410	16,580	3,000-lb forged steel	All
	Upstream of the pressure reducer		Class 300 malleable iron or ductile iron	3 in. NPS
	Downstream of the pressure reducer		1,000-lb rated ductile iron or forged steel	>3 in. NPS
			Class 600 flanged joints	All
IG-55	2,222	15,521	3,000-lb forged steel	All
	Upstream of the pressure reducer		Class 300 malleable iron or ductile iron	3 in. NPS
	Downstream of the pressure reducer		1,000-lb rated ductile iron or forged steel	>3 in. NPS
			Class 600 flanged joints	All
	2,962	20,424		
	Upstream of the pressure reducer		3,000-lb forged steel	All
	Downstream of the pressure reducer		Class 300 malleable iron or ductile iron	3 in. NPS
			1,000-lb rated ductile iron or forged steel	>3 in. NPS
			Class 600 flanged joints	All
	4,443	30,636		
	Upstream of the pressure reducer		3,000-lb forged steel	1 in. NPS
			6,000-lb forged steel	>1 in. NPS
	Downstream of the pressure reducer		Class 300 malleable iron or ductile iron	3 in. NPS
			1,000-lb rated ductile iron or forged steel	>3 in. NPS
			Class 600 flanged joints	All

(Sheet 2 of 2)

Note: The materials itemized above do not preclude the use of other materials and type and/or style of fittings that satisfy the requirements of 2-2.3.1.

Pressure-temperature ratings have been established for certain types of fittings. A list of ANSI standards covering the different types of fittings is given in Table 126.1 of ASME B31.1, *Power Piping Code*. Where fittings not covered by one of these standards are used, the design recommendations of the manufacturer of the fittings should not be exceeded.

A-2-2.4.2 Some of the new clean agents might not be compatible with the elastomers used in Halon 1301 system valves. Before charging a system container with some of the clean agents, it could be necessary to disassemble the discharge valve and completely replace the o-rings and other sealing surfaces with components that will not react to that agent. Make certain that this evaluation has been completed. Also make certain that the change results in the valve, container, and system complying with the appropriate listings or approvals.

A-2-3.2.1 The detection system selection process should evaluate the ambient environmental condition in determining the appropriate device and sensitivity in order to prevent unwanted discharges while still providing the necessary earliest actuation. In high airflow environments, air-sampling detection devices should be considered.

Detectors installed at the maximum spacing as listed or approved for fire alarm use can result in excessive delay in agent release, especially where more than one detection device is required to be in alarm before automatic actuation results.

Where there is a risk of forming flammable atmosphere, the spacing and siting of flammable vapor detectors requires careful consideration to avoid excessive delay in agent release.

A-2-3.5.3 A telephone should be located near the abort switch.

A-2-3.5.6.1 Hazards associated with fast growth fires would include, but not be limited to, flammable liquid storage or transfer and aerosol filling areas.

A-2-3.6 Accidental discharge can be a significant factor in unwanted clean agent emissions. Equipment lockout or service disconnects can be instrumental in preventing false discharges when the clean agent system is being tested or serviced. In addition, servicing of air-conditioning systems with the release of refrigerant aerosols, soldering, or turning electric plenum heaters on for the first time after a long period of idleness could trip the clean agent system. Where used, an equipment service disconnect switch should be of the keyed-access type if external of the control panel or can be of the toggle type if within the locked control panel. Either type should annunciate at the panel when in the out-of-service mode. Written procedures should be established for taking the clean agent system out of service.

A-3-2 The two types of system flow calculations are liquefied compressed gas flow calculations and inert gas flow calculations.

Liquefied compressed gas flow calculations. Analyzing the behavior of two-phase agents in pipelines is a complex subject with numerous solutions. Two calculation methods are commonly used by fire protection professionals. The first is based on enhancements to the work of Hesson (Hesson, 1953) in 1953 and the other is based on modifications to the HFLOW method (DiNenno et al., 1995) completed in 1994. Only those calculation methods that have been listed or approved should be used for design purposes.

The modified HFLOW calculation method is based on major modifications of a calculation method called HFLOW developed by the Jet Propulsion Laboratory by Eliot et al., 1984. The revised method is capable of predicting the two-phase flow characteristics of clean agents based on their thermodynamics properties. This method can calculate the flow characteristics of fire suppression agents across the wide range of real engineering systems in reasonable time scales.

The following basic assumptions are made to simplify the methodology:

(a) The conditions in the cylinder (pressure, temperature, and composition) are solely functions of the initial conditions and the outage fraction (fraction of the initial charge mass having left the cylinder). This assumption effectively ignores the impact of the increased kinetic energy of the fluid leaving the cylinder on the cylinder energy balance.

(b) Quasi-steady flow exists. The average flow rate over a small time interval step is equal to the flow rate that would exist if the cylinder conditions were held steady during that time step.

(c) The heat transferred from the pipe walls to the flowing fluid is often assumed to be insignificant.

(d) The flow through the pipe network is homogeneous. Liquid and vapor flow through the piping is at the same velocity evenly dispersed.

Calculation cannot be done without adequate manufacturer's hardware data. This data includes dip tube and manifold equivalent lengths and nozzle discharge coefficients.

Required input data include cylinder volume, valve, dip tube equivalent lengths, agent mass and temperature, pipe length and diameter, elevation, fittings, nozzle area, and discharge coefficient. Output data for each node (pipe, cylinder, or nozzle) include pressure, temperature, component fraction, phase distribution, mass flow rate, and velocity.

Due to its complexity, this method does not lend itself to hand calculation.

The modified Hesson calculation methodology is a two-phase flow method first developed by Hesson for calculating pressure drop along a pipeline flowing carbon dioxide. Hesson adapted Bernoulli's equation for ease of use with compressible, two-phase flow. It was refined by H. V. Williamson and then Tom Wysocki (Wysocki, 1996) for use with Halon 1301 and other clean agents.

The two-phase flow method models the following three basic flow conditions for a liquefied compressed gas discharge from a storage container:

(1) The initial transient discharge during which agent flows from the container and cools the pipe.

(2) A quasi-steady state flow during which the agent is assumed to maintain a constant enthalpy (adiabatic) condition with constant mass flow rate.

(3) The final transient discharge during which the two-phase liquid and vapor flow is replaced by an essentially vapor discharge as the storage container empties.

The pressure drop during the quasi-steady state flow is based on the work of Hesson. The transient conditions are modeled using standard thermodynamics. During testing of the two-phase methodology with Halon 1301, mechanical separation of the liquid and vapor phases due to centripetal forces was observed. This effect has been noted for every liquefied compressed gas tested to date. The effect is not predicted by thermodynamics but was inferred from test data and confirmed using ultra-high speed photography (HT Research Institute, 1973). To accurately predict the quantity of agent discharge from each nozzle in a system, empirical corrections based on the degree of flow split, orientation of the tee junction, component fraction, and phase distribution are developed for the specific liquefied compressed gas.

The pressure drop calculation for the quasi-steady state flow using Hesson's adaption of Bernoulli's equation can be done by hand. The calculation of transient conditions and the calculation of mechanical separation effects at tees and their effect on pressure drop and quantity of agent discharged from each nozzle in an unbalanced system requires many complex iterations. Manual calculation of these effects is not practical. Therefore a listed and approved computer program must be used for a complete calculation.

Required input data includes cylinder volume, agent mass and temperature, valve and dip tube equivalent lengths, pipe lengths, elevation changes, fittings, and predischarge pipe temperature. Most programs permit the user to specify either the required flow rate or agent quantity for each nozzle or the "as-built" system condition. If flow rate or agent quantity is specified, the program will calculate the required pipe and nozzle diameters. If an "as-built" condition including pipe and nozzle diameters is specified, the program calculates system flow rates. In either case, pressure drop, discharge time, and quantity discharged from each nozzle is reported.

Inert gas flow calculations. Inert gases present a problem in single-phase compressible flow. Many fluid dynamics handbooks provide formulas for compressible gas flow that can be suitable for relatively simple pipe networks with short lengths of pipe. These formulas are inadequate to calculate systems using longer pipe lengths with complex configurations. Wysocki and Christensen (Wysocki et al., 1996) used the work of Hesson and adapted it for use with single-phase compressible gases.

Inert gas discharge from a cylinder into a pipe and nozzle network involves the following three stages:

(a) The initial transient phase as the gas flows into the pipe and fills the pipe up to the nozzles. There is a marked variation between the time at which various nozzles in an unbalanced pipe network begin discharging agent.

(b) Full flow during which all nozzles discharge agent. This is a dynamic condition during which the flow rates, agent temperatures, and pressure conditions constantly change.

(c) Final transient condition during which the storage container and pipeline empties. Complex changes in flow rates at the individual nozzles take place.

Flow in these systems is neither adiabatic nor isothermal (the two classical limits). The complexity of the calculation for large, unbalanced pipe networks requires use of a listed or approved computer program.

Regardless of the method used for flow calculations, certain limits are established during the listing and approval process for the flow calculation. Typical limits include the following:

(1) Limit arc degree of split at tees
(2) Limits on the orientation of tees
(3) Limits on agent arrival time
(4) Limits on agent "run out" or "end of liquid" time differences between nozzles
(5) Minimum pressure limits
(6) Minimum flow density
(7) Maximum and minimum storage container fill density
(8) Additional limits specific to the flow calculation program

The results of the calculation must be checked to verify that limits have not been exceeded. Computerized calculations generally report warning or error messages if the system falls outside program limits.

A-3-2.1 A listed or approved calculation method should predict agent mass discharged per nozzle, average nozzle pressure, and system discharge time within the following limits of accuracy.

(a) The mass of agent predicted to discharge from a nozzle by the flow calculation method should agree with mass of agent measured from the nozzle by −10 percent to +10 percent of the predicted value. A standard deviation of the percentage differences between measured and predicted nozzle agent quantities, relative to zero, should not be greater than 5 percent.

(b) The system discharge time predicted by the flow calculation method should agree with the actual system discharge time value or by ±1 second, for halocarbon systems or ±10 seconds for inert gas systems whichever is greater.

(c) The average nozzle pressures predicted by the flow calculation method should agree with the actual nozzle pressures by −10 percent to +10 percent of the predicted value.

(d) The nozzle pressure should not fall below the minimum or above the maximum nozzle pressure required for the nozzle to uniformly distribute the agent throughout the volume which that nozzle's discharge is to protect.

A-3-3.5 Examples of ventilation systems necessary to ensure safety include cooling of vital equipment required for process safety and ventilation systems required for containment of hazardous materials.

A-3-3.6 Enclosure pressures developed during the discharge of a clean agent system are dependent on many variables including factors unique to each agent, system, and enclosure. Over- or underpressurization of the enclosure can occur during the discharge.

A-3-4.2 Cup burner testing in the past has involved a variety of techniques, apparatus, and investigators. A standard cup burner test procedure with defined apparatus has now been established and is outlined in Appendix B.

Table A-3-4.2 presents cup burner flame extinguishing concentrations for n-Heptane.

Table A-3-4.2 n-Heptane Cup Burner Extinguishment Concentrations

Agent	Cup Burner Value
FC-218	6.5
FC-3-1-10	5.5
FIC-13I1*	3.2
HCFC Blend A	9.9
HCFC-124	6.6
HFC-125	8.7
HFC-227ea	6.5
HFC-23	12.9
HFC-236fa	6.3
IG-01	42
IG-100*	31
IG-541	31
IG-55	35

*Not derived from standardized cup burner method.

A-3-4.2.2 The following details the fire extinguishment/area coverage fire test procedure for engineered and pre-engineered clean agent extinguishing system units.

(a) The general requirements are as follows.

(1) An engineered or pre-engineered extinguishing system should mix and distribute its extinguishing agent and should totally flood an enclosure when tested in accordance with the recommendations of A-3-4.2.2(a)(3) through A-3-4.2.2(f)(6) under the maximum design limitations and most severe installation instructions. See also A-3-4.2.2(a)(2).

(2) When tested as described in A-3-4.2.2(b)(1) through A-3-4.2.2(e)(2), an extinguishing system unit should extinguish all fires within 30 seconds after the end of system discharge. When tested as described in A-3-4.2.2(b)(1) through A-3-4.2.2(c)(3) and A-3-4.2.2(f)(1) through A-3-4.2.2(f)(6), an extinguishing system should prevent reignition of the wood crib after a 10-minute soak period.

(3) The tests described in A-3-4.2.2(b)(1) through A-3-4.2.2(f)(6). Consider the intended use and limitations of the extinguishing system, with specific reference to the following:

a. The area coverage for each type of nozzle
b. The operating temperature range of the system
c. Location of the nozzles in the protected area
d. Either maximum length and size of piping and number of fittings to each nozzle, or minimum nozzle pressure
e. Maximum discharge time
f. Maximum fill density

(b) The test enclosure construction is as follows.

(1) The enclosure for the test should be constructed of either indoor or outdoor grade minimum $^3/_8$-in. (9.5-mm) thick plywood or equivalent material.

(2) An enclosure(s) is to be constructed having the maximum area coverage for the extinguishing system unit or nozzle being tested and the minimum and maximum protected area height limitations.

The test enclosure(s) for the maximum height, flammable liquid, and wood crib fire extinguishment tests need not have the maximum coverage area but should be at least 13.1 ft (4.0 m) wide by 13.1 ft (4.0 m) long and 3351 ft^3 (100 m^3) in volume.

(c) The extinguishing system is as follows.

(1) A pre-engineered-type extinguishing system unit is to be assembled using its maximum piping limitations with respect to number of fittings and length of pipe to the discharge nozzles and nozzle configuration(s) as specified in the manufacturer's design and installation instructions.

(2) An engineered-type extinguishing system unit is to be assembled using a piping arrangement that results in the minimum nozzle design pressure at 70°F (21°C).

(3) Except for the flammable liquid fire test using the $2^1/_2$-ft^2 (0.23-m^2) square pan and the wood crib extinguishment test, the cylinders are to be conditioned to the minimum operating temperature specified in the manufacturer's installation instructions.

(d) The extinguishing concentration is as follows. The extinguishing agent concentration for each test is to be 83.34 percent of the intended end use design concentration specified in the manufacturer's design and installation instructions at the ambient temperature of approximately 70°F (21°C) within the enclosure. The concentration for inert gas clean agents can be adjusted to take into consideration actual leakage measured from the test enclosure. The concentration within the enclosure for halocarbon clean agents should be calculated using the following formula unless it is demonstrated that the test enclosure exhibits significant leakage. If significant test enclosure leakage does exist, the formula used to determine the test enclosure concentration of halocarbon clean agents can be modified to account for the leakage measured.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

where:

W = weight of clean agents (lb)
V = volume of test enclosure (ft^3)
s = specific volume of clean agent at test temperature (ft^3/lb)
C = concentration (percent)

(e) The flammable liquid entinguishment tests are as follows.

(1) Steel test cans having a nominal thickness of 0.216 in. (5.5 mm), for example, Schedule 40 pipe, and 3.0 in. to 3.5 in. (76.2 mm to 88.9 mm) in diameter and at least 4 in. (102 mm) high, containing either heptane or heptane and water, are to be placed within 2 in. (50.8 mm) of the corners of the test enclosure(s) and directly behind the baffle, and located vertically within 12 in. (305 mm) of the top or bottom of the enclosure, or both top and bottom if the enclosure permits such placement. If the cans contain heptane and water, the heptane is to be at least 2 in. (50.8 mm) deep. The level of heptane in the cans should be at least 2 in. (50.8 mm) below the top of the can. For the minimum room height area coverage test, closeable openings are provided directly above the cans to allow for venting prior to system installation. In addition, for the minimum height limitation area coverage test, a baffle is to be installed between the floor and ceiling in the center of the enclosure. The baffle is to be perpendicular to the direction of nozzle discharge, and to be 20 percent of the length or width of the enclosure, whichever is applicable with respect to nozzle location. For the maximum room height extinguishment test, an additional test is to be conducted using a $2^1/_2$-ft^2 (0.23-m^2) square pan located in the center of the room and the storage cylinder conditioned to 70°F (21°C). The test pan is to contain at least 2 in. (50.8 mm) of heptane with the heptane level at least 2 in. (50.8 mm) below the top of the pan. For all tests the heptane is to be ignited and allowed to burn for 30 seconds, upon which time all openings are to be closed and the extinguishing system is to be manually actuated. At the time of actuation, the percent of oxygen within the enclosure should be at least 20.0 percent.

(2) The heptane is to be commercial grade having the following characteristics:

Distillation	
Initial boiling point	90°C (194°F)
50 percent	93°C (199°F)
Dry point	96.5°C (208°F)
Specific gravity (60°F/60°F)	0.719 (15.6°C/15.6°C)
Reid vapor pressure	2.0 psi
Research octane rating	60
Motor octane rating	50

(f) The wood crib extinguishment tests are as follows.

(1) The storage cylinder is to be conditioned to 70°F (21°C). The test enclosure is to have the maximum ceiling height as specified in the manufacturer's installation instructions.

(2) The wood crib is to consist of four layers of six, trade size 2 by 2 ($1^1/_2$ by $1^1/_2$ in.) by 18 in. long, kiln spruce or fir lumber having a moisture content between 9 and 13 percent. The alternate layers of the wood members are to be placed at right angles to one another. The individual wood members in each layer are to be evenly spaced, forming a square determined by the specified length of the wood members. The wood members forming the outside edges of the crib are to be stapled or nailed together.

(3) Ignition of the crib is to be achieved by the burning of commercial grade heptane in a square steel pan $2^{1}/_{2}$ ft^{2} (0.23 m^{2}) in area and not less than 4 in. (101.6 mm) in height. The crib is to be centered with the bottom of the crib 12 to 24 in. (304 to 609.6 mm) above the top of the pan and the test stand constructed so as to allow for the bottom of the crib to be exposed to the atmosphere.

(4) The heptane is to be ignited and the crib is to be allowed to burn freely for approximately 6 minutes outside the test enclosure. The heptane fire is to burn for 3 to $3^{1}/_{2}$-minutes. Approximately $^{1}/_{4}$ gal (0.95 L) of heptane will provide a 3- to $3^{1}/_{2}$-minute burn time. Just prior to the end of the preburn period, the crib is to be moved into the test enclosure and placed on a stand such that the bottom of the crib is between 20 and 28 in. (508 and 711 mm) above the floor. The closure is then to be sealed.

(5) After the crib is allowed to burn for a period of 6 minutes, the system is to be actuated. At the time of actuation, the percent of oxygen within the enclosure at the level of the crib should be at least 20.0 percent.

(6) After the end of system discharge, the enclosure is to remain sealed for a total of 10 minutes. After the 10-minute soak period, the crib is to be removed from the enclosure and observed to determine whether sufficient fuel remains to sustain combustion and to detect signs of reignition.

The following is a schematic of the process to determine the design quantity.

(1) Determine hazard features:
   a. Fuel type: Extinguishing concentration (EC) per 3-4.2 or inerting concentration (IC) per 3-4.3
   b. Enclosure volume
   c. Enclosure temperature
   d. Enclosure barometric pressure

(2) Determine the agent minimum design concentration (MDC) by multiplying EC or IC by the safety factor (SF), therefore:

$$\text{MDC} = (\text{EC or IC})\ \text{SF}$$

(3) Determine the agent minimum design quantity (MDQ) by referring to 3-5.1 for halocarbons or 3-5.2 for inert gases

(4) Determine whether designs factors (DF) apply. See 3-5.3 to determine individual DF(i)s and then determine sum. Therefore:

$$\text{DF} = \Sigma\ \text{DF(i)s}$$

(5) Determine the agent adjusted minimum design quantity (AMDQ) as follows:

$$\text{AMDQ} = \text{MDQ}\ (1 + \text{DF})$$

(6) Determine the pressure correction factor (PCF) per 3-5.3.3

(7) Determine the final design quantity (FDQ) as follows:

$$\text{FDQ} = \text{AMDQ} \times \text{PCF}$$

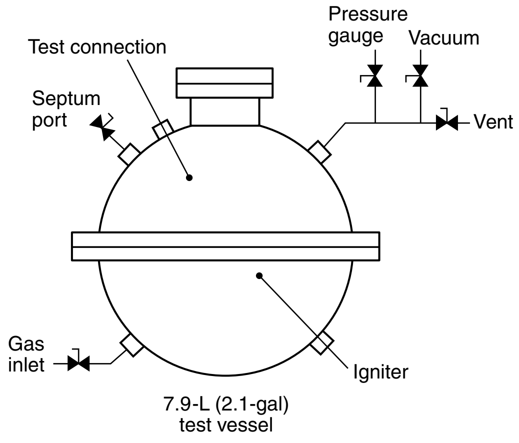
A-3-4.2.4 Deep-seated fires involving Class A fuels can require substantially higher design concentrations and extended holding times than the design concentrations and holding times required for surface-type fires involving Class A fuels. Hazards containing both Class A and Class B fuels should be evaluated on the basis of the fuel requiring the highest design concentration.

A-3-4.3 This appendix section provides a summary of a method of evaluating inerting concentration of a fire extinguishing vapor.

One characteristic of halons and replacement agents is frequently referred to as the inerting, or inhibiting, concentration. Related to this, flammability diagram data (Dalzell, 1975 and Coll, 1976) on ternary systems was published in NFPA 12A, *Standard on Halon 1301 Fire Extinguishing Systems.* The procedures used previously have been used more recently to evaluate inerting concentrations of halons and replacement chemicals against various fuel–air systems. Differences between the earlier studies and the recent work are that the test vessel volume used was 7.9 L (2.1 gal) versus 5.6 L (1.5 gal) previously. The igniter type was the same, that is, carbon rod corona discharge spark, but the capacitor-stored energy levels were higher, approximately 68 J (16.2 cal) versus 6 or 11 J (1.4 or 2.6 cal) on the earlier work. The basic procedure, employing a gap spark, has been adopted to develop additional data.

Ternary fuel–air agent mixtures were prepared at a test pressure of 1 atm and at room temperature in a 7.9-L (2.1-gal) spherical test vessel *(see Figure A-3-4.3)* by the partial pressure method. The vessel was fitted with inlet and vent ports, a thermocouple, and a pressure transducer. The test vessel was first evacuated. Agent was then admitted, and if a liquid, sufficient time was allowed for evaporation to occur. Fuel vapor and finally air were admitted, raising the vessel pressure to 1 atm. An internal flapper allowed the mixtures to be agitated by rocking the vessel back and forth. The pressure transducer was connected to a suitable recording device to measure pressure rise that could occur on actuation of the igniter.

FIGURE A-3-4.3 Spherical test vessel.



The igniter employed consisted of a bundle of 4 graphite rods ("H" pencil leads) held together by 2 wire or metal brand wraps on either end of the bundle leaving a gap between the wraps of about 3 mm (0.12 in.). The igniter was wired in series with two 525 mF 450-V capacitors. The capacitors were charged to a potential of 720 to 730 VDC. The stored energy was, therefore, 68 to 70 J (16.2 to 16.7 cal). The nominal resistance of the rod assembly was about 1 ohm. On switch closure the capacitor discharge current resulted in ionization at the graphite rod surface. A corona spark jumped across the connector gap. The spark energy content was taken as the stored capacitor energy though, in principle, it must be somewhat less than this amount due to line resistance losses.

The pressure rise, if any, resulting from ignition of the test mixture was recorded. The interior of the test vessel was wiped clean with a cloth damp with either water or a solvent between tests to avoid buildup of decomposition residues that could influence the results.

The definition of the flammable boundary was taken as that composition that just produces a pressure rise of 0.07 times the initial pressure, or 1 psi (6.9 kPa) when the initial pressure is 1 atm. Tests were conducted at fixed fuel–air ratios and varying amounts of agent vapor until conditions were found to give rise to pressure increases that bracket 0.07 times the initial pressure. Tests were conducted at several fuel–air ratios to establish that condition requiring the highest agent vapor concentration to inert.

Data obtained on several chemicals that can serve as fire protection agents are given in Table A-3-4.3.

A-3-4.3.2 These conditions are when both the following occurs:

(a) The types and quantity of fuel permitted in the enclosure has the potential to lead to development of a fuel vapor concentration equal to or greater than one-half of the lower flammable limit throughout the enclosure.

(b) The system response is not rapid enough to detect and extinguish the fire before the volatility of the fuel is increased to a dangerous level as a result of the fire.

A-3-5.1 The amount of clean agent required to develop a given concentration will be greater than the final amount of agent in the same enclosure. In most cases, the clean agent must be applied in a manner that promotes progressive mixing of the atmosphere. As the clean agent is injected, the displaced atmosphere is exhausted freely from the enclosure through small openings or through special vents. Some clean agent is therefore lost with the vented atmosphere, and the higher the concentration, the greater the loss of clean agent.

For the purposes of this standard, it is assumed that the clean agent/air mixture lost in this manner contains the final design concentration of the clean agent. This represents the worst case from a theoretical standpoint and provides a built-in safety factor to compensate for non-ideal discharge arrangements.

Tables A-3-5.1(a) through A-3-5.1(r) provide the amount of clean agent needed to achieve design concentration.

Table A-3-4.3 Inerting Concentrations for Various Agents

Fuel	Agent	Volume Percent Inerting Concentration	Reference
i-Butane	HFC-227ea	11.3	Robin
	HCFC Blend A	18.4	Moore
	IG-100	40	Zabetakis
1-Chloro-1,1-difluoroethane (HCFC-142b)	HFC-227ea	2.6	Robin
1,1-Difluoroethane (HFC-152a)	HFC-227ea	8.6	Robin
	HCFC Blend A	13.6	Moore
Difluoromethane (HFC-32)	HFC-227ea	3.5	Robin
	HCFC Blend A	8.6	Moore
Ethane	IG-100	44	Zabetakis
Ethylene oxide	HFC-227ea	13.6	Robin
Hexane	IG-100	42	Zabetakis
Methane	FC-218	8.9	Skaggs
	HFC-125	14.7	Senecal
	HFC-227ea	8.0	Robin
	HFC-23	20.2	Senecal
	HCFC Blend A	18.3	Moore
	IG-100	37	Zabetakis
	IG-541	43.0	Tamanini
Pentane	HFC-227ea	11.6	Robin
	IG-100	42	Zabetakis
Propane	FC-218	11.2	Skaggs
	FC-3-1-10	10.3	Senecal
	FC-3-1-10	9.9	Skaggs
	FC-5-1-14	7.3	Senecal
	FIC-13I1	6.5	Moore
	HFC-125	15.7	Senecal
	HFC-227ea	11.6	Robin
	HFC-23	20.2	Senecal
	HFC-23	20.4	Skaggs
	HCFC Blend A	18.6	Moore
	IG-541	49.0	Tamanini
	IG-100	42	Zabetakis

Table A-3-5.1(a) FC-2-1-8 Total Flooding Quantity (English Units)[a]

Temp. *t* (°F)[c]	Specific Vapor Volume *s* (ft^3/lb)[d]	Weight Requirements of Hazard Volume, *W/V* (lb/ft^3)[b] Design Concentration (% by Volume)[e]							
		5	6	7	8	9	10	11	12
−30	1.6174	0.0325	0.0395	0.0465	0.0538	0.0611	0.0687	0.0764	0.0843
−20	1.6594	0.0317	0.0385	0.0454	0.0524	0.0596	0.0670	0.0745	0.0822
−10	1.7014	0.0309	0.0375	0.0442	0.0511	0.0581	0.0653	0.0726	0.0801
0	1.7434	0.0302	0.0366	0.0432	0.0499	0.0567	0.0637	0.0709	0.0782
10	1.7854	0.0295	0.0358	0.0422	0.0487	0.0554	0.0622	0.0692	0.0764
20	1.8274	0.0288	0.0349	0.0412	0.0476	0.0541	0.0608	0.0676	0.0746
30	1.8694	0.0282	0.0341	0.0403	0.0465	0.0529	0.0594	0.0661	0.0729
40	1.9114	0.0275	0.0334	0.0394	0.0455	0.0517	0.0581	0.0647	0.0713
50	1.9534	0.0269	0.0327	0.0385	0.0445	0.0506	0.0569	0.0633	0.0698
60	1.9954	0.0264	0.0320	0.0377	0.0436	0.0496	0.0557	0.0619	0.0683
70	2.0374	0.0258	0.0313	0.0369	0.0427	0.0485	0.0545	0.0607	0.0669
80	2.0794	0.0253	0.0307	0.0362	0.0418	0.0476	0.0534	0.0594	0.0656
90	2.1214	0.0248	0.0301	0.0355	0.0410	0.0466	0.0524	0.0583	0.0643
100	2.1634	0.0243	0.0295	0.0348	0.0402	0.0457	0.0514	0.0571	0.0630
110	2.2054	0.0239	0.0289	0.0341	0.0394	0.0448	0.0504	0.0560	0.0618
120	2.2474	0.0234	0.0284	0.0335	0.0387	0.0440	0.0494	0.0550	0.0607
130	2.2894	0.0230	0.0279	0.0329	0.0380	0.0432	0.0485	0.0540	0.0596
140	2.3314	0.0226	0.0274	0.0323	0.0373	0.424	0.0477	0.0530	0.0585
150	2.3734	0.0222	0.0269	0.0317	0.0366	0.0417	0.0468	0.0521	0.0575
160	2.4154	0.0218	0.0264	0.0312	0.0360	0.0409	0.0460	0.0512	0.0565
170	2.4574	0.0214	0.0260	0.0306	0.0354	0.0402	0.0452	0.0503	0.0555
180	2.4994	0.0211	0.0255	0.0301	0.0348	0.0396	0.0445	0.0495	0.0546
190	2.5414	0.0207	0.0251	0.0296	0.0342	0.0389	0.0437	0.0486	0.0537
200	2.5834	0.0204	0.0247	0.0291	0.0337	0.0383	0.0430	0.0478	0.0528
210	2.6254	0.0200	0.0243	0.0287	0.0331	0.0377	0.0423	0.0471	0.0519
220	2.6674	0.0197	0.0239	0.0282	0.0326	0.0371	0.0417	0.0463	0.0511

[a] The manufacturer's listing specifies the temperature range for the operation.

[b] *W/V* [agent weight requirements (lb/ft^3)] = pounds of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] *t* [temperature (°F)] = the design temperature in the hazard area

[d] *s* [specific volume (ft^3/lb)] = specific volume of superheated FC-2-1-8 vapor can be approximated by the formula:

$$s = 1.7434 + 0.0042t$$

where t = temperature (°F)

[e] *C* [concentration (%)] = volumetric concentration of FC-2-1-8 in air at the temperature indicated

Table A-3-5.1(b) FC-2-1-8 Total Flooding Quantity (SI Units)[a]

Temp. *t* (°C)[c]	Specific Vapor Volume *s* (m^3/kg)[d]	Weight Requirements of Hazard Volume, *W/V* (kg/m^3)[b] Design Concentration (% by Volume)[e]							
		5	6	7	8	9	10	11	12
–35	0.1008	0.5223	0.6335	0.7470	0.8630	0.9815	1.1027	1.2266	1.3533
–30	0.1031	0.5105	0.6191	0.7301	0.8434	0.9593	1.0777	1.1988	1.3226
–25	0.1054	0.4992	0.6054	0.7139	0.8247	0.9380	1.0538	1.1722	1.2933
–20	0.1078	0.4883	0.5923	0.6984	0.8068	0.9177	1.0310	1.1468	1.2653
–15	0.1101	0.4780	0.5797	0.6836	0.7897	0.8982	1.0091	1.1225	1.2384
–10	0.1124	0.4680	0.5676	0.6694	0.7733	0.8795	0.9881	1.0991	1.2127
–5	0.1148	0.4585	0.5561	0.6557	0.7576	0.8616	0.9680	1.0767	1.1880
0	0.1171	0.4494	0.5450	0.6426	0.7424	0.8444	0.9487	1.0553	1.1643
5	0.1195	0.4406	0.5343	0.6301	0.7279	0.8279	0.9301	1.0346	1.1415
10	0.1218	0.4321	0.5241	0.6180	0.7139	0.8120	0.9123	1.0148	1.1196
15	0.1241	0.4240	0.5142	0.6063	0.7005	0.7967	0.8951	0.9957	1.0985
20	0.1265	0.4162	0.5047	0.5951	0.6876	0.7820	0.8785	0.9773	1.0782
25	0.1288	0.4086	0.4955	0.5843	0.6751	0.7678	0.8626	0.9595	1.0587
30	0.1311	0.4013	0.4867	0.5739	0.6631	0.7541	0.8472	0.9424	1.0398
35	0.1335	0.3943	0.4782	0.5639	0.6514	0.7409	0.8324	0.9259	1.0216
40	0.1358	0.3875	0.4700	0.5542	0.6402	0.7282	0.8181	0.9100	1.0040
45	0.1382	0.3810	0.4620	0.5448	0.6294	0.7159	0.8042	0.8946	0.9870
50	0.1405	0.3746	0.4543	0.5357	0.6189	0.7039	0.7909	0.8797	0.9706
55	0.1428	0.3685	0.4469	0.5270	0.6088	0.6924	0.7779	0.8653	0.9547
60	0.1452	0.3626	0.4397	0.5185	0.5990	0.6813	0.7654	0.8514	0.9393
65	0.1475	0.3568	0.4327	0.5103	0.5895	0.6705	0.7533	0.8379	0.9245
70	0.1498	0.3512	0.4260	0.5023	0.5803	0.6600	0.7415	0.8248	0.9100
75	0.1522	0.3458	0.4194	0.4946	0.5714	0.6499	0.7301	0.8122	0.8961
80	0.1545	0.3406	0.4131	0.4871	0.5628	0.6401	0.7191	0.7999	0.8825
85	0.1569	0.3355	0.4069	0.4799	0.5544	0.6305	0.7084	0.7880	0.8694
90	0.1592	0.3306	0.4010	0.4728	0.5462	0.6213	0.6980	0.7764	0.8566
95	0.1615	0.3258	0.3952	0.4660	0.5383	0.6123	0.6879	0.7652	0.8442
100	0.1639	0.3212	0.3895	0.4593	0.5307	0.6035	0.6781	0.7542	0.8322

[a] The manufacturer's listing specifies the temperature range for the operation.

