

DELETED**First Revision No. 1-NFPA 2001-2019 [Global Input]**

Remove "ANSI/" and "Standard for" from all UL publications referenced in this code.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Wed Apr 24 14:07:11 EDT 2019

Committee Statement

Committee Update of references and removal of repetitive wording and removal of ANSI to eliminate any
Statement: confusion that the standards are UL standards, not developed by ANSI. There are many other
references to standards promulgated by different standards development organizations where they
are considered ANSI approved but do not include ANSI in the reference.

Response FR-1-NFPA 2001-2019

Message:

[Public Input No. 64-NFPA 2001-2018 \[Global Input\]](#)



First Revision No. 35-NFPA 2001-2019 [Global Input]

- (1) Revise Chapter 1 (Administration) in accordance with the attached file.
- (2) Create a new chapter, titled 'General Requirements,' from the existing text in 1.4 through 1.8, with revisions in accordance with the attached file. This chapter should be inserted after the chapter titled 'Definitions.'
- (3) Create a new annex chapter, titled 'Toxicological and Physiological Effects of Clean Agents and Their Decomposition Products,' from the existing text in A.1.5.1.2 and A.1.5.1.3, with revisions in accordance with the attached file. This chapter should be inserted after Annex A.

Supplemental Information

File Name	Description Approved
2001_FR35_Chapter01.docx	For staff use
2001_FR35_Chapter01..pdf	For ballot

Submitter Information Verification

Committee:

Submittal Date: Wed May 01 17:18:26 EDT 2019

Committee Statement

Committee Statement: Sections 1.1 through 1.3 are reorganized in accordance with the Manual of Style. New sections on Equivalency and Retroactivity are also added for consistency with other NFPA standards. The section on Units is completely revised to better describe the usage and enforcement of units and measures throughout the standard. Table 1.4.1.2, which identifies the clean agents that are addressed by the standard, is relocated to the document scope to give a clearer and more immediate indication of what the document covers. Accordingly, the annex material on agent naming conventions (A.1.4.1.2) and physical properties of agents (A.1.4.1) is combined and relocated so that it is associated with the document scope and the list of clean agents.

Sections 1.4 through 1.8 include requirements that do not belong in an administrative chapter. These requirements are moved to a new Chapter 4 for General Requirements.

The discussions on toxicological and physiological effects of clean agents and decomposition products in A.1.5.1.2 and A.1.5.1.3 are moved to a new Annex B so that the material is easier to reference and so that Annex A is smaller and easier to navigate.

Response Message: FR-35-NFPA 2001-2019

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

[2001, FR-35]

Chapter 1 Administration

1.1 Scope.

1.1.1*

This standard contains minimum requirements for the design, installation, approval, and maintenance of total flooding and local application clean-agent fire extinguishing systems that use one of the gaseous agents in Table 1.1.1.

Table 1.1.1 Agents Addressed in NFPA 2001

Agent Designation	Chemical Name	Chemistry
FK-5-1-12	Dodecafluoro-2-methylpentan-3-one	$\text{CF}_3\text{CF}_2\text{C}(\text{O})\text{CF}(\text{CF}_3)_2$
HCFC Blend A	Dichlorotrifluoroethane HCFC-123 (4.75%)	CHCl_2CF_3
=	Chlorodifluoromethane HCFC-22 (82%)	CHClF_2
=	Chlorotetrafluoroethane HCFC-124 (9.5%)	$\text{CHClF}_2\text{CF}_3$
=	Isopropenyl-1-methylcyclohexene (3.75%)	=
HCFC-124	Chlorotetrafluoroethane	$\text{CHClF}_2\text{CF}_3$
HFC-125	Pentafluoroethane	CHF_2CF_3
HFC-227ea	Heptafluoropropane	$\text{CF}_3\text{CHF}_2\text{CF}_3$
HFC-23	Trifluoromethane	CHF_3
HFC-236fa	Hexafluoropropane	$\text{CF}_3\text{CH}_2\text{CF}_3$
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
HFC Blend B	Tetrafluoroethane (86%)	$\text{CH}_2\text{F}_2\text{CF}_3$
=	Pentafluoroethane (9%)	CHF_2CF_3
=	Carbon dioxide (5%)	CO_2

Notes:

(1) Other agents could become available at later dates. They could be added via the NFPA process in future editions or by amendments to the standard.

(2) Composition of inert gas agents is given in percent by volume. Composition of HCFC Blend A is given in percent by weight.

(3) The full analogous ASHRAE nomenclature for FK-5-1-12 is FK-5-1-12mmv2.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

A.1.4.1.2 A.1.1.1

The designations for perfluorocarbons (FCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), fluoroiodocarbons (FICs), and fluoroketones (FKs) are an extension of halocarbon designations in ANSI/ASHRAE 34, prepared by the American National Standards Institute, Inc. (ANSI) and 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 each).

A.1.4.1

The clean agents in Table 1.1.1 currently listed possess the physical properties as detailed in Table A.1.4.1 A.1.1.1(a) through Table A.1.4.1 A.1.1.1(d). These 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).

Table A.1.4.1 A.1.1.1(a) Physical Properties of Clean Halocarbon Agents (U.S. Units)

<u>Physical Property</u>	<u>Units</u>	<u>FIC-131i</u>	<u>FK-5-1-12</u>	<u>HCFC Blend A</u>	<u>HFC Blend B</u>	<u>HCFC-124</u>	<u>HFC-125</u>	<u>HFC-227ea</u>	<u>HFC-23</u>	<u>HFC-236fa</u>
<u>Molecular weight</u>	<u>N/A</u>	<u>195.9</u>	<u>316.04</u>	<u>92.9</u>	<u>99.4</u>	<u>136.5</u>	<u>120.0</u>	<u>170</u>	<u>70.01</u>	<u>152</u>
<u>Boiling point at 760 mm Hg</u>	<u>°F</u>	<u>-8.5</u>	<u>120.2</u>	<u>-37</u>	<u>-14.9</u>	<u>10.5</u>	<u>-54</u>	<u>2.4</u>	<u>-115.6</u>	<u>29.5</u>
<u>Freezing point</u>	<u>°F</u>	<u>-166</u>	<u>-162.4</u>	<u>161</u>	<u>-153.9</u>	<u>-326</u>	<u>-153</u>	<u>-204</u>	<u>-247.4</u>	<u>-153.4</u>
<u>Critical temperature</u>	<u>°F</u>	<u>252</u>	<u>335.6</u>	<u>256</u>	<u>219.9</u>	<u>252.5</u>	<u>150.8</u>	<u>214</u>	<u>79.1</u>	<u>256.9</u>
<u>Critical pressure</u>	<u>psi</u>	<u>586</u>	<u>270.44</u>	<u>964</u>	<u>588.9</u>	<u>527</u>	<u>525</u>	<u>424</u>	<u>700</u>	<u>464.1</u>
<u>Critical volume</u>	<u>ft³/lbm</u>	<u>0.0184</u>	<u>0.0251</u>	<u>0.028</u>	<u>0.031</u>	<u>0.0286</u>	<u>0.0279</u>	<u>0.0280</u>	<u>0.0304</u>	<u>0.02905</u>
<u>Critical density</u>	<u>lbm/ft³</u>	<u>54.38</u>	<u>39.91</u>	<u>36</u>	<u>32.17</u>	<u>34.96</u>	<u>35.81</u>	<u>35.77</u>	<u>32.87</u>	<u>34.42</u>
<u>Specific heat, liquid at 77°F</u>	<u>Btu/lb-°F</u>	<u>0.141</u>	<u>0.2634</u>	<u>0.3</u>	<u>0.339</u>	<u>0.271</u>	<u>0.354</u>	<u>0.281</u>	<u>0.987 at 68°F</u>	<u>0.3012</u>
<u>Specific heat, vapor at constant pressure</u>	<u>Btu/lb-°F</u>	<u>0.86</u>	<u>0.2127</u>	<u>0.16</u>	<u>0.203</u>	<u>0.18</u>	<u>0.19</u>	<u>0.193</u>	<u>0.175 at 68°F</u>	<u>0.201</u>

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

<u>Physical Property</u>	<u>Units</u>	<u>FIC-1311</u>	<u>EK-5-1-12</u>	<u>HCFC Blend A</u>	<u>HFC Blend B</u>	<u>HCFC-124</u>	<u>HFC-125</u>	<u>HFC-227ea</u>	<u>HFC-23</u>	<u>HFC-236fa</u>
<u>±</u> <u>(1 atm)</u>										
<u>±</u> <u>and 77°F</u>										
<u>Heat of vaporization at boiling point</u>	<u>Btu/lb</u>	<u>48.1</u>	<u>37.8</u>	<u>97</u>	<u>93.4</u>	<u>71.3</u>	<u>70.5</u>	<u>56.6</u>	<u>103</u>	<u>68.97</u>
<u>Thermal conductivity of liquid at 77°F</u>	<u>Btu/hr-ft-°F</u>	<u>0.04</u>	<u>0.034</u>	<u>0.052</u>	<u>0.0478</u>	<u>0.0395</u>	<u>0.0343</u>	<u>0.034</u>	<u>0.0305</u>	<u>0.0421</u>
<u>Viscosity, liquid at 77°F</u>	<u>lb/ft-hr</u>	<u>0.473</u>	<u>1.27</u>	<u>0.508</u>	<u>0.485</u>	<u>0.622</u>	<u>0.338</u>	<u>0.579</u>	<u>0.107</u>	<u>0.6906</u>
<u>Relative dielectric strength at ± 1 atm at 734 mm Hg. (N₂ = 1)</u>	<u>N/A</u>	<u>1.41 at 77°F</u>	<u>2.3 at ± 77°F</u>	<u>1.32 at 77°F</u>	<u>1.014 at 77°F</u>	<u>1.55 at 77°F</u>	<u>0.955 at 70°F</u>	<u>2 at ± 77°F</u>	<u>1.04 at 77°F</u>	<u>1.0166 at 77°F</u>
<u>Solubility of water in agent</u>	<u>wt%</u>	<u>0.01 at 70°F</u>	<u><0.001 at 70°F</u>	<u>0.12 at 70°F</u>	<u>0.11 at 70°F</u>	<u>770 at ± 77°F</u>	<u>770 at ± 77°F</u>	<u>0.06 at 70°F</u>	<u>500 at ± 50°F</u>	<u>740 at ± 68°F</u>

Table A-1.4.1 A.1.1.1(b) Physical Properties of Inert Gas Agents (U.S. Units)