[b] *W/V* [agent weight reguirements (kg/m^3)] = kilograms required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] *t* [temperature (°C)] = the design temperature in the hazard area

[d] *s* [specific volume m^3/kg)] = specific volume of superheated FC-2-1-8 vapor can be approximated by the formula:

$$s = 0.11712 = 0.00047t$$

where t = temperature (°C)

[e] *C* [concentration (%)] = volumetric concentration of FC-2-1-8 in air at the temperature indicated

Table A-3-5.1(c) FC-3-1-10 Total Flooding Quantity (English Units)[a]

Temp. *t* (°F)[c]	Specific Vapor Volume *s* (ft³/lb)[d]	Weight Requirements of Hazard Volume, *W/V* (lb/ft³)[b] Design Concentration (% by Volume)[e]								
		4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
–30	1.5020	0.0277	0.0350	0.0425	0.0501	0.0579	0.0658	0.0740	0.0823	0.0908
–40	1.5330	0.0272	0.0343	0.0416	0.0491	0.0567	0.0645	0.0725	0.0806	0.0890
–50	1.5640	0.0266	0.0337	0.0408	0.0481	0.0556	0.0632	0.0710	0.0790	0.0872
–60	1.5950	0.0261	0.0330	0.0400	0.0472	0.0545	0.0620	0.0697	0.0775	0.0855
–70	1.6260	0.0256	0.0324	0.0393	0.0463	0.0535	0.0608	0.0683	0.0760	0.0839
–80	1.6570	0.0251	0.0318	0.0385	0.0454	0.0525	0.0597	0.0671	0.0746	0.0823
–90	1.6880	0.0247	0.0312	0.0378	0.0446	0.0515	0.0586	0.0658	0.0732	0.0808
100	1.7190	0.0242	0.0306	0.0371	0.0438	0.0506	0.0575	0.0646	0.0719	0.0793
110	1.7500	0.0238	0.0301	0.0365	0.0430	0.0497	0.0565	0.0635	0.0706	0.0779
120	1.7810	0.0234	0.0296	0.0358	0.0423	0.0488	0.0555	0.0624	0.0694	0.0766
130	1.8120	0.0230	0.0290	0.0352	0.0415	0.0480	0.0546	0.0613	0.0682	0.0753
140	1.8430	0.0226	0.0286	0.0346	0.0408	0.0472	0.0537	0.0603	0.0671	0.0740
150	1.8740	0.0222	0.0281	0.0341	0.0402	0.0464	0.0528	0.0593	0.0660	0.0728
160	1.9050	0.0219	0.0276	0.0335	0.0395	0.0456	0.0519	0.0583	0.0649	0.0716
170	1.9360	0.0215	0.0272	0.0330	0.0389	0.0449	0.0511	0.0574	0.0638	0.0704
180	1.9670	0.0212	0.0268	0.0325	0.0383	0.0442	0.0503	0.0565	0.0628	0.0693
190	1.9980	0.0209	0.0263	0.0319	0.0377	0.0435	0.0495	0.0556	0.0619	0.0683
200	2.0290	0.0205	0.0259	0.0315	0.0371	0.0429	0.0487	0.0548	0.0609	0.0672

[a] The manufacturer's listing specifies the temperature range for operation.

[b] *W/V* [agent weight requirements (lb/ft³)] = pounds of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] *t* [temperature (°F)] = the design temperature in the hazard area

[d] *s* [specific volume of superheated agent vapor at 1 atm and temperature, *t* (ft³/lb)] = specific volume of superheated FC-3-1-10 vapor can be approximated by the formula:

$$s = 1.409 + 0.0031t$$

where t = temperature (°F)

[e] *C* [concentration (%)] = volumetric concentration of FC-3-1-10 in air at the temperature indicated

Table A-3-5.1(d) FC-3-1-10 Total Flooding Quantity (SI Units)[a]

Temp. t (°C)[c]	Specific Vapor Volume s (m^3/kg)[d]	Weight Requirements of Hazard Volume, W/V (kg/m^3)[b]							
		Design Concentration (% by Volume)[e]							
		5	6	7	8	9	10	11	12
0	0.0941	0.5593	0.6783	0.7998	0.9240	1.0510	1.1807	1.3134	1.4491
10	0.0976	0.5395	0.6543	0.7715	0.8913	1.0138	1.1389	1.2669	1.3978
15	0.0993	0.5301	0.6429	0.7581	0.8758	0.9961	1.1191	1.2448	1.3734
20	0.1010	0.5210	0.6319	0.7451	0.8608	0.9791	1.1000	1.2235	1.3499
25	0.1027	0.5123	0.6213	0.7326	0.8464	0.9626	1.0815	1.2030	1.3272
30	0.1045	0.5038	0.6110	0.7205	0.8324	0.9467	1.0636	1.1831	1.3053
35	0.1062	0.4956	0.6011	0.7088	0.8188	0.9313	1.0463	1.1638	1.2841
40	0.1079	0.4877	0.5914	0.6974	0.8057	0.9164	1.0295	1.1452	1.2635
45	0.1097	0.4800	0.5821	0.6864	0.7930	0.9020	1.0133	1.1272	1.2436
50	0.1114	0.4725	0.5731	0.6758	0.7807	0.8880	0.9976	1.1097	1.2243
55	0.1131	0.4653	0.5643	0.6655	0.7688	0.8744	0.9824	1.0927	1.2056
60	0.1148	0.4583	0.5558	0.6555	0.7572	0.8613	0.9676	1.0763	1.1875
65	0.1166	0.4515	0.5476	0.6457	0.7460	0.8485	0.9532	1.0603	1.1699
70	0.1183	0.4449	0.5396	0.6363	0.7351	0.8361	0.9393	1.0449	1.1528
75	0.1200	0.4385	0.5318	0.6272	0.7245	0.8241	0.9258	1.0298	1.1362
80	0.1217	0.4323	0.5243	0.6183	0.7143	0.8124	0.9127	1.0152	1.1201
85	0.1235	0.4263	0.5170	0.6096	0.7043	0.8010	0.8999	1.0010	1.1044
90	0.1252	0.4204	0.5098	0.6012	0.6945	0.7900	0.8875	0.9872	1.0892
95	0.1269	0.4147	0.5029	0.5930	0.6851	0.7792	0.8754	0.9738	1.0744
100	0.1287	0.4091	0.4961	0.5850	0.6759	0.7687	0.8636	0.9607	1.0599

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (kg/m^3)] = kilograms required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°C)] = the design temperature in the hazard area

[d] s [specific volume (m^3/kg)] = specific volume of superheated FC-3-1-10 vapor can be approximated by the formula:

$$s = 0.094104 + 0.00034455t$$

where t = temperature (°C)

[e] C [concentration (%)] = volumetric concentration of FC-3-1-10 in air at the temperature indicated

Table A-3-5.1(e) HCFC Blend A Total Flooding Quantity (English Units)[a]

Temp. t (°F)[c]	Specific Vapor Volume s (ft^3/lb)[d]	Weight Requirements of Hazard Volume, W/V (lb/ft^3)[b] Design Concentration (% by Volume)[e] 8.6	9	10	11	12	13	14	15
−50	3.2192	0.0292	0.0307	0.0345	0.0384	0.0424	0.0464	0.0506	0.0548
−40	3.2978	0.0285	0.03	0.0337	0.0375	0.0414	0.0453	0.0494	0.0535
−30	3.3763	0.0279	0.0293	0.0329	0.0366	0.0404	0.0443	0.0482	0.0523
−20	3.4549	0.0272	0.0286	0.0322	0.0358	0.0395	0.0433	0.0471	0.0511
−10	3.5335	0.0266	0.028	0.0314	0.035	0.0386	0.0423	0.0461	0.0499
0	3.6121	0.026	0.0274	0.0308	0.0342	0.0378	0.0414	0.0451	0.0489
10	3.6906	0.0255	0.0268	0.0301	0.0335	0.0369	0.0405	0.0441	0.0478
20	3.7692	0.025	0.0262	0.0295	0.0328	0.0362	0.0396	0.0432	0.0468
30	3.8478	0.0245	0.0257	0.0289	0.0321	0.0354	0.0388	0.0423	0.0459
40	3.9264	0.024	0.0252	0.0283	0.0315	0.0347	0.0381	0.0415	0.0449
50	4.0049	0.0235	0.0247	0.0277	0.0309	0.034	0.0373	0.0406	0.0441
60	4.0835	0.023	0.0242	0.0272	0.0303	0.0334	0.0366	0.0399	0.0432
70	4.1621	0.0226	0.0238	0.0267	0.0297	0.0328	0.0359	0.0391	0.0424
80	4.2407	0.0222	0.0233	0.0262	0.0291	0.0322	0.0352	0.0384	0.0416
90	4.3192	0.0218	0.0229	0.0257	0.0286	0.0316	0.0346	0.0377	0.0409
100	4.3978	0.0214	0.0225	0.0253	0.0281	0.031	0.034	0.037	0.0401
110	4.4764	0.021	0.0221	0.0248	0.0276	0.0305	0.0334	0.0364	0.0394
120	4.555	0.0207	0.0217	0.0244	0.0271	0.0299	0.0328	0.0357	0.0387
130	4.6336	0.0203	0.0213	0.024	0.0267	0.0294	0.0322	0.0351	0.0381
140	4.7121	0.02	0.021	0.0236	0.0262	0.0289	0.0317	0.0345	0.0375
150	4.7907	0.0196	0.0206	0.0232	0.0258	0.0285	0.0312	0.034	0.0368
160	4.8693	0.0193	0.0203	0.0228	0.0254	0.028	0.0307	0.0334	0.0362
170	4.9479	0.019	0.02	0.0225	0.025	0.0276	0.0302	0.0329	0.0357
180	5.0264	0.0187	0.0197	0.0221	0.0246	0.0271	0.0297	0.0324	0.0351
190	5.105	0.0184	0.0194	0.0218	0.0242	0.0267	0.0293	0.0319	0.0346
200	5.1836	0.0182	0.0191	0.0214	0.0238	0.0263	0.0288	0.0314	0.034

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (lb/ft^3)] = pounds of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°F)] = the design temperature in the hazard area

[d] s [specific volume (ft^3/lb)] = specific volume of superheated HCFC Blend A vapor can be approximated by the formula:

$$s = 3.612 + 0.0079t$$

where t = temperature (°F)

[e] C [concentration (%)] = volumetric concentration of HCFC Blend A in air at the temperature indicated

Table A-3-5.1(f) HCFC Blend A Total Flooding Quantity (SI Units)[a]

Temp.	Specfic Vapor Volume	Weight Requirements of Hazard Volume, *W/V* (kg/m^3)[b]							
		Design Concentration (% by Volume)[e]							
t (°C)[c]	*s* (m^3/kg)[d]	8.6	9	10	11	12	13	14	15
–50	0.1971	0.4774	0.5018	0.5638	0.6271	0.6919	0.7582	0.8260	0.8954
–45	0.2015	0.4669	0.4908	0.5514	0.6134	0.6767	0.7415	0.8079	0.8758
–40	0.2059	0.4569	0.4803	0.5396	0.6002	0.6622	0.7256	0.7906	0.8570
–35	0.2103	0.4473	0.4702	0.5283	0.5876	0.6483	0.7104	0.7740	0.8390
–30	0.2148	0.4381	0.4605	0.5174	0.5755	0.635	0.6958	0.7580	0.8217
–25	0.2192	0.4293	0.4513	0.507	0.5639	0.6222	0.6818	0.7428	0.8052
–20	0.2236	0.4208	0.4423	0.497	0.5528	0.6099	0.6683	0.7281	0.7893
–15	0.228	0.4127	0.4338	0.4873	0.5421	0.5981	0.6554	0.7140	0.7740
–10	0.2324	0.4048	0.4255	0.4781	0.5318	0.5867	0.6429	0.7004	0.7593
–5	0.2368	0.3973	0.4176	0.4692	0.5219	0.5758	0.6309	0.6874	0.7451
0	0.2412	0.39	0.41	0.4606	0.5123	0.5652	0.6194	0.6748	0.7315
5	0.2457	0.383	0.4026	0.4523	0.5031	0.5551	0.6083	0.6627	0.7183
10	0.2501	0.3762	0.3955	0.4443	0.4942	0.5453	0.5975	0.6510	0.7057
15	0.2545	0.3697	0.3886	0.4366	0.4856	0.5358	0.5871	0.6397	0.6934
20	0.2589	0.3634	0.382	0.4291	0.4774	0.5267	0.5771	0.6288	0.6816
25	0.2633	0.3573	0.3756	0.422	0.4694	0.5178	0.5675	0.6182	0.6702
30	0.2677	0.3514	0.3694	0.415	0.4616	0.5093	0.5581	0.6080	0.6591
35	0.2722	0.3457	0.3634	0.4083	0.4541	0.501	0.549	0.5981	0.6484
40	0.2766	0.3402	0.3576	0.4017	0.4469	0.493	0.5403	0.5886	0.6381
45	0.281	0.3349	0.352	0.3954	0.4399	0.4853	0.5318	0.5793	0.6280
50	0.2854	0.3297	0.3465	0.3893	0.4331	0.4778	0.5236	0.5704	0.6183
55	0.2898	0.3247	0.3412	0.3834	0.4265	0.4705	0.5156	0.5617	0.6089
60	0.2942	0.3198	0.3361	0.3776	0.4201	0.4634	0.5078	0.5533	0.5998
65	0.2987	0.3151	0.3312	0.372	0.4138	0.4566	0.5003	0.5451	0.5909
70	0.3031	0.3105	0.3263	0.3666	0.4078	0.4499	0.493	0.5371	0.5823
75	0.3075	0.306	0.3216	0.3614	0.402	0.4435	0.486	0.5294	0.5739
80	0.3119	0.3017	0.3171	0.3562	0.3963	0.4372	0.4791	0.5219	0.5658
85	0.3163	0.2975	0.3127	0.3513	0.3907	0.4311	0.4724	0.5146	0.5579
90	0.3207	0.2934	0.3084	0.3464	0.3854	0.4252	0.4659	0.5076	0.5502
95	0.3251	0.2894	0.3042	0.3417	0.3801	0.4194	0.4596	0.5007	0.5427

[a] The manufacturer's listing specifies the temperature range for operation.

[b] *W/V* [agent weight requirements (kg/m^3)] = kilograms required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] *t* [temperature (°C)] = the design temperature in the hazard area

[d] *s* [specific volume (m^3/kg)] = specific volume of superheated HCFC Blend A vapor can be approximated by the formula:

$$s = 0.2413 + 0.00088\,t$$

where t = temperature (°C)

[e] *C* [concentration (%)] = volumetric concentration of HCFC Blend A in air at the temperature indicated

Table A-3-5.1(g) HCFC-124 Total Flooding Quantity (English Units)[a]

Temp. t (°F)[c]	Specific Vapor Volume s (ft^3/lb)[d]	Weight Requirements of Hazard Volume, W/V (lb/ft^3)[b]							
		Design Concentration (% by Volume)[e]							
		5	6	7	8	9	10	11	12
20	2.4419	0.0216	0.0261	0.0308	0.0356	0.0405	0.0455	0.0506	0.0558
30	2.5049	0.0210	0.0255	0.0300	0.0347	0.0395	0.0444	0.0493	0.0544
40	2.5667	0.0205	0.0249	0.0293	0.0339	0.0385	0.0433	0.0482	0.0531
50	2.6277	0.0200	0.0243	0.0286	0.0331	0.0376	0.0423	0.0470	0.0519
60	2.6878	0.0196	0.0237	0.0280	0.0324	0.0368	0.0413	0.0460	0.0507
70	2.7471	0.0192	0.0232	0.0274	0.0317	0.0360	0.0404	0.0450	0.0496
80	2.8059	0.0188	0.0227	0.0268	0.0310	0.0352	0.0396	0.0440	0.0486
90	2.8642	0.0184	0.0223	0.0263	0.0304	0.0345	0.0388	0.0432	0.0476
100	2.9219	0.0180	0.0218	0.0258	0.0298	0.0338	0.0380	0.0423	0.0467
110	2.9795	0.0177	0.0214	0.0253	0.0292	0.0332	0.0373	0.0415	0.0458
120	3.0363	0.0173	0.0210	0.0248	0.0286	0.0326	0.0366	0.0407	0.0449
130	3.0931	0.0170	0.0206	0.0243	0.0281	0.0320	0.0359	0.0400	0.0441
140	3.1494	0.0167	0.0203	0.0239	0.0276	0.0314	0.0353	0.0392	0.0433
150	3.2059	0.0164	0.0199	0.0235	0.0271	0.0308	0.0347	0.0386	0.0425
160	3.2616	0.0161	0.0196	0.0231	0.0267	0.0303	0.0341	0.0379	0.0418
170	3.3176	0.0159	0.0192	0.0227	0.0262	0.0298	0.0335	0.0373	0.0411
180	3.3729	0.0156	0.0189	0.0223	0.0258	0.0293	0.0329	0.0366	0.0404
190	3.4283	0.0154	0.0186	0.0220	0.0254	0.0288	0.0324	0.0361	0.0398
200	3.4840	0.0151	0.0183	0.0216	0.0250	0.0284	0.0319	0.0355	0.0391

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (lb/ft^3)] = pounds of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°F)] = the design temperature in the hazard area

[d] s [specific volume (ft^3/lb)] = specific volume of superheated HCFC-124 vapor can be approximated by the formula:

$$s = 2.3395 + 0.0058\,t$$

where t = temperature (°F)

[e] C [concentration (%)] = volumetric concentration of HCFC-124 in air at the temperature indicated

Table A-3-5.1(h) HCFC-124 Total Flooding Quantity (SI Units)[a]

Temp. t (°C)[c]	Specific Vapor Volume s (m^3/kg)[d]	Weight Requirements of Hazard Volume, W/V (kg/m^3)[b] Design Concentration (% by Volume)[e]							
		5	6	7	8	9	10	11	12
−10	0.1500	0.3509	0.4255	0.5018	0.5797	0.6593	0.7407	0.8240	0.9091
−5	0.1536	0.3427	0.4156	0.4900	0.5661	0.6439	0.7234	0.8047	0.8878
0	0.1572	0.3348	0.4060	0.4788	0.5532	0.6291	0.7068	0.7862	0.8675
5	0.1606	0.3277	0.3974	0.4687	0.5414	0.6158	0.6919	0.7696	0.8491
10	0.1640	0.3209	0.3892	0.4590	0.5302	0.6031	0.6775	0.7536	0.8315
15	0.1674	0.3144	0.3813	0.4496	0.5195	0.5908	0.6637	0.7383	0.8146
20	0.1708	0.3081	0.3737	0.4407	0.5091	0.5790	0.6505	0.7236	0.7984
25	0.1741	0.3023	0.3666	0.4323	0.4995	0.5681	0.6382	0.7099	0.7832
30	0.1774	0.2967	0.3598	0.4243	0.4902	0.5575	0.6263	0.6967	0.7687
35	0.1806	0.2914	0.3534	0.4168	0.4815	0.5476	0.6152	0.6844	0.7551
40	0.1839	0.2862	0.3471	0.4093	0.4728	0.5378	0.6042	0.6721	0.7415
45	0.1871	0.2813	0.3412	0.4023	0.4648	0.5286	0.5939	0.6606	0.7288
50	0.1903	0.2766	0.3354	0.3955	0.4569	0.5197	0.5839	0.6495	0.7166
55	0.1934	0.2721	0.3300	0.3892	0.4496	0.5114	0.5745	0.6391	0.7051
60	0.1966	0.2677	0.3247	0.3829	0.4423	0.5031	0.5652	0.6287	0.6936
65	0.1998	0.2634	0.3195	0.3767	0.4352	0.4950	0.5561	0.6186	0.6825
70	0.2029	0.2594	0.3146	0.3710	0.4286	0.4874	0.5476	0.6091	0.6721
75	0.2061	0.2554	0.3097	0.3652	0.4219	0.4799	0.5391	0.5997	0.6616
80	0.2092	0.2516	0.3051	0.3598	0.4157	0.4728	0.5311	0.5908	0.6518
85	0.2123	0.2479	0.3007	0.3545	0.4096	0.4659	0.5234	0.5822	0.6423
90	0.2154	0.2443	0.2963	0.3494	0.4037	0.4592	0.5158	0.5738	0.6331
95	0.2185	0.2409	0.2921	0.3445	0.3980	0.4526	0.5085	0.5657	0.6241

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (kg/m^3)] = kilograms required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°C)] = the design temperature in the hazard area

[d] s [specific volume (m^3/kg)] = specific volume of superheated HCFC-124 vapor can be approximated by the formula:

$$s = 0.1575 + 0.0006t$$

where t = temperature (°C)

[e] C [concentration (%)] = volumetric concentration of HCFC-124 in air at the temperature indicated

Table A-3-5.1(i) HFC-125 Total Flooding Quantity (English Units)[a]

Temp. t (°F)[c]	Specific Vapor Volume s (ft^3/lb)[d]	Weight Requirements of Hazard Volume, W/V (lb/ft^3)[b] Design Concentration (% by Volume)[e]									
		7	8	9	10	11	12	13	14	15	16
–50	2.3912	0.0315	0.0364	0.0414	0.0465	0.0517	0.0570	0.0625	0.0681	0.0738	0.0797
–40	2.4576	0.0306	0.0354	0.0402	0.0452	0.0503	0.0555	0.0608	0.0662	0.0718	0.0775
–30	2.5240	0.0298	0.0345	0.0392	0.0440	0.0490	0.0540	0.0592	0.0645	0.0699	0.0755
–20	2.5893	0.0291	0.0336	0.0382	0.0429	0.0477	0.0527	0.0577	0.0629	0.0682	0.0736
–10	2.6553	0.0283	0.0327	0.0372	0.0418	0.0465	0.0514	0.0563	0.0613	0.0665	0.0717
0	2.7203	0.0277	0.0320	0.0364	0.0408	0.0454	0.0501	0.0549	0.0598	0.0649	0.0700
10	2.7855	0.0270	0.0312	0.0355	0.0399	0.0444	0.0490	0.0536	0.0584	0.0634	0.0684
20	2.8506	0.0264	0.0305	0.0347	0.0390	0.0434	0.0478	0.0524	0.0571	0.0619	0.0668
30	2.9146	0.0258	0.0298	0.0339	0.0381	0.0424	0.0468	0.0513	0.0559	0.0605	0.0654
40	2.9789	0.0253	0.0292	0.0332	0.0373	0.0415	0.0458	0.0502	0.0546	0.0592	0.0639
50	3.0432	0.0247	0.0286	0.0325	0.0365	0.0406	0.0448	0.0491	0.0535	0.0580	0.0626
60	3.1075	0.0242	0.0280	0.0318	0.0358	0.0398	0.0439	0.0481	0.0524	0.0568	0.0613
70	3.1706	0.0237	0.0274	0.0312	0.0350	0.0390	0.0430	0.0471	0.0513	0.0557	0.0601
80	3.2342	0.0233	0.0269	0.0306	0.0344	0.0382	0.0422	0.0462	0.0503	0.0546	0.0589
90	3.2971	0.0228	0.0264	0.0300	0.0337	0.0375	0.0414	0.0453	0.0494	0.0535	0.0578
100	3.3602	0.0224	0.0259	0.0294	0.0331	0.0368	0.0406	0.0445	0.0484	0.0525	0.0567
110	3.4223	0.0220	0.0254	0.0289	0.0325	0.0361	0.0398	0.0437	0.0476	0.0516	0.0557
120	3.4855	0.0216	0.0249	0.0284	0.0319	0.0355	0.0391	0.0429	0.0467	0.0506	0.0546
130	3.5486	0.0212	0.0245	0.0279	0.0313	0.0348	0.0384	0.0421	0.0459	0.0497	0.0537
140	3.6101	0.0208	0.0241	0.0274	0.0308	0.0342	0.0378	0.0414	0.0451	0.0489	0.0528
150	3.6724	0.0205	0.0237	0.0269	0.0303	0.0337	0.0371	0.0407	0.0443	0.0481	0.0519
160	3.7341	0.0202	0.0233	0.0265	0.0298	0.0331	0.0365	0.0400	0.0436	0.0473	0.0510
170	3.7965	0.0198	0.0229	0.0261	0.0293	0.0326	0.0359	0.0394	0.0429	0.0465	0.0502
180	3.8595	0.0195	0.0225	0.0256	0.0288	0.0320	0.0353	0.0387	0.0422	0.0457	0.0494
190	3.9200	0.0192	0.0222	0.0252	0.0283	0.0315	0.0348	0.0381	0.0415	0.0450	0.0486
200	3.9825	0.0189	0.0218	0.0248	0.0279	0.0310	0.0342	0.0375	0.0409	0.0443	0.0478

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (lb/ft^3)] = pounds of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°F)] = the design temperature in the hazard area

[d] s [specific volume (ft^3/lb)] = specific volume of superheated HFC-125 vapor can be approximated by the formula:

$$s = 2.7200 + 0.00064\,t$$

where t = temperature (°F)

[e] C [concentration (%)] = volumetric concentration of HFC-125 in air at the temperature indicated

Table A-3-5.1(j) HFC-125 Total Flooding Quantity (SI Units)[a]

Temp. t **(°C)**[c]	**Specific Vapor Volume** s **(m³/kg)**[d]	**Weight Requirements of Hazard Volume,** W/V **(kg/m³)**[b] **Design Concentration (% by Volume)**[e]									
		7	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
–45	0.1497	0.5028	0.5809	0.6607	0.7422	0.8256	0.9109	0.9982	1.0874	1.1788	1.2724
–40	0.1534	0.4907	0.5669	0.6447	0.7243	0.8057	0.8889	0.9741	1.0612	1.1504	1.2417
–35	0.1572	0.4788	0.5532	0.6291	0.7068	0.7862	0.8675	0.9505	1.0356	1.1226	1.2117
–30	0.1608	0.4681	0.5408	0.6151	0.6910	0.7686	0.8480	0.9293	1.0124	1.0975	1.1846
–25	0.1645	0.4576	0.5286	0.6012	0.6754	0.7513	0.8290	0.9084	0.9896	1.0728	1.1579
–20	0.1682	0.4475	0.5170	0.5880	0.6606	0.7348	0.8107	0.8884	0.9678	1.0492	1.1324
–15	0.1719	0.4379	0.5059	0.5753	0.6464	0.7190	0.7933	0.8693	0.9470	1.0266	1.1081
–10	0.1755	0.4289	0.4955	0.5635	0.6331	0.7042	0.7770	0.8514	0.9276	1.0055	1.0853
–5	0.1791	0.4203	0.4855	0.5522	0.6204	0.6901	0.7614	0.8343	0.9089	0.9853	1.0635
0	0.1828	0.4118	0.4757	0.5410	0.6078	0.6761	0.7460	0.8174	0.8905	0.9654	1.0420
5	0.1864	0.4038	0.4665	0.5306	0.5961	0.6631	0.7316	0.8016	0.8733	0.9467	1.0219
10	0.1900	0.3962	0.4577	0.5205	0.5848	0.6505	0.7177	0.7864	0.8568	0.9288	1.0025
15	0.1935	0.3890	0.4494	0.5111	0.5742	0.6387	0.7047	0.7722	0.8413	0.9120	0.9844
20	0.1971	0.3819	0.4412	0.5018	0.5637	0.6271	0.6919	0.7581	0.8259	0.8953	0.9664
25	0.2007	0.3750	0.4333	0.4928	0.5536	0.6158	0.6794	0.7445	0.8111	0.8793	0.9491
30	0.2042	0.3686	0.4258	0.4843	0.5441	0.6053	0.6678	0.7318	0.7972	0.8642	0.9328
35	0.2078	0.3622	0.4185	0.4759	0.5347	0.5948	0.6562	0.7191	0.7834	0.8492	0.9166
40	0.2113	0.3562	0.4115	0.4681	0.5258	0.5849	0.6454	0.7072	0.7704	0.8352	0.9014
45	0.2149	0.3503	0.4046	0.4602	0.5170	0.5751	0.6345	0.6953	0.7575	0.8212	0.8863
50	0.2184	0.3446	0.3982	0.4528	0.5088	0.5659	0.6244	0.6842	0.7454	0.8080	0.8721
55	0.2219	0.3392	0.3919	0.4457	0.5007	0.5570	0.6145	0.6734	0.7336	0.7953	0.8584
60	0.2254	0.3339	0.3858	0.4388	0.4930	0.5483	0.6050	0.6629	0.7222	0.7829	0.8451
65	0.2289	0.3288	0.3799	0.4321	0.4854	0.5400	0.5957	0.6528	0.7112	0.7710	0.8321
70	0.2324	0.3239	0.3742	0.4256	0.4781	0.5318	0.5868	0.6430	0.7005	0.7593	0.8196
75	0.2358	0.3192	0.3688	0.4194	0.4712	0.5242	0.5783	0.6337	0.6904	0.7484	0.8078
80	0.2393	0.3145	0.3634	0.4133	0.4643	0.5165	0.5698	0.6244	0.6803	0.7374	0.7960
85	0.2428	0.3100	0.3581	0.4073	0.4576	0.5090	0.5616	0.6154	0.6705	0.7268	0.7845
90	0.2463	0.3056	0.3531	0.4015	0.4511	0.5018	0.5536	0.6067	0.6609	0.7165	0.7734
95	0.2498	0.3013	0.3481	0.3959	0.4448	0.4948	0.5459	0.5982	0.6517	0.7064	0.7625

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (kg/m³)] = kilograms required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°C)] = the design temperature in the hazard area

[d] s [specific volume (m³/kg)] = specific volume of superheated HFC-125 vapor can be approximated by the formula:

$$s = 0.1825 + 0.0007\,t$$

where t = temperature (°C)

[e] C [concentration (%)] = volumetric concentration of HFC-125 in air at the temperature indicated

Table A-3-5.1(k) HFC-227ea Total Flooding Quantity (English Units)[a]

Temp. t (°F)[c]	Specific Vapor Volume s (ft^3/lb)[d]	Weight Requirements of Hazard Volume, W/V (lb/ft^3)[b] Design Concentration (% by Volume)[e]									
		6	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
10	1.9264	0.0331	0.0391	0.0451	0.0513	0.057	0.0642	0.0708	0.0776	0.0845	0.0916
20	1.9736	0.0323	0.0381	0.0441	0.0501	0.0563	0.0626	0.0691	0.0757	0.0825	0.0894
30	2.0210	0.0316	0.0372	0.0430	0.0489	0.0550	0.0612	0.0675	0.0739	0.0805	0.0873
40	2.0678	0.0309	0.0364	0.0421	0.0478	0.0537	0.0598	0.0659	0.0723	0.0787	0.0853
50	2.1146	0.0302	0.0356	0.0411	0.0468	0.0525	0.0584	0.0645	0.0707	0.0770	0.0835
60	2.1612	0.0295	0.0348	0.0402	0.0458	0.0514	0.0572	0.0631	0.0691	0.0753	0.0817
70	2.2075	0.0289	0.0341	0.0394	0.0448	0.0503	0.0560	0.0618	0.0677	0.0737	0.0799
80	2.2538	0.0283	0.0334	0.0386	0.0439	0.0493	0.0548	0.0605	0.0663	0.0722	0.0783
90	2.2994	0.0278	0.0327	0.0378	0.0430	0.0483	0.0538	0.0593	0.0650	0.0708	0.0767
100	2.3452	0.0272	0.0321	0.0371	0.0422	0.0474	0.0527	0.0581	0.0637	0.0694	0.0752
110	2.3912	0.0267	0.0315	0.0364	0.0414	0.0465	0.0517	0.0570	0.0625	0.0681	0.0738
120	2.4366	0.0262	0.0309	0.0357	0.0406	0.0456	0.0507	0.0560	0.0613	0.0668	0.0724
130	2.4820	0.0257	0.0303	0.0350	0.0398	0.0448	0.0498	0.0549	0.0602	0.0656	0.0711
140	2.5272	0.0253	0.0298	0.0344	0.0391	0.0440	0.0489	0.0540	0.0591	0.0644	0.0698
150	2.5727	0.0248	0.0293	0.0338	0.0384	0.0432	0.0480	0.0530	0.0581	0.0633	0.0686
160	2.6171	0.0244	0.0288	0.0332	0.0378	0.0425	0.0472	0.0521	0.0571	0.0622	0.0674
170	2.6624	0.0240	0.0283	0.0327	0.0371	0.0417	0.0464	0.0512	0.0561	0.0611	0.0663
180	2.7071	0.0236	0.0278	0.0321	0.0365	0.0410	0.0457	0.0504	0.0552	0.0601	0.0652
190	2.7518	0.0232	0.0274	0.0316	0.0359	0.0404	0.0449	0.0496	0.0543	0.0592	0.0641
200	2.7954	0.0228	0.0269	0.0311	0.0354	0.0397	0.0442	0.0488	0.0535	0.0582	0.0631

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (lb/ft^3)] = pounds of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°F)] = the design temperature in the hazard area

[d] s [specific volume (ft^3/lb)] = specific volume of superheated HFC-227ea vapor can be approximated by the formula:

$$s = 1.885 + 0.0046\,t$$

where t = temperature (°F)

[e] C [concentration (%)] = volumetric concentration of HFC-227ea in air at the temperature indicated

Table A-3-5.1(l) HFC-227ea Total Flooding Quantity (SI Units)[a]

Temp. t (°C)[c]	Specific Vapor Volume s (m^3/kg)[d]	Weight Requirements of Hazard Volume, W/V (kg/m^3)[b] Design Concentration (% per Volume)[e]									
		6	7	8	9	10	11	12	13	14	15
–10	0.1215	0.5254	0.6196	0.7158	0.8142	0.9147	1.0174	1.1225	1.2301	1.3401	1.4527
–5	0.1241	0.5142	0.6064	0.7005	0.7987	0.8951	0.9957	1.0985	1.2038	1.3114	1.4216
0	0.1268	0.5034	0.5936	0.6858	0.78	0.8763	0.9748	1.0755	1.1785	1.2839	1.3918
5	0.1294	0.4932	0.5816	0.6719	0.7642	0.8586	0.955	1.0537	1.1546	1.2579	1.3636
10	0.132	0.4834	0.57	0.6585	0.749	0.8414	0.936	1.0327	1.1316	1.2328	1.2264
15	0.1347	0.474	0.5589	0.6457	0.7344	0.8251	0.9178	1.0126	1.1096	1.2089	1.3105
20	0.1373	0.465	0.5483	0.6335	0.7205	0.8094	0.9004	0.9934	1.0886	1.1859	1.2856
25	0.1399	0.4564	0.5382	0.6217	0.7071	0.7944	0.8837	0.975	1.0684	1.164	1.2618
30	0.1425	0.4481	0.5284	0.6104	0.6943	0.78	0.8676	0.9573	1.049	1.1428	1.2388
35	0.145	0.4401	0.519	0.5996	0.6819	0.7661	0.8522	0.9402	1.0303	1.1224	1.2168
40	0.1476	0.4324	0.5099	0.5891	0.6701	0.7528	0.8374	0.9230	1.0124	1.1029	1.1956
45	0.1502	0.425	0.5012	0.579	0.6586	0.7399	0.823	0.908	0.995	1.084	1.1751
50	0.1527	0.418	0.4929	0.5694	0.6476	0.7276	0.8093	0.8929	0.9784	1.066	1.1555
55	0.1553	0.4111	0.4847	0.56	0.6369	0.7156	0.796	0.8782	0.9623	1.0484	1.1365
60	0.1578	0.4045	0.477	0.551	0.6267	0.7041	0.7832	0.8641	0.9469	1.0316	1.1183
65	0.1604	0.398	0.4694	0.5423	0.6167	0.6929	0.7707	0.8504	0.9318	1.0152	1.1005
70	0.1629	0.3919	0.4621	0.5338	0.6072	0.6821	0.7588	0.8371	0.9173	0.9994	1.0834
75	0.1654	0.3859	0.455	0.5257	0.5979	0.6717	0.7471	0.8243	0.9033	0.9841	1.0668
80	0.1679	0.3801	0.4482	0.5178	0.0589	0.6617	0.736	0.812	0.8898	0.9694	1.0509
85	0.1704	0.3745	0.4416	0.5102	0.5803	0.6519	0.7251	0.8	0.8767	0.9551	1.0354
90	0.173	0.369	0.4351	0.5027	0.5717	0.6423	0.7145	0.7883	0.8638	0.9411	1.0202

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (kg/m^3)] = kilograms of agent per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°C)] = the design temperature in the hazard area

[d] s [specific volume (m^3/kg)] = specific volume of superheated HFC-227ea vapor can be approximated by the formula:

$$s = 0.1269 + 0.0005\,t$$

where t = temperature (°C)

[e] C [concentration (%)] = volumetric concentration of HFC-227ea in air at the temperature indicated

Table A-3-5.1(m) HFC-23 Total Flooding Quantity (English Units)[a]

Temp. *t* (°F)[c]	Specific Vapor Volume *s* (ft³/lb)[d]	Weight Requirements of Hazard Volume, *W/V* (lb/ft³)[b] Design Concentration (% by Volume)[e] 10	12	14	15	16	17	18	20	22	24
−70	3.9573	0.0281	0.0345	0.0411	0.0446	0.0481	0.0518	0.0555	0.0632	0.0713	0.0798
−60	4.0700	0.0273	0.0335	0.0400	0.0434	0.0468	0.0503	0.0539	0.0614	0.0693	0.0776
−50	4.1817	0.0266	0.0326	0.0389	0.0422	0.0455	0.0490	0.0525	0.0598	0.0674	0.0755
−40	4.2926	0.0259	0.0318	0.0379	0.0411	0.0444	0.0477	0.0511	0.0582	0.0657	0.0736
−30	4.4029	0.0252	0.0310	0.0370	0.0401	0.0433	0.0465	0.0499	0.0568	0.0641	0.0717
−20	4.5125	0.0246	0.0302	0.0361	0.0391	0.0422	0.0454	0.0486	0.0554	0.0625	0.0700
−10	4.6216	0.0240	0.0295	0.0352	0.0382	0.0412	0.0443	0.0475	0.0541	0.0610	0.0683
0	4.7302	0.0235	0.0288	0.0344	0.0373	0.0403	0.0433	0.0464	0.0529	0.0596	0.0668
10	4.8384	0.0230	0.0282	0.0336	0.0365	0.0394	0.0423	0.0454	0.0517	0.0583	0.0653
20	4.9463	0.0225	0.0276	0.0329	0.0357	0.0385	0.0414	0.0444	0.0505	0.0570	0.0638
30	5.0538	0.0220	0.0270	0.0322	0.0349	0.0377	0.0405	0.0434	0.0495	0.0558	0.0625
40	5.1610	0.0215	0.0264	0.0315	0.0342	0.0369	0.0397	0.0425	0.0484	0.0547	0.0612
50	5.2680	0.0211	0.0259	0.0309	0.0335	0.0362	0.0389	0.0417	0.0475	0.0535	0.0599
60	5.3748	0.0207	0.0254	0.0303	0.0328	0.0354	0.0381	0.0408	0.0465	0.0525	0.0588
70	5.4814	0.0203	0.0249	0.0297	0.0322	0.0347	0.0374	0.0400	0.0456	0.0515	0.0576
80	5.5878	0.0199	0.0244	0.0291	0.0316	0.0341	0.0367	0.0393	0.0447	0.0505	0.0565
90	5.6940	0.0195	0.0239	0.0286	0.0310	0.0335	0.0360	0.0386	0.0439	0.0495	0.0555
100	5.8001	0.0192	0.0235	0.0281	0.0304	0.0328	0.0353	0.0378	0.0431	0.0486	0.0544
110	5.9061	0.0188	0.0231	0.0276	0.0299	0.0323	0.0347	0.0372	0.0423	0.0478	0.0535
120	6.0119	0.0185	0.0227	0.0271	0.0294	0.0317	0.0341	0.0365	0.0416	0.0469	0.0525
130	6.1176	0.0182	0.0223	0.0266	0.0288	0.0311	0.0335	0.0359	0.0409	0.0461	0.0516
140	6.2233	0.0179	0.0219	0.0262	0.0284	0.0306	0.0329	0.0353	0.0402	0.0453	0.0507
150	6.3289	0.0176	0.0215	0.0257	0.0279	0.0301	0.0324	0.0347	0.0395	0.0446	0.0499
160	6.4343	0.0173	0.0212	0.0253	0.0274	0.0296	0.0318	0.0341	0.0389	0.0438	0.0491
170	6.5398	0.0170	0.0209	0.0249	0.0270	0.0291	0.0313	0.0336	0.0382	0.0431	0.0483
180	6.6451	0.0167	0.0205	0.0245	0.0266	0.0287	0.0308	0.0330	0.0376	0.0424	0.0475
190	6.7504	0.0165	0.0202	0.0241	0.0261	0.0282	0.0303	0.0325	0.0370	0.0418	0.0468

[a] The manufacturer's listing specifies the temperature range for operation.

[b] *W/V* [agent weight requirements (lb/ft³)] = pounds of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] *t* [temperature (°F)] = the design temperature in the hazard area

[d] *s* [specific volume (ft³/lb)] = specific volume of superheated HFC-23 vapor can be approximated by the formula:

$$s = 4.7250 + 0.0107\,t$$

where t = temperature (°F)

[e] *C* [concentration (%)] = volumetric concentration of HFC-23 in air at the temperature indicated

Table A-3-5.1(n) HFC-23 Total Flooding Quantity (SI Units)[a]

Temp. t (°C)[c]	Specific Vapor Volume s (m³/kg)[d]	Weight Requirements of Hazard Volume, W/V (kg/m³)[b] Design Concentration (% by Volume)[e] 10	12	14	15	16	17	18	20	22	24
−60	0.2428	0.4576	0.5616	0.6705	0.7268	0.7845	0.8436	0.9041	1.0297	1.1617	1.3006
−55	0.2492	0.4459	0.5472	0.6533	0.7081	0.7644	0.8219	0.8809	1.0032	1.1318	1.2672
−50	0.2555	0.4349	0.5337	0.6371	0.6907	0.7455	0.8016	0.8591	0.9785	1.1039	1.2360
−45	0.2617	0.4246	0.5211	0.6221	0.6743	0.7278	0.7826	0.8388	0.9553	1.0778	1.2067
−40	0.2680	0.4146	0.5088	0.6074	0.6585	0.7107	0.7643	0.8191	0.9328	1.0524	1.1783
−35	0.2742	0.4052	0.4973	0.5937	0.6436	0.6947	0.7470	0.8006	0.9117	1.0286	1.1517
−30	0.2803	0.3964	0.4865	0.5808	0.6296	0.6795	0.7307	0.7831	0.8919	1.0062	1.1266
−25	0.2865	0.3878	0.4760	0.5682	0.6160	0.6648	0.7149	0.7662	0.8726	0.9845	1.1022
−20	0.2926	0.3797	0.4660	0.5564	0.6031	0.6510	0.7000	0.7502	0.8544	0.9639	1.0793
−15	0.2987	0.3720	0.4565	0.5450	0.5908	0.6377	0.6857	0.7349	0.8370	0.9443	1.0572
−10	0.3047	0.3647	0.4475	0.5343	0.5792	0.6251	0.6722	0.7204	0.8205	0.9257	1.0364
−5	0.3108	0.3575	0.4388	0.5238	0.5678	0.6129	0.6590	0.7063	0.8044	0.9075	1.0161
0	0.3168	0.3507	0.4304	0.5139	0.5570	0.6013	0.6465	0.6929	0.7891	0.8903	0.9968
5	0.3229	0.3441	0.4223	0.5042	0.5465	0.5899	0.6343	0.6798	0.7742	0.8735	0.9780
10	0.3289	0.3378	0.4146	0.4950	0.5365	0.5791	0.6227	0.6674	0.7601	0.8576	0.9601
15	0.3349	0.3318	0.4072	0.4861	0.5269	0.5688	0.6116	0.6555	0.7465	0.8422	0.9429
20	0.3409	0.3259	0.4000	0.4775	0.5177	0.5587	0.6008	0.6439	0.7334	0.8274	0.9263
25	0.3468	0.3204	0.3932	0.4694	0.5089	0.5492	0.5906	0.6330	0.7209	0.8133	0.9106
30	0.3528	0.3149	0.3865	0.4614	0.5002	0.5399	0.5806	0.6222	0.7086	0.7995	0.8951
35	0.3588	0.3097	0.3801	0.4537	0.4918	0.5309	0.5708	0.6118	0.6968	0.7861	0.8801
40	0.3647	0.3047	0.3739	0.4464	0.4839	0.5223	0.5616	0.6019	0.6855	0.7734	0.8659
45	0.3707	0.2997	0.3679	0.4391	0.4760	0.5138	0.5525	0.5922	0.6744	0.7609	0.8519
50	0.3766	0.2950	0.3621	0.4323	0.4686	0.5058	0.5439	0.5829	0.6638	0.74489	0.8385
55	0.3826	0.2904	0.3564	0.4255	0.4612	0.4978	0.5353	0.5737	0.6534	0.7372	0.8254
60	0.3885	0.2860	0.3510	0.4190	0.4542	0.4903	0.5272	0.5650	0.6435	0.7260	0.8128
65	0.3944	0.2817	0.3457	0.4128	0.4474	0.4830	0.5193	0.5566	0.6339	0.7151	0.8007
70	0.4004	0.2775	0.3406	0.4066	0.4407	0.4757	0.5115	0.5482	0.6244	0.7044	0.7887

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (kg/m³)] = kilograms required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°C)] = the design temperature in the hazard area

[d] s [specific volume (m³/kg)] = specific volume of superheated HFC-23 vapor can be approximated by the formula:

$$s = 0.3164 + 0.0012\,t$$

where t = temperature (°C)

[e] C [concentration (%)] = volumetric concentration of HFC-23 in air at the temperature indicated

Table A-3-5.1(o) HFC-236fa Total Flooding Quantity (English Units)[a]

Temp. t (°F)[c]	Specific Vapor Volume s (ft^3/lb)[d]	Weight Requirements of Hazard Volume, W/V (lb/ft^3)[b] Design Concentration (% by Volume)[e]										
		5	6	7	8	9	10	11	12	13	14	15
30	2.2520	0.0234	0.0283	0.0334	0.0386	0.0439	0.0493	0.0549	0.0606	0.0664	0.0723	0.0784
40	2.3034	0.0228	0.0277	0.0327	0.0378	0.0429	0.0482	0.0537	0.0592	0.0649	0.0707	0.0766
50	2.3547	0.0224	0.0271	0.0320	0.0369	0.0420	0.0472	0.0525	0.0579	0.0635	0.0691	0.0749
60	2.4060	0.0219	0.0265	0.0313	0.0361	0.0411	0.0462	0.0514	0.0567	0.0621	0.0677	0.0733
70	2.4574	0.0214	0.0260	0.0306	0.0354	0.0402	0.0452	0.0503	0.0555	0.0608	0.0662	0.0718
80	2.5087	0.0210	0.0254	0.0300	0.0347	0.0394	0.0443	0.0493	0.0544	0.0596	0.0649	0.0703
90	2.5601	0.0206	0.0249	0.0294	0.0340	0.0386	0.0434	0.0483	0.0533	0.0584	0.0636	0.0689
100	2.6114	0.0202	0.0244	0.0288	0.0333	0.0379	0.0425	0.0473	0.0522	0.0572	0.0623	0.0676
110	2.6627	0.0198	0.0240	0.0283	0.0327	0.0371	0.0417	0.0464	0.0512	0.0561	0.0611	0.0663
120	2.7141	0.0194	0.0235	0.0277	0.0320	0.0364	0.0409	0.0455	0.0502	0.0551	0.0600	0.0650
130	2.7654	0.0190	0.0231	0.0272	0.0314	0.0358	0.0402	0.0447	0.0493	0.0540	0.0589	0.0638
140	2.8168	0.0187	0.0227	0.0267	0.0309	0.0351	0.0394	0.0439	0.0484	0.0530	0.0578	0.0626
150	2.8681	0.0184	0.0223	0.0262	0.0303	0.0345	0.0387	0.0431	0.0475	0.0521	0.0568	0.0615
160	2.9194	0.0180	0.0219	0.0258	0.0298	0.0339	0.0381	0.0423	0.0467	0.0512	0.0558	0.0604
170	2.9708	0.0177	0.0215	0.0253	0.0293	0.0333	0.0374	0.0416	0.0459	0.0503	0.0548	0.0594
180	3.0221	0.0174	0.0211	0.0249	0.0288	0.0327	0.0368	0.0409	0.0451	0.0494	0.0539	0.0584
190	3.0735	0.0171	0.0208	0.0245	0.0283	0.0322	0.0362	0.0402	0.0444	0.0486	0.0530	0.0574
200	3.1248	0.0168	0.0204	0.0241	0.0278	0.0317	0.0356	0.0396	0.0436	0.0478	0.0521	0.0565

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (lb/ft^3)] = pounds of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°F)] = the design temperature in the hazard area

[d] s [specific volume (ft^3/lb)] = specific volume of superheated HFC-236fa vapor can be approximated by the formula:

$$s = 2.098 + 0.0051\,t$$

where t = temperature (°F)

[e] C [concentration (%)] = volumetric concentration of HFC-236fa in air at the temperature indicated

Table A-3-5.1(p) HFC-236fa Total Flooding Quantity (SI Units)[a]

Temp. t (°C)[c]	Specific Vapor Volume s (m^3/kg)[d]	Weight Requirements of Hazard Volume, W/V (kg/m^3)[b] Design Concentration (% by Volume)[e]										
		5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
0	0.1413	0.3725	0.4517	0.5327	0.6154	0.6999	0.7863	0.8747	0.9651	1.0575	1.1521	1.2489
5	0.1442	0.3650	0.4427	0.5220	0.6031	0.6860	0.7706	0.8572	0.9458	1.0364	1.1291	1.2240
10	0.1471	0.3579	0.4340	0.5118	0.5913	0.6725	0.7555	0.8404	0.9273	1.0161	1.1070	1.2000
15	0.1499	0.3510	0.4257	0.5020	0.5799	0.6596	0.7410	0.8243	0.9095	0.9966	1.0857	1.1769
20	0.1528	0.3444	0.4177	0.4925	0.5690	0.6472	0.7271	0.8088	0.8923	0.9778	1.0652	1.1548
25	0.1557	0.3380	0.4100	0.4834	0.5585	0.6352	0.7136	0.7938	0.8758	0.9597	1.0455	1.1334
30	0.1586	0.3319	0.4025	0.4746	0.5483	0.6237	0.7007	0.7794	0.8599	0.9423	1.0266	1.1128
35	0.1615	0.3260	0.3953	0.4662	0.5386	0.6125	0.6882	0.7655	0.8446	0.9255	1.0082	1.0930
40	0.1643	0.3203	0.3884	0.4580	0.5291	0.6018	0.6761	0.7521	0.8298	0.9092	0.9906	1.0738
45	0.1672	0.3147	0.3817	0.4501	0.5200	0.5914	0.6645	0.7391	0.8155	0.8936	0.9735	1.0553
50	0.1701	0.3094	0.3752	0.4425	0.5112	0.5814	0.6532	0.7266	0.8017	0.8785	0.9570	1.0375
55	0.1730	0.3043	0.3690	0.4351	0.5027	0.5717	0.6423	0.7145	0.7883	0.8638	0.9411	1.0202
60	0.1759	0.2993	0.3630	0.4280	0.4945	0.5624	0.6318	0.7028	0.7754	0.8497	0.9257	1.0035
65	0.1787	0.2945	0.3571	0.4211	0.4865	0.5533	0.6216	0.6915	0.7629	0.8360	0.9108	0.9873
70	0.1816	0.2898	0.3514	0.4144	0.4788	0.5445	0.6118	0.6805	0.7508	0.8227	0.8963	0.9716
75	0.1845	0.2853	0.3460	0.4080	0.4713	0.5360	0.6022	0.6699	0.7391	0.8099	0.8823	0.9565
80	0.1874	0.2809	0.3406	0.4017	0.4641	0.5278	0.5930	0.6596	0.7277	0.7974	0.8688	0.9418
85	0.1903	0.2766	0.3355	0.3956	0.4570	0.5198	0.5840	0.6496	0.7167	0.7854	0.8556	0.9275
90	0.1931	0.2725	0.3305	0.3897	0.4502	0.5121	0.5753	0.6399	0.7060	0.7737	0.8429	0.9137
95	0.1960	0.2685	0.3256	0.3840	0.4436	0.5045	0.5668	0.6305	0.6957	0.7623	0.8305	0.9003

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (kg/m^3)] = kilograms of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°C)] = the design temperature in the hazard area

[d] s [specific volume (m^3/kg)] = specific volume of superheated HFC-236fa vapor can be approximated by the formula:

$$s = 0.1413 + 0.0006\,t$$

where t = temperature (°C)

[e] C [concentration (%)] = volumetric concentration of HFC-236fa in air at the temperature indicated

Table A-3-5.1(q) FIC-13I1 Total Flooding Quantity (English Units)[a]

Temp. t (°F)[c]	Specific Vapor Volume s (ft^3/lb)[d]	Weight Requirements of Hazard Volume, W/V (lb/ft^3)[b] Design Concentration (% by Volume)[e]							
		3	4	5	6	7	8	9	10
0	1.6826	0.0184	0.0248	0.0313	0.0379	0.0447	0.0517	0.0588	0.0660
10	1.7264	0.0179	0.0241	0.0305	0.0370	0.0436	0.0504	0.0573	0.0644
20	1.7703	0.0175	0.0235	0.0297	0.0361	0.0425	0.0491	0.0559	0.0628
30	1.8141	0.0170	0.0230	0.0290	0.0352	0.0415	0.0479	0.0545	0.0612
40	1.8580	0.0166	0.0224	0.0283	0.0344	0.0405	0.0468	0.0532	0.0598
50	1.9019	0.0163	0.0219	0.0277	0.0336	0.0396	0.0457	0.0520	0.0584
60	1.9457	0.0159	0.0214	0.0270	0.0328	0.0387	0.0447	0.0508	0.0571
70	1.9896	0.0155	0.0209	0.0265	0.0321	0.0378	0.0437	0.0497	0.0558
80	2.0335	0.0152	0.0205	0.0259	0.0314	0.0370	0.0428	0.0486	0.0546
90	2.0773	0.0149	0.0201	0.0253	0.0307	0.0362	0.0419	0.0476	0.0535
100	2.1212	0.0146	0.0196	0.0248	0.0301	0.0355	0.0410	0.0466	0.0524
110	2.1650	0.0143	0.0192	0.0243	0.0295	0.0348	0.0402	0.0457	0.0513
120	2.2089	0.0140	0.0189	0.0238	0.0289	0.0341	0.0394	0.0448	0.0503
130	2.2528	0.0137	0.0185	0.0234	0.0283	0.0334	0.0286	0.0439	0.0493
140	2.2966	0.0135	0.0181	0.0229	0.0278	0.0328	0.0379	0.0431	0.0484
150	2.3405	0.0132	0.0178	0.0225	0.0273	0.0322	0.0372	0.0423	0.0475
160	2.3843	0.0130	0.0175	0.0221	0.0268	0.0316	0.0365	0.0415	0.0466
170	2.4282	0.0127	0.0172	0.0217	0.0263	0.0310	0.0358	0.0407	0.0458
180	2.4721	0.0125	0.0169	0.0213	0.0258	0.0304	0.0352	0.0400	0.0449
190	2.5159	0.0123	0.0166	0.0209	0.0254	0.0299	0.0346	0.0393	0.0442
200	2.5598	0.0121	0.0163	0.0206	0.0249	0.0294	0.0340	0.0386	0.0434

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (lb/ft^3)] = pounds of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°F)] = the design temperature in the hazard area

[d] s [specific volume (ft^3/lb)] = specific volume of superheated FIC-13I1 vapor can be approximated by the formula:

$$s = 1.683 + 0.0044\,t$$

where t = temperature (°F)

[e] C [concentration (%)] = volumetric concentration of FIC-13I1 in air at the temperature indicated

Table A-3-5.1(r) FIC-13I1 Total Flooding Quantity (SI Units)[a]

Temp. t (°C)[c]	Specific Vapor Volume s (m^3/kg)[d]	Weight Requirements of Hazard Volume, W/V (kg/m^3)[b] Design Concentration (% by Volume)[e]							
		3	4	5	6	7	8	9	10
–40	0.0938	0.3297	0.4442	0.5611	0.6805	0.8024	0.9270	1.0544	1.1846
–30	0.0988	0.3130	0.4217	0.5327	0.6461	0.7618	0.8801	1.0010	1.1246
–20	0.1038	0.2980	0.4014	0.5070	0.6149	0.7251	0.8377	0.9528	1.0704
–10	0.1088	0.2843	0.3830	0.4837	0.5867	0.6918	0.7992	0.9090	1.0212
0	0.1138	0.2718	0.3661	0.4625	0.5609	0.6614	0.7641	0.8691	0.9764
10	0.1188	0.2603	0.3507	0.4430	0.5373	0.6336	0.7320	0.8325	0.9353
20	0.1238	0.2498	0.3366	0.4251	0.5156	0.6080	0.7024	0.7989	0.8975
30	0.1288	0.2401	0.3235	0.4086	0.4956	0.5844	0.6751	0.7679	0.8627
40	0.1338	0.2311	0.3114	0.3934	0.4771	0.5625	0.6499	0.7392	0.8304
50	0.1388	0.2228	0.3002	0.3792	0.4599	0.5423	0.6265	0.7125	0.8005
60	0.1438	0.2151	0.2898	0.3660	0.4439	0.5234	0.6047	0.6878	0.7727
70	0.1488	0.2078	0.2800	0.3537	0.4290	0.5058	0.5844	0.6647	0.7467
80	0.1538	0.2011	0.2709	0.3422	0.4150	0.4894	0.5654	0.6431	0.7224
90	0.1588	0.1948	0.2624	0.3314	0.4020	0.4740	0.5476	0.6228	0.6997
100	0.1638	0.1888	0.2544	0.3213	0.3897	0.4595	0.5309	0.6038	0.6783

[a] The manufacturer's listing specifies the temperature range for operation.

[b] W/V [agent weight requirements (kg/m^3)] = kilograms required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$W = \frac{V}{s}\left(\frac{C}{100 - C}\right)$$

[c] t [temperature (°C)] = the design temperature in the hazard area

[d] s [specific volume (m^3/kg)] = specific volume of superheated FIC-13I1 vapor can be approximated by the formula:

$$s = 0.1138 + 0.0005\,t$$

where t = temperature (°C)

[e] C [concentration (%)] = volumetric concentration of FIC-13I1 in air at the temperature indicated

A-3-5.2 The volume of inert gas clean agent required to develop a given concentration will be greater than the final volume remaining in the same enclosure. In most cases the inert gas clean agent must be applied in a manner that promotes progressive mixing of the atmosphere. As the clean agent is injected, the displaced atmosphere is exhausted freely from the enclosure through small openings or through special vents. Some inert gas clean agent is therefore lost with the vented atmosphere. This loss becomes greater at high concentrations. This method of application is called "free efflux" flooding.

Under these conditions the volume of inert gas clean agent required to develop a given concentration in the atmosphere is expressed by the following equations:

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

or

$$X = 2.303\ \mathrm{Log}_{10}\ \frac{100}{100 - \%\ IG}$$

where:

% IG = volume percent of inert gas
X = volume of inert gas added per volume of space

Tables A-3-5.2(a) through A-3-5.2(h) provide the amount of clean agent needed to achieve design concentration.

Table A-3-5.2(a) IG-01 Total Flooding Quantity (English Units)[a]

Temp. t (°F)[c]	Specific Vapor Volume s (ft^3/lb)[d]	Volume Requirements of Agent per Unit Volume of Hazard, $V_{agent}/V_{enclosure}$[b] Design Concentration (% by Volume)[e]							
		34	**37**	**40**	**42**	**47**	**49**	**58**	**62**
−40	7.67176	0.524	0.583	0.645	0.688	0.801	0.850	1.095	1.221
−30	7.85457	0.512	0.570	0.630	0.672	0.783	0.830	1.069	1.193
−20	8.03738	0.501	0.557	0.615	0.656	0.765	0.811	1.045	1.166
−10	8.22019	0.489	0.544	0.602	0.642	0.748	0.793	1.022	1.140
0	8.40299	0.479	0.532	0.589	0.628	0.732	0.776	1.000	1.115
10	8.58580	0.469	0.521	0.576	0.614	0.716	0.759	0.978	1.091
20	8.76861	0.459	0.510	0.564	0.602	0.701	0.744	0.958	1.088
30	8.95142	0.449	0.500	0.553	0.589	0.687	0.728	0.938	1.047
40	9.13422	0.440	0.490	0.541	0.577	0.673	0.714	0.920	1.026
50	9.31703	0.432	0.480	0.531	0.566	0.660	0.700	0.902	1.006
60	9.49984	0.424	0.471	0.521	0.555	0.647	0.686	0.884	0.986
70	9.68265	0.416	0.462	0.511	0.545	0.635	0.673	0.868	0.958
80	9.86545	0.408	0.453	0.501	0.535	0.623	0.661	0.851	0.950
90	10.04826	0.400	0.445	0.492	0.525	0.612	0.649	0.836	0.932
100	10.23107	0.393	0.437	0.483	0.516	0.601	0.637	0.821	0.916
110	10.41988	0.386	0.430	0.475	0.506	0.590	0.626	0.807	0.900
120	10.59668	0.380	0.422	0.467	0.498	0.580	0.615	0.793	0.884
130	10.77949	0.373	0.415	0.459	0.489	0.570	0.605	0.779	0.869
140	10.96230	0.367	0.408	0.451	0.481	0.561	0.595	0.766	0.855
150	11.14511	0.361	0.401	0.444	0.473	0.552	0.585	0.754	0.841
160	11.32791	0.355	0.395	0.437	0.466	0.543	0.576	0.742	0.827
170	11.51072	0.350	0.389	0.430	0.458	0.534	0.586	0.730	0.814
180	11.69353	0.344	0.383	0.423	0.451	0.526	0.558	0.718	0.801
190	11.87634	0.339	0.377	0.416	0.444	0.518	0.549	0.707	0.789
200	12.05914	0.334	0.371	0.410	0.437	0.510	0.541	0.697	0.777

[a] The manufacturer's listing specifies the temperature range for operation.

[b] X [agent volume requirements (lb/ft^3)] = volume of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \times \left(\frac{V_S}{s}\right) \times \mathrm{Log}_{10}\left(\frac{100}{100 - C}\right) = \left(\frac{V_S}{s}\right) \times \ln\left(\frac{100}{100 - C}\right)$$

[c] t [temperature (°F)] = the design temperature in the hazard area

[d] s [specific volume (ft^3/lb)] = specific volume of superheated IG-01 vapor can be approximated by the formula:

$$s = 8.514 + 0.0185t$$

where t = temperature (°F)

[e] C [concentration (%)] = volumetric concentration of IG-01 in air at the temperature indicated

Note: V_S = The term $X = \ln\,[100/(100 - C)]$ gives the volume at a rated concentration (%) and temperature to reach an air–agent mixture at the end of flooding time in a volume of 1 m^3.

Table A-3-5.2(b) IG-01 Total Flooding Quantity (SI Units)[a]

Temp. t **(°C)**[c]	**Specific Vapor Volume** s **(m^3/kg)**[d]	**Volume Requirements of Agent per Unit Volume of Hazard, $V_{agent}/V_{enclosure}$**[b] **Design Concentration (% by Volume)**[e]							
		34	**37**	**40**	**42**	**47**	**49**	**58**	**62**
–20	0.5201	0.4812	0.5350	0.5915	0.6308	0.7352	0.7797	1.0046	1.1205
–10	0.5406	0.4629	0.5147	0.5691	0.6068	0.7073	0.7501	0.9664	1.0779
0	0.5612	0.4459	0.4950	0.5482	0.5846	0.6814	0.7226	0.9310	1.0384
10	0.5817	0.4302	0.4784	0.5289	0.5640	0.6573	0.6971	0.8981	1.0018
15	0.5920	0.4227	0.4701	0.5197	0.5542	0.6459	0.6850	0.8828	0.9844
20	0.6023	0.4155	0.4620	0.5108	0.5447	0.6349	0.6733	0.8675	0.9676
30	0.6228	0.4018	0.4468	0.4940	0.5268	0.6139	0.6511	0.8389	0.9357
35	0.6331	0.3953	0.4395	0.4860	0.5182	0.6040	0.6406	0.8253	0.9205
40	0.6434	0.3890	0.4325	0.4762	0.5099	0.5943	0.0303	0.8121	0.9058
50	0.6639	0.3769	0.4191	0.4634	0.4942	0.5759	0.6108	0.7870	0.8778
60	0.6845	0.3656	0.4066	0.4495	0.4793	0.5587	0.5925	0.7633	0.8514
70	0.7050	0.3550	0.3947	0.4304	0.4054	0.5424	0.5752	0.7411	0.0200
80	0.7256	0.3449	0.3835	0.4240	0.4522	0.5270	0.5589	0.7201	0.8032
90	0.7461	0.3354	0.3730	0.4124	0.4397	0.5125	0.5436	0.7003	0.7811
100	0.7666	0.3264	0.3630	0.4013	0.4270	0.4988	0.5290	0.6815	0.7601
110	0.7872	0.3179	0.3535	0.3008	0.4168	0.4857	0.5152	0.6637	0.7403
120	0.8077	0.3098	0.3445	0.3809	0.4062	0.4734	0.5021	0.6468	0.7215

[a] The manufacturer's listing specifies the temperature range for operation.

[b] X [agent volume requirements (kg/m^3)] = volume of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \times \left(\frac{V_S}{s}\right) \times \text{Log}_{10}\left(\frac{100}{100 - C}\right) = \left(\frac{V_S}{s}\right) \times \ln\left(\frac{100}{100 - C}\right)$$

[c] t [temperature (°C)] = the design temperature in the hazard area

[d] s [specific volume (m^3/kg)] = specific volume of superheated IG-01 vapor can be approximated by the formula:

$$s = 0.5685 + 0.00208t$$

where t = temperature (°C)

[e] C [concentration (%)] = volumetric concentration of IG-01 in air at the temperature indicated

Note: The term $X = \ln[100/(100 - C)]$ gives the volume at a rated concentration (%) and temperature to reach an air–agent mixture at the end of flooding time in a volume of 1 m^3.