<u>Physical Property</u>	<u>Units</u>	<u>IG-01</u>	<u>IG-100</u>	<u>IG-541</u>	<u>IG-55</u>
<u>Molecular weight</u>	<u>N/A</u>	<u>39.9</u>	<u>28.0</u>	<u>34.0</u>	<u>33.95</u>
<u>Boiling point at 760 mm Hg</u>	<u>°F</u>	<u>-302.6</u>	<u>-320.4</u>	<u>-320</u>	<u>-310.2</u>
<u>Freezing point</u>	<u>°F</u>	<u>-308.9</u>	<u>-346.0</u>	<u>-109</u>	<u>-327.5</u>
<u>Critical temperature</u>	<u>°F</u>	<u>-188.1</u>	<u>-232.4</u>	<u>N/A</u>	<u>-210.5</u>
<u>Critical pressure</u>	<u>psia</u>	<u>711</u>	<u>492.9</u>	<u>N/A</u>	<u>602</u>
<u>Specific heat, vapor at constant pressure (1 atm) and 77°F</u>	<u>Btu/lb °F</u>	<u>0.125</u>	<u>0.445</u>	<u>0.195</u>	<u>0.187</u>
<u>Heat of vaporization at boiling point</u>	<u>Btu/lb</u>	<u>70.1</u>	<u>85.6</u>	<u>94.7</u>	<u>77.8</u>
<u>Relative dielectric strength at ± 1 atm at 734 mm Hg. 77°F (N₂ = 1.0)</u>	<u>N/A</u>	<u>1.01</u>	<u>1.0</u>	<u>1.03</u>	<u>1.01</u>
<u>Solubility of water in agent at 77°F</u>	<u>N/A</u>	<u>0.006%</u>	<u>0.0013%</u>	<u>0.015%</u>	<u>0.006%</u>

Table A-1.4.1 A.1.1.1(c) Physical Properties of Clean Halocarbon Agents (SI Units)

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

<u>Physical Property</u>	<u>Units</u>	<u>FIC-13I1</u>	<u>FK-5-1-12</u>	<u>HCFC Blend A</u>	<u>HFC Blend B</u>	<u>HCFC-124</u>	<u>HFC-125</u>	<u>HFC-227ea</u>	<u>HFC-23</u>	<u>HFC-236fa</u>
<u>Molecular weight</u>	<u>N/A</u>	<u>195.91</u>	<u>316.04</u>	<u>92.90</u>	<u>99.4</u>	<u>136.5</u>	<u>120</u>	<u>170</u>	<u>70.01</u>	<u>152</u>
<u>Boiling point at 760 mm Hg</u>	<u>°C</u>	<u>-22.5</u>	<u>49</u>	<u>-38.3</u>	<u>-26.1</u>	<u>-12.0</u>	<u>-48.1</u>	<u>-16.4</u>	<u>-82.1</u>	<u>-1.4</u>
<u>Freezing point</u>	<u>°C</u>	<u>-110</u>	<u>-108</u>	<u><107.2</u>	<u>-103</u>	<u>-198.9</u>	<u>-102.8</u>	<u>-131</u>	<u>-155.2</u>	<u>-103</u>
<u>Critical temperature</u>	<u>°C</u>	<u>122</u>	<u>168.66</u>	<u>124.4</u>	<u>101.1</u>	<u>122.6</u>	<u>66</u>	<u>101.7</u>	<u>26.1</u>	<u>124.9</u>
<u>Critical pressure</u>	<u>kPa</u>	<u>4041</u>	<u>1865</u>	<u>6647</u>	<u>4060</u>	<u>3620</u>	<u>3618</u>	<u>2912</u>	<u>4828</u>	<u>3200</u>
<u>Critical volume</u>	<u>cc/mole</u>	<u>225</u>	<u>494.5</u>	<u>162</u>	<u>198</u>	<u>243</u>	<u>210</u>	<u>274</u>	<u>133</u>	<u>276*</u>
<u>Critical density</u>	<u>kg/m³</u>	<u>871</u>	<u>639.1</u>	<u>577</u>	<u>515.3</u>	<u>560</u>	<u>574</u>	<u>621</u>	<u>527</u>	<u>551.3</u>
<u>Specific heat, liquid at 25°C</u>	<u>kJ/kg - °C</u>	<u>0.592 at 25°C</u>	<u>1.103 at 25°C</u>	<u>1.256 at 25°C</u>	<u>1.44 at 25°C</u>	<u>1.153 at 25°C</u>	<u>1.407 at 25°C</u>	<u>1.184 at 25°C</u>	<u>4.130 at 20°C</u>	<u>1.264 at 25°C</u>
<u>Specific heat, vapor at constant pressure (1 atm) and 25°C</u>	<u>kJ/kg - °C</u>	<u>0.3618 at 25°C</u>	<u>0.891 at 25°C</u>	<u>0.67 at 25°C</u>	<u>0.848 at 25°C</u>	<u>0.742 at 25°C</u>	<u>0.797 at 25°C</u>	<u>0.808 at 25°C</u>	<u>0.731 at 20°C</u>	<u>0.840 at 25°C</u>
<u>Heat of vaporization at boiling point</u>	<u>kJ/kg</u>	<u>112.4</u>	<u>88</u>	<u>225.6</u>	<u>217.2</u>	<u>165.9</u>	<u>164.1</u>	<u>132.6</u>	<u>239.3</u>	<u>160.4</u>
<u>Thermal conductivity of liquid at 25°C</u>	<u>W/m - °C</u>	<u>0.07</u>	<u>0.059</u>	<u>0.09</u>	<u>0.082</u>	<u>0.0684</u>	<u>0.0592</u>	<u>0.069</u>	<u>0.0534</u>	<u>0.0729</u>
<u>Viscosity, liquid at 25°C</u>	<u>centipoise</u>	<u>0.196</u>	<u>0.524</u>	<u>0.21</u>	<u>0.202</u>	<u>0.257</u>	<u>0.14</u>	<u>0.184</u>	<u>0.044</u>	<u>0.286</u>
<u>Relative dielectric strength at 1 atm at 25°C</u>	<u>N/A</u>	<u>1.41 at 25°C</u>	<u>2.3 at 25°C</u>	<u>1.32 at 25°C</u>	<u>1.014 at 25°C</u>	<u>1.55 at 25°C</u>	<u>0.955 at 21°C</u>	<u>2 at 25°C</u>	<u>1.04 at 25°C</u>	<u>1.0166 at 25°C</u>

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

<u>Physical Property</u>	<u>Units</u>	<u>FIC-13I1</u>	<u>FK-5-1-12</u>	<u>HCEC Blend A</u>	<u>HFC Blend B</u>	<u>HCEC-124</u>	<u>HFC-125</u>	<u>HFC-227ea</u>	<u>HFC-23</u>	<u>HFC-236fa</u>
734 mm Hg										
$\pm$ (N ₂ = 1.0)										
Solubility of water in agent	ppm	1.0062% by weight	<0.001	0.12% by weight	0.11% by weight	700 at 25°C	700 at 25°C	0.06% by weight	500 at 10°C	740 at $\pm$ 20°C

Table A.1.4.1A.1.1.1(d) Physical Properties of Inert Gas Agents (SI Units)

<u>Physical Property</u>	<u>Units</u>	<u>IG-01</u>	<u>IG-100</u>	<u>IG-541</u>	<u>IG-55</u>
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	$\frac{\text{kJ}}{\text{kg}}$ °C	0.519	1.04	0.574	0.782
Heat of vaporization at boiling point	$\frac{\text{kJ}}{\text{kg}}$	163	199	220	181
Relative dielectric strength at $\pm$ 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%

1.1.2

~~The scope of this standard~~ does not ~~cover include~~ 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 by 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 alternative arrangements provided the level of safety prescribed by this standard is not lowered.~~

A.1.2

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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.

1.2.21.3 Application.

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.

1.4 Retroactivity.

The provisions of this standard reflect a consensus of what is necessary to provide an acceptable degree of protection from the hazards addressed in this standard at the time the standard was issued.

1.4.1

Unless otherwise specified, the design, installation, and maintenance requirements of Chapter 4 through Chapter 8 and Chapter 10 shall not apply to facilities, equipment, structures, or installations that existed or were approved for construction or installation prior to the effective date of the standard.

1.4.2

Unless otherwise specified, inspection, testing, and maintenance requirements in Chapter 9 shall apply to new and existing facilities, equipment, structures, or installations.

1.4.3

In those cases where the authority having jurisdiction determines that the existing situation presents an unacceptable degree of risk, the authority having jurisdiction shall be permitted to apply retroactively any portions of this standard deemed appropriate.

1.4.4

Requirements that are retroactively applied in accordance with this standard shall be permitted to be modified if their application clearly would be impractical in the judgment of the authority having jurisdiction, and only where it is clearly evident that a reasonable degree of safety is provided.

1.5 Equivalency.

Nothing in this standard is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this standard.

1.5.1

Technical documentation shall be submitted to the authority having jurisdiction to demonstrate equivalency.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

1.5.2

The system, method, or device shall be approved for the intended purpose by the authority having jurisdiction.

1.31.6 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 outside of but recognized by SI (liter and bar) are commonly used in international fire protection. The SI units and their conversion factors are listed in Table 1.3. 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 1.3 Metric Conversion Factors

Commented [CB1]: Moved to 1.6.2.2

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 SI10.

1.6.1 Primary Units.

Primary units of measurement are in accordance with U.S. customary units (inch-pound units), except where specific units are customary for industry practice.

1.6.2 Secondary Units and Conversions.

1.6.2.1

Secondary units of measurement, where provided, are in accordance with the modernized metric system known as the International System of Units (SI), except where specific units are customary for industry practice.

1.6.2.2

Where secondary units are not provided, converted values in accordance with Table 1.6.2.2 and converted trade sizes can be used.

Table 1.6.2.2 Metric Conversion Factors

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

<u>Name of Unit</u>	<u>Unit Symbol</u>	<u>Conversion Factor</u>
<u>millimeter</u>	<u>mm</u>	<u>1 in. = 25.4 mm</u>
<u>liter</u>	<u>L</u>	<u>1 gal = 3.785 L</u>
<u>cubic meter</u>	<u>m³</u>	<u>1 ft³ = 0.028317 m³</u>
<u>kilogram</u>	<u>kg</u>	<u>1 lb = 0.4536 kg</u>
<u>kilograms per cubic meter</u>	<u>kg/m³</u>	<u>1 lb/ft³ = 16.0185 kg/m³</u>
<u>pascal</u>	<u>Pa</u>	<u>1 psi = 6895 Pa</u>
<u>bar</u>	<u>bar</u>	<u>1 psi = 0.0689 bar</u>
<u>bar</u>	<u>bar</u>	<u>1 bar = 10⁵ Pa</u>

Notes:

(1) For additional conversions and information, see ASTM SI10.