Table A-3-5.2(c) IG-100 Total Flooding Quantity (English Units)[a]

Temp. t (°F)[c]	Specific Vapor Volume s (ft^3/lb)[d]	Volume Requirements of Agent per Unit Volume of Hazard, $V_{agent}/V_{enclosure}$[b]							
		Design Concentration (% by Volume)[e]							
		34	**37**	**40**	**42**	**47**	**49**	**58**	**62**
–40	10.934	0.522	0.581	0.642	0.685	0.798	0.847	1.091	1.216
–30	11.195	0.510	0.567	0.627	0.669	0.780	0.827	1.065	1.188
–20	11.455	0.499	0.554	0.613	0.654	0.762	0.808	1.041	1.161
–10	11.716	0.488	0.542	0.599	0.639	0.745	0.790	1.018	1.135
0	11.976	0.477	0.530	0.586	0.625	0.729	0.773	0.996	1.111
10	12.237	0.467	0.519	0.574	0.612	0.713	0.756	0.975	1.087
20	12.497	0.457	0.508	0.562	0.599	0.698	0.741	0.954	1.064
30	12.758	0.448	0.498	0.550	0.587	0.684	0.726	0.935	1.043
40	13.018	0.439	0.488	0.539	0.575	0.670	0.711	0.916	1.022
50	13.279	0.430	0.478	0.529	0.564	0.657	0.697	0.898	1.002
60	13.540	0.422	0.469	0.519	0.553	0.645	0.684	0.881	0.982
70	13.800	0.414	0.460	0.509	0.543	0.632	0.671	0.864	0.964
80	14.061	0.406	0.452	0.499	0.533	0.621	0.658	0.848	0.946
90	14.321	0.399	0.444	0.490	0.523	0.609	0.646	0.833	0.929
100	14.582	0.392	0.436	0.482	0.514	0.599	0.635	0.818	0.912
110	14.842	0.385	0.428	0.473	0.505	0.588	0.624	0.803	0.896
120	15.103	0.378	0.421	0.465	0.496	0.578	0.613	0.790	0.881
130	15.363	0.372	0.413	0.457	0.487	0.568	0.602	0.776	0.866
140	15.624	0.366	0.407	0.449	0.479	0.559	0.592	0.763	0.851
150	15.885	0.360	0.400	0.442	0.471	0.549	0.583	0.751	0.837
160	16.145	0.354	0.393	0.435	0.464	0.541	0.573	0.739	0.824
170	16.406	0.348	0.387	0.428	0.456	0.532	0.564	0.727	0.811
180	16.666	0.343	0.381	0.421	0.449	0.524	0.555	0.716	0.798
190	16.927	0.337	0.375	0.415	0.442	0.516	0.547	0.705	0.786
200	17.187	0.332	0.370	0.409	0.436	0.508	0.539	0.694	0.774

[a] The manufacturer's listing specifies the temperature range for operation.

[b] X [agent volume requirements (lb/ft^3)] = volume of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \times \left(\frac{V_S}{s}\right) \times \mathrm{Log}_{10}\left(\frac{100}{100-C}\right) = \left(\frac{V_S}{s}\right) \times \ln\left(\frac{100}{100-C}\right)$$

[c] t [temperature (°F)] = the design temperature in the hazard area

[d] s [specific volume (ft^3/lb)] = specific volume of superheated IG-100 vapor can be approximated by the formula:

$$s = 11.976 + 0.02606t$$

where t = temperature (°F)

[e] C [concentration (%)] = volumetric concentration of IG-100 in air at the temperature indicated

Note: V_S = The term $X = \ln[100/(100 - C)]$ gives the volume at a rated concentration (%) and temperature to reach an air–agent mixture at the end of flooding time in a volume of 1 ft^3.

Table A-3-5.2(d) IG-100 Total Flooding Quantity (SI Units)[a]

Temp. t (°C)[c]	Specific Vapor Volume s (m^3/kg)[d]	Volume Requirements of Agent per Unit Volume of Hazard, $V_{agent}/V_{enclosure}$[b] Design Concentration (% by Volume)[e]							
		34	**37**	**40**	**42**	**47**	**49**	**58**	**62**
–40	0.6826	0.5225	0.5809	0.6423	0.6849	0.7983	0.8466	1.0908	1.2166
–30	0.7119	0.5009	0.5570	0.6159	0.6567	0.7654	0.8118	1.0459	1.1665
–20	0.7412	0.4811	0.5350	0.5915	0.6308	0.7352	0.7797	1.0045	1.1204
–10	0.7704	0.4629	0.5147	0.5691	0.6069	0.7073	0.7501	0.9664	1.0779
0	0.7997	0.4459	0.4959	0.5482	0.5846	0.6814	0.7227	0.9310	1.0384
10	0.8290	0.4302	0.4783	0.5289	0.5640	0.6573	0.6971	0.8981	1.0017
20	0.8582	0.4155	0.4621	0.5109	0.5448	0.6349	0.6734	0.8676	0.9677
30	0.8875	0.4018	0.4468	0.4940	0.5268	0.6140	0.6512	0.8389	0.9357
40	0.9168	0.3890	0.4325	0.4782	0.5100	0.5943	0.6304	0.8121	0.9058
50	0.9461	0.3769	0.4191	0.4634	0.4942	0.5759	0.6108	0.7870	0.8778
60	0.9753	0.3657	0.4066	0.4495	0.4794	0.5587	0.5925	0.7634	0.8515
70	1.0046	0.3550	0.3947	0.4364	0.4654	0.5424	0.5753	0.7411	0.8266
80	1.0339	0.3449	0.3835	0.4241	0.4522	0.5270	0.5590	0.7201	0.8032
90	1.0631	0.3355	0.3730	0.4124	0.4398	0.5126	0.5436	0.7004	0.7812
100	1.0924	0.3265	0.3630	0.4013	0.4280	0.4988	0.5290	0.6816	0.7602

[a] The manufacturer's listing specifies the temperature range for operation.

[b] X [agent volume requirements (kg/m^3)] = volume of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \times \left(\frac{V_S}{s}\right) \times \text{Log}_{10}\left(\frac{100}{100 - C}\right) = \left(\frac{V_S}{s}\right) \times \ln\left(\frac{100}{100 - C}\right)$$

[c] t [temperature (°C)] = the design temperature in the hazard area

[d] s [specific volume (m^3/kg)] = specific volume of superheated IG-100 vapor can be approximated by the formula:

$$s = 0.7997 + 0.00293\,t$$

where t = temperature (°C)

[e] C [concentration (%)] = volumetric concentration of IG-100 in air at the temperature indicated

Note: The term $X = \ln[100/(100 - C)]$ gives the volume at a rated concentration (%) and temperature to reach an air–agent mixture at the end of flooding time in a volume of 1 m^3.

Table A-3-5.2(e) IG-541 Total Flooding Quantity (English Units)[a]

Temp.	**Specific Vapor Volume**	**Volume Requirements of Agent per Unit Volume of Hazard, $V_{agent}/V_{enclosure}$**[b] **Design Concentration (% by Volume)**[e]							
t **(°F)**[c]	***s*** **(ft^3/lb)**[d]	**34**	**38**	**42**	**46**	**50**	**54**	**58**	**62**
–40	9.001	0.524	0.603	0.686	0.802	0.873	0.977	1.096	1.218
–30	9.215	0.513	0.590	0.672	0.760	0.855	0.958	1.070	1.194
–20	9.429	0.501	0.576	0.657	0.743	0.836	0.936	1.046	1.166
–10	9.644	0.490	0.563	0.642	0.726	0.817	0.915	1.022	1.140
0	9.858	0.479	0.551	0.628	0.710	0.799	0.895	1.000	1.116
10	10.072	0.469	0.539	0.615	0.695	0.782	0.876	0.979	1.092
20	10.286	0.459	0.528	0.602	0.681	0.766	0.858	0.958	1.069
30	10.501	0.450	0.517	0.590	0.667	0.750	0.840	0.939	1.047
40	10.715	0.441	0.507	0.578	0.653	0.735	0.824	0.920	1.026
50	10.929	0.432	0.497	0.566	0.641	0.721	0.807	0.902	1.006
60	11.144	0.424	0.487	0.555	0.628	0.707	0.792	0.885	0.987
70	11.358	0.416	0.478	0.545	0.616	0.693	0.777	0.868	0.968
80	11.572	0.408	0.469	0.535	0.605	0.681	0.762	0.852	0.950
90	11.787	0.401	0.461	0.525	0.594	0.668	0.749	0.836	0.933
100	12.001	0.393	0.453	0.516	0.583	0.656	0.735	0.821	0.916
110	12.215	0.386	0.445	0.507	0.573	0.645	0.722	0.807	0.900
120	12.429	0.380	0.437	0.498	0.563	0.634	0.710	0.793	0.884
130	12.644	0.373	0.430	0.489	0.554	0.623	0.698	0.779	0.869
140	12.858	0.367	0.422	0.481	0.544	0.612	0.686	0.766	0.855
150	13.072	0.361	0.415	0.473	0.535	0.602	0.675	0.754	0.841
160	13.287	0.355	0.409	0.466	0.527	0.593	0.664	0.742	0.827
170	13.501	0.350	0.402	0.458	0.518	0.583	0.653	0.730	0.814
180	13.715	0.344	0.396	0.451	0.510	0.574	0.643	0.718	0.801
190	13.930	0.339	0.390	0.444	0.502	0.565	0.633	0.707	0.789
100	14.144	0.334	0.384	0.437	0.495	0.557	0.624	0.697	0.777

[a] The manufacturer's listing specifies the temperature range for operation.

[b] X [agent volume requirements (lb/ft^3) = volume of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \times \left(\frac{V_S}{s}\right) \times \text{Log}_{10}\left(\frac{100}{100-C}\right) = \left(\frac{V_S}{s}\right) \times \ln\left(\frac{100}{100-C}\right)$$

[c] t [temperature (°F)] = the design temperature in the hazard area

[d] s [specific volume (ft^3/lb)] = specific volume of superheated IG-541 vapor can be approximated by the formula:

$$s = 9.8579 + 0.02143t$$

where t = temperature (°F)

[e] C [concentration (%)] = volumetric concentration of IG-541 in air at the temperature indicated

Note: V_S = The term $X = \ln[100/(100-C)]$ gives the volume at a rated concentration (%) and temperature to reach an air–agent mixture at the end of flooding time in a volume of 1 ft^3.

Table A-3-5.2(f) IG-541 Total Flooding Quantity (SI Units)[a]

Temp. t (°C)[c]	Specific Vapor Volume s (m^3/kg)[d]	Volume Requirements of Agent per Unit Volume of Hazard, $V_{agent}/V_{enclosure}$[b] Design Concentration (% by Volume)[e]							
		34	38	42	46	50	54	58	62
–40	0.562	0.524	0.603	0.686	0.802	0.873	0.977	1.093	1.218
–30	0.591	0.502	0.578	0.657	0.769	0.837	0.936	1.048	1.167
–20	0.611	0.482	0.555	0.631	0.738	0.803	0.899	1.006	1.121
–10	0.635	0.464	0.534	0.608	0.711	0.774	0.866	0.969	1.080
0	0.659	0.447	0.515	0.568	0.685	0.745	0.834	0.933	1.040
10	0.683	0.431	0.496	0.565	0.660	0.719	0.804	0.900	1.003
20	0.707	0.417	0.480	0.546	0.639	0.695	0.778	0.870	0.970
30	0.731	0.403	0.464	0.528	0.617	0.672	0.752	0.841	0.937
40	0.755	0.390	0.449	0.511	0.597	0.650	0.727	0.814	0.907
50	0.780	0.378	0.435	0.495	0.579	0.630	0.705	0.788	0.878
60	0.804	0.356	0.422	0.480	0.562	0.611	0.684	0.766	0.853
70	0.828	0.346	0.410	0.466	0.545	0.593	0.664	0.743	0.828
80	0.852	0.337	0.398	0.453	0.530	0.576	0.645	0.722	0.804
90	0.876	0.337	0.387	0.441	0.516	0.561	0.628	0.702	0.783
100	0.900	0.328	0.377	0.429	0.502	0.546	0.611	0.684	0.762

[a] The manufacturer's listing specifies the temperature range for operation.

[b] X [agent volume requirements (kg/m^3) = volume of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \times \left(\frac{V_S}{s}\right) \times \text{Log}_{10}\left(\frac{100}{100 - C}\right) = \left(\frac{V_S}{s}\right) \times \ln\left(\frac{100}{100 - C}\right)$$

[c] t [temperature (°C)] = the design temperature in the hazard area

[d] s [specific volume (m^3/kg)] = specific volume of superheated IG-541 vapor can be approximated by the formula:

$$s = 0.65799 + 0.00239\,t$$

where t = temperature (°C)

[e] C [concentration (%)] = volumetric concentration of IG-541 in air at the temperature indicated

Note: The term $X = \ln[100/(100 - C)]$ gives the volume at a rated concentration (%) and temperature to reach an air–agent mixture at the end of flooding time in a volume of 1 m^3.

Table A-3-5.2(g) IG-55 Total Flooding Quantity (English Units)[a]

Temp. t (°F)[c]	Specific Vapor Volume s (ft^3/lb)[d]	Volume Requirements of Agent per Unit Volume of Hazard, $V_{agent}/V_{enclosure}$[b] Design Concentration (% by Volume)[e]							
		34	38	42	46	50	54	58	62
–40	9.02108	0.524	0.603	0.688	0.778	0.875	0.980	1.095	1.221
–30	9.23603	0.512	0.589	0.672	0.760	0.854	0.957	1.069	1.193
–20	9.45099	0.501	0.576	0.656	0.742	0.835	0.935	1.045	1.166
–10	9.66594	0.489	0.563	0.642	0.726	0.816	0.915	1.022	1.140
0	9.88090	0.479	0.551	0.628	0.710	0.799	0.895	1.000	1.115
10	10.09586	0.469	0.539	0.614	0.695	0.782	0.876	0.978	1.091
20	10.31081	0.459	0.528	0.602	0.680	0.765	0.857	0.958	1.068
30	10.52577	0.449	0.517	0.589	0.667	0.750	0.840	0.938	1.047
40	10.74073	0.440	0.507	0.577	0.653	0.735	0.823	0.920	1.026
50	10.95568	0.432	0.497	0.566	0.640	0.720	0.807	0.902	1.006
60	11.17064	0.424	0.487	0.555	0.628	0.706	0.791	0.884	0.986
70	11.38560	0.416	0.478	0.545	0.616	0.693	0.777	0.868	0.968
80	11.60055	0.408	0.469	0.535	0.605	0.680	0.762	0.851	0.950
90	11.81551	0.400	0.461	0.525	0.594	0.668	0.748	0.836	0.932
100	12.03046	0.393	0.452	0.516	0.583	0.656	0.735	0.821	0.916
110	12.24542	0.386	0.444	0.506	0.573	0.644	0.722	0.807	0.900
120	12.46038	0.380	0.437	0.498	0.563	0.633	0.710	0.793	0.884
130	12.67533	0.373	0.429	0.489	0.553	0.623	0.698	0.779	0.869
140	12.89029	0.367	0.422	0.481	0.544	0.612	0.686	0.766	0.855
150	13.10525	0.361	0.415	0.473	0.535	0.602	0.675	0.754	0.841
160	13.32020	0.355	0.409	0.466	0.527	0.592	0.664	0.742	0.827
170	13.53516	0.350	0.402	0.458	0.518	0.583	0.653	0.730	0.814
180	13.75012	0.344	0.396	0.451	0.510	0.574	0.643	0.718	0.801
190	13.96507	0.339	0.390	0.444	0.502	0.565	0.633	0.707	0.789
200	14.18003	0.334	0.384	0.437	0.495	0.557	0.623	0.697	0.777

[a] The manufacturer's listing specifies the temperature range for operation.

[b] X [agent volume requirements (lb/ft^3)] = volume of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \times \left(\frac{V_S}{s}\right) \times \mathrm{Log}_{10}\left(\frac{100}{100 - C}\right) = \left(\frac{V_S}{s}\right) \times \ln\left(\frac{100}{100 - C}\right)$$

[c] t [temperature (°F)] = the design temperature in the hazard area

[d] s [specific volume (ft^3/lb)] = specific volume of superheated IG-55 vapor can be approximated by the formula:

$$s = 9.8809 + 0.0215\,t$$

where t = temperature (°F)

[e] C [concentration (%)] = volumetric concentration of IG-55 in air at the temperature indicated

Note: V_S = The term $X = \ln[100/(100 - C)]$ gives the volume at a rated concentration (%) and temperature to reach an air–agent mixture at the end of flooding time in a volume of 1 ft^3.

Table A-3-5.2(h) IG-55 Total Flooding Quantity (SI Units)[a]

Temp. t (°C)[c]	Specific Vapor Volume s (m^3/kg)[d]	Volume Requirements of Agent per Unit Volume of Hazard, $V_{agent}/V_{enclosure}$[b] Design Concentration (% by Volume)[e]							
		34	38	42	46	50	54	58	62
−40	0.56317	0.524	0.603	0.688	0.778	0.875	0.980	1.095	1.221
−35	0.56324	0.513	0.591	0.673	0.761	0.856	0.959	1.072	1.196
−30	0.58732	0.503	0.579	0.659	0.746	0.839	0.940	1.050	1.171
−25	0.59940	0.493	0.567	0.646	0.731	0.822	0.921	1.029	1.147
−20	0.61148	0.483	0.556	0.633	0.716	0.806	0.903	1.008	1.125
−15	0.62355	0.474	0.545	0.621	0.702	0.790	0.885	0.989	1.103
−10	0.63563	0.465	0.535	0.609	0.689	0.775	0.868	0.970	1.082
−5	0.64771	0.456	0.525	0.598	0.676	0.761	0.852	0.952	1.062
0	0.65979	0.448	0.515	0.587	0.664	0.747	0.837	0.935	1.042
5	0.67186	0.440	0.506	0.576	0.652	0.733	0.822	0.918	1.024
10	0.68394	0.432	0.497	0.566	0.640	0.720	0.807	0.902	1.006
15	0.69602	0.424	0.488	0.556	0.629	0.708	0.793	0.886	0.988
20	0.70810	0.417	0.480	0.547	0.619	0.696	0.779	0.871	0.971
25	0.72017	0.410	0.472	0.538	0.608	0.684	0.766	0.856	0.955
30	0.73225	0.403	0.464	0.529	0.598	0.673	0.754	0.842	0.939
35	0.74433	0.397	0.456	0.520	0.588	0.662	0.742	0.828	0.924
40	0.75641	0.390	0.449	0.512	0.579	0.651	0.730	0.815	0.909
45	0.76848	0.384	0.442	0.504	0.570	0.641	0.718	0.802	0.895
50	0.78056	0.378	0.435	0.496	0.561	0.631	0.707	0.790	0.881
55	0.79264	0.373	0.429	0.488	0.553	0.622	0.696	0.778	0.868
60	0.80471	0.367	0.422	0.481	0.544	0.612	0.686	0.766	0.855
65	0.81679	0.362	0.416	0.474	0.536	0.603	0.676	0.755	0.842
70	0.82887	0.356	0.410	0.467	0.528	0.594	0.666	0.744	0.830
75	0.84095	0.351	0.404	0.460	0.521	0.586	0.656	0.733	0.818
80	0.85302	0.346	0.398	0.454	0.513	0.578	0.647	0.723	0.806
85	0.86510	0.341	0.393	0.448	0.506	0.569	0.638	0.713	0.795
90	0.87718	0.337	0.387	0.441	0.499	0.562	0.629	0.703	0.784
95	0.88926	0.332	0.382	0.435	0.493	0.554	0.621	0.693	0.773
100	0.90133	0.328	0.377	0.430	0.486	0.547	0.612	0.684	0.763

[a] The manufacturer's listing specifies the temperature range for operation.

[b] X [agent volume requirements (kg/m^3) = volume of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \times \left(\frac{V_S}{s}\right) \times \mathrm{Log}_{10}\left(\frac{100}{100-C}\right) = \left(\frac{V_S}{s}\right) \times \ln\left(\frac{100}{100-C}\right)$$

[c] t [temperature (°C)] = the design temperature in the hazard area

[d] s [specific volume (m^3/kg)] = specific volume of superheated IG-55 vapor can be approximated by the formula:

$$s = 0.6598 + 0.00242\,t$$

where t = temperature (°C)

[e] C [concentration (%)] = volumetric concentration of IG-55 in air at the temperature indicated

Note: The term $X = \ln\,[100/(100 - C)]$ gives the volume at a rated concentration (%) and temperature to reach an air–agent mixture at the end of flooding time in a volume of 1 m^3.

A-3-5.3 The minimum design concentration based on the cup burner extinguishing concentration plus 30 percent or Class A fire test extinguishing concentration plus 20 percent should encompass design tolerances for most applications. However, these safety factors do not account for specific conditions or requirements for some particular applications that can require additional agent to ensure complete fire extinguishment. The following list gives certain conditions or considerations that can require the use of design factors that would increase the amount of agent used.

(a) *Unclosable openings (see also 3-7.2).* Special considerations should be taken into account when designing a fire suppression system for an enclosure that cannot or will not be sealed or closed before the fire suppression system is discharged. The loss of agent through the openings needs to be compensated for by some method.

Compensation for unclosable openings can be handled through extending the discharge time, which in turn extends the period of agent application. A method of determining the additional agent required/rate of application can be accomplished by conducting an enclosure integrity test per Appendix C.

When applying agent to compensate for the loss through an unclosable opening, consideration needs to be taken to extend the discharge of agent to enable the concentration within the enclosure to be held for a longer period of time. The discharge time defined in 3-7.1.2.1 is for the time required for the initial agent required to protect the enclosure without leakage through the unclosable openings. Without extending the discharge time for the additional agent being applied, leak rates through the unclosable openings will increase.

(b) *Acid gas formation considerations.* High concentrations of hydrogen fluoride (HF) can be expected at cup burner design concentrations. HF can be reduced by increasing the design concentration. Dramatic reduction can be achieved by increasing design concentration up to cup burner plus 30 percent. Above cup burner plus 30 percent, reduction in HF is not as dramatic. For further information see references Sheinson et al., 1994, and Sheinson et al., 1995.

(c) *Fuel geometry considerations.* For Class A and B fires, fuel geometry and compartment obstructions can affect agent concentration at the fire. Full-scale machinery space tests conducted by the Naval Research Laboratory (NRL) have shown that for a large (30,000-ft^3) enclosure with a complex obstructed fuel geometry, agent concentration can vary ±20 percent. Increasing the design concentration or adding or relocating discharge nozzles can compensate for concentrations below the design concentration. For further information see the Naval Research Laboratory report.

(d) *Enclosure geometry.* Typically in applications involving unusual enclosure geometries, agent distribution is addressed through nozzle placement. If the geometry of the enclosure (or system design) is such that the agent distribution can not be adequately addressed through nozzle placement, additional concentration should be considered. An example of such applications could be enclosures having very high or low aspect ratios (length/width).

(e) *Obstructions within the enclosure.* The three considerations that should be given to enclosure obstructions are as follows:

(1) Room volume should be calculated considering the room empty. Exceptions can only be made for structural components or shafts that pass through the room.

(2) For small room volumes, consideration should be given to equipment/storage that take up a considerable percentage of the room volume. Specifically, consider if the reduced volume will raise the effective concentration of the agent from the NOAEL to the LOAEL, in normally occupied spaces. However, this consideration must be closely balanced against the need to maintain an adequate concentration even when the room is empty.

(3) Obstructions located near the nozzle could block or impede agent discharge from the nozzle and could affect the distribution of the agent within the enclosure. Obstructions such as ducts, cable, trays, large conduits, and light fixtures have the potential to disrupt the flow pattern of the agent from the nozzle. If the flow of the agent is forced down to the floor, for example, it is unlikely that concentration will be achieved at the mid or upper elevations. Certainly uniform dispersion and concentration will not be achieved.

A-3-5.3.1 This design factor is meant to compensate for the uncertainty in the quantity of agent flowing through a pipe as the agent passes through an increasing number of tees. The listing tests generally incorporate systems with a very limited number of tees (2 to 4). If the number of tees in a system is greater than this, additional agent is required to compensate for the uncertainty at the tee splits to ensure that a sufficient quantity of agent is delivered to each hazard. Tees that deliver agent only to nozzles within a hazard are not counted for this design factor because it is believed mixing within the hazard will compensate for any discrepancy.

The design factor for the inert gases is less than the halocarbons because it is believed that the flow of inert gases can be more accurately predicted and inert gases are less sensitive to pipe variability.

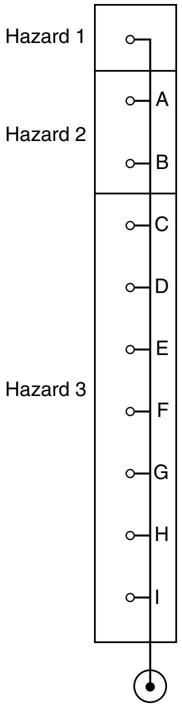
The following two examples illustrate the method for determining the design factor tee count. These examples may not represent good design practice.

(a) *Example 1.*

Hazard	Design Factor Tee Count *[See Figure A-3-5.3.1(a)]*
1	9 (tees A, B, C, D, E, F, G, H, I)
2	8 (tees C, D, E, F, G, H, I, A)
3	1 (tee C)

Therefore, if the system used a halocarbon agent, the design factor is 0.05, and if the system used an inert gas agent, the design factor would be 0.01.

FIGURE A-3-5.3.1(a) Piping for design factor tee count for Example 1.



(b) *Example 2.*

Hazard	Design Factor Tee Count *[See Figure A-3-5.3.1(b)]*
1	5 (tees B, C, D, E, F)
2	3 (tees B, E, H)
3	2 (tees E, F)

For Hazard 1, the branch consisting of tees H, I, and J, F is not used because the other branch has a greater tee count.

Therefore, if the system used a halocarbon agent, the design factor is 0.01, and if the system used an inert gas agent, the design factor would be 0.00.

A-3-5.3.2 The listing of engineered halon alternative systems requires running a number of tests that include measuring the agent quantity from each nozzle. To successfully pass these tests, the flow calculation software cannot overpredict the measured mass by more than 5 percent nor underpredict the measured mass by more than 10 percent. Experience performing these tests indicates the maximum laboratory accuracy for the calculations is ±5 percent of the measured value with a 90 percent certainty. This means that 90 percent of the measured agent quantities will be within ±5 percent of the predicted value. If the error is due to random factors, then this can be represented statistically by a normal (Gausian) distribution. A normal distribution curve is shown in Figure A-3-5.3.2(a), with the measured mass normalized by the predicted value. The resulting standard deviation is 0.0304 from standard tables (ref). These systems generally have 2 tees and 3 nozzles.

FIGURE A-3-5.3.1(b) Piping for design factor tee count for Example 2.

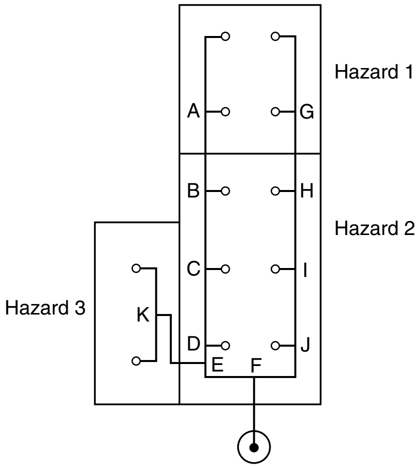
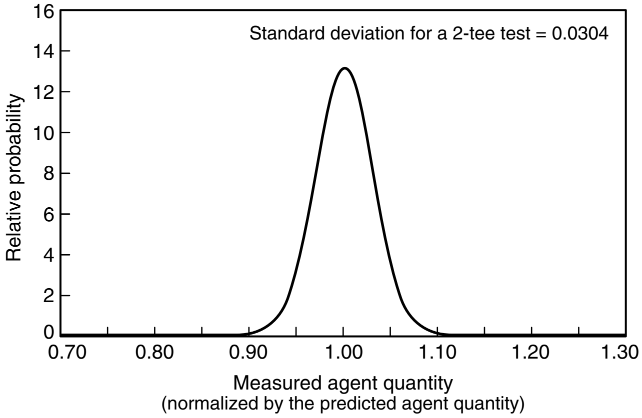


FIGURE A-3-5.3.2(a) Normal distribution curve.



For a system that utilizes more than 2 tees, the error will propagate and the certainty for the prediction of the agent quantity will be less. The more tees between a nozzle and the cylinder, the lower the certainty. This propagation of error can be calculated and results in a new normal distribution with a greater standard deviation. This can be calculated for any number of tees (ref). For example, the standard deviation for a system with 8 tees would be 0.0608.

For the purpose of this standard, the uncertainty for the prediction for an installed system is limited to having at least 99 percent of the nozzles deliver at least 90 percent of the predicted agent quantity. This implies not "using up" more than one half of the 20-percent safety factor for 99 percent of the nozzles. For a normal distribution with a standard deviation of 0.0608, the tail area representing 1 percent of the systems occurs at a normalized mass value of 0.859.

It is apparent that significantly more than 1 percent of the systems will have less than 90 percent of the predicted mass delivered. To rectify this situation, more agent shall be used in the system. This would move the entire probability curve up. The quantity of agent that would need to be added is as follows:

$$0.90 - 0.859 = 0.041 \quad \text{or} \quad 4.1 \text{ percent}$$

The addition of 4.1 percent more agent would ensure that 99 percent of the nozzles deliver at least 90 percent of the required mass of agent.

The analysis for Table A-3-5.3.2 was performed for up to 19 tees, 20 nozzles, in a system. *[See Figures A-3-5.3.2(b) through A-3-5.3.2(g).]*

Table A-3-5.3.2 Plastic Fuel Properties

Fuel	Description/Source	Density (g/cm^3)	Ignition Time at 25 kW/m^2 Irradiance(s)	180 Second Average Heat Release Rate at 25 kW/m^2 Irradiance(s)
PMMA	Polycast acrylic sheet Polycast Technology Corporation	1.190	77 (±10%)	304 (±10%)
PP	Polypropylene homopolymer/Poly Hi solidur Menasha Corporation	0.905	91 (±10%)	200 (±10%)
ABS	Absylux Westlake Plastics Company	1.040	115 (±10%)	425 (±10%)

FIGURE A-3-5.3.2(b) Distribution curve.

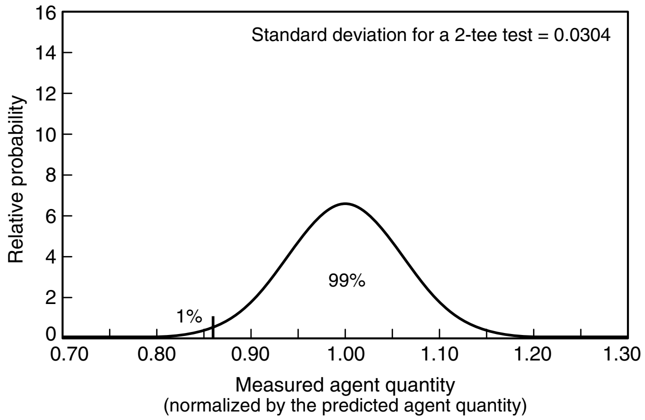


FIGURE A-3-5.3.2(c) Distribution curve.

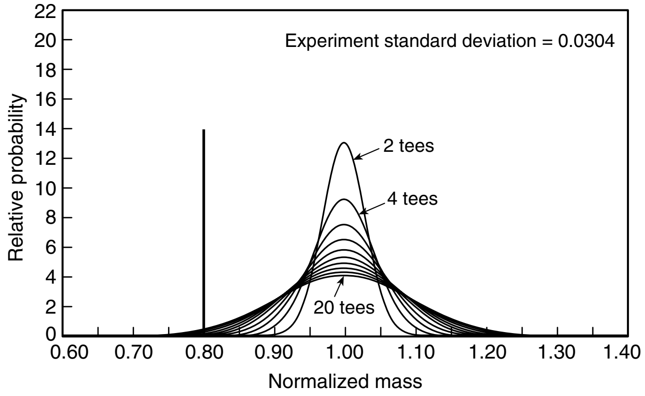


FIGURE A-3-5.3.2(d) Distribution curve.

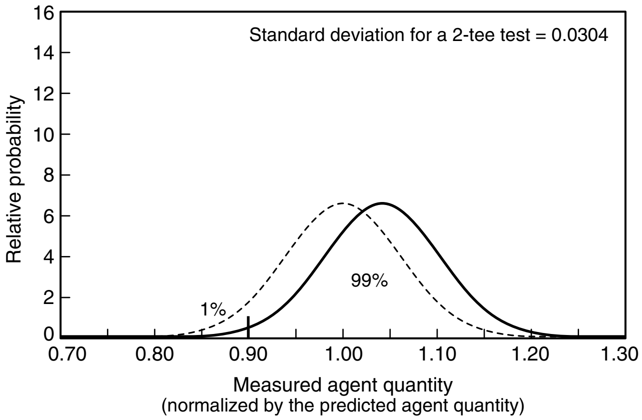


FIGURE A-3-5.3.2(e) Distribution curve.

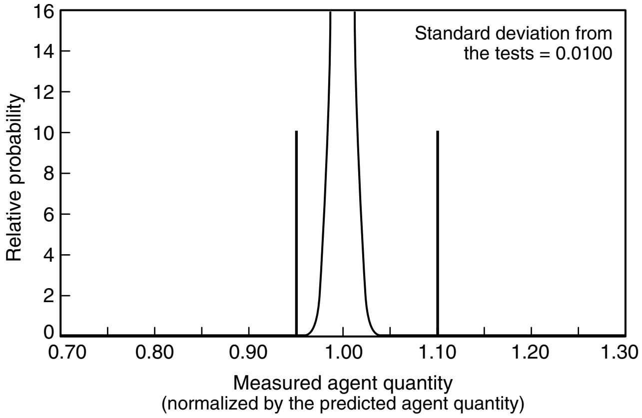


FIGURE A-3-5.3.2(f) Distribution curve.

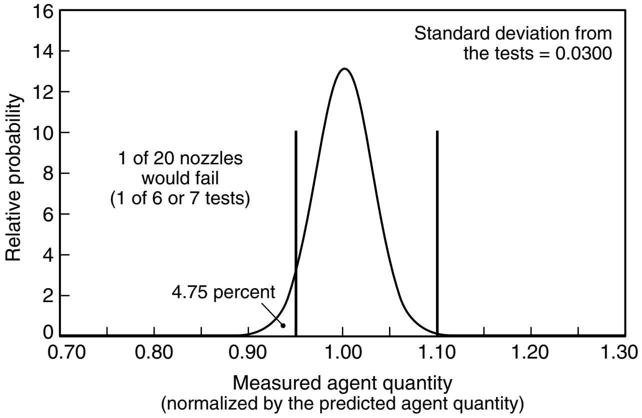
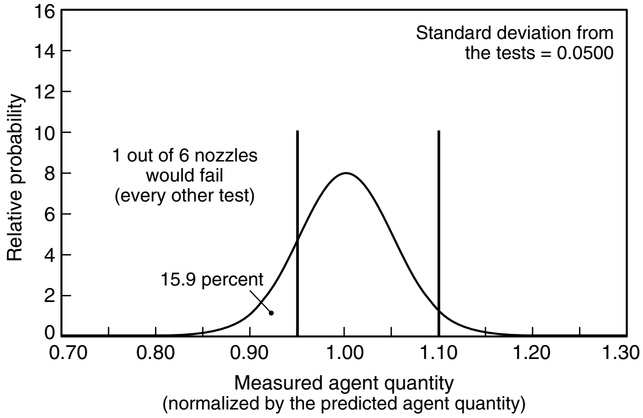


FIGURE A-3-5.3.2(g) Distribution curve.



A-3-5.3.3 Some areas effected by pressures other than sea level include hyperbaric enclosures, facilities where ventilation fans are used to create artificially higher or lower pressures such as test chambers, and facilities at altitudes above or below sea level. Although mines are usually below normal ground levels, they occasionally have to be ventilated so that personnel can work in that environment. Ambient pressures in that situation can be considerably different from those expected by a pure altitude correction.

Although adjustments are required for barometric pressures equivalent to 3000 ft (915 m) or more above or below sea level, adjustments can be made for any ambient pressure condition.

The atmospheric correction factor is not linear. However, in the moderate range discussed it can be closely approximated with two lines:

For –3000 ft to 5500 ft of equivalent altitude:

$Y = (-0.000036 \times X) + 1$

For 5501 ft to 10,000 ft of equivalent altitude:

$Y = (-0.00003 \times X) + 0.96$

where:

Y = correction factor

X = altitude (ft)

For SI units, 1 ft = 0.305 m.

The increase in safety factor for manually actuated systems and systems protecting Class B hazards, from the 1996 edition, is intended to account for the uncertainty in minimum design concentration associated with these types of systems and hazards.

The presence of hot metal surfaces, large fire sizes, increased fuel temperatures, and other variables associated with longer preburn times may increase the minimum extinguishing concentration needed for these types of fires. In addition the increased safety factor will serve to reduce decomposition product formation for halocarbon agents in the presence of larger fires expected in manually operated systems and Class B hazards.

There have been no reported system failures associated with these types of fires in fueled installations, and successful extinguishment events have been reported for systems designed and installed in accordance with previous editions of this standard.

This change is intended to enhance the overall effectiveness of new clean agent systems and is based on theoretical and laboratory experience. This change in safety factor does not apply to existing systems. No field experience indicates that any existing system designed with a 20-percent safety factor will not perform as intended.

The ambient pressure is affected by changes in altitude, pressurization or depressurization of the protected enclosure, and weather-related barometric pressure changes. The design factor to account for cases where the pressure of the protected hazard is different from atmospheric pressure is computed as the ratio of the nominal absolute pressure within the hazard divided by the average atmospheric pressure at sea level [14.7 psia/(1 bar)].

A-3-6 In establishing the hold time, designers and authorities having jurisdiction should consider the following or other unique factors that can influence the performance of the suppression system:

(1) Response time of trained personnel
(2) Sources of persistent ignition
(3) Excessive enclosure leakage
(4) System enclosure venting requirements
(5) Inertion and reflash hazards
(6) Wind down of rotating equipment

The hold time for the duration of protection should be sufficient to control the initial event and allow for support should resurgence occur once the agent has dissipated.

Energized electrical equipment that could provide a prolonged ignition source should be de-energized prior to or during agent discharge.

If electrical equipment cannot be de-energized, consideration should be given to the use of extended atent discharge, higher initial concentration, and the possibility of the formation of combustion and decomposition products. Additional testing can be needed on suppression of energized electrical equipment fires to determine these quantities.

Examples of methods developed to simulate overcurrents and heating along an electrical conductor are contained in two reports one by Hughes Associates Inc., Baltimore, MD, is as follows:

The first test, designed to replicate an overcurrent event, is called the Ohmic Heating Test. In this test, a length of power cable was overloaded electrically by connection to an arc welder, resulting in internal over-heating of the cable that leads to pyrolysis of the insulation material. A small pilot flame was applied to the sample after the conductors were heated and smoke was issuing from the center of the cable. A short pre-burn was allowed to reach a fully developed fire, and then the clean agent was discharged. Current was applied throughout the discharge, and continued for approximately 10 minutes following discharge to check for reflash (none was observed). The results of tests using HFC-227ea as the extinguishing agent, were reported in Table A-3-6(a).

In the second test method, called the Conductive Heating Test, the lower 4 in. (101 mm) of a 10.25-in. (260-mm) long sample of 350-mcm diameter power cable was clamped vertically inside a ring heater, ensuring firm contact between the inside of the heater and the copper conductor. The heater was set to 890°C, and the sample was heated until the temperature at the top of the sample reached 310°C. The sample was then ignited by a small pilot flame, and the ensuing fire was allowed to fully develop before agent discharge. The heater was energized throughout the discharge and for 10 minutes thereafter to check for reflash (none was observed). The results of tests using HFC-227ea as the extinguishing agent, were reported in Table A-3-6(b).

Table A-3-6(a) Ohmic Heating Suppression Test Results

Sample	Current	Number of Tests	HFC-227ea Concentration (%)	Extinguishment[1]
8 awg, cross-linked polyethylene, arranged in a horizontal bundle of 5 cables with only the center cable powered	350 A	4 1	5.8 5.0	Yes Yes
8 awg, cross-linked polyethylene cable, arranged in a vertical bundle of 5 cables with only the center cable powered	350 A	4 1	5.8 5.0	Yes Yes
12 awg, SJTW-A, 3 conductors per cable, arranged in a horizontal bundle of 6 cables with 4 of the 18 conductors powered	150 A	3 2 1	5.8 5.5 5.0	Yes Yes Yes
8 awg, PVC cable, arranged in a horizontal bundle of 7 cables with the center cable powered	325 A	3	5.8	Yes
18 awg, 3 conductors per cable, polyethylene insulation on conductors, with chrome PVC jacket around twisted conductors, 4 cable horizontal bundle, with 12 conductors powered	29 A	4	5.8	Yes[2]
16 awg, 12 conductors per cable, neoprene over rubber insulation, single horizontal cable, 9 conductors powered	56 A	3	5.8	Yes
18 awg, polyethylene insulated coaxial cable with the outer jacket and braided conductor removed (i.e., center core of the coaxial cable only), arranged in a horizontal bundle of 4 cables, all 4 conductors powered[3]	119 A	1 1 2 4 3	5.7 5.8 6.5 6.8 7.2	No No No Yes Yes

[1] In all cases where the fire was extinguished, the time to extinguishment from beginning of agent discharge was between 3 and 15 seconds.

[2] In one test the gas did not completely extinguish the fire.

[3] In this series, the polyethylene insulation melted and formed a pool fire. A tray was installed under the wire bundle so that the glowing wires were in contact with the molten pool of polyethylene.

Table A-3-6(b) Conductive Heating Suppression Test Results

Sample	Number of Tests	HFC-227ea Concentration (%)	Extinguishment	Average Time to Extinguishment (sec)
350 mcm copper cable, Hypalon insulation with cotton braid sheathing and saturant (Lucent KS-5482L)	1	5.2	Yes	20
	2	5.8		11
	1	5.9		7
	2	6.0		10
350 mcm copper cable, Hypalon insulation (Lucent KS-20921)	3	5.8	Yes	9
	1	5.9		11
	1	6.0		10

The second report is by Modular Protection Corporation, which is an update on the evaluation of selected NFPA agents for suppressing Class C energized fires.

The objective of the tests conducted by Modular Protection Corporation was to investigate the effectiveness of new clean agents to extinguish Class C energized fires of polymeric materials ignited by heat flux. Specific tests were conducted to determine the minimum agent concentration required to extinguish Class C energized fires and the minimum agent concentration required to prevent reflash/reignition.

The clean agents selected for testing were FC-2-1.8 (3M), FC-3-1-10 (3M), HFC-23 (DuPont), HFC-227ea (Great Lakes), and HFC-236fa (DuPont).

The criteria used for conducting tests on these clean agents were as follows:

Preburn	60 seconds
Discharge time	≤10 seconds
Flame extinguishment	<30 seconds
No reflash/reignition	≥10 seconds

Each clean agent was tested for minimum concentration required for flame extinguishment and minimum concentration required to prevent reflash/reignition for a period up to 10 minutes after flame extinguishment. The test protocol used to conduct the clean agent tests are displayed in Table A-3-6(c).

The results of the clean agent tests to determine minimum concentrations required to extinguish and to prevent reflash/reignition at energy levels of 48 W and 192 W are displayed in Table A-3-6(d).

Fire Extinguishment Test (Noncellulosic) Class A Surface Fires. The purpose of the tests outlined in this procedure is to develop the minimum extinguishing concentration (MEC) for a gaseous fire suppression agent for a range of noncellulosic, solid polymeric combustibles. It is intended that the MEC will be increased by appropriate safety factors and flooding factors as provided for in the standard.

These Class A tests should be conducted in a draft-free room with a volume of at least 100 m^3 and a minimum height of 3.5 m and each wall at least 4 m long. Provisions should be made for relief venting if required.

Table A-3-6(c) Test Protocol

Test Protocol	Fuel Sample/Wire Configuration	Energy Level (W)	Agent	Tests Conducted
1	4-in. long, 24-gauge, nichrome wire inserted in center of PMMA block (3 in. × 1 in. × $^{5}/_{8}$ in.)	48	FC-2-1-8	10
			FC-3-1-10	8
			HFC-23	7
			HFC-227ea	7
			HFC-236fa	13
2	12-in. long, 20-gauge, nichrome wire wrapped around PMMA block (3 in. × 2 in. × $^{1}/_{4}$ in.)	192	FC-2-1-8	6
			FC-3-1-10	12
			HFC-23	5
			HFC-227ea	7
			HFC-236fa	8

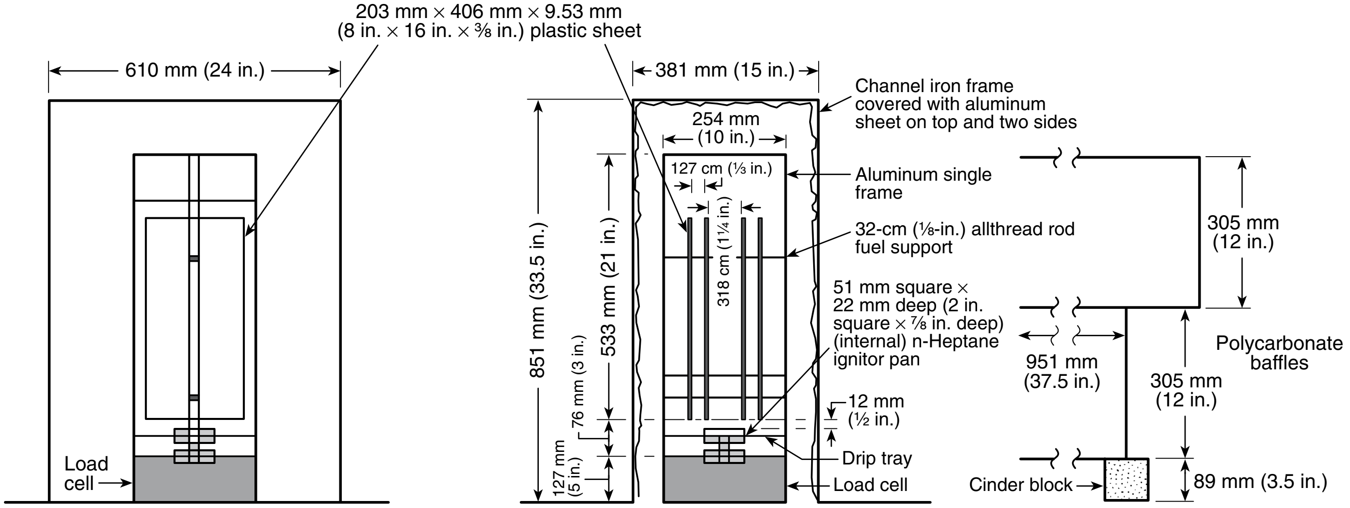
Table A-3-6(d) Test Results

Agent	Energy Level (W)	Extinguish (Minimum Concentration, Percent by Volume)	Prevent Reflash/ Reignition (Minimum Concentration, Percent by Volume)
FC-2-1-8	48	7.0	7.5
	192	9.0	12.0
FC-3-1-10	48	5.5	8.0
	192	6.5	9.5
HFC-23	48	13.0	16.0
	192	14.0	20.0
HFC-227ea	48	6.5	8.0
	192	8.0	9.0
HFC-236fa	48	6.3	6.5
	192	6.5	9.0

The test objects are as follows.

(a) The polymer fuel array consists of 4 sheets of polymer, 9.5 mm thick, 406 mm tall, and 203 mm wide. Sheets are spaced and located per Figure A-3-6(a). The bottom of the fuel array is located 203 mm from the floor. The fuel sheets should be mechanically fixed at the required spacing.

FIGURE A-3-6(a) Four piece modified plastic setup.



(b) A fuel shield consisting of a metal frame with sheet steel on the top and two sides is provided around the fuel array as indicated in Figure A-3-6(a). The fuel shield is 381 mm wide, 851 mm high, and 610 mm deep. The 610 mm wide × 851 mm high sides and the 610 mm × 381 mm top are sheet steel. The remaining two sides and the bottom are open. The fuel array is oriented in the fuel shield such that the 203-mm dimension of the fuel array is parallel to the 610-mm side of the fuel shield.

(c) Two external baffles measuring 0.95 m^2 and 305 mm tall are located around the exterior of the fuel shield as shown in Figure A-3-6(c). The baffles are placed 89 mm above the floor. The top baffle is rotated 45 degrees with respect to the bottom baffle.

(d) Tests are conducted for three plastic fuels — polymethyl methacrylate (PMMA), polypropylene (PP), and acrylonitrile-butadiene-styrene polymer (ABS). Plastic properties are given in Table A-3-6(e).

(e) The ignition source is a heptane pan 51 mm × 51 mm × 22 mm deep centered 12 mm below the bottom of the plastic sheets. The pan is filled with 3.0 mL of heptane to provide 90 seconds of burning.

(f) The agent delivery system should be distributed through an approved nozzle. The system should be operated at the minimum nozzle pressure (±10 percent) and the maximum discharge time (±1 second).

The test procedure is as follows.

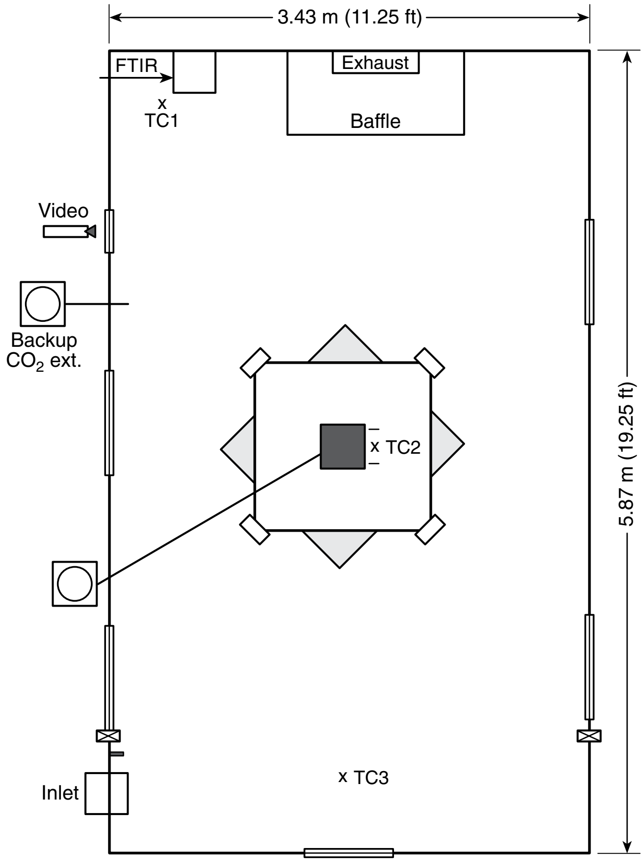
(a) The procedures for ignition are as follows:

(1) The heptane pan is ignited and allowed to burn for 90 seconds.

(2) The agent is discharged 210 seconds after ignition of heptane.

(3) The compartment remains sealed for 600 seconds after the end of discharge. Extinguishment time is noted. If the fire is not extinguished within 600 seconds of the end agent discharge, a higher minimum extinguishing concentration must be utilized.

FIGURE A-3-6(c) Chamber plan view.



x TC1 — 0 mm (0 in.), 305 mm (12 in.), 610 mm (24 in.), 915 mm (48 in.), 1.8 m (72 in.), 2.4 m (96 in.), 3 m (120 in.) from ceiling
x TC2 — 0 mm (0 in.), 305 mm (12 in.), 610 mm (24 in.), 915 mm (48 in.), 1.8 m (72 in.), 2.4 m (96 in.), 3 m (120 in.) from ceiling
x TC3 — 0 mm (0 in.), 305 mm (12 in.), 610 mm (24 in.), 915 mm (48 in.), 1.8 m (72 in.), 2.4 m (96 in.), 3 m (120 in.) from ceiling
☒ ODM — 305 mm (12 in.) down from ceiling
→ FTIR — 686 mm (27 in.) up from floor
▬ Noisemeter — 305 mm (12 in.) down from ceiling

Table A-3-6(e) Plastic Fuel Properties

25 kW/m² Exposure in Cone Calorimeter - ASTM E 1354								
			Ignition Time		180-Second Average Heat Release Rate		Effective Heat of Combustion	
Fuel	Color	Density (g/cm²)	sec	Tolerance	kW/m²	Tolerance	MJ/kg	Tolerance
PMMA	Black	1.19	77	±30%	286	25%	23.3	±15%
Polypropylene	Natural (White)	0.905	91	±30%	225	25%	39.8	±15%
ABS	Natural (Cream)	1.04	115	±30%	484	25%	29.1	±15%

(4) The test is repeated two times for each fuel for each concentration evaluated and the extinguishment time averaged for each fuel. Any one test with an extinguishment time above 600 seconds is considered a failure.
(5) If the fire is extinguished during the discharge period, the test is repeated at a lower concentration or additional baffling provided to ensure that local transient discharge effects are not impacting the extinguishment process.
(6) At the beginning of the tests, the oxygen concentration must be within 2 percent (approximately 0.5 percent by volume O_2) of ambient value.

During the postdischarge period, the oxygen concentration should not fall below 0.5 percent by volume of the oxygen level measured at the end of agent discharge.

(b) The observation and recording procedures are as follows:

(1) The following data must be continuously recorded during the test:
   a. Oxygen concentration (±0.5 percent)
   b. Fuel mass loss (±5 percent)
   c. Agent concentration (±5 percent) (Inert gas concentration can be calculated based on oxygen concentration.)
(2) The following event is timed and recorded:
   a. Time at which heptane is ignited
   b. Time of heptane pan burn out
   c. Time of plastic sheet ignition
   d. Time of beginning of agent discharge
   e. Time of end of agent discharge
   f. Time all visible flame is extinguished

The minimum extinguishing concentration is determined by all of the following conditions.

(1) All visible flame extinguished within 600 seconds of agent discharge.
(2) The fuel weight loss between 10 seconds and 600 seconds after the end of discharge should not exceed 15.0 g.
(3) No ignition of the fuel at the end of the 600-second soak time and subsequent test compartment ventilation.

A-3-7.1.2 The optimum discharge time is a function of many variables. The following five variables are very important:

(1) Limitation of decomposition products
(2) Limitation of fire damage and its effects
(3) Enhanced agent mixing
(4) Limitation of compartment overpressure
(5) Secondary nozzle effects

With regard to the potential threat to life or assets associated with a fire, it is essential that the end user understand that both the products of combustion and decomposition products formed from the suppression agent contribute to the total threat.

Essentially all fires will produce carbon monoxide and carbon dioxide, and the contribution of these products to the toxic threat posed by the fire event is well known. In the case of large fires, the high temperatures encountered can by themselves lead to life- and asset-threatening conditions. In addition, most fires produce smoke, and it is well documented that damage to sensitive assets can occur at very low levels of smoke. Depending upon the particular fuel involved, numerous toxic products of combustion can be produced in a fire, for example HCl, HBr, HF, HCN, CO, and other toxic products.

The halogenated hydrocarbon fire extinguishing agents described in this standard will break down into their decomposition products as they are exposed to a fire. It is essential that the end user understand this process as the selection of the discharge time and other design factors will be impacted by the amount of decomposition products the protected hazard can tolerate.

The concentration of thermal decomposition products produced from a halogenated fire suppression agent is dependent upon several factors. The size of the fire at the time of system activation and the discharge time of the suppression agent play major roles in determining the amount of decomposition products formed. The smaller the fire, the less energy (heat) is available to cause thermal decomposition of the suppression agent, and hence the lower the concentration of thermal decomposition products. The size of the fire at the time of system activation is dependent upon the fire growth rate, the detector sensitivity, and the system discharge delay time. The first factor is primarily a function of the fuel type and geometry, whereas the latter two are adjustable characteristics of the fire protection system. The discharge time affects the production of thermal decomposition products, as it determines the exposure time to the fire of sub-extinguishing concentrations of the fire suppression agent. Suppression systems have traditionally employed a combination of rapid detection and rapid discharge to limit both the production of thermal decomposition products and damage to assets by providing rapid flame extinguishment.

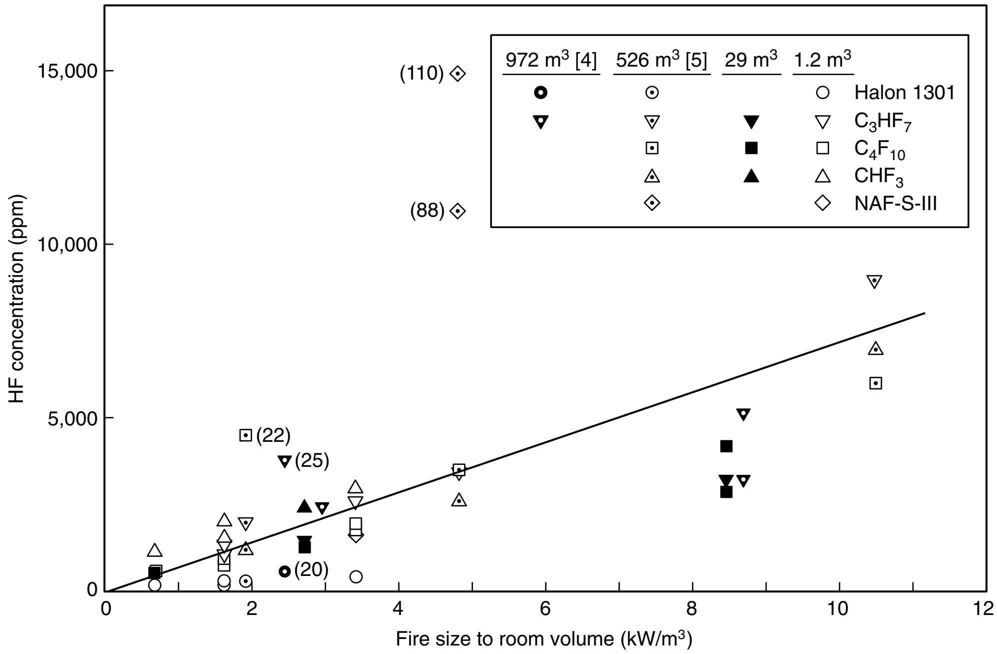
The enclosure volume also affects the concentration of thermal decomposition products produced, since larger volumes, that is, smaller fire size to room volume ratios, will lead to dilution of decomposition products. Additional factors affecting the concentration of thermal decomposition products include vaporization and mixing of the agent, the preburn time, the presence of hot surfaces or deep-seated fires, and the suppression agent concentration.

This decomposition issue is not unique to the new clean halogenated agents. The thermal decomposition products resulting from the extinguishment of fires with Halon 1301 have been investigated by numerous authors (Ford, 1972, and Cholin, 1972), and it is well established that the most important Halon 1301 thermal decomposition products from the standpoint of potential toxicity to humans or potential corrosion of electronic equipment are the halogen acids HF and HBr. Concentrations of acid halides produced from Halon 1301 ranging from a few ppm to over 7000 ppm HF and HBr have been reported, depending upon the exact nature of the fire scenario (Sheinson et al., 1981). Smaller amounts of additional decomposition products can be produced, depending upon the particular conditions of the fire. Under certain conditions, thermal decomposition of Halon 1301 in a fire has been reported to produce small amounts of carbonyl fluoride (COF_2), carbonyl bromide ($COBr_2$), and bromine (Br_2), in addition to relatively large amounts of HF and HBr. Note that all of these products are subject to relatively rapid hydrolysis to form the acid halides HF and HBr (Cotton et al., 1980), and hence these acids constitute the product of primary concern from the standpoint of potential toxicity or corrosion.

As was the case for Halon 1301, the thermal decomposition products of primary concern for the halogenated agents described in this standard are the associated halogen acids, HF in the case of HFCs and PFCs, HF and HCl in the case of HCFC agents, and HF and HI in the case of I-containing agents. As was the case for Halon 1301, smaller amounts of other decomposition products can be produced, depending upon the particular conditions of the fire. In a fire, HFC or PFC agents can potentially produce small amounts of carbonyl fluoride (COF_2). HCFC agents can potentially produce carbonyl fluoride (COF_2), carbonyl chloride ($COCl_2$), and elemental chlorine (Cl_2), and I-containing compounds can potentially produce carbonyl fluoride (COF_2) and elemental iodine (I_2). All of these products are subject to relatively rapid hydrolysis (Cotton et al., 1980) to produce the associated halogen acid (HF or HCl or HI), and hence as indicated above, from the standpoint of potential toxicity to humans or potential corrosion of electronic equipment the halogen acids are the decomposition products of concern.

The dependence of decomposition product formation on the discharge time and fire size has been extensively evaluated (Sheinson et al., 1994; Brockway, 1994; Moore et al., 1993; Back et al., 1994; Forssell and DiNenno, 1995; DiNenno, 1993; Purser, 1998; and Dierdorf et al., 1993). Figure A-3-7.1.2(a) is a plot of peak HF concentration as a function of the fire size to room volume ratio. The data encompass room scales of 1.2 m^3 to 972 m^3. The 526-m^3 results are from U.S. Coast Guard (USCG) testing; the 972-m^3 results are based on NRL testing. These fires include diesel and heptane pool and spray fires. The design concentration in all cases except HCFC Blend A (at 8.6 percent) are at least 20 percent above the cup burner value. For fires where the extinguishment times were greater than 17 seconds, the extinguishment time is noted in brackets. Note that excessively high extinguishment times (>60 seconds), which is generally an indication of inadequate agent concentrations, yield qualitatively high HF concentrations. In addition, Halon 1301 will yield bromine and hydrogen bromide in addition to HF.

FIGURE A-3-7.1.2(a) Peak HF concentrations.



Extinguishment times (seconds) are given in brackets for fires that took longer than 17 seconds to extinguish.
If more than one fire was utilized, the longer extinguishment time is given.

The quantity of HF formed in the tests is approximately three to eight times higher for all of the halocarbon agents tested relative to Halon 1301 (which also forms bromine and hydrogen bromide). It is important to note that as pointed out by Peatross and Forssell (Peatross et al., 1996), in many of these large fire scenarios the levels of combustion products (e.g., CO) and the high temperatures involved make it unlikely that a person could survive large fires such as these, irrespective of the HF exposure. The iodine-containing agent CF_3I was not tested in the USCG or NRL studies, but other data available on CF_3I indicate that its production of HF is comparable to that of Halon 1301. In addition elemental iodine (I_2) is formed from CF_3I.

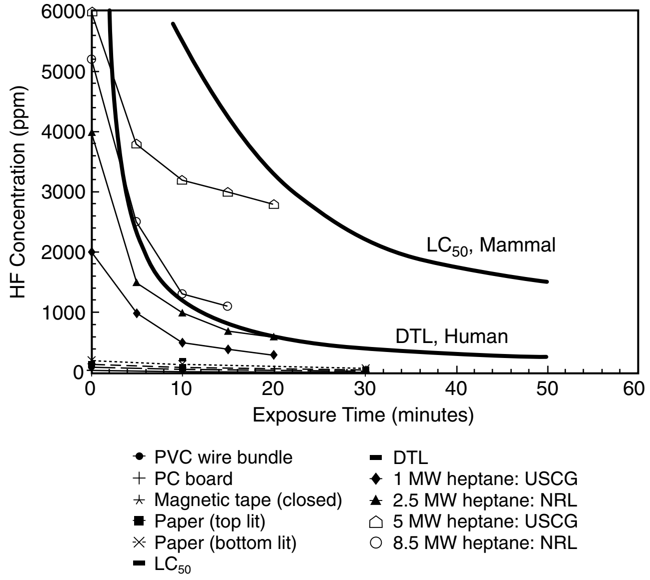
There may be differences between the various HFC/HCFC compounds tested, but it is not clear from these data whether such differences occur. In all the data reported, the fire sources — heptane or diesel pans of varying sizes — were baffled to prevent direct interaction with the agent.

While the above results are based upon Class B fuels, fires involving some Class A combustibles produce lower HF concentrations. For example, hazards such as those in electronic data processing and telecommunication facilities often result in fire sizes of less than 10 kW at detection (Meacham, 1974). In many cases in the telecommunication industry, detection at fire sizes of 1 kW is desired (Nist, 1998). Skaggs and Moore (Skaggs et al., 1994) have pointed out that for typical computer rooms and office spaces, the analysis of DiNenno, et al., (DiNenno, 1993) employing fire growth models and test data indicate that thermal decomposition product concentrations from the halogenated agents would be comparable to that from Halon 1301.

Tests by Hughes Associates, Inc., (Hughes Assoc., 1995) evaluated the thermal decomposition products resulting from the extinguishment of Class A fires typical of those encountered in telecommunication and electronic data processing (EDP) facilities by HFC-227ea. The test fuels included shredded paper, PC boards, PVC-coated wire cables, and magnetic tape, representing the most common fuel sources expected to burn in a computer room environment. All fires were extinguished with the minimum design concentration of 7 percent HFC-227ea. Figure A-3-7.1.2(b) (Peatross et al., 1996) shows the HF concentration resulting from these tests. Also shown in Figure A-3-7.1.2(b) is the approximate mammalian LC_{50} (Sax, 1984) and the dangerous toxic load (DTL) for humans based upon the analysis of Meldrum (Meldrum, 1993). As seen in Figure A-3-7.1.2(b), the HF levels produced in the computer room were below both the estimated mammalian LC_{50} and DTL curves. Peatross and Forssell (Peatross et al., 1996) in their analysis of the test results, concluded that "from an examination of the HF exposures, it is evident that this type of fire does not pose a toxic threat." Also shown in Figure A-3-7.1.2(b) are HF levels produced upon extinguishment of Class B fires of various sizes. In the case of these large Class B fires, HF levels in some cases can be seen to exceed the human DTL. It is important to note that as pointed out by Peatross and Forssell (Peatross et al., 1996), in many of these large fire scenarios the levels of combustion products (e.g., CO) and the high temperatures involved make it unlikely that a person could survive large fires such as these, irrespective of the HF exposure.

Some agents, such as inert gases, will not form decomposition products and hence do not require discharge time limitations on this basis. However, the increased combustion products and oxygen level reduction associated with longer discharge times should be considered.

FIGURE A-3-7.1.2(b) Hazard assessment of HF concentrations. Extinguishment of Typical EDP and Class B hazards with 7 percent HFC-227ea.



Agent mass flow rates must be sufficiently high to cause adequate agent mixing and distribution in the compartment. In general, this parameter is determined by the listing of system hardware.

Overpressurization of the protected compartment should also be considered in determining minimum discharge time.

Other secondary flow effects on personnel and equipment include formation of missiles caused by very high discharge velocities, higher noise levels, lifting ceiling panels, and so forth. These increase if the maximum discharge time is set too low.

The maximum 10-second discharge time given in this standard reflects a reasonable value based on experience with Halon 1301 systems. The maximum and minimum discharge times should reflect consideration of the factors described above.

For inert gases, the measured discharge time is considered to be the time when the measuring device starts to record reduction of oxygen until the design oxygen reduction level is achieved.

Systems designed for explosion prevention present particular design challenges. These systems typically discharge the agent, before ignition occurs, upon detection of some specified fraction of the lower flammable limit of the flammable vapors present.

A-3-7.1.2.1 The minimum design concentration for flame extinguishment is defined in 3-4.2.2 and includes safety factors for both Class A (surface fires) and Class B hazards. However, many applications involve the use of higher than normal design concentrations for flame extinguishment in order to accomplish the following:

(1) Provide an initial concentration that will pass minimum holding time requirements
(2) Allow hot surfaces to cool in order to prevent reignition
(3) Provide protection for electrical equipment that remains energized
(4) Provide inerting concentrations to protect against the worst-case possibility of explosion of gas vapors, without a fire developing

In the examples cited in A-3-7.1.2.1(1) through A-3-7.1.2.1(4), it is the intent of 3-7.1.2 to allow discharge times greater than 10 seconds for halocarbon agents and greater than 60 seconds for inert gas agents (for that portion of the agent mass that exceeds the quantity required to achieve the minimum design concentration for flame extinguishment). The additional quantity of clean agent is to be introduced into the hazard at the same nominal flow rate required to achieve the flame extinguishing design concentration, using the same piping and nozzle(s) distribution system, or as an alternative, separate piping networks with different flow rates can be used.

A-3-7.1.2.2 See A-3-7.1.2.1.

A-3-7.1.2.3 For third-party listing or approval of pre-engineered systems or flow calculation software for engineered systems *(see 3-2.1)* direct measurement of the point of 95 percent of the agent mass discharged from the nozzle is not necessary to satisfy compliance with the intent of 3-7.1.2.3. For some agents the measurement of the point in time where 95 percent of the total agent mass coming from a given nozzle is extremely difficult to measure. Rather, for a given agent, a surrogate measurement based on engineering principles can be used. For instance, for some halocarbon agents, the point where the agent discharge changes from predominately liquid to gas represents approximately 95 percent of the agent mass out of the nozzle and has been previously used in the listing/approval testing for discharge time. For low boiling point agents, the point where the agent discharge changes from predominately liquid to gas may not be appropriate because this can occur before the point of 95 percent mass discharged. For such agents a method has been developed that utilizes an equation of state and measured cylinder conditions from the point where the agent discharge changes from predominately liquid to gas to calculate an agent mass balance in the cylinder/pipe network. The experimental discharge time is taken as the point where the summed calculated mass discharged from all nozzles equals 95 percent of the agent required to achieve minimum design concentration.