1.6.2.3

Where extracted text contains values expressed in only one system of units, the values in the extracted text have been retained without conversion to preserve the values established by the responsible technical committee in the source document.

1.6.3 Measurements of Pressure.

All measurements of pressure are gauge values, unless otherwise noted.

1.6.4 Unit Application and Enforcement.

1.6.4.1*

The values presented in this standard are expressed with a degree of precision that is appropriate for practical application and enforcement.

1.6.4.2*

Either the primary units or secondary units are acceptable for satisfying the requirements in this standard.

4.4 Chapter 4 General Information Requirements.

4.4.1* Applicability of Agents:

A.1.4.1

The agents currently listed possess the physical properties as detailed in Table A.1.4.1(a) through Table A.1.4.1(d). These 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).

Table A.1.4.1(a) Physical Properties of Clean Halocarbon Agents (U.S. Units)

Commented [CB2]: New Chapter 4 to be inserted after the 'Definitions' chapter

Commented [CB3]: Moved to A.1.1.1

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Physical Property	Units	HFC-124	HFC-125	HFC Blend A	HFC Blend B	HFC-124	HFC-125	HFC-227ea	HFC-23	HFC-236fa
Molecular weight	N/A	195.9	316.04	92.9	99.4	136.5	120.0	170	70.01	152
Boiling point at 760 mm Hg	°F	-8.5	120.2	-37	-14.9	10.5	-54	2.4	-115.6	29.5
Freezing point	°F	-166	-162.4	161	-153.9	-326	-153	-204	-247.4	-153.4
Critical temperature	°F	252	335.6	256	219.9	252.5	150.8	214	79.1	256.9
Critical pressure	psi	586	270.44	964	588.9	527	525	424	700	464.1
Critical volume	ft ³ /lbm	0.0184	0.0251	0.028	0.031	0.0286	0.0279	0.0280	0.0304	0.02905
Critical density	lbm/ft ³	54.38	39.91	36	32.17	34.96	35.81	35.77	32.87	34.42
Specific heat, liquid at 77°F	Btu/lb-°F	0.141	0.2634	0.3	0.339	0.271	0.354	0.281	0.987 at 68°F	0.3012
Specific heat, vapor at constant pressure * (1 atm) * and 77°F	Btu/lb-°F	0.86	0.2127	0.16	0.203	0.18	0.19	0.193	0.175 at 68°F	0.201
Heat of vaporization at boiling point	Btu/lb	48.1	37.8	97	93.4	71.3	70.5	56.6	103	68.97
Thermal conductivity of liquid at 77°F	Btu/hr-ft-°F	0.04	0.034	0.052	0.0470	0.0395	0.0343	0.034	0.0305	0.0421
Viscosity, liquid at 77°F	lb/ft-hr	0.473	1.27	0.508	0.485	0.622	0.338	0.579	0.107	0.6906
Relative dielectric strength at * 1 atm at 734 mm Hg, (N ₂ —1)	N/A	1.41 at 77°F	2.3 at 77°F	1.32 at 77°F	1.014 at 77°F	1.55 at 77°F	0.955 at 70°F	2 at 77°F	1.04 at 77°F	1.0166 at 77°F

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Physical Property	Units	FK-1	FK-5	HFC Blend A	HFC Blend B	HFC-124	HFC-125	HFC-227ea	HFC-23	HFC-236fa
Solubility of water in agent	wt%	0.01 at 70°F	<0.001 at 70°F	0.12 at 70°F	0.11 at 70°F	770 at 77°F	770 at 77°F	0.06 at 70°F	500 at 50°F	740 at 68°F

Table A-1.4.1(b) Physical Properties of Inert Gas Agents (U.S. Units)

Physical Property	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 77°F	N/A	0.006%	0.0013%	0.015%	0.006%

Table A-1.4.1(c) Physical Properties of Clean Halocarbon Agents (SI Units)

Physical Property	Units	FK-1	FK-5	HFC Blend A	HFC Blend B	HFC-124	HFC-125	HFC-227ea	HFC-23	HFC-236fa
Molecular weight	N/A	195.01	316.04	92.90	99.4	136.5	120	170	70.01	152
Boiling point at 760 mm Hg	°C	−22.5	49	−38.3	−26.1	−12.0	−48.1	−16.4	−82.1	−14
Freezing point	°C	−110	−100	−107.2	−103	−198.9	−102.0	−131	−155.2	−103
Critical temperature	°C	122	168.66	124.4	101.1	122.6	66	101.7	26.1	124.9
Critical pressure	kPa	4041	1865	6647	4060	3620	3618	2912	4828	3200
Critical volume	cc/mole	225	494.5	162	198	243	210	274	133	276*
Critical density	kg/m ³	871	639.1	577	515.3	560	574	621	527	551.3

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Physical Property	Units	IG-101	IG-541	IG-55 Blend A	IG-55 Blend B	IG-104	IG-125	IG-227ea	IG-230	IG-236fa
Specific heat, liquid at 25°C	kJ/kg-°C	0.592 at 25°C	1.103 at 25°C	1.256 at 25°C	1.44 at 25°C	1.153 at 25°C	1.407 at 25°C	1.184 at 25°C	4.130 at 20°C	1.264 at 25°C
Specific heat, vapor at constant pressure (1 atm) and 25°C	kJ/kg-°C	0.3618 at 25°C	0.891 at 25°C	0.67 at 25°C	0.848 at 25°C	0.742 at 25°C	0.797 at 25°C	0.808 at 25°C	0.731 at 20°C	0.840 at 25°C
Heat of vaporization at boiling point	kJ/kg	112.4	88	225.6	217.2	165.9	164.1	132.6	239.3	160.4
Thermal conductivity of liquid at 25°C	W/m-°C	0.07	0.059	0.09	0.082	0.0684	0.0592	0.069	0.0534	0.0729
Viscosity, liquid at 25°C	centipoise	0.196	0.524	0.21	0.202	0.257	0.14	0.184	0.044	0.286
Relative dielectric strength at 1-atm at 734 mm-Hg (N=1.0)	N/A	1.41 at 25°C	2.3 at 25°C	1.32 at 25°C	1.014 at 25°C	1.55 at 25°C	0.955 at 21°C	2 at 25°C	1.04 at 25°C	1.0166 at 25°C
Solubility of water in agent	ppm	1.0062% by weight	<0.001	0.12% by weight	0.11% by weight	700 at 25°C	700 at 25°C	0.06% by weight	500 at 10°C	740 at 20°C

Table A.1.4.1(d) Physical Properties of Inert Gas Agents (SI Units)

Physical Property	Units	IG-01	IG-100	IG-541	IG-55
Molecular weight	N/A	29.9	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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Physical Property	Units	IG-01	IG-100	IG-541	IG-55
Specific heat, vapor at constant pressure (1 atm) and 25°C	kJ/kg ΔC	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%

~~1.4.1.1~~

~~The fire extinguishing agents addressed in this standard shall be electrically nonconducting and leave no residue upon evaporation.~~

~~1.4.1.2*~~

~~Agents that meet the criteria of 1.4.1.1 shall be shown in Table 1.4.1.2.~~

~~Table 1.4.1.2 Agents Addressed in NFPA 2001~~

Commented [CB4]: Moved to 1.1.1

Agent Designation	Chemical Name	Chemistry
FK 5-1-12	Dodecafluoro 2-methylpentan-3-one	CF₃CF₂C(O)CF(CF₃)₂
HCFC Blend A	Dichlorotrifluoroethane HCFC 123 (4.75%)	CHCl ₂ CF 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 ₃ CF ₃
HFC 227ea	Heptafluoropropane	CF ₃ CHFCF ₃
HFC 23	Trifluoromethane	CHF ₃
HFC 236fa	Hexafluoropropane	CF ₃ CH ₂ CF ₃
FIG 1311	Trifluoroiodide	CF₃I
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
HFC Blend B	Tetrafluoroethane (86%)	CH ₂ FCF ₃
-	Pentafluoroethane (9%)	CHF ₂ CF ₃
-	Carbon dioxide (5%)	CO ₂

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

~~Notes:~~

~~(1) Other agents could become available at later dates. They could be added via the NFPA process in future editions or by amendments to the standard.~~

~~(2) Composition of inert gas agents is given in percent by volume. Composition of HCFC Blend A is given in percent by weight.~~

~~(3) The full analogous ASHRAE nomenclature for FK 5-1-12 is FK 5-1-12mm2.~~

~~A.1.4.1.2~~

~~The designations for perfluorocarbons (FCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), fluoroiodocarbons (FICs), and fluoroketones (FKs) are an extension of halocarbon designations in ANSI/ASHRAE 34, prepared by the American National Standards Institute, Inc. (ANSI) and 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 each).~~

Commented [CB5]: Moved to A.1.1.1

~~4.4.1.34.1~~ **Personnel Qualifications and Training.**

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

~~4.5.1.64.1.1~~

All persons who inspect, test, maintain, or operate fire extinguishing systems shall be trained in all aspects of safety related to the systems.

4.1.2

Persons that inspect, service, test, or maintain clean agent systems shall be qualified and trained in accordance with 8.1.2.

4.4.24.2* Use and Limitations of Clean Agent Systems.

A.1.4.2A.4.2

Clean agent fire extinguishing systems are useful within the limits of this standard for 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.

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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

(5) Telecommunications facilities

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

~~1.4.2.4.2.1~~ Pre-Engineered Systems.

All pre-engineered systems shall be installed to protect hazards within the limitations that have been established by the listing. Pre-engineered systems shall be listed to one of the following types:

- (1) Those consisting of system components designed to be installed according to pre-tested limitations by a testing laboratory. These pre-engineered systems shall be permitted to 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 shall apply.
- (2) Automatic extinguishing units incorporating special nozzles, flow rates, methods of application, nozzle placement, actuation techniques, piping materials, discharge times, mounting techniques, and pressurization levels that could differ from those detailed elsewhere in this standard.

~~1.4.2.4.2.2~~ Incompatible Hazards.

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

- (1) Certain chemicals or mixtures of chemicals, such as cellulose nitrate and gunpowder, which 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, pyrophoric materials, and hydrazine

~~1.4.2.3*~~

~~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.~~

~~A.1.4.2.3~~

~~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.~~

Commented [CB6]: Moved to existing A.5.3 (new A.7.1)

~~1.4.2.4.2.3*~~ High Temperature Applications.