A-3-7.2 Special consideration should be given to safety and health issues when considering extended discharge systems.

The impact of decomposition products on electronic equipment is a potential area of concern. Sufficient data at present is not available to predict the effects of a given HF exposure scenario on all electronic equipment. Several evaluations of the impact of HF on electronics equipment have been performed relative to the decomposition of Halon 1301, where decomposition products include HF and HBr. One of the more notable was a National Aeronautics and Space Administration (NASA) study where the space shuttle Orbiter electronics were exposed to 700, 7000, and 70,000 ppm HF and HBr (Pedley, 1995). In these tests, exposures up to 700 ppm HF and HBr caused no failures. At 7000 ppm, severe corrosion was noted; there were some operating failures at this level.

Dumayas (Dumayas, 1992) exposed IBM-PC compatible multifunction cards to environments produced by a range of fire sizes as part of an evaluation program on halon alternatives. He found no loss of function of these boards following a 15-minute exposure to postfire extinguishment atmosphere up to 5000 ppm HF, with unconditioned samples stored at ambient humidity and temperature conditions for up to 30 days. Forssell et al. (Forssell et al., 1994) exposed multifunction boards for 30 minutes in the postfire extinguishment environment; no failures were reported up to 90 days posttest. HF concentrations up to 550 ppm were evaluated.

While no generic rule or statement can be made at this time, it appears that short term damage (<90 days) resulting in electronic equipment malfunction is not likely for exposures up to 500 ppm HF for up to 30 minutes. This damage, however, is dependent on the characteristics of the equipment exposed, post-exposure treatment, exposure to other combustion products, and relative humidity. Important equipment characteristics include its location in the space, existence of equipment enclosures, and the sensitivity of the equipment to damage.

Extended discharge applications inherently have a performance objective of maintaining the agent concentration at or above the design concentration within the enclosure. This objective is valid if there is mixing of agent continually in the enclosure during the hold period, and the enclosure thereby experiences a decaying concentration over time as opposed to a descending interface. The application of agent should be done with sufficient turbulence as to accomplish mixing of the additional agent throughout the enclosure. To accomplish this, the extended discharge probably will need to be accomplished through a separate network of piping and nozzles. These systems are outside the scope of current design requirements and testing procedures for total flooding systems. Systems should be designed and fully discharge tested on a case by case basis until the body of knowledge is sufficient enough to be addressed specifically in this standard.

A-4-1.4 All inert gas clean agents based on those gases normally found in the earth's atmosphere need not be recycled.

A-4-5.3 The method of sealing should not introduce any new hazards.

A-4-6.2 Training should cover the following:

(1) Health and safety hazards associated with exposure to extinguishing agent caused by inadvertent system discharge
(2) Difficulty in escaping spaces with inward swinging doors that are overpressurized due to an inadvertent system discharge
(3) Possible obscuration of vision during system discharge
(4) Need to block open doors at all times during maintenance activities
(5) Need to verify a clear escape path exists to compartment access
(6) A review of how the system could be accidentally discharged during maintenance, including actions required by rescue personnel should accidental discharge occur

A-4-7.2.2.10 A discharge test is generally not recommended.

A-4-7.2.2.13 The purpose is to conduct a flow test of short duration (also known as a "puff test") through the piping network to determine that the flow is continuous, check valves are properly oriented, and the piping and nozzles are unobstructed.

The flow test should be performed using gaseous nitrogen or an inert gas at a pressure not to exceed the normal operating pressure of the clean agent system.

The nitrogen or an inert gas pressure should be introduced into the piping network at the clean agent cylinder connection. The quantity of nitrogen or an inert gas used for this test should be sufficient to verify that each and every nozzle is unobstructed.

Visual indicators should be used to verify that nitrogen or an inert gas has discharged out of each and every nozzle in the system.

A-4-7.2.3 If the authority having jurisdiction wants to quantify the enclosure's leakage and predicted retention time, Appendix B of NFPA 12A, *Standard on Halon 1301 Fire Extinguishing Systems*, can be used. Adjustment to the existing formulas must be made to account for differences in gas density between Halon 1301 and the proposed alternate extinguishing agent. Specifically, Equation 8 in B-2.7.1.4 of NFPA 12A must be modified by substituting the alternate agent's gas density (in kg/m^3) for the existing value of 6283, which is the value for Halon 1301. See Appendix C of this standard.

A-4-8 Safety should be a prime concern during installation, service, maintenance, testing, handling, and recharging of clean agent systems and agent containers.

One of the major causes of personnel injury and property damage is attributed to the improper handling of agent containers by untrained and unqualified personnel. In the interest of safety, and in order to minimize the potential for personnel injury and property damage, the following guidelines should be adhered to:

(a) If any work is to be performed on the fire suppression system, qualified fire service personnel, trained and experienced in the type of equipment installed, should be engaged to do the work.

(b) Personnel involved with fire suppression system cylinders must be thoroughly trained in the safe handling of the containers as well as in the proper procedures for installation, removal, handling, shipping, and filling; and connection and removal of other critical devices, such as discharge hoses, control heads, discharge heads, initiators, and antirecoil devices.

(c) The procedures and cautions outlined on the cylinder nameplates, and in the operation and maintenance manuals, owner's manuals, service manuals, and service bulletins, that are provided by the equipment manufacturer for the specified equipment installed, should be followed.

(d) Most fire suppression system cylinders are furnished with valve outlet antirecoil devices and in some cases cylinder valve protection caps. Do not disconnect cylinders from the system piping, or move or ship the cylinders, if the antirecoil devices or protection caps are missing. Obtain these parts from the distributor of the manufacturer's equipment or the equipment manufacturer. These devices are provided for safety reasons and should be installed at all times, except when the cylinders are connected into the system piping or being filled.

(e) All control heads, pressure-operated heads, initiators, discharge heads, or other type of actuation devices should be removed before disconnecting the cylinders from the system piping; and antirecoil devices and/or protection caps immediately installed before moving or shipping the cylinders. Most fire suppression system equipment varies from manufacturer to manufacturer; therefore, it is important to follow the instructions and procedures provided in the equipment manufacturer's manuals. These actions should only be undertaken by qualified fire suppression system service personnel.

(f) Safety is of prime concern! Never assume that a cylinder is empty. Treat all cylinders as if they are fully charged. Most fire suppression system cylinders are equipped with high flow rate valves that are capable of producing high discharge thrusts out of the valve outlet if not handled properly. Remember, pressurized cylinders are extremely hazardous. Failure to follow the equipment manufacturer's instructions and the guidelines contained herein can result in serious bodily injury, death, or property damage.

A-5-2.1 Some typical hazards that could be suitable include, but are not limited to, the following:

(1) Machinery spaces such as main machinery spaces
(2) Emergency generator rooms
(3) Pump rooms
(4) Flammable liquid storage and handling areas and paint lockers
(5) Control rooms and electronic equipment spaces

A-5-2.2 General cargo should not be protected with halocarbon agents due to the possibility of deep-seated cargo fires and due to wide variations in cargo materials. Dry cargoes, such as containerized cargoes, often include a wide mix of commodities that can include materials or storage arrangements not suitably protected using halocarbon agents. The volume of agent needed to protect cargo spaces varies depending on the volume of the cargo space minus the volume of the cargo carried. This quantity varies as cargo volume changes and can affect fire extinguishing effectiveness or agent toxicity.

A-5-3.2 Subchapter J of 46 *CFR* 111.59 requires busways to comply with Article 364 of NFPA 70, *National Electrical Code®*. Article 364 requires compliance with Article 300 for clearances around busways.

A-5-4.2 Agent cylinder storage spaces should be adequately ventilated. Entrances to such spaces should be from an open deck.

A-5-4.6 Corrosion resistance is required to prevent clogging of nozzles with scale. Examples of suitable materials are hot dipped galvanized steel piping inside and out or stainless steel.

A-5-4.7 Fittings conforming to ASTM F 1387, *Standard Specification for Performance of Mechanically Attached Fittings,* and fire tested with zero leakage conform to the requirements of 5-4.7.

A-5-5.1.2 The intent of this subsection is to ensure that a suppression system will not interfere with the safe navigation of the vessel. Many internal combustion propulsion engines and generator prime movers draw combustion air from the protected space in which they are installed. Because these types of engines are required to be shut down prior to system discharge, an automatically discharged system would shut down propulsion and electricity supply when needed most. A nonautomatic system gives the ship's crew the flexibility to decide the best course of action. For example, while navigating in a high-density shipping channel, a ship's ability to maneuver can be more important than immediate system discharge. For small vessels, the use of automatic systems is considered appropriate taking into consideration the vessel's mass, cargo, and crew training.

A-5-5.2.3 The intent is to prevent accidental or malicious system operation. Some examples of acceptable actuation stations are as follows:

(1) Breaking a glass enclosure and pulling a handle
(2) Breaking a glass enclosure and opening a valve
(3) Opening an enclosure door and flipping a switch

All are examples of acceptable manual actuation stations.

A-5-6.1 Heat detectors are typically used in machinery spaces and are sometimes combined with smoke detectors. Listed or approved optical flame detectors can also be used provided they are additional to the required quantity of heat and/or smoke detectors.

A-5-6.2 This requirement is derived from SOLAS Merchant Marine Circular 9/93, Regulation II-2/Regulation 5.3, Halogenated Hydrocarbon Systems.

A-5-6.3 This requirement is derived from SOLAS Merchant Marine Circular 9/93, Regulation II-2/Regulation 5.3, Halogenated Hydrocarbon Systems.

A-5-6.4 This requirement is derived from SOLAS Merchant Marine Circular 9/93, Regulation II-2/Regulation 5.3, Halogenated Hydrocarbon Systems.

A-5-6.5 This requirement is derived from SOLAS Merchant Marine Circular 9/93, Regulation II-2/Regulation 5.3, Halogenated Hydrocarbon Systems.

A-5-6.6 This requirement is derived from SOLAS Merchant Marine Circular 9/93, Regulation II-2/Regulation 5.3, Halogenated Hydrocarbon Systems.

A-5-7.1 A well-sealed enclosure is vital to proper operation of the system and subsequent extinguishment of fires in the protected space. Gastight boundaries of the protected space, such as those constructed of welded steel, offer a highly effective means for holding the fire extinguishing gas concentration. Where the space is fitted with openings, avenues for escape of the gas exist. Automatic closure of openings is the preferred method of ensuring enclosure integrity prior to discharge. Manually closed openings introduce added delay and an added human element into the chain of proper operation of the system. Failure of personnel to properly close all openings has been a recurring cause of gaseous systems not performing as intended. It is recognized that some openings in the enclosures cannot be fitted with automatically operated closers due to personnel hazards or other limitations, such as maintenance hatches and watertight doors. In these cases an indicator is required to alert the system operator that an opening has not been closed as required and thus the system is not ready for operation.

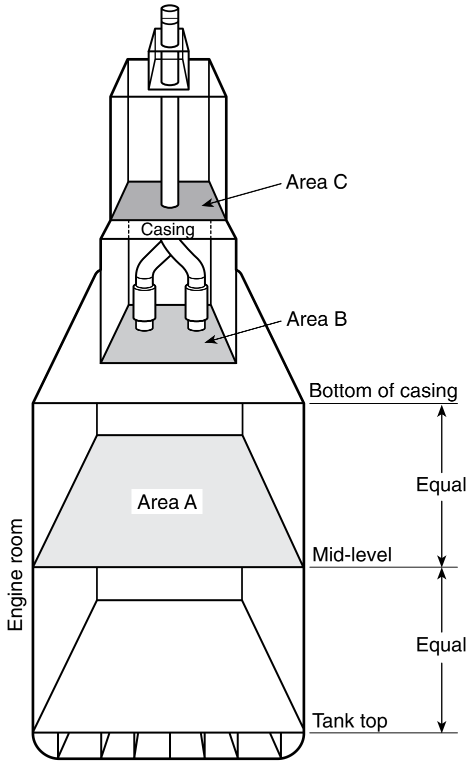
A-5-7.2 Automatic shutdowns are the preferred method for shutting down a ventilation system. Shutdowns requiring personnel to find and manually close dampers far from the fire extinguishing system discharge station should not be permitted.

A-5-8.4 When calculating the net volume of the machinery space, the net volume should include the volume of the bilge and the volume of the stack uptake. The volume calculation should be permitted to exclude the portions of the stack uptake that have a horizontal cross-sectional area less than 40 percent of the horizontal cross-sectional area of the main machinery space. The horizontal cross-sectional area of the main machinery space should be measured midway between the lowest level (tank top) and the highest level (bottom of the stack casing). *(See Figure A-5-8.4.)*

The objects that occupy volume in the protected space should be subtracted from the volume of the space. These objects include, but are not necessarily limited to, the following:

(1) Auxiliary machinery
(2) Boilers
(3) Condensers
(4) Evaporators
(5) Main engines
(6) Reduction gears
(7) Tanks
(8) Trunks

FIGURE A-5-8.4 Machinery space and stack uptake.



For the casing to be considered separate from the gross volume of the machinery space, Area B must be 40 percent or less of Area A.

If Area B is greater than 40 percent of Area A, the volume of casing up to Area C (or where the area is 40 percent or less of Area A) must be included in the gross volume of the space.

Any area of the casing containing boilers, internal combustion machinery, or oil-fired installations must be included in the gross volume of the engine room.

The Maritime Safety Committee, at its sixty-seventh session (2 to 6 December 1996), approved guidelines for the approval of equivalent fixed gas fire extinguishing systems, as referred to in SOLAS 74, for machinery spaces and cargo pump rooms, as MSC/Circ. 776.

The Subcommittee on Fire Protection, at its forty-second session (8 to 12 December 1997), recognized the need of technical improvement to the guidelines contained in MSC/Circ. 776 to assist in their proper implementation and, to that effect, prepared amendments to the guidelines.

The committee, at its sixty-ninth session (11 to 20 May 1998), approved revised guidelines for the approval of equivalent fixed gas fire extinguishing systems, as referred to in SOLAS 74, for machinery spaces and cargo pump rooms, as set out in the annex, to supersede the guidelines attached to MSC/Circ. 776.

Member governments are invited to apply the annexed guidelines when approving equivalent fixed gas fire extinguishing systems for use in machinery spaces of category A and cargo pump rooms.

The quantity of extinguishing agent for the protected space should be calculated at the minimum expected ambient temperature using the design concentration based on the net volume of the protected space, including the casing.

The net volume of a protected space is that part of the gross volume of the space that is accessible to the free extinguishing agent gas.

When calculating the net volume of a protected space, the net volume should include the volume of the bilge, the volume of the casing, and the volume of free air contained in air receivers that in the event of a fire is released into the protected space.

The objects that occupy volume in the protected space should be subtracted from the gross volume of the space. They include, but are not necessarily limited to, the following:

(1) Auxiliary machinery
(2) Boilers
(3) Condensers
(4) Evaporators
(5) Main engines
(6) Reduction gears
(7) Tank
(8) Trunks

Subsequent modifications to the protected space that alter the net volume of the space require the quantity of extinguishing agent to be adjusted to meet the requirements of this paragraph and the following paragraph.

No fire suppression agent should be used that is carcinogenic, mutagenic, or teratogenic at concentrations expected during use. No agent should be used in concentrations greater than the cardiac sensitization NOAEL, without the use of controls as provided in SOLAS Regulation II-2/Regulations 5.2, Carbon Dioxide Systems. In no case should an agent be used above its LOAEL nor approximate lethal concentration (ALC) calculated on the net volume of the protected space at the maximum expected ambient temperature.

A-5-8.5 Maintaining the design concentration is equally important in all classes of fires because a persistent ignition source, such as an electric arc, boiler front, heat source, engine exhaust, turbo charger, hot metal, or deep-seated fire, can lead to resurgence of the initial event once the clean agent has dissipated.

A-5-11.3 When determining container pressure, the original container fill density should be obtained from the system manufacturer and the temperature/pressure relation should be obtained from tables published by the system manufacturer. When determining container liquid level, the liquid level/temperature relationship should be obtained from the system manufacturer.

Appendix B Cup Burner Test Procedure

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

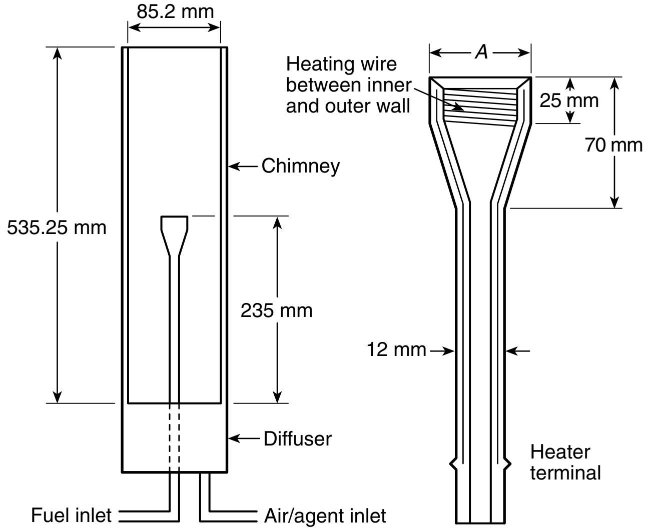
B-1 Scope. This procedure sets out the minimum requirements for determining the flame extinguishing concentration of a gaseous extinguishant in air for flammable liquids and gases employing the cup burner apparatus.

B-2 Principle. Diffusion flames of fuels burning in a round reservoir (cup) centrally positioned in a coaxially flowing air stream are extinguished by addition of a gaseous extinguishant to the air.

B-3 Apparatus. The cup burner apparatus for these measurements shall be arranged and constructed as in Figure B-3.1, employing the dimensions shown. The tolerance for all dimensions is ±5 percent unless otherwise indicated.

B-3.1 Cup. The cup shall be round; shall be constructed of glass, quartz, or steel; have an outside diameter in the range of 28 mm to 31 mm, with a wall thickness of 1 mm to 2 mm; have a 45 degrees chamfer ground into the top edge of the cup; have a means of temperature measurement of the fuel inside the cup at a location 2 mm to 5 mm below the top of the cup; have a means of heating the fuel; shall be substantially similar in shape to the example shown in Figure B-3.1. A cup intended for use with gaseous fuels shall have a means of attaining a uniform gas flow at the top of the cup (e.g., the cup can be packed with refractory materials).

FIGURE B-3.1 Cup burner apparatus.



A = 28- to 31-mm outside diameter; 1- to 2-mm wall thickness

B-3.2 Chimney. The chimney shall be of round glass or quartz construction; have an inside diameter of 85 mm ± 2 mm and a wall thickness of 2 mm to 5 mm; and have a height of 533 mm ± 10 mm.

B-3.3 Diffuser. The diffuser shall have a means of fitting to the bottom end of the chimney, have a means of admitting a premixed stream of air and extinguishant, and have a means of uniformly distributing the air/extinguishant flow across the cross section of the chimney.

B-3.4 Fuel Supply, Liquids. A liquid fuel supply shall be capable of delivering liquid fuel to the cup while maintaining a fixed, but adjustable, liquid level therein.

B-3.5 Fuel Supply, Gaseous. A gaseous fuel supply shall be capable of delivering the fuel at a controlled and fixed rate to the cup.

B-3.6 Manifold. A manifold shall receive air and extinguishant and deliver them as a single mixed stream to the diffuser.

B-3.7 Air Supply. A means for delivering air to the manifold shall allow adjustment of the airflow rate; and have a calibrated means of measuring the airflow rate.

B-3.8 Extinguishant Supply. A means for delivering extinguishant to the manifold shall allow adjustment of the extinguishant flow rate and have a calibrated means of measuring the extinguishant rate.

B-3.9 Delivery System. The delivery system shall deliver a representative and measurable sample of the agent to the cup burner in a gaseous form.

B-4 Materials.

B-4.1 Air. Air shall be clean, dry, and oil-free. The oxygen concentration shall be 20.9 ± 0.5 percent v/v. The source and oxygen content of the air employed shall be recorded.

("Air" supplied in a commercial high-pressure cylinder may have an oxygen content significantly different from 20.9 percent v/v.)

B-4.2 Fuel. Fuel shall be of a certified type and quality.

B-4.3 Extinguishant. Extinguishant shall be of a certified type and shall meet the specifications of the supplier. Multicomponent extinguishants shall be provided premixed.

B-5 Procedure for Flammable Liquids.

B-5.1 Place the flammable liquid in the fuel supply reservoir.

B-5.2 Admit fuel to the cup, adjusting the liquid level to within 5 mm to 10 mm of the top of the cup.

B-5.3 Operate the heating arrangement for the cup to bring the fuel temperature to 25°C ± 1°C or to 5°C ± 1°C above the open cup flash point, whichever is higher.

B-5.4 Adjust the airflow to achieve a flow rate of 10 L/min.

B-5.5 Ignite the Fuel.

B-5.6 Allow the fuel to burn for a period of 90 to 120 seconds before beginning flow of extinguishant. During this period, the liquid level in the cup should be adjusted so that the fuel level is at the top of the cup.

B-5.7 Begin the flow of extinguishant. Increase the extinguishant flow rate in increments until flame extinguishment occurs, and record the extinguishant and airflow rates at extinguishment. The flow rate increment should result in an increase in the flow rate of no more than 2 percent of the previous value. Adjustments in the extinguishant flow rate are to be followed by a brief waiting period (10 seconds) to allow the new proportions of extinguishant and air in the manifold to reach the cup position. During this procedure, the liquid level in the cup is to be maintained at the top of the cup.

On an initial run, it is convenient to employ relatively large flow increments to ascertain the approximate extinguishant flow required for extinguishment, and on subsequent runs to start at a flow rate close to the critical and to increase the flow by small amounts until extinguishment is achieved.

B-5.8 Determine the extinguishing concentration of the extinguishant in accordance with B-7.

B-5.9 Prior to subsequent tests, remove the fuel from the cup and remove any deposits of residue or soot that are present on the cup.

B-5.10 Repeat B-5.1 to B-5.9 employing airflow rates of 20, 30, 40, and 50 L/min.

B-5.11 Determine the air flow rate corresponding to the maximum agent concentration required for flame extinguishment from a plot of the extinguishing concentration versus airflow.

A "plateau region" in the extinguishing concentration versus airflow plot occurs over which the extinguishing concentration is at a maximum and is independent of the airflow. For the purpose of determining the airflow corresponding to the maximum required extinguishing concentration, extinguishing concentrations differing by ±0.2 percent shall be considered to be equivalent. If the "plateau region" in the concentration versus air flow plot has not been reached at an airflow rate of 50 L/min, further measurements employing higher flow rates shall be made until the plateau region can be found.

B-5.12 Repeat steps B-5.1 through B-5.9 employing an airflow corresponding to the maximum required agent concentration, as determined B-5.11.

In the case that a range of airflows exist over which the extinguishing concentration is constant to within ±0.2 percent and is at a maximum, employ an airflow rate in the middle of said range.

B-5.13 Determine the extinguishing concentration of the extinguishant in accordance with B-7 by establishing the average of the five tests.

The current task group considered the determination of extinguishing concentrations for the case of elevated fuel temperatures and decided not to include such information in this standard. This decision was based upon the fact that the relevance of such data to real-world fire scenarios is currently unknown.

B-6 Procedure for Flammable Gases. A cup intended for use with gaseous fuels shall have a means of attaining a uniform gas flow at the top of the cup. For example, the cup employed for liquid fuels can be packed with refractory materials.

B-6.1 Gaseous fuel shall be from a pressure-regulated supply with a calibrated means of adjusting and measuring the gas flow rate.

B-6.2 Adjust the airflow to 10 L/min.

B-6.3 Begin fuel flow to the cup and adjust the fuel flow rate to attain a gas velocity nominally equal to the air velocity past the cup.

B-6.4 Ignite the Fuel.

B-6.5 Allow the fuel to burn for a period of 60 seconds before beginning flow of extinguishant.

B-6.6 Begin the flow of extinguishant. Increase the extinguishant flow rate in increments until flame extinguishment, occurs, and record the air, extinguishant, and fuel flow rates at extinguishment. The extinguishant flow rate increment should result in an increase in the flow rate of no more than 2 percent of the previous value. Adjustments in the extinguishant flow rate are to be followed by a brief waiting period (10 seconds) to allow the new proportions of extinguishant and air in the manifold to reach the cup position. During this procedure, the liquid level in the cup is to be maintained at the top of the cup.

On an initial run, it is convenient to employ relatively large flow increments to ascertain the approximate extinguishant flow required for extinguishment, and on subsequent runs to start at a flow rate close to the critical and to increase the flow by small amounts until extinguishment is achieved.

B-6.7 Upon flame extinguishment shut off the flow of flammable gas.

B-6.8 Prior to subsequent tests, remove deposits of residue or soot if present on the cup.

B-6.9 Determine the extinguishing concentration of the extinguishant in accordance with B-7.

B-6.10 Repeat steps B-6.3 through B-6.9 at airflow rates of 20, 30, 40, and 50 L/min.

B-6.11 Determine the airflow rate corresponding to the maximum agent concentration required for flame extinguishment from a plot of the extinguishing concentration versus airflow.

A "plateau region" in the extinguishing concentration versus airflow plot occurs over which the extinguishing concentration is at a maximum and is independent of the airflow. For the purpose of determining the airflow corresponding to the maximum required extinguishing concentration, extinguishing concentrations differing by ±0.2 percent shall be considered to be equivalent. If the "plateau region" in the concentration versus airflow plot has not been reached at an airflow rate of 50 L/min, further measurements employing higher flow rates shall be made until the plateau region can be found.

B-6.12 Repeat steps B-6.3 through B-6.9 employing an airflow corresponding to the maximum required agent concentration, as determined in B-6.11.

In the case that a range of airflows exist over which the extinguishing concentration is constant to within ±0.2 percent and is at a maximum, employ an airflow rate in the middle of said range.

B-6.13 Determine the extinguishing concentration of the extinguishant in accordance with B-7 by establishing the average of five tests.

B-7 Extinguishant Extinguishing Concentration.

B-7.1 Preferred Method. The preferred method for determining the concentration of extinguishant vapor in the extinguishant plus air mixture that just causes flame extinguishment is to employ a gas-analyzing device calibrated for the concentration range of extinguishant–air mixtures being measured. The device can have continuous sampling capability, for example, on-line gas analyzer, or can be of a type that analyzes discrete samples, for example, gas chromatography. Continuous measurement techniques are preferred.

Alternatively, the remaining oxygen concentration in the chimney can be measured with a continuous oxygen analysis device. The extinguishant concentration is then calculated as follows:

$$C = 100\left(1 - \frac{O_2}{O_{2(\text{sup})}}\right)$$

where:

C = extinguishant concentration (% v/v)
O_2 = oxygen concentration in chimney (v/v)
$O_{2(\text{sup})}$ = oxygen concentration in supply air (% v/v)

B-7.2 Alternative Method. Extinguishant concentration in the extinguishant plus air mixture can, alternatively, be calculated from the measured flow rates of extinguishant and air. Where mass flow rate devices are employed, the resulting mass flow rates need to be converted to volumetric flow rates as follows:

$$V_i = \frac{M_i}{\rho_i}$$

where:

V_i = volumetric flow rate of gas i (L/min)
M_i = mass flow rate of gas i (g/min)
ρ_i = density of gas i (g/L)

Care should be taken to employ the actual vapor density. The vapor density of many halogenated hydrocarbons at ambient temperature and pressure can differ from that calculated by the ideal gas law by several percent. By way of example, the density of HFC-227ea vapor at a pressure 101.3 kPa and temperature of 295°K is approximately 2.4 percent higher than would be calculated as an equivalent ideal gas. At a pressure of 6.7 kPa (6.6 volume percent), however, the difference between the actual vapor density and that calculated as an ideal gas is less than 0.2 percent. Published property data should be used where possible. Lacking published data, estimation techniques can be used. The source of physical property values used should be recorded in the test report.

The concentration of extinguishant in volume percent, C, is calculated as follows:

$$C = \left(\frac{V_{ext}}{V_{air} + V_{ext}}\right)100$$

where:

C = extinguishant concentration (% v/v)
V_{air} = volumetric flow rate of air (L/min)
V_{ext} = volumetric flow rate of extinguishant (L/min)

B-8 Reporting of Results. As a minimum, the following information should be included in the report of results:

(1) Schematic diagram of apparatus, including dimensions
(2) Source and assay of the extinguishant, fuel, and air
(3) For each test, the temperature of the air–extinguishant mixture at extinguishment
(4) Extinguishant and gaseous fuel and airflow rates at extinguishment
(5) Method employed to determine the extinguishing concentration
(6) Extinguishant concentration determined for each test
(7) Measurement error analysis and statistical analysis of results

Appendix C Enclosure Integrity Procedure

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

C-1 Procedure Fundamentals.

C-1.1 Scope.

C-1.1.1 This procedure outlines a method to equate enclosure leakage as determined by a door fan test procedure to worst-case halon leakage. The calculation method provided makes it possible to predict the time it will take for a descending interface to fall to a given height or, for the continually mixed cases, the time for the concentration to fall to a given percentage concentration.

C-1.1.2 Enclosure integrity testing is not intended to verify other aspects of clean agent system reliability, that is, hardware operability, agent mixing, hydraulic calculations, and piping integrity.

C-1.1.3 This procedure is limited to door fan technology. This is not intended to preclude alternative technology such as acoustic sensors.

C-1.1.4 This procedure should not be considered to be an exact model of a discharge test. The complexity of this procedure should not obscure the fact that most failures to hold concentration are due to the leaks in the lower surfaces of the enclosure, but the door fan does not differentiate between upper and lower leaks. The door fan provides a worst case leakage estimate that is very useful for enclosures with complex hidden leaks, but it will generally require more sealing than is necessary to pass a discharge test.

C-1.2 Limitations and Assumptions.

C-1.2.1 Clean Agent System Enclosure. The following should be considered regarding the clean agent system and the enclosure:

(a) *Clean Agent System Design.* This test procedure concerns only halon total flooding fire suppression systems using clean agent that are designed, installed, and maintained in accordance with this standard.

(b) *Enclosure Construction.* Clean agent protected enclosures, absent of any containing barriers above the false ceiling, are not within the scope of this document.

(c) *Clean Agent Concentration.* Special consideration should be given to clean agent systems with concentrations greater than 10 percent where the concern exists that high concentrations can result in significant overpressures from the discharge event in an enclosure with minimal leakage.

(d) *Enclosure Height.* Special consideration should be given to high enclosures where the static pressure due to the clean agent column is higher than the pressure possible to attain by means of the door fan.

(e) *Static Pressures.* Where at all possible, static pressure differentials (HVAC system, elevator connections, etc.) across the enclosure envelope should be minimized during the door fan test. The test can only be relied on for enclosures having a range of static pressures outlined in C-2.5.2.3.

C-1.2.2 Door Fan Measurements. The following should be considered regarding the door fan and its associated measurements:

(a) *Door Fan Standards.* Guidance regarding fan pressurization apparatus design, maintenance, and operation is provided by ASTM E 779, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization,* and CAN/CGSB-149.10-M86, *Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method.*

(b) *Attached Volumes.* There can be no significant attached volumes within or adjoining the enclosure envelope that will allow detrimental halon leakage that would not be measured by the door fan. Such an attached volume would be significant if it is absent of any leakage except into the design envelope and is large enough to adversely affect the design concentration.

(c) *Return Path.* All significant leaks must have an unrestricted return path to the door fan.

(d) *Leak Location.* The difficulty in determining the specific leak location on the enclosure envelope boundaries using the door fan is accounted for by assuming halon leakage occurs through leaks at the worst location. This is when one-half of the total equivalent leakage area is assumed to be at the maximum enclosure height and the other half is at the lowest point in the enclosure. In cases where the below false ceiling leakage area (BCLA) is measured using C-2.6.2, the value attained for BCLA is assumed to exist entirely at the lowest point in the enclosure.

(e) *Technical Judgment.* Enclosures with large overhead leaks but no significant leaks in the floor slab and walls will yield unrealistically short retention time predictions. Experience has shown that enclosures of this type can be capable of retaining clean agent for prolonged periods. However, in such cases the authority having jurisdiction might waive the quantitative results in favor of a detailed witnessed leak inspection of all floors and walls with a door fan and smoke pencil.

C-1.2.3 Retention Calculations. The following information in C-1.2.3.1 through C-1.2.3.10 should be considered regarding the retention calculations and its associated theory.

C-1.2.3.1 Dynamic Discharge Pressures. Losses due to the dynamic discharge pressures resulting from halon system actuation are not specifically addressed.

C-1.2.3.2 Static Pressure. Variable external static pressure differences (wind, etc.) are additive and should be considered.

C-1.2.3.3 Temperature Differences. When temperature differences exceeding 18°F (10°C) exist between the enclosure under test and the other side of the door fan, special considerations outlined in this document should be considered.

C-1.2.3.4 Floor Area. The floor area is assumed to be the volume divided by the maximum height of the protected enclosure.

C-1.2.3.5 Descending Interface. The enclosure integrity procedure assumes a sharp interface. When a clean agent is discharged, a uniform mixture occurs. As leakage takes place, air enters the room. This procedure assumes that the incoming air rides on top of the remaining mixture. In reality, the interface usually spreads because of diffusion and convection. These effects are not modeled because of their complexity. Where a wide interface is present, the descending interface is assumed to be the midpoint of a wide interface zone. Because of the conservatism built into the procedure, the effects of interface spreading can be ignored. If continual mechanical mixing occurs, a descending interface might not be formed *(see C-2.7.1.6).*

C-1.2.3.6 Leak Flow Characteristics. All leak flow is one-dimensional and does not take into account stream functions.

C-1.2.3.7 Leak Flow Direction. A particular leak area does not have bidirectional flow at any point in time. Flow through a leak area is either into or out of the enclosure.

C-1.2.3.8 Leak Discharge. The outflow from the leak discharges into an infinitely large space.

C-1.2.3.9 Leak Locations. Calculations are based on worst-case clean agent leak locations.

C-1.2.3.10 Clean Agent Delivery. The calculations assume that the design concentration of clean agent will be achieved. If a suspended ceiling exists, it is assumed that the clean agent discharge will not result in displacement of the ceiling tiles. Increased confidence can be obtained if ceiling tiles are clipped within 4 ft (1.2 m) of the nozzles and all perimeter tiles.

C-1.3 Definitions. For the purposes of Appendix C, the following definitions are to apply.

C-1.3.1 *Area, Effective Floor.* The volume divided by the maximum halon protected height.

C-1.3.2 *Area, Effective Flow.* The area that results in the same flow area as the existing system of flow areas when it is subjected to the same pressure difference over the total system of flow paths.

C-1.3.3 *Area, Equivalent Leakage (ELA).* The total combined area of all leaks, cracks, joints, and porous surfaces that act as leakage paths through the enclosure envelope. This is represented as the theoretical area of a sharp edged orifice that would exist if the flow into or out of the entire enclosure at a given pressure were to pass solely through it. For the purposes of this document, the ELA is calculated at the column pressure.

C-1.3.4 *Area, Return Path.* The effective flow area that the air being moved by the door fan must travel through to complete a return path back to the leak.

C-1.3.5 *Attached Volumes.* A space within or adjoining the enclosure envelope that is not protected by halon and cannot be provided with a clearly defined return path.

C-1.3.6 *Blower.* The component of the door fan used to move air.

C-1.3.7 *Ceiling Slab.* The boundary of the enclosure envelope at the highest elevation.

C-1.3.8 *Column Pressure.* The theoretical maximum positive pressure created at the floor slab by the column of the halon–air mixture.

C-1.3.9 *Descending Interface.* The enclosure integrity procedure assumes a sharp interface. When clean agent is discharged, a uniform mixture occurs. As leakage takes place, air enters the room. This procedure assumes that the incoming air rides on top of the remaining mixture. In reality, the interface usually spreads because of diffusion and convection. These effects are not modeled because of their complexity. Where a wide interface is present, the descending interface is assumed to be the mid-point of a wide interface zone. Because of the conservatism built into the procedure, the effects of interface spreading can be ignored. If continual mechanical mixing occurs, a descending interface might not be formed. (*See C-2.7.1.6.*)

C-1.3.10 *Door Fan.* The device used to pressurize or depressurize an enclosure envelope to determine its leakage characteristics. Also called the fan pressurization apparatus.

C-1.3.11 *Enclosure.* The volume being tested by the door fan. This includes the halon protected enclosure and any attached volumes.

C-1.3.12 *Enclosure Envelope.* The floor, walls, ceiling, or roof that together constitute the enclosure.

C-1.3.13 *Enclosure, Protected.* The volume protected by the clean agent extinguishing system.

C-1.3.14 *Fan Pressurization Apparatus.* The device used to pressurize or depressurize an enclosure envelope to determine its leakage characteristics. Also called the door fan.

C-1.3.15 *Floor Slab.* The boundary of the enclosure envelope at the lowest elevation.

C-1.3.16 *Pressure Gauge, Flow.* The component of the door fan used to measure the pressure difference across the blower to give a value used in calculating the flow into or out of the enclosure envelope.

C-1.3.17 *Pressure Gauge, Room.* The component of the door fan used to measure the pressure differential across the enclosure envelope.

C-1.3.18 *Protected Height, Maximum.* The design height of the clean agent column from the floor slab. This does not include the height of unprotected ceiling spaces.

C-1.3.19 *Protected Height, Minimum.* The minimum acceptable height from the floor slab to which the descending interface is allowed to fall during the retention time as specified by the authority having jurisdiction.

C-1.3.20 *Return Path.* The path outside the enclosure envelope that allows air to travel to/from the leak to/from the door fan.

C-1.3.21 *Static Pressure Difference.* The pressure differential across the enclosure envelope not caused by the discharge process or by the weight of the clean agent. A positive static pressure difference indicates that the pressure inside the enclosure is greater than on the outside, that is, smoke would leave the enclosure at the enclosure boundary.

C-2 Test Procedure.

C-2.1 Preliminary Preparations. Contact the individual(s) responsible for the protected enclosure and establish, obtain, and provide the following preliminary information:

(1) Provide a description of the test
(2) Advise the time required
(3) Determine the staff needed (to control traffic flow, set HVAC, and so forth)
(4) Determine the equipment required (for example, ladders)
(5) Obtain a description of the HVAC system
(6) Establish the existence of a false ceiling space and the size of ceiling tiles
(7) Visually determine the readiness of the room with respect to the completion of obvious sealing
(8) Determine if conflict with other building trades will occur
(9) Determine the size of doorways
(10) Determine the existence of adequate return path area outside the enclosure envelope used to accept or supply the door fan air
(11) Evaluate other conflicting activities in and around space (for example, interruption to the facility being tested)
(12) Obtain appropriate architectural HVAC and halon system design documents

C-2.2 Equipment Required. The following equipment is required to test an enclosure using fan pressurization technology.

C-2.2.1 Door Fan System.

C-2.2.1.1 The door fan(s) should have a total airflow capacity capable of producing a pressure difference at least equal to the predicted column pressure or 10 Pa, whichever is greater.

C-2.2.1.2 The fan should have a variable speed control or a control damper in series with the fan.

C-2.2.1.3 The fan should be calibrated in airflow units or be connected to an airflow metering system.

C-2.2.1.4 The accuracy of airflow measurement should be +5 percent of the measured flow rate.

C-2.2.1.5 The room pressure gauge should be capable of measuring pressure differences from 0 Pa to at least 50 Pa. It should have an accuracy of +1 Pa and divisions of 2 Pa or less. Inclined oil-filled manometers are considered to be traceable to a primary standard and need not be calibrated. All other pressure-measurement apparatus (for example, electronic transducer or magnehelic) should be calibrated at least yearly.

C-2.2.1.6 Door fan systems should be checked for calibration every 5 years under controlled conditions, and a certificate should be available for inspection at all integrity tests. The calibration should be performed according to manufacturer's specifications.

The certificate should include the following:

(1) Description of calibration facility and responsible technician.
(2) Date of calibration and serial number of door fan.
(3) Room pressure gauge error estimates at 8, 10, 12, 15, 20, and 40 Pa measured by both ascending and descending pressures (minimum).
(4) Fan calibration at a minimum of 3 leakage areas (approximate): 0.5 m^2, 0.25 m^2, and 0.05 m^2 measured at a pressure of 10 Pa.

C-2.2.1.7 A second blower or multiple blowers with flex duct and panel to flow to above-ceiling spaces is optional.

C-2.2.2 Accessories. The following equipment is also useful:

(1) Smoke pencil, fully charged

CAUTION

> Use of chemically generated smoke as a means of leak detection can result in activation of building or halon system smoke detectors. Appropriate precautions should be taken. Due to corrosive nature of the smoke, it should be used sparingly.

(2) Bright light source
(3) Floor tile lifter
(4) Measuring tape
(5) Masking or duct tape
(6) Test forms
(7) Multitip screwdrivers
(8) Shop knife or utility knife
(9) Several sheets of thin plastic and cardboard
(10) Door stops
(11) Signs to post on doors that say "DO NOT SHUT DOOR — FAN TEST IN PROGRESS" or "DO NOT OPEN DOOR — FAN TEST IN PROGRESS"
(12) Thermometer

C-2.2.3 Field Calibration Check.

C-2.2.3.1 This procedure enables the authority having jurisdiction to obtain an indication of the door fan and system calibration accuracy upon request.

C-2.2.3.2 The field calibration check should be done in a separate enclosure. Seal off any HVAC registers and grilles if present. Install the door fan per manufacturer's instructions and C-2.4. Determine if a static pressure exists using C-2.5.2. Check openings across the enclosure envelope for airflow with chemical smoke. If any appreciable flow or pressure exists, choose another room or eliminate the source.

C-2.2.3.3 Install a piece of rigid material less than $^{1}/_{8}$-in. (3-mm) thickness (free of any penetrations) in an unused blower port or other convenient enclosure opening large enough to accept an approximately 15.5 in.^{2} (0.01 m^2) sharp-edged round or square opening.

C-2.2.3.4 Ensure that the door fan flow measurement system is turned to properly measure pressurization or depressurization and operate the blower to achieve a convenient pressure differential, preferably 10 Pa.

C-2.2.3.5 At the pressure achieved, measure the flow and calibrate an initial ELA value using C-2.6.3. Repeat the ELA measurement under positive pressure and average the two results.

C-2.2.3.6 Create a sharp-edged round or square opening in the rigid material. The area of this opening should be at least 33 percent of the initial ELA measured. Typical opening sizes are approximately 0.05 m^2, 0.1 m^2, and 0.2 m^2 (77.5 in.^{2}, 155 in.^{2}, and 310 in.^{2}), depending on the initial leakage of the enclosure. Adjust the blower to the previously used positive or negative pressure differential. Measure the flows and calculate an average ELA value using C-2.6.3.

C-2.2.3.7 Field calibration is acceptable if the difference between the first and second ELA value is within +15 percent of the hole area cut in the rigid material. If the difference in ELA values is greater than +15 percent, the door fan apparatus should be recalibrated according to the manufacturer's recommendations and either ASTM E 779, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*, or CAN/CGSB-149.10-M86, *Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method.*

C-2.3 Initial Enclosure Evaluation.

C-2.3.1 Inspection.

C-2.3.1.1 Note the areas outside the enclosure envelope that will be used to supply or accept the door fan air.

C-2.3.1.2 Inspect all openable doors, hatches, and movable partitions for their ability to remain shut during the test.

C-2.3.1.3 Obtain or generate a sketch of the floor plan showing walls, doorways, and the rooms connected to the test space. Number or name each doorway.

C-2.3.1.4 Look for large attached volumes open to the test space via the floor or walls of the test space. Note volumes and apparent open connecting areas.

C-2.3.1.5 Check floor drains and sink drains for traps with liquid.

C-2.3.2 Measurement of Enclosure.

C-2.3.2.1 Measure the clean agent protected enclosure volume. Record all dimensions. Deduct the volume of large solid objects to obtain the net volume.

C-2.3.2.2 Measure the highest point in the clean agent protected enclosure.

C-2.3.2.3 Calculate the effective floor area by dividing the net halon protected volume by the maximum clean agent protected enclosure height.

C-2.3.3 Preparation.

C-2.3.3.1 Advise supervisory personnel in the area about the details of the test.

C-2.3.3.2 Remove papers and objects likely to be affected by the air currents from the discharge of the door fan.

C-2.3.3.3 Secure all doorways and openings as for a halon discharge. Post personnel to ensure they stay shut/open. Open doorways inside the protected enclosure even though they could be closed upon discharge.

C-2.3.3.4 Get the user's personnel and/or the halon contractor to set up the room in the same state as when a discharge would occur, that is, HVAC shutdown, dampers closed, and so forth. Confirm that all dampers and closeable openings are in the discharge-mode position.

C-2.4 Door Fan Installation.

C-2.4.1 The door fan apparatus generally consists of a single door fan. A double or multiple door fan for larger spaces or for neutralizing leakage through a suspended ceiling can be used for certain applications.

C-2.4.2 Set up one blower unit in the most convenient doorway leading into the space. Choose the doorway that opens into the largest return path area. Consideration should be given to individuals requiring access into or out of the facility.

C-2.4.3 Follow the manufacturer's instructions regarding setup.

C-2.4.4 Examine the sealing around the door (before door fan installation) that the door fan will be mounted in to determine if significant leakage exists. If significant leaks are found they should be corrected. If the manufacturer's stated door fan sealing system leakage is less than the apparent remaining leakage of the doorway, the difference must be added to the leakage calculated in C-2.6 *(see C-2.6.3.5).*

C-2.4.5 Ensure all pressure gauges are leveled and zeroed prior to connecting them to the fan apparatus. This should be done by first gently blowing into or drawing from the tubes leading to the pressure gauges so the needle fluid or readout moves through its entire span and stays at the maximum gauge reading for 10 seconds. This confirms proper gauge operation. If using a magnehelic gauge, gently tap the gauge face for 10 seconds. With both ports of each gauge on the same side of the doorway (using tubes if necessary), zero the gauges with their particular adjusting method.

C-2.4.6 Connect the tubing for the room pressure gauge. Ensure the tube is at the floor slab elevation and extends at least 10 ft (3 m) away from the outlet side of the door fan blower, away from its air stream path, and away from all significant air streams (that is, HVAC airflows or openings where airflow could impinge on the tube).

C-2.4.7 The door fan should be arranged to alternately blow out of (depressurize) and blow into the space (pressurize). Both measurements should be taken as described in C-2.6.

C-2.5 Door Fan Enclosure Evaluation.

C-2.5.1 Pressure Runup Inspection.

C-2.5.1.1 Activate the blower and adjust the enclosure pressure to negative 15 Pa or maximum negative achievable (up to 15 Pa).

C-2.5.1.2 Inspect all dampers with smoke to ensure they are closing properly. Record problems and notify individuals responsible for the enclosure of the problems.

C-2.5.1.3 Inspect doors and hatches to ensure correct closure. Record problems and notify individuals responsible for the enclosure of the problems.

C-2.5.1.4 Inspect the wall perimeter (above and below the false floor) and the floor slab for major leaks. Note location and size of major leaks. Track down major airflow currents.

C-2.5.2 Static Pressure Measurement.

C-2.5.2.1 Seal the blower opening with the door fan properly installed but without the blower operating. Observe the room pressure gauge for at least 30 seconds. Look for minor fluctuations in pressure.

C-2.5.2.2 Under discharge conditions, measure the worst-case (greatest) pressure differential (P_{SH}) across a section of envelope containing the largest quantity of leaks expected to leak halon. If the subfloor is pressurized at discharge, measure the differential between the subfloor and outside the envelope. Call this value P_{SH} (for static at discharge). Determine the flow direction with smoke or other indicating method.

C-2.5.2.3 If the static pressure (P_{SH}) has an absolute value greater than 25 percent of the column pressure calculated in C-2.6.1.3 it must be permanently reduced. Large static pressures decrease the level of certainty inherent in this procedure. The most common causes of excessive static pressure are leaky dampers, ducts, and failure to shut down air-handling equipment serving the enclosure.

C-2.5.2.4 Record the position of all doorways, whether open or shut, when the static pressure (P_{SH}) is measured.

C-2.6 Door Fan Measurement.

C-2.6.1 Total Enclosure Leakage Method.

C-2.6.1.1 This method determines the equivalent leakage area of the entire enclosure envelope. It is determined by measuring the enclosure leakage under both positive and negative pressures and averaging the readings. This approach is used in order to minimize the influence of static pressures on the ELA calculation.

C-2.6.1.2 The procedures for determining the equivalent leakage area of the entire enclosure envelope are as follows:

(a) Block open all doorways around the enclosure and post personnel to ensure they stay open.

(b) Ensure adequate return path area is provided to allow an unrestricted return airflow path back to the door fan from enclosure leaks.

(c) Remove 1 percent of the floor tiles (for false floors) if an equivalent area is not already open.

(d) If agent is designed to discharge above the false ceiling, remove 1 percent of the ceiling tiles.

(e) Remeasure the static pressure (P_{ST}) at the time of the door fan test, between the room (not below the false floor) and the return path space.

(f) Make every effort to reduce the static pressure (P_{ST}) by shutting down air-handling equipment even though it can operate during discharge.

(g) Record P_{ST} and determine its direction using smoke or other means.

(h) Record the position of each doorway, open/shut.

(i) If the static pressure fluctuates due to wind, use a wind-damping system incorporating four averaging tubes on each side of the building to eliminate its effects. CAN/CGSB-149.10-M86, *Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method,* can be used.

(j) If a subfloor pressurization airhandler cannot be shut down for the test and leaks exist in the subfloor, these leaks cannot be accurately measured. Every attempt should be made to reduce subfloor leaks to insignificance. During the test as many floor tiles as possible should be lifted to reduce the amount of subfloor pressurization. Note that under such conditions the suspended ceiling leakage neutralization method will be difficult to conduct due to massive air turbulence in the room.

CAUTION

The removal of raised floor tiles creates a serious safety hazard. Appropriate precautions should be taken.

C-2.6.1.3 Calculate the column pressure in the clean agent protected enclosure using the following equation:

$$P_c = (g)(H_o)(r_m - r_a) \qquad \text{(C.1)}$$

where:

P_c = pressure due to the halon column (Pa)
g = acceleration due to gravity (9.81 m/sec^2)
H_o = height of protected enclosure (m)
r_m = clean agent/air mixture density (kg/m^3, see Equation C.9)
r_a = air density (1.202 kg/m^3)

If the calculated column pressure is less than 10 Pa, use 10 Pa as the column pressure.

C-2.6.1.4 Depressurize the enclosure with a door fan blower(s) until the measured pressure differential reading on the gauge (P_m) goes through a total pressure reduction (dP_m) equal to the column pressure (P_c). As an example, if the static pressure (P_{ST}) measured in C-2.6.1.2 was +1 Pa, and the calculated column pressure is 10 Pa, blow air out of the room until a P_m of +11 Pa is obtained. If the static pressure (P_{ST}) was +1 Pa, and the calculated column pressure is 10 Pa, blow air out of the room until a P_m of +9 Pa is obtained. If using magnehelic gauges, tap both the room pressure and flow pressure gauges for 10 seconds each. Wait a further 30 seconds before taking the readings.

C-2.6.1.5 Measure the airflow (Q_u) required to obtain the pressure reduction (dP_m) required. It is important to ensure that manufacturer's instructions are followed to ensure that airflow is accurately measured with respect to direction of flow.

C-2.6.1.6 The pressure reduction generated dP_m can be up to 30 percent greater, but not lower in absolute value than the calculated column pressure.

C-2.6.1.7 Repeat the procedure in C-2.6.1.4 through C-2.6.1.6 while pressurizing the enclosure. For example, if the static pressure (P_{ST}) measured in C-2.6.1.2 is ±1 Pa, and the calculated column pressure is 10 Pa, blow air into the room until +9 Pa is obtained. If the static pressure is +1 Pa, and the calculated column pressure is 10 Pa, blow air into the room until +11 Pa is obtained.

C-2.6.1.8 Ensure that the door fan flow measurement system is actually turned around between tests to properly measure pressurization or depressurization and that the motor rotation is not simply reversed. Ensure that the airflow entering the room is not deflected upward, which can cause lifting of any existing ceiling tiles.

C-2.6.1.9 Measure the air temperature within the enclosure (T_I) and outside the enclosure (T_O).

C-2.6.2 Suspended Ceiling Leakage Neutralization Method (Optional).

C-2.6.2.1 Where an unobstructed suspended ceiling exists, the leakage area below the ceiling can optionally be measured by neutralizing ceiling leaks. This method provides a more accurate estimate of leakage rates. This method should not be used if the walls between rooms within the zone are sealed at the ceiling slab. This method cannot be used when the system is designed to protect above this suspended ceiling. This test method does not imply that leakage above the suspended ceiling is acceptable. This technique can be difficult or impossible to perform under the following conditions:

(1) Air movement within the room could make it difficult to observe neutralization, particularly in small rooms.
(2) Obstructions above the suspended ceiling, that is, beams, ducts, and partitions, could make it difficult to obtain uniform neutralization.
(3) Limited clearance above the suspended ceiling, for example, less than 1 ft (0.3 m), could make it difficult to obtain neutralization.

C-2.6.2.2 If not already done, obtain the ELA of the protected enclosure using the total enclosure leakage method in C-2.6.1.

C-2.6.2.3 Ceiling level supply registers and return grilles can be temporarily sealed off to increase the accuracy of this method. If sealed, P_{ST} should be remeasured.

Temporary sealing of such openings is not permitted when conducting a total enclosure leakage test.

C-2.6.2.4 Install two separate door fans or a multiple blower door fan with one blower ducted to the above suspended ceiling space and the other into the room space below the suspended ceiling. It is not necessary to measure airflow through the upper fan.

C-2.6.2.5 Depressurize above and below the suspended ceiling by adjusting two separate blowers until the required pressure reduction and suspended ceiling leak neutralization (that is, no airflow through the suspended ceiling) is achieved.

Leaks are neutralized when, at opened locations in the suspended ceiling, smoke does not move up or down when emitted within $^1/_4$ in. (6 mm) of the openings. If neutralization is not possible at all locations, ensure that either smoke does not move or moves down but not up. Choose undisturbed locations away from flex duct flows, airstreams, and lighting fixtures because local air velocities make neutralization difficult to detect.

C-2.6.2.6 Measure the airflow *(Q_u)* through the fan that is depressurizing the volume below the false ceiling to obtain the pressure reduction *(dP_m)* required.

C-2.6.2.7 The pressure reduction generated in the volume below the false ceiling can be up to 30 percent greater, but not lower in absolute value, than the calculated column pressure.

C-2.6.2.8 Repeat the procedure in C-2.6.2.5 through C-2.6.2.7 while pressurizing the enclosure, except ensure that either smoke does not move or moves up but not down.

C-2.6.2.9 An alternate method for measuring the below-ceiling leaks consists of temporarily sealing identifiable ceiling level leaks using a flexible membrane, such as polyethylene sheet and tape, and then measuring the below-ceiling leakage solely using door fans drawing from the lower part of the room. No flex duct is needed. Examples of sealable leaks are undampered ceiling level supply registers or return grilles or an entire suspended ceiling lower surface.

C-2.6.3 Equivalent Leakage Area Calculation.

C-2.6.3.1 Subsection C-2.6.3 outlines the door fan calculation to be used in conjunction with C-2.6.1 and C-2.6.2.

C-2.6.3.2 The leakage area is generally derived per CAN/CGSB-149.10-M86, *Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method.* The CAN/CGSB document calculates area at 10 Pa only, whereas this procedure calculates area at a minimum of 10 Pa but allows for calculation at the halon column pressure, which could be greater than 10 Pa.

C-2.6.3.3 The airflow should be corrected for temperature if the difference between the temperature of the air being blown through the door fan and the temperature of the air going into or out of the leaks during the door fan test exceeds 10°C (18°F). If this condition exists, correct the flows as follows:

$$Q_c = Q_u\left(\frac{T_L + 273}{T_F + 273}\right)^{0.5} \tag{C.2}$$

where:

Q_c = corrected flow (m^3/sec)
Q_u = uncorrected flow (m^3/sec)
T_L = temperature of air going through room leaks (°C)
T_F = temperature of air going through door fan (°C)

When depressurizing:

$$T_L = T_O$$
$$T_F = T_I$$

When pressurizing:

$$T_L = T_I$$
$$T_F = T_O$$

C-2.6.3.4 For Equation C.2, corrections for barometric pressure are not necessary because they cancel out, and corrections for humidity are too small to be of concern. No other corrections apply. If Equation C.2 is not used, then:

$$Q_c = Q_u$$

C-2.6.3.5 After measurements are taken from pressurizing and depressurizing the enclosure, the leakage area in each direction should be calculated, and the results should be averaged. Each leakage area is calculated assuming the density of air is 1.202 kg/m^3 and the discharge coefficient for a hole in a flat plate (door fan) is 0.61. The equation is as follows:

$$A = \frac{1.271\,Q_c}{\left(\frac{P_m}{\sqrt{P_m}} - \frac{P_{ST}}{\sqrt{P_{ST}}}\right)} \tag{C.3}$$

The final value for *A* is determined by averaging the areas obtained under both a positive and negative pressure.

C-2.6.3.6 Equation C.3 should be used for both the total enclosure leakage method *(see C-2.6.1)* and the optional suspended ceiling leakage neutralization method *(see C-2.6.2).* For C-2.6.1, the area of leaks *(A)* equals the ELA. For C-2.6.2, the area of leaks *(A)* equals the below-ceiling leakage area (BCLA).

C-2.7 Retention Calculation.

C-2.7.1 Calculation.

C-2.7.1.1 Total Leakage Area. Calculate the total leakage area (A_T) using the ELA determined from the door fan measurements as per C-2.6.3. This should be based on a discharge coefficient of 0.61 that is used with the door fan apparatus. The following equations apply:

$$\text{ELA} = \frac{A_d + A_p}{2} \tag{C.4}$$

where:

A_d = leakage area (depressurization)
A_p = leakage area (pressurization)

$$A_T = 0.61 \times \text{ELA} \tag{C.5}$$

where:

A_T = total leakage area (m^2)
ELA = equivalent leakage area (m^2)

C-2.7.1.2 Lower Leakage Area. If the leakage area is measured using only C-2.6.1, total enclosure leakage method, then Equation C.6 should be used to calculate the lower leakage area (A_{LL}). If the below-ceiling leakage area (BCLA) is measured using C-2.6.2, suspended ceiling leakage neutralization method, then Equation C.7 applies instead. These equations are as follows:

$$A_{LL} = \frac{A_T}{2} \qquad (C.6)$$

$$A_{LL} = 0.61 \times \text{BCLA} \qquad (C.7)$$

where:

A_{LL} = lower leakage area (m^2)
BCLA = below-ceiling leakage area (m^2)

C-2.7.1.3 Leak Fraction. Determine the lower leak fraction *(F_A)* using the following equation:

$$F_A = \frac{A_{LL}}{A_T} \qquad (C.8)$$

C-2.7.1.4 Agent Mixture Density. Calculate the density of the agent/air mixture *(r_m)* using the following equation:

$$r_m = V_d \frac{C}{100} + \left(r_a \frac{(100 - C)}{100}\right) \qquad (C.9)$$

where:

r_m = clean agent/air mixture density (kg/m^3)
r_a = air density (1.202 kg/m^3)
C = clean agent concentration (%)
V_d = agent vapor density at 21°C (kg/m^3)

FC-3-1-10: 9.85 kg/m^3 (0.615 lb/ft^3)
HCFC Blend A: 3.84 kg/m^3 (0.240 lb/ft^3)
HFC-124: 5.83 kg/m^3 (0.364 lb/ft^3)
HFC-125: 5.06 kg/m^3 (0.316 lb/ft^3)
HFC-227ea: 7.26 kg/m^3 (0.453 lb/ft^3)
HFC-23: 2.915 kg/m^3 (0.182 lb/ft^3)
FIC-13I1: 8.051 kg/m^3 (0.503 lb/ft^3)
IG-01: 1.70 kg/m^3 (0.106 lb/ft^3)
IG-541: 1.41 kg/m^3 (0.088 lb/ft^3)
IG-55: 1.41 kg/m^3 (0.088 lb/ft^3)

C-2.7.1.5 Static Pressure. Determine the correct value for *(P_{SH})* to be used in Equation C.12. If the *(P_{SH})* recorded is negative, let it equal zero (0) and if it is positive, use the recorded value.

C-2.7.1.6 Minimum Height. Determine from the authority having jurisdiction the minimum height from the floor slab *(H)* that is not to be affected by the descending interface during the holding period.

If continuous mechanical mixing occurs during the retention time such that a descending interface does not form and the halon concentration is constant throughout the protected enclosure, calculate an assumed value for *H* based on the initial and final specified concentrations using the following equation:

$$H = \frac{C_F}{c} H_o \qquad (C.10)$$

where:

H = assumed value for H for mixing calculation (m)
c = actual agent concentration (%)
C_F = final agent concentration per authority having jurisdiction requirement (%)
H_o = maximum protection height

Example: H_o = 4 m, initial concentration = 7%, final = 5%, $H = {}^5/_7 \times 4$ m = 2.86 m. Ensure mixing is not created by ductwork that leaks excessively to zones outside the enclosure.

C-2.7.1.7 Time. Calculate the minimum time *(t)* that the enclosure is expected to maintain the descending interface above *(H)*, using the following equations:

$$C_3 = \frac{2g\,(r_m - r_a)}{r_m + r_a\left(\frac{F_A}{1 - F_A}\right)} \qquad (C.11)$$

$$C_4 = \frac{2P_{SH}}{r_m} \qquad (C.12)$$

$$t = 2A_R\left(\frac{\sqrt{C_3 H_o + C_4} - \sqrt{C_3 H + C_4}}{C_3 F_A A_T}\right) \qquad (C.13)$$

where:

t = time (seconds)
C_3 = constant for equation simplification
C_4 = constant for equation simplification
A_R = room floor area (m^2)
g = acceleration due to gravity (9.81 m/sec^2)
P_{SH} = static pressure during discharge (Pa)
H_o = height of ceiling (m)
H = height of interface from floor (m)

C-2.7.2 Acceptance Criteria. The time *(t)* that was calculated in C-2.7.1.7 must equal or exceed the holding time period specified by the authority having jurisdiction.

C-2.8 Leakage Control.

C-2.8.1 Leakage Identification.

C-2.8.1.1 While the enclosure envelope is being pressurized or depressurized, a smoke pencil or other smoke source should be used to locate and identify leaks.

The smoke source should not be produced by an open flame or any other source that is a potential source of fire ignition. Chemical smoke should be used only in small quantities and consideration should be given to the corrosive nature of certain chemical smokes and their effects on the facility being tested.

C-2.8.1.2 Leakage identification should focus on obvious points of leakage including wall joints, penetrations of all kinds, HVAC ductwork, doors, and windows.

C-2.8.1.3 Alternate methods for leakage identification are available and should be considered. One method is the use of a directional acoustic sensor that can be selectively aimed at different sound sources. Highly sensitive acoustic sensors are available that can detect air as it flows through an opening. Openings can be effectively detected by placing an acoustic source on the other side of the barrier and searching for acoustic transmission independent of fan pressurization or depressurization. Another alternative is to use an infrared scanning device if temperature differences across the boundary are sufficient.

C-2.8.2 Leakage Alteration.

C-2.8.2.1 Procedure.

C-2.8.2.1.1 Protected areas should be enclosed with wall partitions that extend from the floor slab to ceiling slab or floor slab to roof.

C-2.8.2.1.2 If a raised floor continues out of the protected area into adjoining rooms, partitions should be installed under the floor directly under above-floor border partitions. These partitions should be caulked top and bottom. If the adjoining rooms share the same under-floor air handlers, then the partitions should have dampers installed the same as required for ductwork.

C-2.8.2.1.3 Any holes, cracks, or penetrations leading into or out of the protected area should be sealed. This includes pipe chases and wire troughs. All walls should be caulked around the inside perimeter of the room where the walls rest on the floor slab and where the walls intersect with the ceiling slab or roof above.

C-2.8.2.1.4 Porous block walls should be sealed slab-to-slab to prevent gas from passing through the block. Multiple coats of paint could be required.

C-2.8.2.1.5 All doors should have door sweeps or drop seals on the bottoms, and weather stripping around the jambs, latching mechanisms, and door closer hardware. In addition, double doors should have a weather-stripped astragal to prevent leakage between doors and a coordinator to ensure proper sequence of closure.

C-2.8.2.1.6 Windows should have solid weather stripping around all joints.

C-2.8.2.1.7 All unused and out-of-service ductwork leading into or from a protected area should be permanently sealed off (airtight) with metal plates caulked and screwed in place. Ductwork still in service with the building air-handling unit should have butterfly blade-type dampers installed with neoprene seals. Dampers should be spring-loaded or motor-operated to provide 100-percent air shutoff. Alterations to air conditioning, heating, ventilating ductwork, and related equipment should be in accordance with NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*, or NFPA 90B, *Standard for the Installation of Warm Air Heating and Air-Conditioning Systems*, as applicable.

C-2.8.2.1.8 All floor drains should have traps and the traps should be designed to have water or other compatible liquid in them at all times.

C-2.8.2.2 Materials.

C-2.8.2.2.1 All materials used in altering leaks on enclosure envelope boundaries, including walls, floors, partitions, finish, acoustical treatment, raised floors, suspended ceilings, and other construction, should have a flame spread rating that is compatible with the flame spread requirements of the enclosure.

C-2.8.2.2.2 Exposed cellular plastics should not be used for altering leakage unless considered acceptable by the authority having jurisdiction.

C-2.8.2.2.3 Cable openings or other penetrations into the enclosure envelope should be firestopped with material that is compatible with the fire rating of the barrier.

C-2.9 Test Report. Upon completion of a door fan test, a written test report should be prepared for the authority having jurisdiction and made part of the permanent record. The test report should include the following:

(1) Date, time, and location of test
(2) Names of witnesses to the test
(3) Room dimensions and volume
(4) All data generated during test, including computer printouts
(5) Descriptions of any special techniques utilized by test technician (that is, use of optional ceiling neutralization and temporary sealing of suspended ceiling)
(6) In case of technical judgment, a full explanation and documentation of the judgment
(7) Test equipment make, model, and serial number
(8) Copy of current calibration certificate of test equipment
(9) Name and affiliation of testing technician and signature

Appendix D Referenced Publications

D-1 The following documents or portions thereof are referenced within this standard for informational purposes only and are thus not considered part of the requirements of this standard unless also listed in Chapter 6. The edition indicated here for each reference is the current edition as of the date of the NFPA issuance of this standard.

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

NFPA 12A, *Standard on Halon 1301 Fire Extinguishing Systems*, 1997 edition.

NFPA 70, *National Electrical Code*®, 1999 edition.

NFPA 77, *Recommended Practice on Static Electricity*, 1993 edition.

NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*, 1999 edition.

NFPA 90B, *Standard for the Installation of Warm Air Heating and Air-Conditioning Systems*, 1999 edition.

D-1.2 Other Publications.

D-1.2.1 ASHRAE Publication. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329-2305.

ANSI/ASHRAE 34, *Number Designation and Safety Classification of Refrigerants,* 1992.

D-1.2.2 ASME Publications. American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990.

ASME/ANSI B31, *Code for Pressure Piping,* 1992.

ASME B31.1, *Power Piping Code,* 1992.

D-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,* 1994.

ASTM A 106, *Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service,* 1994.