The effects of agent decomposition on fire protection effectiveness and equipment shall be considered where clean agents are used in hazards with high ~~ambient~~ temperatures (e.g., furnaces and ovens).

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

~~A.1.4.2.4~~A.4.2.3

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

~~1.5 Safety~~

~~1.5.14.3~~* Hazards to Personnel.

~~A.1.5.14.3~~A.4.3

Potential hazards to be considered for individual systems are the following:

- (1) *Noise*. Discharge of a system can cause noise loud enough to be startling but ordinarily insufficient to cause traumatic injury.
- (2) *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.
- (3) *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.

~~1.5.1.14.3.1~~* Clean Agent Evaluation.

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 (EPA) Significant New Alternatives Policy (SNAP) Program for total flooding agents.

~~A.1.5.1.14.3.1~~A.4.3.1

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 the *Federal Register*, "EPA SNAP Program."

~~1.5.1.2~~* Halocarbon Agents

~~A.1.5.1.2~~

~~Table A.1.5.1.2(a) provides information on the toxicological effects of halocarbon agents covered by this standard. The no observable adverse effect level (NOAEL) is the highest concentration at which no adverse physiological or toxicological effect has been~~

Commented [CB7]: Moved to new Annex B (see below)

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

~~observed. The lowest observable adverse effect level (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.1.5.1.2(a) Toxicity Information for Halocarbon Clean Agents

Agent	LC₅₀ or ALC = (%)	NOAEL = (%)	LOAEL = (%)
FIC 1311	>12.0	0.2	0.4
FK 5-1-12	>10.0	40	>10.0
HCFC Blend A	64	40	>10.0
HCFC 124	23-29	4	2.5
HFC 125	>70	7.5	40
HFC 227ea	>80	9	40.5
HFC 23	>65	30	>30
HFC 236fa	>45.7	40	45
HFC Blend B	56.7*	5.0*	7.5*

Notes:

(1) LC₅₀ 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.

*These values are for the largest component of the blend (HFCB 134A).

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).

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

- ~~(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 its 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 concentrations 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; thus, cardiac sensitization will not occur. Accordingly, in the tables in 1.5.1.2.1, 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, means should be provided such that personnel are exposed for no longer than 1.67 minutes. Examples of suitable exposure-limiting mechanisms~~

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

~~include self-contained breathing apparatuses and planned and rehearsed evacuation routes.~~

~~The requirement for pre-discharge alarms and time delays is 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 1.5.1.2.1. The concentrations and times given in the tables 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.~~

~~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 patterns would be expected to change primarily from nose breathing to primarily mouth breathing. This change in breathing pattern determines 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 (1996), rats were exposed by nose-only or mouth-only breathing. In the mouth-only breathing 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 breathe through the nose but inhale through the mouth, thereby maximizing the deposition of HF into the lower respiratory tract.~~

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

~~In the nose-only breathing model, 2-minute or 10-minute exposures of rats to about 6400 or 1700 ppm, respectively, produced similar effects; that is, no mortality resulted but significant cell damage in the nose was observed. In contrast, marked differences in toxicity were evident in the mouth-only 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 9600 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, such as 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 was observed 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 (1993) proposed the concept of the dangerous toxic load (DTL) as a means of predicting the effects of, for example, HF in humans. Meldrum developed the argument that the toxic effects of certain chemicals tend to follow Haber's law:~~

$$C \times t = k \quad \text{[A-1.5-1.2]}$$

~~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, such as fire fighters, and those with compromised health. Exposure to higher concentrations of HF would be expected to be tolerated more in healthy individuals, whereas equal concentrations can have escape impairing effects in those with compromised health. The following discussion assumes that the effects described at the various concentrations and durations are for the healthy individual.~~

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Inflammation (irritation) of tissues represents a continuum from "no irritation" to "severe, deep penetrating" irritation. Use of the 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 (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 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.1.5.1.2(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 a 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.

Table A.1.5.1.2(b) Potential Human Health Effects of Hydrogen Fluoride in Healthy Individuals

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Exposure Time	Concentration of 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 effects 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, such as 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. (1934) and 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.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

4.3.2* Exposure to Halocarbon Agents, 4.5.1.2.1*

Unnecessary exposure to halocarbon clean agents — including exposure at and below the no observable adverse effects level (NOAEL) — and halocarbon decomposition products shall be avoided.

Commented [CB8]: Existing A.1.5.1.2.1 is associated with new 4.3.2.3 after the paragraph is separated into individually numbered subs (see below)

A.4.3.2

See Section B.1 for information on the toxicological effects of halocarbon agents.

4.3.2.1

Means shall be provided to limit exposure to halocarbon agents to no longer than 5 minutes.

4.3.2.2

-Unprotected personnel shall not enter a protected space during or after agent discharge.

4.3.2.3*

-The following additional provisions shall apply:

- (1) Halocarbon systems for spaces that are normally occupied and designed to concentrations up to the NOAEL [*see Table ~~4.5.1.2-14.3.2.3(a)~~*] shall be permitted. ~~The maximum exposure in any case shall not exceed 5 minutes.~~
- (2) Halocarbon systems for spaces that are normally occupied and designed to concentrations above the NOAEL [*see Table ~~4.5.1.2-14.3.2.3(a)~~*] shall be permitted if means are provided to limit exposure to the design concentrations shown in Table ~~4.5.1.2-14.3.2.3(b)~~ through Table ~~4.5.1.2-14.3.2.3(e)~~ that correspond to an allowable human exposure time of 5 minutes. Higher design concentrations associated with human exposure times less than 5 minutes as shown in Table ~~4.5.1.2-14.3.2.3(b)~~ through Table ~~4.5.1.2-14.3.2.3(e)~~ shall not be permitted in normally occupied spaces.
- (3) In spaces that are not normally occupied and that are protected by a halocarbon system designed to concentrations above the lowest observable adverse effects level (LOAEL) [*see Table ~~4.5.1.2-14.3.2.3(a)~~*] and where personnel could possibly be exposed, means shall be provided to limit exposure times using Table ~~4.5.1.2-14.3.2.3(b)~~ through Table ~~4.5.1.2-14.3.2.3(e)~~.
- (4) In spaces that are not normally occupied and in the absence of the information needed to fulfill the conditions ~~listed in 4.5.1.2-14.3.2.3(3)~~, the following provisions shall apply:
 - (a) 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.
 - (b) Concentrations exceeding the LOAEL shall be permitted provided that any personnel in the area can escape within 30 seconds.
 - (c) A pre-discharge alarm and time delay shall be provided in accordance with the provisions of 4.3.5.6 of this standard.

Commented [CB9]: Existing x-ref should point to Section 9.7 after structural changes

Table ~~4.5.1.2-14.3.2.3(a)~~ Information for Halocarbon Clean Agents

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Agent	NOAEL (vol %)	LOAEL (vol %)
FK-5-1-12	10.0	>10.0
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	30	>30
HFC-236fa	10	15
HFC Blend B*	5.0*	7.5*

*These values are for the largest component of the blend (HFC 134A).

Table 4.5.1.2.14.3.2.3(b) Time for Safe Human Exposure at Stated Concentrations for HFC-125

HFC-125 Concentration		Maximum Permitted Human Exposure Time
vol %	ppm	(min)
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 4.5.1.2.14.3.2.3(c) Time for Safe Human Exposure at Stated Concentrations for HFC-227ea

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

HFC-227ea		Maximum Permitted
Concentration		Human Exposure Time
vol %	ppm	(min)
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 4-5.1.2-14.3.2.3(d) Time for Safe Human Exposure at Stated Concentrations for HFC-236fa

HFC-236fa		Maximum Permitted
Concentration		Human Exposure Time
vol %	ppm	(min)
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 4-5.1.2-14.3.2.3(e) Time for Safe Human Exposure at Stated Concentrations for FIC-1311

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

FIC-13I1		Maximum Permitted
Concentration		Human Exposure Time
vol %	ppm	(min)
0.20	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.

~~A.4.3.2.1~~ **A.4.3.2.3**

One objective of pre-discharge alarms and time delays is to prevent human exposure to agents.

~~4.5.1.34.3.3*~~ **4.3.3.3* Exposure to Inert Gas Clean Agents.**

Unnecessary exposure to inert gas agent systems resulting in low oxygen atmospheres shall be avoided.

A.4.3.3

See Section B.2 for information on the physiological effects of inert gas agents.

4.3.3.1

Means shall be provided to limit exposure to low oxygen atmospheres to no longer than 5 minutes. The maximum exposure time in any case shall not exceed 5 minutes.

4.3.3.2

See Table 5.5.3.3 for the atmospheric correction factors that specified in Table 5.5.3.3 shall be considered when determining the inert gas design concentrations. One objective of pre-discharge alarms and time delays is to prevent human exposure to agents.

4.3.3.3*

A pre-discharge alarm and time delay shall be provided in accordance with the provisions of 4.3.5.6 of this standard.

Commented [CB10]: Moved to A.4.3.3.3

Commented [CB11]: Existing x-ref should point to Section 9.7 after structural changes

A.4.3.3.3

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

One objective of pre-discharge alarms and time delays is to prevent human exposure to agents.

4.3.3.4

Unprotected personnel shall not enter ~~the area~~ protected space during or after agent discharge.

4.3.3.5

The following additional provisions shall apply:

- (1) 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 where means are provided to limit exposure to no longer than 5 minutes.
- (2) 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 where means are provided to limit exposure to no longer than 3 minutes.
- (3) Inert gas systems designed to concentrations between 52 and 62 percent (corresponding to between 10 and 8 percent oxygen, sea level equivalent of oxygen) shall be permitted given the following:
 - (a) The space is normally unoccupied.
 - (b) Where personnel could possibly be exposed, means are provided to limit the exposure to less than 30 seconds.
- (4) Inert gas systems designed to concentrations above 62 percent (corresponding to 8 percent oxygen or below, sea level equivalent of oxygen) shall be used only in unoccupied areas where personnel are not exposed to such oxygen depletion.