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

ASTM E 779, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization,* 1987.

ASTM E 1354, *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter,* 1999.

ASTM F 1387, *Standard Specification for Performance of Mechanically Attached Fittings,* 1993.

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

CGA C-6, *Standard for Visual Inspection of Steel Compressed Gas Cylinders,* 1993.

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

CAN/CGSB-149.10-M86, Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method.

D-1.2.6 IMO Publications. International Maritime Organization, 4 Albert Embankment, London, England, SE1 TSR.

SOLAS Regulation II-2/Regulation 5.2, Carbon Dioxide Systems, 1997.

SOLAS Regulation II-2/Regulation 5.3, Halogenated Hydrocarbon Systems, 1997.

D-1.2.7 U.S. Government Publications. U.S. Government Printing Office, Washington, DC 20402.

Title 49, *Code of Federal Regulations,* Part 111.59, Subchapter J.

Federal Register, Volume 59, Page 13044, EPA SNAP Program.

D-1.3 Other References.

Cholin, R. R., "Testing the Performance of Halon 1301 on Real Computer Installations," *Fire Journal,* Sept. 1972.

Coll, John P., Fenwal, CRC Report No. PSR-661, "Inerting Characteristics of Halon 1301 and 1211 Using Various Combustibles," August 16, 1976.

Cotton, F. A., and G. Wilkinson, *Advanced Inorganic Chemistry,* John Wiley & Sons, New York, 1980, p. 364.

Dalby, W. Evaluation of the toxicity of hydrogen fluoride at short exposure times. Stonybrook Laboratories, Inc., 311 Pennington-Rocky Hill Road, Pennington, NJ, sponsored by the Petroleum Environmental Research Forum (PERF), PERF Project No. 92-90, 1996.

Dalzell, Warner, Fenwal, CRC Report No. PSR-624, "A Determination of the Flammability Envelope of Four Tenrary Fuel-Air-Halon 1301 Systems," October 7, 1975.

DiNenno, P. J., *Engineering Evaluation and Comparison of Halon Alternatives and Replacements,* 1993 International CFC & Halon Alternatives Conference, Washington, DC, 1993.

DiNenno, P. J., and E. K. Budnick, "A Review of Discharge Testing of Halon 1301 Total Flooding Systems," National Fire Protection Research Foundation, Quincy, MA, 1988.

DiNenno, P. J., and E. W. Forssell, et al., "Evaluation of Halon 1301 Test Gas Simulants," *Fire Technology,* 25 (1), 1989.

DiNenno, P. J., and E. W. Forssell, et al., "Hydraulic Performance Tests of Halon 1301 Test Gas Simulants," *Fire Technology,* 26 (2), May 1990, pp. 121–140.

DiNenno, P. J., E. W. Forssell, M. J. Ferreria, C. P. Hanauska, and B. A. Johnson, "Modeling of the Flow Properties and Discharge of Halon Replacement Agents," Process Safety Progress, Vol. 14, No. 1, January 1995.

DuPont. Acute inhalation of hydrogen fluoride in rats. Haskell Laboratory Report HLR 365-90, 1990.

Elliot, D. G., P. W. Garrison, G. A. Klein, K. M. Moran, and M. P. Zydowicz, "Flow of Nitrogen-Pressurized Halon 1301 in Fire Extinguishing Systems," *JPL* Publication 84-62, Jet Propulsion Laboratory, Pasadena, CA November 1984.

Fellows, B. R., R. G. Richard, and I. R. Shankland, "Electrical Characterization of Alternative Refrigerants," XVIII International Congress of Refrigeration, August 10–17, 1991.

Fernandez, R., "DuPont's Alternatives to Halon 1301 and 1211, Recent Findings," Proceedings of the Halon Technical Working Conference, April 30–May 1, 1991, Albuquerque, NM.

Ferreira, M. J., C. P. Hanauska, and M. T. Pike, "Thermal Decomposition Products Results Utilizing PFC-410 (3M Brand PFC 410 Clean Extinguishing Agent)," 1992 Halon Alternatives Working Conference, Albuquerque, NM, May 12–14, 1992.

Ferreira, M. J., J. A. Pignato, and M. T. Pike, "An Update on Thermal Decomposition Product Results Utilizing PFC-410," 1992, International CFC and Halon Alternative Conference, Washington, D.C., October 1, 1992.

Ford, C. L., *Halon 1301 Computer Fire Test Program: Interim Report,* 1972.

Hanauska, C., "Perfluorocarbons as Halon Replacement Candidates," Proceedings of the Halon Technical Working Conference, April 30–May 1, 1991, Albuquerque, NM.

Hesson, J. C., "Pressure Drop For Two Phase Carbon Dioxide Flowing in Pipe Lines," Master of Science Thesis in CH.E. Illinois Institute of Technology, Jan. 1953.

Hirt, C. W., and N. C. Romero, "Application of a Drift-Flux Model to Flashing in Straight Pipes," Los Alamos Scientific Laboratory, Los Alamos, NM, 1976.

Hughes Associates, Inc., *Hazard Assessment of Thermal Decomposition Products of FM-200™ in Electronics and Data Processing Facilities,* Hughes Associates, 1995.

Lambertsen, C. J., "Research Bases for Improvements of Human Tolerance to Hypoxic Atmospheres in Fire Prevention and Extinguishment," Institute for Environmental Medicine, University of Pennsylvania, October 30, 1992.

Lambertsen, C. J., "Short Duration INERGEN Exposures, Relative to Cardiovascular or Pulmonary Abnormality," Institute for Environmental Medicine, University of Pennsylvania, February 1, 1993.

Largent, E. J., The metabolism of fluorides in man. *Arch Ind. Health* 21:318-323, 1960.

Machle, W., and K. R. Kitzmiller, The effects of the inhalation of hydrogen fluoride. II. The response following exposure to low concentrations. *J. Ind. Hyg. Toxicol.* 17:223-229, 1935.

Machle, W., F. Tharnann, K. R. Kitzmiller, and J. Cholak, The effects of the inhalation of hydrogen fluoride. I. The response following exposure to high concentrations. *J. Ind. Hyg. Toxicol.* 16:129-145, 1934.

Meacham, B. J., *Fire Technology*, First Quarter, 1993, 35.

Meldrum, M. *Toxicology of Substances in Relation to Major Hazards: Hydrogen Fluoride*. Health and Safety Executive (HSE) Information Centre, Sheffield S37HQ, England, 1993.

Naval Research Laboratory Report Ser 6180/0049.2 of 26 January 1995, "Agent Concentration Inhomogeneities in Real Scale Halon Replacement."

Nicholas, J. S., and S. W. Hansen, "Summary of the Physiology of INERGEN," Ansul Fire Protection, April 1, 1993.

Peatross, M. J., and E. W. Forssell, *A Comparison of Thermal Decomposition Product Testing of Halon 1301 Alternative Agents*, 1996 Halon Options Technical Working Conference, Albuquerque, NM, 1996.

Pedley, M. D., *Corrosion of Typical Orbiter Electronic Components Exposed to Halon 1301 Pyrolysius Products*, NASA TR-339-001, 1995.

Robin, M. L., "Halon Alternatives: Recent Technical Progress," 1992 Halon Alternatives Working Conference, Albuquerque, NM, May 12–14, 1992.

Robin, M. L., "Evaluation of Halon Alternatives," Proceedings of the Halon Technical Working Conference, April 30–May 1, 1991, Albuquerque, NM, p. 16.

Sax, N. I., *Dangerous Properties of Industrial Materials*, 6th ed., Van Nostran Rheinhold, New York, 1984.

Senecal, Joseph A., Fenwal Safety Systems CRC Technical Note No. 361, Agent Inerting Concentrations for Fuel-Air Systems, May 27, 1992.

Sheinson et al., R. S., *J. Fire & Flamm.*, 12, 229, 1981.

Sheinson, R. S., "Halon Alternatives — Compartment Total Flooding Testing," Proceedings of the International Conference on CFC and Halon Alternatives, December 3–5, 1991, Baltimore, MD, 1991, p. 629.

Sheinson, Ronald S., Harold G. Eaton, Bruce Black, Roger Brown, Howard Burchell, Alexander Maranghides, Clark Mitchell, Glen Salmon, and Walter D. Smith, "Halon 1301 Total Flooding Fire Testing, Intermediate Scale," Proceedings Halon Alternatives Technical Working Conference, May 3–5, 1994, Albuquerque, NM.

Sheinson, Ronald S., Alexander Maranaghides, Harold G. Eaton, Doug Baryliski, Bruce H. Black, Roger Brown, Howard Burchell, Peter Byne, Tom Friderichs, Clark Mitchell, Michelle Peatross, Glen Salmon, Walter D. Smith, and Frederick W. William, "Large Scale (840M3) Total Flooding Fire Extinguishment Results," Proceedings Halon Alternatives Technical Working Conference, May 1995, Albuquerque, NM.

Skaggs, S. R., and T. Moore, *Toxicological Properties of Halon Replacements*, 208th ACS National Meeting, Washington, DC, 1994; S.R. Skaggs and T. Moore, *Toxicology of Halogenated Halon Substitutes*, Fire Safety Without Halon Conference, Zurich, Switzerland, September 1994.

Skaggs, S. R., R. E. Tapscott, and T. A. Moore, "Technical Assessment for the SNAP Program," 1992 Halon Alternatives Working Conference, Albuquerque, NM, May 12–14, 1992.

Tamanini, F. "Determination of Inerting Requirements for Methane/Air and Propane/Air Mixtures by an Ansul Inerting Mixture of Argon, Carbon Dioxide and Nitrogen," Factory Mutual Research, August 24, 1992.

United Nations Environment Programme, Montreal Protocal on Substances that Deplete the Ozone Layer — Final Act 1987, UNEP/RONA, Room DCZ-0803, United Nations, New York, NY, 10017.

Wysocki, T. J., "Single Point Flow Calculations for Liquefied Compressed Gas Fire Extinguishing Agents," Halon Options Technical Working Conference Proceedings, Albuquerque, NM, 1996.

Wysocki, T. J., and B. C. Christensen, "Inert Gas Fire Suppression Systems Using IG541 (Inergen) Solving the Hydraulic Calculation Problem," Halon Options Technical Working Conference Proceedings, Albuquerque, NM, 1996.

Index

-A-

- **Abort switches** 2-3.5.3, 4-7.2.4.13, A-2-3.5.3
- **Acceptance, installation** 4-7.2, A-4-7.2
- **Accidental discharge** *see* Unwanted system operation
- **Actuation systems** 2-3.1, 2-3.3, 4-7.2.4.4
  - Marine systems 5-5, A-5-5.1.2, A-5-5.2.3
- **Adjusted minimum design quantity (AMDQ) (definition)** 1-3.1
- **Agent concentration**
  - Definition 1-3.2
  - Design concentration requirements 3-4, A-3-4
    - Marine systems 5-8, A-5-8.4
  - Sea level equivalent of agent (definition) 1-3.23
- **Alarm systems** 2-3.1.1, 4-7.2.4.4 to 4-7.2.4.6, 4-7.2.4.10 to 4-7.2.4.13
  - Equipment failure 2-3.5.4
  - Hazardous atmosphere A-1-6.1.4.1(e)
  - Marine systems protecting Class B hazards 5-6.1 to 5-6.2, 5-6.5, A-5-6.1 to A-5-6.2, A-5-6.5
  - Operating alarms 2-3.5
  - Time delays 2-3.5.6
- **Application, rate of** 3-7.1, A-3-7.1.2
- **Approval of installations** 4-7, A-4-7
  - Marine systems 5-12
- **Approved (definition)** 1-3.3, A-1-3.3
- **Argon, as inerting agent** A-1-5.1.2
- **Attached volumes**
  - Definition C-1.3.1
  - Door fan measurements C-1.2.2.2
- **Authority having jurisdiction (definition)** 1-3.4, A-1-3.4

-B-

- **Blower (definition)** C-1.3.2

-C-

- **Canadian Transport Commission, regulations** 2-1.4.3, 4-2.1
- **Carbon dioxide, as inerting agent** A-1-5.1.2
- **Cargo spaces, protection of** A-5-2.2
- **Cast-iron pipe and fittings** 2-2.1.2, 2-2.3.2
- **Ceiling slab (definition)** C-1.3.3
- **Chemical fires, use on** 1-5.2.5(1), 1-5.2.5(4), 5-2.2(1), 5-2.2(4)
- **Class A fires**
  - Definition 1-3.5
  - Flame extinguishment concentrations 3-4.2.2, 3-4.2.4, A-3-4.2.2
- **Class B fires**
  - Definition 1-3.6
  - Flame extinguishment concentrations 3-4.2.1, 3-4.2.3, 5-8.3
- **Class B hazards greater than 6000 ft, marine systems protecting** 5-6, A-5-6
- **Class C fires**
  - Definition 1-3.7
  - Flame extinguishment concentrations 3-4.2.5
- **Clean agents** *see also* Agent concentration
  - Applicability 1-5.1, A-1-5.1
  - Compatibility with other agents 1-9, A-1-9.1
  - Decomposition of 1-5.2.8, 5-2.3, A-1-5.2.8, A-1-6.1.1
  - Definition 1-3.8
  - Mixture density calculation C-2.7.1.4
  - Quality 2-1.2, A-2-1.2
  - Quantity 2-1.1, 4-1.3, 4-1.5, 4-7.2.2.11, A-2-1.1.2
  - Recycling or disposal of 4-1.4 to 4-1.5, A-2-1.4.2
  - Retrofitability 1-8
  - Supply 2-1, A-2-1
    - Marine systems 5-4, A-5-4
- **Clearances**
  - Definition 1-3.9
  - Electrical 1-6.2, 5-3.2, A-5-3.2
- **Column pressure**
  - Calculation C-2.6.1.3
  - Definition C-1.3.4
- **Compatibility of clean agents** 1-9, A-1-9.1
- **Components** Chap. 2
- **Conductors, ungrounded, electrostatic charging of** 1-5.2.6
- **Containers**
  - Arrangement 2-1.3, A-2-1.3.2
    - Marine systems 5-4.2, A-5-4.2
  - Characteristics 2-1.4, A-2-1.4.1
  - Inspection, testing, and maintenance 4-1.3 to 4-1.6, 4-2, 4-7.2.2.8 to 4-7.2.2.9
  - Marine systems 5-4.2 to 5-4.5, A-5-4.2
  - Nonrefillable 4-1.5
  - Pressure 5-4.2.1.1; *see also* Pressurization levels
  - Refillable 4-1.4, 5-11.2, 5-11.3.1
- **Control systems** 2-3.1, 2-3.4, 4-7.2.4.4, 4-7.2.4.14, A-2-3.6
  - Marine systems 5-5, A-5-5.1.2, A-5-5.2.3
  - Primary power source, testing of 4-7.2.5.4
- **Cylinders, stored, protection for** 5-6, A-5-6

-D-

- **Decomposition, clean agents** 1-5.2.8, 5-2.3, A-1-5.2.8, A-1-6.1.1 to A-1-6.1.3
  - Discharge time and A-3-7.1.2
- **Definitions** 1-3, 5-1.2, A-1-3, C-1.3
- **Descending interface**
  - Definition C-1.3.5
  - Minimum time calculation C-2.7.1.7
  - Retention calculations C-1.2.3.5
- **Design concentration requirements** 3-4, A-3-4
  - Marine systems 5-8, A-5-8.4
- **Design factor (DF) (definition)** 1-3.10
- **Design quantity** 3-5, A-3-5
  - Adjusted minimum design quantity (AMDQ) (definition) 1-3.1
  - Final design quantity (FDQ) (definition) 1-3.13
  - Marine systems 5-8.4, A-5-8.4
  - Minimum design quantity (MDQ) (definition) 1-3.18
- **Detection systems** 2-3.1 to 2-3.2, 4-7.2.4.4, 4-7.2.4.7 to 4-7.2.4.9, A-2-3.2.1
  - Marine systems 5-5, 5-6.1, A-5-5.1.2, A-5-5.2.3, A-5-6.1
- **Discharge delays** 2-3.5.6
- **Discharge nozzles** 2-2.5
- **Discharge pressures, dynamic** C-1.2.3.1
- **Discharge tests** 4-7.2.2.10, A-4-7.2.2.10
- **Discharge time** 3-7.1.2, A-3-7.1.2
  - Marine systems 5-9.2
- **Disposal of agents** 4-1.4 to 4-1.5, A-2-1.4.2

- **Distribution system** 2-2, A-2-2
  - Discharge time 3-7.1.2, A-3-7.1.2
    - Marine systems 5-9.2
  - Extended discharge 3-7.2, A-3-7.2
  - Inspection and testing of 4-7.2.2, A-4-7.2.2.13
  - Marine systems 5-9
  - Rate of application 3-7.1, A-3-7.1.2
    - Marine systems 5-9.1
- **Door fan measurement** C-1.2.2
  - Equivalent leakage area (ELA) calculation C-2.6.3
  - Suspended ceiling leakage neutralization method C-2.6.2
  - Total enclosure leakage method C-2.6.1
- **Door fans**
  - Definition C-1.3.6
  - Enclosure evaluation C-2.5
  - Installation C-2.4
  - System design C-2.2.1
  - Test C-1.2.1.5, C-1.2.3.2, C-2.5.2
- **DOT** *see* U.S. Dept. of Transportation (DOT), regulations
- **Duration of protection** 3-6, A-3-6
  - Marine systems 5-8.5

-E-

- **Effective floor area (definition)** C-1.3.7
- **Effective flow area (definition)** C-1.3.8
- **Electric control equipment** 2-3.4.1
- **Electrical and electronic hazards, use for** 1-5.2.3(1), A-1-5.2.3, A-3-6
  - Marine systems 5-2.1(5)
- **Electrical clearances** 1-6.2, 5-3.2, A-5-3.2
- **Electrical components, inspection of** 4-7.2.4
- **Electrical systems, marine** 5-14
  - Circuits, cylinder storage space 5-6.2 to 5-6.4, 5-6.6, A-5-6.2 to A-5-6.4, A-5-6.6
- **Electrostatic charging, ungrounded conductors** 1-5.2.6
- **Employees**
  - Hazards to 1-6.1, 5-3, A-1-6.1, A-5-3.2
  - Safety requirements 1-6.1.4, 4-8, A-1-6.1.4, A-4-8
  - Training 4-6, A-4-6.2
- **Enclosure envelope (definition)** C-1.3.10
- **Enclosure integrity procedure** App. C; *see also* Door fans
  - Definitions C-1.3.10
  - Field calibration check C-2.2.3
  - Fundamentals C-1
  - Leakage control C-2.8
  - Limitations/assumptions C-1.2
  - Retention calculation C-1.2.3, C-2.7
  - Scope C-1.1
  - Test procedure C-2
- **Enclosures** 1-5.2.7
  - Definition C-1.3.9
  - Design 3-3, A-3-3.5
  - Explosion hazard of A-1-5.2.4
  - Inspection 4-4
  - Integrity, inspection of 4-7.2.3, A-4-7.2.3
  - Marine systems 5-7, A-5-7
  - Overpressure A-3-7.1.2
  - Sealing 4-5.3, 5-7.1(1), A-4-5.3, A-5-7.1
  - Total flooding systems used in 1-5.2.3, A-1-5.2.3
- **Engineered system (definition)** 1-3.11
- **Environmental factors** 1-7, A-1-7, A-2-1.4.2
- **Equivalent leakage area (ELA)**
  - Calculation C-2.6.1.1, C-2.6.3
  - Definition C-1.3.11
- **Explosion prevention/suppression** 1-5.2.4, A-1-5.2.4
- **Extended discharge** 3-7.2, A-3-7.2

-F-

- **Fan pressurization apparatus (definition)** C-1.3.12
- **Field calibration check, enclosure integrity** C-2.2.3
- **Fill density**
  - Containers 2-1.4.1, A-2-1.4.1
  - Definition 1-3.12
- **Final design quantity (FDQ) (definition)** 1-3.13
- **Fittings** 2-2.3, A-2-2.3.1
  - Marine systems 5-4.6 to 5-4.7, A-5-4.6 to A-5-4.7
- **Flame extinguishment concentrations** 3-4.2, A-3-4.2.2
  - Cup burner test procedure App. B
  - Marine systems 5-8.3
- **Flammable and combustible liquid fires** *see* Class B fires
- **Floor area, enclosure integrity** C-1.2.3.4
- **Floor slab (definition)** C-1.3.13
- **Flow calculations** 3-1.2.5, 3-2, A-3-2
- **Flow pressure gauge (definition)** C-1.3.14
- **Flow tests** 4-7.2.2.13, A-4-7.2.2.13
- **Fluorine** A-1-5.1.2
- **Fluoroiodocarbons (FICs)** A-1-5.1.2
- **Forced-air ventilating systems** 3-3.5, A-3-3.5
- **Functional testing** 4-7.2.5

-H-

- **Halocarbon agents**
  - Cargo spaces, protection of A-5-2.2
  - Containers 2-1.4.2(1), 2-1.4.5(a), A-2-1.4.2
  - Decomposition A-1-6.1.2
  - Definition 1-3.14, A-1-3.14
  - Design concentration 3-5.1, A-3-5.1
  - Discharge time 3-7.1.2.1, 3-7.1.2.3, 5-9.2.1 to 5-9.2.2, A-3-7.1.2.1
  - Employees, hazards to 1-6.1.2, A-1-6.1.2
  - Flame extinguishment concentrations 3-4.2.2, A-3-4.2.2
  - Inspection and tests 4-1.3.1, 4-1.6, 5-11.3, A-5-11.3
  - Physical properties A-1-5.1
  - Piping, minimum requirements A-2-2.1
  - Recycling or disposal of 4-1.4, A-2-1.4.2
- **Halon 1301**
  - Decomposition products A-3-7.1.2
  - System valves A-2-2.4.2
- **Hazards**
  - Clean agent systems used for 1-5.2, A-1-6, A-3-6
  - To employees 1-6.1, 5-3, A-1-6.1, A-5-3.2
- **Hose test** 4-3
- **Hydrochlorofluorocarbons (HCFCs)** A-1-5.1.2, Figs. A-2-1.4.1(k) to (p)
- **Hydrofluorocarbons (HFCs)** A-1-5.1.2, Fig. A-2-1.4.1(q) to (v)
- **Hydrogen fluoride (HF)** A-1-5.1.2, A-3-7.1.2

-I-

- **Identification**
  - Containers 2-1.4.4, A-2-1.4.2
  - Piping systems 2-2.1.3
- **IG-541** A-1-5.1.2
  - Classification A-2-1.4.1
  - Decomposition products A-1-5.1.3
  - Isometric diagram Fig. A-2-1.4.1(v)

Indicators, operating 2-3.5
Inert gas, flow test using 4-7.2.2.13, A-4-7.2.2.13
Inert gas agents
  Containers 2-1.4.2(2), 2-1.4.5(b)
  Decomposition A-1-6.1.3
  Definition 1-3.15
  Design concentration 3-5.2, A-3-5.2
  Designations for A-1-5.1.2
  Discharge time 3-7.1.2.2, 5-9.2.3, A-3-7.1.2
  Employees, hazards to 1-6.1.3, A-1-6.1.3
  Inspection and tests 4-1.3.2, 4-1.6, 5-11.3.1
  Piping, minimum requirements A-2-2.1
  Recycling or disposal of 4-1.4, A-2-1.4.2
Inert gas flow calculations A-3-2
Inerting concentrations 3-4.3
Inspection 4-1
  Electrical components 4-7.2.4
  Enclosures 4-4, 4-7.2.3, A-4-7.2.3, C-2.3.1
  Marine systems 5-11, A-5-11.3
  Mechanical components 4-7.2.2, A-4-7.2.2.13
  Records/reports 4-1.2, 4-1.6, 4-2.2, 5-2.2, 5-11.1 to 5-11.2, A-5-2.2
  Visual 4-2.2, 5-2.2 to 5-2.3
Installations, approval of 4-7, A-4-7
  Marine systems 5-12

-J-

Joints, pipe 2-2.2, 4-7.2.2.3

-L-

Leaks, enclosure 4-7.2.3, A-4-7.2.3; *see also* Equivalent leakage area (ELA)
  Alteration C-2.8.2
  Discharge C-1.2.3.8
  Flow characteristics C-1.2.3.6
  Flow direction C-1.2.3.7
  Identification C-2.8.1
  Leak fraction calculation C-2.7.1.3
  Location C-1.2.2.4, C-1.2.3.9
  Measurement C-2.6.1, C-2.6.2
  Retention calculation C-2.7.1
Limitations, of systems 1-5.2, A-1-5.2
  Marine systems 5-2, A-5-2.2
Liquefied compressed gas flow calculations A-3-2
Listed (definition) 1-3.16, A-1-3.16
Lower leakage area calculation C-2.7.1.2
Lowest observable adverse effect level (LOAEL) A-3-5.3.3
  Definition 1-3.17
  Employee safety 1-6.1.2.1, A-1-6.1.2

-M-

Machinery spaces
  Definition 5-1.2.3
  Hazards to employees 5-3.1
  Total flooding systems 5-2.1(1)
Maintenance 4-5, A-4-5.3
Manifolded storage containers 2-1.3.5, 2-1.4.5, A-2-1.1.2
Manual actuation systems 2-3.3.5 to 2-3.3.7, 2-3.3.10
  Marine systems 5-5.2.2 to 5-5.2.4, A-5-5.2.3
Marine systems Chap. 5
  Agent supply 5-4, A-5-4
  Approval of installations 5-12
  Class B hazards greater than 6000 ft, systems protecting 5-6, A-5-6
  Definition 5-1.2.2
  Design concentration requirements 5-8, A-5-8.4
  Detection, actuation, and control systems 5-5, A-5-5.1.2, A-5-5.2.3
  Distribution system 5-9
  Electrical systems, compliance of 5-14
  Enclosure 5-7, A-5-7
  Hazards to personnel 5-3, A-5-3.2
  Inspection and tests 5-11, A-5-11.3
  Nozzle choice and location 5-10
  Periodic puff testing 5-13
  Use and limitations of 5-2, A-5-2.2
Maximum protected height (definition) C-1.3.15
Measurement, units of 1-4
Mechanical components, inspection of 4-7.2.2, A-4-7.2.2.13
Metal fires, use on 1-5.2.5(2) to (3), 5-2.2(2) to (3)
Minimum design quantity (MDQ) (definition) 1-3.18
Minimum protected height
  Calculation C-2.7.1.6
  Definition C-1.3.16
Minimum time calculation C-2.7.1.7

-N-

Nitrogen
  Flow testing with 4-7.2.2.13, A-4-7.2.2.13
  Inerting use A-1-5.1.2
No observed adverse effect level (NOAEL) A-3-5.3.3
  Definition 1-3.19
  Employee safety 1-6.1.2.1, A-1-6.1.2, A-1-6.1.4.2
Normally occupied area
  Definition 1-3.20, A-1-3.20
  Halocarbon fire extinguishing agents 1-6.1.2.1, A-1-6.1.2
Nozzles
  Choice and location 3-8, 5-10
  Discharge 2-2.5, 4-7.2.2.3, 4-7.2.2.5
  Inspection and testing of 4-7.2.2.2 to 4-7.2.2.7
  Marine systems 5-4.7, A-5-4.6

-O-

Operating devices 2-3.3, 2-3.5
  Marine systems 5-5.2.5
Out-of-service system A-2-3.6
Oxygen, sea level equivalent of (definition) 1-3.24
Oxygen concentrations, personnel safety 1-6.1.2.2, 1-6.1.3, A-1-6.1.2 to A-1-6.1.3

-P-

Perfluorocarbons (FCs) A-1-5.1.2
Periodic puff testing 5-13, A-4-7.2.2.13
Piping 2-2.1 to 2-2.2, A-2-2.1
  Inspection and testing of 4-7.2.2, A-4-7.2.2.13
  Joints 4-7.2.2.3
  Marine systems 5-4.6 to 5-4.7, A-5-4.6
Plans, working 3-1.2
  Approval of 3-1.3
  Flow calculations 3-1.2.5, 3-2, A-3-2
Pneumatic control equipment 2-3.4.2
Pneumatic pressure testing 4-7.2.2.12
Power sources
  Marine systems 5-5.2.1
  Testing of 4-7.2.5.4

- **Pre-engineered systems**
  - Definition 1-3.21
  - Design 3-1.2.3 Ex.
  - Flow calculations 3-2.1 Ex.
  - Use and limitations 1-5.2.1
- **Preliminary functional test** 4-7.2.5.1
- **Pressure, stored cylinders** 5-6.5, A-5-6.5
- **Pressure adjustment** 3-5.3.3, A-3-5.3.3
- **Pressure differentials, enclosure** A-3-7.1.2, C-1.2.1.5, C-1.2.3.2, C-2.5.2, C-2.7.1.5
- **Pressure relief devices** 2-2.1.6 to 2-2.1.7, A-2-1.4.1
- **Pressure testing** 4-1.3, 4-7.2.2.12
- **Pressurization levels**
  - Containers 2-1.4.1, 2-1.4.4, A-2-1.4.1
  - Enclosures 3-3.3, 3-5.3.3, A-3-5.3.3
  - Fittings 2-2.3.1, 2-2.3.6, A-2-2.3.1
  - Marine systems 5-11.2 to 5-11.3, A-5-11.3
  - Piping 2-2.1.1, 2-2.1.6, A-2-2.1
- **Primary agent supply** 2-1.1.1
- **Primary power source**
  - Marine systems 5-5.2.1
  - Testing of 4-7.2.5.4
- **Protected enclosure (definition)** C-1.3.17
- **"Puff test"** 5-13, A-4-7.2.2.13
- **Pump rooms**
  - Definition 5-1.2.4
  - Total flooding systems 5-2.1(3)
- **Purpose of standard** 1-2

-R-

- **Records/reports**
  - Cup burner test procedure B-8
  - Enclosure integrity procedure C-2.9
  - Inspection 4-2.2, 5-2.2, 5-11.1 to 5-11.2, A-5-2.2
- **Recycling of agents** 4-1.4 to 4-1.5, A-2-1.4.2
- **Referenced publications** Chap. 6, App. D
- **Remote monitoring operations** 4-7.2.5.3
- **Reports** *see* Records/reports
- **Reserve agent supply** 2-1.1.2, 5-4.1, A-2-1.1.2
- **Retention calculation, enclosure** C-1.2.3, C-2.7
- **Retrofitability, clean agents to existing system** 1-8
- **Return path**
  - Definition C-1.3.18
  - Door fan measurements C-1.2.2.3
- **Return path area (definition)** C-1.3.19
- **Room pressure gauge (definition)** C-1.3.20

-S-

- **Safety** 1-6, 4-8, A-1-6, A-4-8
- **Safety factor (SF) (definition)** 1-3.22
- **Scope of standard** 1-1
- **Sea level equivalent of agent (definition)** 1-3.23
- **Sea level equivalent of oxygen (definition)** 1-3.24
- **Shall (definition)** 1-3.25
- **Shipping containers, DOT regulations** 2-1.4.3
- **Should (definition)** 1-3.26
- **Signs, warning and instruction** 2-3.5.5
- **Spaces (electronic/electrical equipment, marine)** 5-2.1(5)
  - Definition 5-1.2.1
- **Specifications** 3-1.1
- **Static pressure differential**
  - Calculation C-2.7.1.5
  - Definition C-1.3.21
  - Door fan test C-1.2.1.5, C-1.2.3.2, C-2.5.2
- **Steel pipe** 2-2.1.2, 2-2.3.6
- **Storage containers** *see* Containers
- **Superpressurization**
  - Containers 2-1.4.1, 2-1.4.4, A-2-1.4.1
  - Definition 1-3.27
- **Suspended ceiling leakage neutralization method, door fan measurement** C-2.6.2
- **System design** Chap. 3
- **System flow calculations** A-3-2
- **System functional operational test** 4-7.2.5.2

-T-

- **Temperatures** 5-4.2.1.2
  - Clean agents and 1-5.2.8, 2-2.1.1, A-1-5.2.8, A-1-6.1(c), A-2-1.4.1, Figs. A-2-1.4.1(a) to (hh)
  - Containers 2-1.4.6, A-2-1.4.1
  - Enclosure integrity C-1.2.3.3
- **Tests** 4-1
  - Container 4-2
  - Cup burner test procedure App. B
  - Discharge 4-7.2.2.10, A-4-7.2.2.10
  - Door fan test C-1.2.1.5, C-1.2.3.2, C-2.5.2
  - Extinguishing concentration, evaluation of A-3-4.2.2
  - Flow 4-7.2.2.13, A-4-7.2.2.13
  - Functional 4-7.2.5
  - Hose 4-3
  - Marine systems 5-11, 5-13, A-5-11.3
  - Piping, pneumatic testing of 4-7.2.2.12
  - Primary power source 4-7.2.5.4
- **Time delays** 2-3.5.6
- **Total enclosure leakage method, door fan measurement** C-2.6.1
- **Total flooding**
  - Definition 1-3.28
  - Quantity 3-5, A-3-5
    - Marine systems 5-8.4, A-5-8.4
- **Total flooding system**
  - Definition 1-3.29
  - Design 3-3.1
  - Enclosure integrity 4-7.2.3, A-4-7.2.3
  - Use and limitations 1-5.2.3, A-1-5.2.3
    - Marine systems 5-2.1
- **Total leakage area calculation** C-2.7.1.1
- **Training** 4-6, A-4-6.2

-U-

- **U.S. Dept. of Transportation (DOT), regulations** 2-1.4.3, 4-2.1
- **Unwanted system operation** 2-3.6, A-2-3.6
- **Uses, of systems** 1-5.2, A-1-5.2, A-3-6
  - Marine systems 5-2, A-5-2.2

-V-

- **Valves** 2-2.4, A-2-2.4.2
  - Marine systems 5-4.6
- **Ventilating systems** 3-3.5, A-3-3.5
  - Marine systems 5-7.2, A-5-7.2
- **Venting, piping systems** 2-2.1.6
- **Visual inspection** 4-2.2, 5-2.2 to 5-2.3