~~A.1.5.1.3~~

~~Paragraph 1.5.1.3 makes reference to limiting concentrations of inert gas agents corresponding to certain values of "sea level equivalent" of oxygen. The mean atmospheric pressure of air at sea level is 760 mm Hg. Atmospheric air is 21 volume percent oxygen. The partial pressures of oxygen in ambient air and air diluted agent to the limiting sea level concentrations corresponding to permissible exposure times of 5 minutes, 3 minutes, and 1/2 minute are given in Table A.1.5.1.3(a).~~

Commented [CB12]: Moved to new Annex B (see below)

~~Table A.1.5.1.3(a) Oxygen Partial Pressure at Sea Level Corresponding to Exposure Limits Given in 1.5.1.3~~

Exposure Time (min)	Agent Concentration (vol %)	O₂% at Sea Level	Partial Pressure of O₂ (mm Hg)
Air reference	0	21	159.6
5	43	12.0	91.0
3	52	10.1	76.6

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Exposure Time (min)	Agent Concentration (vol.%)	O ₂ % at Sea level	Partial Pressure of O ₂ (mm Hg)
60	62	8.0	60.6

Note: Mean atmospheric pressure at sea level is 760 mm Hg.

In 3.3.35, sea level equivalent of oxygen is defined in terms of the partial pressure at sea level. The mean atmospheric pressure decreases with increasing altitude, as shown in Table 5.5.3.3. The partial pressure of oxygen is 21 percent of the atmospheric pressure. The concentration of added agent, which dilutes air to the sea level limiting partial pressure of oxygen, is given by

$$\text{Vol \% agent} = \frac{0.21P_{\text{ATM}} - P_{\text{O}_2, \text{LM}}}{0.21P_{\text{ATM}}} \times 100$$

[A.1.5.1.3]

where:

P_{ATM} = local mean atmospheric pressure

$P_{\text{O}_2, \text{LM}}$ = limiting partial pressure of oxygen corresponding to a sea level exposure time limit

The effect of altitude on limiting agent concentrations is given in Table A.1.5.1.3(b).

Table A.1.5.1.3(b) Relationship of Altitude to Atmospheric Pressure, Oxygen Partial Pressure in Air, and Limiting Agent Concentration

Altitude Above-Sea level (ft)	P_{ATM} (mm Hg)	O ₂ Partial Pressure in Air (mm Hg)	Limiting Agent Concentration (vol.%)		
			5-min Exposure $P(\text{O}_2)$ 64 mm Hg	3-min Exposure $P(\text{O}_2)$ 76.6 mm Hg	30-sec Exposure $P(\text{O}_2)$ 60.6 mm Hg
-3,000	840	176.4	48.4	56.6	65.6
-2,000	812	170.5	46.6	55.1	64.5
-1,000	787	165.3	44.9	53.7	63.3
0	760	159.6	43.0	52.0	62.0
1,000	733	153.9	40.9	50.2	60.6
2,000	705	148.1	38.5	48.3	59.1
3,000	679	142.6	36.2	46.3	57.5
4,000	650	136.5	33.3	43.9	55.6
5,000	622	130.6	30.3	41.4	53.6
6,000	596	125.2	27.3	38.8	51.6
7,000	570	119.7	24.0	36.0	49.4

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Altitude Above-Sea Level (ft)	P_{atm} (mm Hg)	P_{O_2} Partial Pressure in Air (mm-Hg)	Limiting Agent Concentration (vol %)		
			5-min Exposure $P(\text{O}_2) =$	30-min Exposure $P(\text{O}_2) =$	90-sec Exposure $P(\text{O}_2) =$
			91 mm-Hg	76.6 mm-Hg	60.6 mm-Hg
0,000	550	115.5	21.2	33.7	47.5
9,000	520	110.9	17.9	30.9	45.9
10,000	505	106.1	14.2	27.8	42.9

Table A.1.5.1.3(c) 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 10 percent (sea level equivalent) is required for normally occupied areas. This corresponds to an agent concentration of no more than 52 percent.

Table A.1.5.1.3(c) Physiological Effects of 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.

4.5.1.44.3.4* Egress Time Study.

An egress time study shall be performed to verify that the maximum exposure time limits in 4.5.1.2.4.3.2 and/or 4.5.1.34.3.3 are achieved.

A.1.5.1.4A.4.3.4

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Many studies have been conducted and technical guidance has been published regarding occupant egress time prediction. One source of such information is the *SFPE Handbook of Fire Protection Engineering, 5th Edition*. Various approaches are described, which can be used by the designer to calculate the available safe egress time (ASET) from a space protected by a clean agent extinguishing system. The ASET value can then be compared to required safe egress time (RSET), which is the maximum allowed exposure time limit in ~~1.5.1.2.4.3.2~~ and ~~1.5.1.3.4.3.3~~. The ASET value should be less than the RSET value. If the ASET value is initially determined to be equal to or exceed the RSET value, egress facilities should be modified so that the ASET value is less than the RSET value. Alternatively, an egress study involving the time recording of an actual egress simulation in the protected space is considered an acceptable means of verifying compliance with the maximum allowed exposure time limits.

~~1.5.1.5 Safety Requirements.~~

~~1.5.1.5.1.4.3.5* Safeguards.~~

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.~~

~~A.1.5.1.5.1A.4.3.5~~

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:

- (1) Provision of adequate aiseways and routes of exit and procedures to keep them clear at all times.
- (2) Provision of emergency lighting and directional signs as necessary to ensure quick, safe evacuation.
- (3) Provision of alarms within such areas that will operate immediately upon detection of the fire.
- (4) Provision of only outward-swinging, self-closing doors at exits from hazardous areas and, where such doors are latched, provision of panic hardware.
- (5) Provision of continuous alarms at entrances to such areas until the atmosphere has been restored to normal.
- (6) 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.
- (7) 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.
- (8) 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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

into the area, to ensure their correct action when a clean agent system operates.

- (9) 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.
- (10) Prohibition against smoking by persons until the atmosphere has been determined to be free of the clean agent.
- (11) Provision of such other steps and safeguards that a careful study of each particular situation indicates is necessary to prevent injury or death.

4.3.6* Adjacent Areas.

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

A.4.3.6

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.

4.3.7 Normally Unoccupied Spaces.

~~For~~ Systems protecting occupiable enclosures or spaces where the clean agent design concentration exceeds that approved for use in normally occupied spaces ~~(see Section 1.5)~~ in accordance with 4.3.2 or 4.3.3, ~~systems~~ shall include the following:

- (1) Supervised system lockout valves
- (2) Pneumatic pre-discharge alarms
- (3) Pneumatic time delays
- (4) Warning signs

4.3.7.1*

Pneumatic pre-discharge alarms shall be operated by an inert gas. ~~For an inert gas clean agent fire extinguishing system, the quantity of inert gas discharged to operate a pneumatic pre-discharge alarm discharging into the protected space shall be considered, together with the quantity of agent discharged, when making a determination of post-discharge oxygen concentration with respect to compliance with the requirements of 1.5.1.3.~~

A.4.3.7.1

Inert gases used to operate pre-discharge alarms include inert gas clean agents, nitrogen, and carbon dioxide.

4.3.7.2

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

~~For an inert gas clean agent fire extinguishing system, the quantity of inert gas discharged to operate a pneumatic pre-discharge alarm discharging into the protected space shall be considered, together with the quantity of agent discharged, when making a determination of post-discharge oxygen concentration with respect to compliance with the requirements of 4.5.1.3.4.3.3.~~

~~4.5.1.6~~

~~All persons who inspect, test, maintain, or operate fire extinguishing systems shall be trained in all aspects of safety related to the systems.~~

4.3.8 Warning Signs.

Warning and instruction signs shall be provided at the following locations:

1. At entrances to protected areas
2. Inside protected areas
3. Outside each entrance to cylinder storage rooms

4.3.8.1

Warning and safety instruction signs shall be located such that they will be readily visible to personnel in the area.

4.3.8.2

The safety sign format and color and the letter style of the signal words shall be in accordance with ANSI Z535.2.

4.4 System Technician Safety.

4.5.1.6.14.4.1

Before system cylinders are handled or moved, the following steps shall be taken:

- (1) Cylinder outlets shall be fitted with anti-recoil devices, cylinder caps, or both whenever the cylinder outlet is not connected to the system pipe inlet.
- (2) Actuators shall be disabled or removed before cylinders are removed from retaining bracketing.

4.5.1.6.24.4.2

Safe handling procedures shall be followed when transporting system cylinders.

4.5.1.6.2.14.4.2.1

Equipment designed for transporting cylinders shall be used.

4.4.2.2

When dollies or carts are used, cylinders shall be secured.

4.5.1.6.2.24.4.3

The system manufacturer's service procedures shall be followed for specific details on system operation, maintenance, and safety considerations.

4.5.24.5 Electrical Clearances.

4.5.2.14.5.1

All system components shall be located to maintain no less than minimum clearances from energized electrical parts.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

4.5.2

The following references shall be considered as the minimum electrical clearance requirements for the installation of clean agent systems:

- (1) IEEE C2, *National Electrical Safety Code*
- (2) NFPA 70, *National Electrical Code*
- (3) 29 CFR 1910, Subpart S, "Electrical Engineering"

~~4.5.2.2~~ 4.5.3

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.

~~4.5.2.3~~ 4.5.4

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

~~4.5.2.4~~ 4.5.5*

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 insulation on any individual component.

~~A.1.5.2.4~~ A.4.5.5

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.

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.

See NFPA 77.

~~4.5.2.5~~ 4.5.6

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.

~~4.6.4.6~~* 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 impacts, including, but not limited to, ozone depletion potential (ODP) and global warming potential (GWP) of the clean agents that could be used

~~A.1.6.4~~ A.4.6

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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

that eliminate or minimize the potential environmental impact (see Table A-1.6A.4.6). General guidelines to be followed to minimize this impact include the following:

- (1) Not performing unnecessary discharge testing
- (2) Considering the ozone depletion and global warming impact of the agent under consideration and weighing those impacts against the fire safety concerns
- (3) Recycling all agents where possible
- (4) Consulting the most recent environmental regulations on each agent

The unnecessary emission of clean extinguishing agents with non-zero ODP, non-zero GWP, or 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 into the environment.

GWP is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale that compares the gas in question to the same mass of carbon dioxide whose GWP is by convention equal to 1.

It is important to understand that the impact of a gas on climate change is a function of both the GWP of the gas and the amount of the gas emitted.

The ODP of an agent provides a relative comparison of the ability to react with ozone at altitudes within the stratosphere. ODP values are reported relative to the same mass CFC-11, which has an ODP equal to 1. When the environmental profile of a compound is considered, both the ODP and the GWP values should be considered to ensure that the agent selected complies with all local and regional regulations balanced with end user specifications. Good independent resources for environmental properties in terms of GWP and ODP of clean agent alternatives are available from the Montreal Protocol and the Intergovernmental Panel on Climate Change (IPCC).

Table A-1.6A.4.6 Potential Environmental Impacts

Agent	GWP (IPCC 2013)	ODP
FIC-1311	≤1	0*
FK-5-1-12	<1	0
HCFC Blend A	1500	0.048
HFC Blend B	1400	0
HCFC-124	527	0.022
HFC-125	3170	0
HFC-227ea	3350	0
HFC-23	12,400	0
HFC-236fa	8060	0
IG-01	0	0
IG-100	0	0
IG-541	0	0
IG-55	0	0

Note: GWP is reported over a 100-year integrated time horizon.

*Agent might have a non-zero ODP if released at altitudes high above ground level.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

~~4.7.4.7~~ Retrofitability.

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

~~4.8.4.8~~ Compatibility with Other Agents.

~~4.8.14.8.1~~*

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

~~A.1.8.1~~A.4.8.1

It is generally believed that, because of the highly stable nature of the compounds that are derived from the families that include 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 the 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 clearly is not the intent of 1.8.1 to deal with compatibility of the agents with components of the extinguishing hardware nor to deal with the subject of storability or storage life of individual agents or mixtures of those agents. Each of these concerns is addressed elsewhere in this standard.

~~4.8.24.8.2~~

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

Annex B Toxicological and Physiological Effects of Clean Agents and Their Decomposition Products

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

A.1.5.1.2B.1 Halocarbon Agents.

B.1.1 Toxicological Effects of Halocarbon Agents.

Table A.1.5.1.2B.1.1(a) provides information on the toxicological effects of halocarbon agents covered by this standard. The no observable adverse effect level (NOAEL) is the highest concentration at which no adverse physiological or toxicological effect has been observed. The lowest observable adverse effect level (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.1.5.1.2(a)B.1.1 Toxicity Information for Halocarbon Clean Agents

Commented [CB13]: NEW Annex B should be inserted after Annex A

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

<u>Agent</u>	<u>LC₅₀ or ALC</u> <u>(%)</u>	<u>NOAEL</u> <u>(%)</u>	<u>LOAEL</u> <u>(%)</u>
<u>FIC-13I1</u>	<u>>12.8</u>	<u>0.2</u>	<u>0.4</u>
<u>EK-5-1-12</u>	<u>>10.0</u>	<u>10</u>	<u>>10.0</u>
<u>HCFC Blend A</u>	<u>64</u>	<u>10</u>	<u>>10.0</u>
<u>HCFC-124</u>	<u>23-29</u>	<u>1</u>	<u>2.5</u>
<u>HFC-125</u>	<u>>70</u>	<u>7.5</u>	<u>10</u>
<u>HFC-227ea</u>	<u>>80</u>	<u>9</u>	<u>10.5</u>
<u>HFC-23</u>	<u>>65</u>	<u>30</u>	<u>>30</u>
<u>HFC-236fa</u>	<u>>45.7</u>	<u>10</u>	<u>15</u>
<u>HFC Blend B</u>	<u>56.7*</u>	<u>5.0*</u>	<u>7.5*</u>

Notes:

(1) LC₅₀ 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.

*These values are for the largest component of the blend (HFCB 134A).

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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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 its 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 concentrations 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; thus, cardiac sensitization will not occur. Accordingly, in the tables in 1.5.1.2.1, 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, 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 pre-discharge alarms and time delays is 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 1.5.1.2.1. The concentrations and times given in the tables 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.

B.1.2 Toxicological Effects of Hydrogen Fluoride.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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 patterns would be expected to change primarily from nose breathing to primarily mouth breathing. This change in breathing pattern determines 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 (1996), rats were exposed by nose-only or mouth-only breathing. In the mouth-only breathing 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 breathe through the nose but inhale through the mouth, thereby maximizing the deposition of HF into the lower respiratory tract.

In the nose-only breathing model, 2-minute or 10-minute exposures of rats to about 6400 or 1700 ppm, respectively, produced similar effects: that is, no mortality resulted but significant cell damage in the nose was observed. In contrast, marked differences in toxicity were evident in the mouth-only 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, such as 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 was observed 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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

exposure duration to about 1 minute, skin, eye, and respiratory tract irritation occurs (Machle and Kitzmiller, 1935).

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

$$C \times t = k \quad \text{[A.1.5.1.2 B.1.2]}$$

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, such as fire fighters, and those with compromised health. Exposure to higher concentrations of HF would be expected to be tolerated more in healthy individuals, whereas equal concentrations can have escape-impairing effects in those with compromised health. The following discussion assumes 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 the 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 (1996) showed, exposing mouth-breathing rats to HF concentrations of about 600 ppm for 2 minutes was

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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 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.1.5.1.2(b) B.1.2 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 a 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.

Table A.1.5.1.2(b) B.1.2 Potential Human Health Effects of Hydrogen Fluoride in Healthy Individuals

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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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, such as 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. (1934) and 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.

A-1.5.1.3B.2 Physiological Effects of Inert Gas Agents.

Paragraph 4.3.3.5 makes reference to limiting concentrations of inert gas agents corresponding to certain values of "sea level equivalent" of oxygen. The mean atmospheric pressure of air at sea level is 760 mm Hg. Atmospheric air is 21 volume percent oxygen. The partial pressures of oxygen in ambient air and air diluted agent to the limiting sea level concentrations corresponding to permissible exposure times of 5 minutes, 3 minutes, and 1/2 minute are given in Table A-1.5.1.3B.2(a).

Table A-1.5.1.3B.2(a) Oxygen Partial Pressure at Sea Level Corresponding to Exposure Limits Given in 4.3.3.5

<u>Exposure</u> <u>Time</u> <u>(min)</u>	<u>Agent</u> <u>Concentration</u> <u>(vol %)</u>	<u>O₂% at</u> <u>Sea</u> <u>Level</u>	<u>Partial Pressure of O₂ (mm Hg)</u>
Air reference	0	21	159.6
5	43	12.0	91.0
3	52	10.1	76.6
1/2	62	8.0	60.6

Note: Mean atmospheric pressure at sea level is 760 mm Hg.

In 3.3.35, *sea level equivalent of oxygen* is defined in terms of the partial pressure at sea level. The mean atmospheric pressure decreases with increasing altitude, as shown in Table 5.5.3.3. The partial pressure of oxygen is 21 percent of the atmospheric pressure. The concentration of added agent, which dilutes air to the sea level limiting partial pressure of oxygen, is given by

$$\text{Vol \% agent} = \frac{0.21P_{\text{ATM}} - P_{\text{O}_2, \text{LM}}}{0.21P_{\text{ATM}}} \times 100$$

[A-1.5.1.3B.2]

where:

Commented [CB14]: Existing x-ref will be Table 7.3.3.3 after all structural changes

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

P_{ATM} = local mean atmospheric pressure

$P_{O_2, LIM}$ = limiting partial pressure of oxygen corresponding to a sea level exposure time limit

The effect of altitude on limiting agent concentrations is given in Table A.1.5.1.3B.2(b).

Table A.1.5.1.3B.2(b) Relationship of Altitude to Atmospheric Pressure, Oxygen Partial Pressure in Air, and Limiting Agent Concentration

Altitude Above Sea Level (ft)	P_{ATM} (mm Hg)	O ₂ Partial Pressure in Air (mm Hg)	Limiting Agent Concentration (vol %)		
			5 min Exposure	3 min Exposure	30 sec Exposure
			$P(O_2) =$	$P(O_2) =$	$P(O_2) =$
			91 mm Hg	76.6 mm Hg	60.6 mm Hg
-3,000	840	176.4	48.4	56.6	65.6
-2,000	812	170.5	46.6	55.1	64.5
-1,000	787	165.3	44.9	53.7	63.3
0	760	159.6	43.0	52.0	62.0
1,000	733	153.9	40.9	50.2	60.6
2,000	705	148.1	38.5	48.3	59.1
3,000	679	142.6	36.2	46.3	57.5
4,000	650	136.5	33.3	43.9	55.6
5,000	622	130.6	30.3	41.4	53.6
6,000	596	125.2	27.3	38.8	51.6
7,000	570	119.7	24.0	36.0	49.4
8,000	550	115.5	21.2	33.7	47.5
9,000	528	110.9	17.9	30.9	45.3
10,000	505	106.1	14.2	27.8	42.9

Table A.1.5.1.3B.2(c) 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 10 percent (sea level equivalent) is required for normally occupied areas. This corresponds to an agent concentration of no more than 52 percent.

Table A.1.5.1.3B.2(c) Physiological Effects of 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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

*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.



First Revision No. 36-NFPA 2001-2019 [Global Input]

Create a new chapter, titled "Detection, Actuation, Alarm, and Control Systems for Clean Agent Releasing Applications," from the existing content in Section 4.3 with revisions in accordance with the attached document. The new chapter should be placed after the chapter titled "Local Application Systems."

Supplemental Information

File Name	Description Approved
2001_FR36_Section4.3.docx	For staff use
2001_FR36_Section4.3..pdf	For ballot

Submitter Information Verification

Committee:

Submittal Date: Wed May 01 17:50:07 EDT 2019

Committee Statement

Committee Statement: Chapter 4 covers system components, but many of the requirements in Section 4.3 apply to a higher level of integration than at the component level. Therefore, Section 4.3 is converted to a stand-alone chapter to better reflect the importance of system-level design considerations.

Editorial revisions are incorporated to comply with the Manual of Style and to improve readability.

A new requirement for supervising the position of lockout valves is included in Section 9.9. It is customary to supervise any valve or device that can affect the performance of a fire protection system.

Response Message: FR-36-NFPA 2001-2019

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

[2001, FR-36]

Chapter 9 Detection, Actuation, Alarm, and Control Systems for Clean Agent Releasing Applications

Commented [CB1]: Create NEW chapter inserted after the chapter titled 'Local Application Systems'

~~4.3.1.1~~ General.

~~4.3.1.1.1~~ * Control Panel for Releasing Service.

Detection, actuation, alarm, and control systems shall be installed, tested, and maintained in accordance with ~~appropriate NFPA protective signaling systems standards NFPA 72. (See NFPA 70 and NFPA 72. In Canada refer to CAN/ULC S524-14 and CAN/ULC S529-16.)~~

~~A.4.3.1.1~~ A.9.1.1

The FSSA Application Guide Detection & Control for Fire Suppression Systems offers the designer information of the various types of detection and control equipment.

~~4.3.1.1.1.1~~

The clean agent suppression system or group of systems shall be controlled by a listed clean agent releasing control panel(s) that is listed for monitoring the associated initiating devices, meets the listed compatibility requirements per ~~4.3.4.19.4.8 and 9.4.9~~ for actuation of the associated suppression system releasing device(s), and controls the associated suppression system notification appliances.

~~4.3.2.29.1.1.2~~

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.

~~4.3.1.1.29.1.1.3~~ *

A protected premises building fire alarm system shall be permitted to serve as a clean agent suppression system releasing control panel only if it is listed for release with the specific clean agent suppression system's releasing device, per ~~4.3.4.19.4.8 and 9.4.9~~.

~~A.4.3.1.1.2~~ A.9.1.1.3

Any output or relay (dry contact output) from the protected premises building fire alarm panel or another detection system not listed with the specific clean agent suppression system releasing device should not be used to directly release the system.

~~4.3.1.1.32.1.1.4~~

If the clean agent suppression system releasing control panel is located in a protected premises having a separate building fire alarm system, ~~it the releasing control panel~~ shall be monitored by the building fire alarm system for alarm, supervisory, and trouble signals.

~~4.3.1.1.49.1.1.5~~

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

The clean agent suppression system releasing control panel shall not be dependent upon or affected by the operation or failure of the protected premises building fire alarm panel.

4.3.1.29.1.2 Initiation and Actuation.

Automatic detection and automatic actuation shall be used.

4.3.1.2.19.1.2.1

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

4.3.1.39.1.3* Wiring Methods.

Initiating and releasing circuit wiring shall be installed in raceways.

A.4.3.1.3A.9.1.3

Paragraph 4.3.1.3 does not preclude the use of listed wireless initiating devices. The use of raceways is intended to protect against physical damage to circuit wiring.

4.3.1.3.19.1.3.1

Other than as permitted in 4.3.1.3.2, alternating current (ac) and direct current (dc) wiring shall not be combined in a common conduit or raceway.

4.3.1.3.29.1.3.2

It shall be permitted to combine ac and dc wiring in a common conduit or raceway where shielded and grounded.

4.3.29.2 Automatic Detection.

4.3.2.19.2.1*

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.

A.4.3.2.1A.9.2.1

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 air flow 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 a flammable atmosphere being formed, the spacing and siting of flammable vapor detectors should be carefully considered to avoid excessive delay in agent release.

4.3.2.2

~~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.~~

4.3.2.39.2.2

Commented [CB2]: Moved to 9.1.1.2

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Where 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 ensure 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.~~

A.9.2.2

One goal of this analysis is to limit the decomposition products from a suppression event where halocarbon agents are used.

4.3.3.5.3 Manual Release.

A means of manual release of the system shall be provided, except where permitted to be omitted in accordance with 9.3.4.

9.3.1

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 provides a low-battery signal.

9.3.2

The manual release shall cause simultaneous operation of automatically operated valves controlling agent release and distribution.

4.3.3.5.1 9.3.3*

A discharge pressure switch that provides an alarm-initiating signal to the releasing panel shall be required where a releasing panel is used and mechanical system actuation is possible.

A.4.3.3.5.1 A.9.3.3

A discharge pressure switch can serve to initiate electrical functions that normally occur upon system actuation, such as shutdown functions and control panel actuation.

4.3.3.5.2

The discharge pressure switch shall provide an alarm-initiating signal to the releasing panel.

4.3.3.5.2 9.3.4

A means of manual release shall not be required for automatic systems when the hazard being protected is unoccupiable and the hazard is in a remote location where personnel are not normally present.

4.3.3.6 9.3.5

The normal manual control(s) for actuation shall be located for easy accessibility at all times, including at the time of a fire.

4.3.3.6.1 9.3.6

The manual control(s) shall be of distinct appearance and clearly recognizable for the purpose intended.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

~~4.3.3.6.2~~ **9.3.7**

Operation of any manual control shall cause the complete system to operate as designed.

~~4.3.3.7~~ **9.3.8**

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.

9.3.9

At least one manual control for activation shall be located not more than 4 ft (1.2 m) above the floor.

~~4.3.3.10~~ **9.3.10**

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

~~4.3.3.4~~ **Operating Devices and Control Equipment for Agent Release, Discharge Control, and Equipment Shutdown.**

~~4.3.3.1~~

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

~~4.3.3.2~~ **9.4.1**

~~Operation of agent-releasing devices or valves, discharge controls, and shutdown equipment necessary for successful performance of the system shall be by listed mechanical, electrical, or pneumatic means. With an adequate and reliable source of energy shall be used.~~

~~4.3.3.3~~ **9.4.2**

~~All Operating devices shall be designed for the service they will encounter.~~

9.4.3

~~and~~ Operating devices shall not readily be rendered inoperative or susceptible to accidental operation.

9.4.4

~~Devices~~ Operating 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.

~~4.3.3.4~~ **9.4.5**

~~All~~ Operating 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.

~~4.3.3.5~~

~~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 provides a low battery signal. The release shall cause simultaneous operation of automatically operated valves controlling agent release and distribution.~~

~~4.3.3.5.1~~

~~A discharge pressure switch shall be required where mechanical system actuation is possible.~~

~~A.4.3.3.5.1~~

Commented [CB3]: Moved to 9.3.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

~~A discharge pressure switch can serve to initiate electrical functions that normally occur upon system actuation, such as shutdown functions and control panel actuation.~~

~~4.3.3.5.2~~

~~The discharge pressure switch shall provide an alarm initiating signal to the releasing panel.~~

~~4.3.3.5.3~~

~~A means of manual release shall not be required for automatic systems when the hazard being protected is unoccupiable and the hazard is in a remote location where personnel are not normally present.~~

~~4.3.3.6~~

~~The normal manual control(s) for actuation shall be located for easy accessibility at all times, including at the time of a fire.~~

~~4.3.3.6.1~~

~~The manual control(s) shall be of distinct appearance and clearly recognizable for the purpose intended.~~

~~4.3.3.6.2~~

~~Operation of any manual control shall cause the complete system to operate as designed.~~

~~4.3.3.7~~

~~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.~~

4.3.3.89.4.6

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

4.3.3.92.4.7

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

~~4.3.3.10~~

~~All manual operating devices shall be identified as to the hazard they protect.~~

4.3.4 Control Equipment. 4.3.4.19.4.8

The control equipment shall be specifically listed for the number and type of actuating devices utilized.

9.4.9

~~and their~~ The control equipment and actuating devices compatibility shall ~~have been~~ be listed for compatibility.

4.3.4.29.4.10*

Removal of an electric actuator from the agent storage container discharge valve or selector valve that it controls shall result in an audible and visual indication of system impairment at the system releasing control panel.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

~~A.4.3.4.2~~A.9.4.10

NFPA 72, 14.2.6.4, requires that "Suppression systems shall be secured from inadvertent actuation, including disconnection of releasing solenoids or electric actuators, closing of valves, other actions, or combinations thereof, for the specific system, for the duration of the fire alarm system testing."

Commented [CB4]: Correct for 2019 edition.

Clean agent systems generally have a device attached to one or more agent storage container discharge valves that, upon signal from the fire system releasing control unit, causes the discharge valve(s) to operate to release the agent. The device is referred to as an electric actuator. These actuators are typically either a solenoid operated device or a squib operated device.

During system maintenance, it is a common procedure to remove the solenoid operated actuators from the agent storage container discharge valve to prevent accidental discharge of the system and permit functional testing of the actuator. Some systems that incorporate selector valves also have electric actuators attached to the selector valves to control their operation by electrical signal from the control panel. These electric actuators might also need to be routinely removed from their selector valves during maintenance.

Since the electrical connection between the solenoid and the system control panel is not broken by this maintenance procedure, special provision is required to provide an indication of system impairment at the releasing control panel when the electric actuator is physically removed from the valve it controls. There have been numerous reports of systems inadvertently left disabled after maintenance because the technician failed to reinstall the actuator on its valve. Fortunately in all reported cases, the impairment was discovered before the system was required to operate, and only successful extinguishments have been reported — no failures to operate under fire conditions have come to the attention of the technical committee responsible for this standard.

Squib actuators are covered by this requirement only if the manufacturer's maintenance instruction requires physical removal of the squib operated device from the valve it controls.

With the evolution of technology, cost effective means to monitor the placement of actuators can be developed. Because of the time required to develop hardware and to obtain listings and approvals for the hardware, the effective date for this provision of the standard is January 1, 2016.

~~4.3.4.2-19.4.10.1~~

Paragraph 4.3.4.29.4.10 shall become effective January 1, 2016.

~~4.3.4.2-29.4.10.2~~

Paragraph 4.3.4.29.4.10 shall not apply to systems covered under Chapter 9 of this standard with the exception of those systems included under Section 9.6.

Commented [CB5]: Existing x-ref should be Chapter 12 after structural changes

~~4.3.4.3-~~

~~Removal of an electric actuator from the selector valve it controls shall result in an audible and visual indication of system impairment at the system releasing control panel.~~

Commented [CB6]: Existing x-ref should be Section 12.6 after structural changes

~~4.3.4.3.1-~~

~~Paragraph 4.3.4.3 shall become effective January 1, 2016.~~

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

~~4.3.4.3.2~~

~~Paragraph 4.3.4.3 shall not apply to systems covered under Chapter 9 of this standard with the exception of those systems included under Section 9.6.~~

~~4.3.4.49.4.11~~

The control equipment shall supervise the actuating devices and associated wiring and, as required, cause actuation.

~~4.3.4.59.4.12~~

Removal of the primary agent container actuating device from the discharge valve and/or selector valve shall cause a trouble or supervisory signal at the releasing control unit.

~~4.3.4.69.4.13~~

Where pneumatic control equipment is used, the lines shall be protected against crimping and mechanical damage.

9.4.14

Where installations of pneumatic control equipment 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.~~

~~4.3.59.5~~ **Operating Alarms and Indicators.**

~~4.3.5.19.5.1~~

Alarms or indicators or both shall be used to indicate the operation of the system, hazards to personnel, or failure of any supervised device.

9.5.2

The type (audible, visual, or olfactory), number, and location of the indicating devices shall be such that their purpose is satisfactorily accomplished.

9.5.3

The extent and type of alarms or indicator equipment or both shall be approved.

~~4.3.5.29.5.4~~

Audible and visual pre-discharge alarms shall be provided within the protected area of occupiable spaces to give positive warning of impending discharge.

9.5.5

The operation of the warning devices shall be continued after agent discharge until positive action has been taken to acknowledge the alarm and to proceed with appropriate action.

~~4.3.5.49.5.6~~

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

~~4.3.5.39.6*~~ **Abort Switches.**

Abort switches shall be permitted to be installed for clean agent releasing systems.

9.6.1*

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Abort switches, ~~where provided,~~ shall be located within the protected area and ~~shall be located~~ near the means of egress for the area.

~~A.4.3.5.3~~ **A.9.6.1**

~~A telephone should be located near the abort switch.~~

9.6.2

The abort switch shall be of a type that requires constant manual pressure to cause abort.

9.6.3

~~In all cases, t~~The normal manual controls ~~and the manual emergency control~~ shall override the abort function.

9.6.4

Operation of the abort function shall result in both audible and distinct visual indication of system impairment.

9.6.5

~~The a~~Abort switches shall be clearly recognizable for the purpose intended.

~~A.4.3.5.3~~

~~A telephone should be located near the abort switch.~~

~~4.3.5.4~~

~~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.~~

~~4.3.5.5~~

~~Warning and instruction signs at entrances to and inside protected areas shall be provided.~~

~~4.3.5.5.1~~

~~Warning and safety instruction signs shall be located such that they will be readily visible to personnel in the area where the clean agent design concentration exceeds that approved for use in normally occupied spaces. The safety sign format and color and the letter style of the signal words shall be in accordance with ANSI Z535.2.~~

~~4.3.5.5.2~~

~~Warning and safety instruction signs shall be located outside each entrance to clean agent cylinder storage rooms. The safety sign format and color and the letter style of the signal words shall be in accordance with ANSI Z535.2.~~

9.7 Time Delays.

~~4.3.5.6.1~~ **9.7.1***

~~For clean agent extinguishing systems, a~~A pre-discharge alarm and time delay, ~~sufficient to allow personnel evacuation prior to discharge,~~ shall be provided.

9.7.2*

Commented [CB7]: Moved to 9.5.6

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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.

~~A.4.3.5.6.4~~A.9.7.2

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

~~4.3.5.6.29.7.3~~

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

~~4.3.5.6.39.7.4~~

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

~~4.3.69.8*~~ ~~Unwanted System Operation~~Disconnect Switch.

~~A.4.3.6A.9.8~~

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 disconnect switch should be of the keyed-access type if external to the control panel, or it 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. Care should be taken to thoroughly evaluate and correct any factors that could result in unwanted discharges.

~~4.3.6.19.8.1~~

To avoid unwanted discharge of an electrically actuated clean agent system, a supervised disconnect switch shall be provided.

~~4.3.6.29.8.2~~

The disconnect switch shall interrupt the releasing circuit to the suppression system.

~~4.3.6.39.8.3~~

~~The Operation of the~~ disconnect switch shall cause a supervisory signal at the releasing control unit.

~~4.3.6.49.8.4~~

The disconnect switch shall be secured against unauthorized use by one of the following methods:

- (1) Locate inside a lockable releasing control panel
- (2) Locate inside a lockable enclosure
- (3) Require a key for activation of the switch

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

4.3.6.59.8.5

When the disconnect switch requires a key for activation, the access key shall not be removable while the releasing circuit is disconnected.

A.9.8.5

~~so~~If the key remains with the switch, the suppression system can be quickly returned to the operational condition in the event of a fire.

4.3.6.69.8.6

~~Suppression~~Disarming the suppression system disconnect-achieved release sequence via software programming shall not be acceptable for use in lieu of a physical disconnect switch.

4.3.6.79.8.7

The disconnect switch shall be listed.

9.9 Lockout Valves.

If a lockout valve is installed, the releasing panel shall indicate a supervisory signal when the lockout valve is not in the fully-open position.



First Revision No. 37-NFPA 2001-2019 [Global Input]

- (1) Revise Chapter 5 (System Design) in accordance with the attached file.
- (2) Create a new chapter, titled "Total Flooding Systems," from the existing material in Sections 5.3 through 5.8 in accordance with the attached file. This chapter should be placed after the chapter titled "System Design."

Supplemental Information

File Name	Description Approved
2001_FR37_Chapter05.docx	For staff use
2001_FR37_Chapter05..pdf	For ballot

Submitter Information Verification

Committee:

Submittal Date: Wed May 01 17:58:57 EDT 2019

Committee Statement

Committee Statement: Sections 5.1 and 5.2 are general system design requirements that apply to both total flooding and local application systems, while Sections 5.3 through 5.8 are specific requirements that apply only to total flooding systems. This is not clear in the existing chapter arrangement, so the requirements are separated into individual chapters.

Response Message: FR-37-NFPA 2001-2019

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

[2001, FR-37]

Chapter 5 System Design

5.1 Specifications, Plans, and Approvals.

5.1.1 Specifications.

5.1.1.1

Specifications for total flooding and local application 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.

5.1.1.2

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.

5.1.2 Working Plans.

5.1.2.1

Working plans and calculations shall be submitted for approval to the authority having jurisdiction before system installation or remodeling begins.

5.1.2.2

~~These documents~~ Working plans and calculations shall be prepared only by persons fully experienced and qualified in the design of total flooding and local application clean agent fire extinguishing systems.

5.1.2.3

Deviation from ~~these documents~~ working plans shall require permission of the authority having jurisdiction.

5.1.2.2-4

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

- (1) Name of owner and occupant
- (2) Location, including street address
- (3) Point of compass and symbol legend
- (4) Location and construction of protected enclosure walls and partitions
- (5) Location of fire walls
- (6) Enclosure cross section, shown as a full-height or schematic diagram, including location and construction of building floor-ceiling assemblies above and below, raised access floor, and suspended ceiling
- (7) Agent being used
- (8) Agent concentration at the lowest temperature and the highest temperature for which the enclosure is protected
- (9) Description of occupancies and hazards being protected, designating whether the enclosure is normally occupied
- (10) For an enclosure protected by a clean agent fire extinguishing system, an estimate of the maximum positive pressure and the maximum negative pressure, relative to ambient pressure, expected to be developed upon the discharge of agent
- (11) Description of exposures surrounding the enclosure
- (12) 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

Commented [CB1]: This chapter will be renumbered as Chapter 6, due to the creation of new Chapter 4 (General Requirements)

This chapter should remain located after the chapter titled 'Components'

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

- (13) Description of nozzle(s) used, including size, orifice port configuration, and equivalent orifice area
- (14) Description of pipe and fittings used, including material specifications, grade, and pressure rating
- (15) 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; and required method of making wire terminations
- (16) Description of the method of detector mounting
- (17) Equipment schedule or bill of materials for each piece of equipment or device showing device name, manufacturer, model or part number, quantity, and description
- (18) 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
- (19) 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, strainers, and orientation of tees; and nozzles, including size, orifice port configuration, flow rate, and equivalent orifice area
- (20) Scale drawing showing the layout of the annunciator panel graphics if required by the authority having jurisdiction
- (21) Details of each unique rigid pipe support configuration showing method of securement to the pipe and to the building structure
- (22) Details of the method of container securement showing method of securement to the container and to the building structure
- (23) Complete step-by-step description of the system sequence of operations, including functioning of abort and maintenance switches, delay timers, and emergency power shutdown
- (24) Point-to-point wiring schematic diagrams showing all circuit connections to the system control panel and graphic annunciator panel
- (25) Point-to-point wiring schematic diagrams showing all circuit connections to external or add-on relays
- (26) Complete calculations to determine enclosure volume, quantity of clean agent, and size of backup batteries; method used to determine number and location of audible and visual indicating devices; and number and location of detectors
- (27) Details of any special features
- (28) *Pressure relief vent area, or equivalent leakage area, for the protected enclosure to prevent development, during system discharge, of a pressure difference across the enclosure boundaries that exceeds a specified enclosure pressure limit

A.5.1.2.24(28)

"Specified enclosure pressure limit" is a value determined or estimated with confidence to be less than the enclosure pressure strength. It is not intended to necessarily be the same as the "enclosure pressure strength" which would be determined by a structural engineering analysis. Guidance to determine "pressure relief vent area" can be found in the *FSSA Application Guide to Estimating Enclosure Pressure & Pressure Relief Vent Area for Use with Clean Agent Fire Extinguishing Systems*. That guide can assist the designer in accurately determining the required information for inclusion on the working plans.

5.1.2.3-5

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

The detail on the system shall include information and calculations on the quantity 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.

5.1.2.5.1

Pipe size reduction and orientation of tees shall be clearly indicated.

5.1.2.5.2

Information shall be submitted pertaining to the location and function of the detection devices, operating devices, auxiliary equipment, and electrical circuitry, if used.

5.1.2.5.3

Apparatus and devices used shall be identified.

5.1.2.5.4

Any special features shall be adequately explained.

5.1.2.3-5.5

Pre-engineered systems shall not be required to specify an internal volume of the container, nozzle flow rates, equivalent lengths of pipe, fittings, and hose, or flow calculations, when used within their listed limitations.

5.1.2.5.6

~~For pre-engineered systems, 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.

5.1.2.4-6

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.

5.1.2.5-7 Flow Calculations.

5.1.2.5.1

Flow calculations along with the working plans shall be submitted to the authority having jurisdiction for approval.

5.1.2.7.2

The version of the flow calculation program shall be identified on the computer calculation printout.

5.1.2.5-7.3

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

5.1.2.5-7.4

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

5.1.3 Approval of Plans.

5.1.3.1

Plans and calculations shall be approved prior to installation.

5.1.3.2

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

5.1.3.3

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

5.2* System Flow Calculations.

A.5.2

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 process with numerous methods. Two calculation methods are commonly used by fire protection professionals. The first is based on modifications to the HFLOW Method (DiNenno et al., 1995), completed in 1994, and the other is based on enhancement to the work of Hesson (Hesson, 1953) in 1953. Only those calculation methods that have been listed or approved should be used for design purposes.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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

To simplify the methodology, the following basic assumptions are made:

- (1) 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 effect on the cylinder energy balance of the increased kinetic energy of the fluid leaving the cylinder.
- (2) 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.
- (3) The heat transferred from the pipe walls to the flowing fluid is often insignificant.
- (4) The flow through the pipe network is homogeneous. Liquid flow and vapor flow through the piping are at the same velocity and 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 and dip tube equivalent lengths, agent mass and temperature, pipe length and diameter, elevation, fittings, nozzle area, and discharge coefficients. 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, the HFLOW 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 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 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 (1953). 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, require 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 include cylinder volume, agent mass and temperature, valve and dip tube equivalent lengths, pipe lengths, elevation changes, fittings, and pre-discharge pipe temperature. Most programs permit the user to specify either the required flow rate or the 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 are 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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

systems using longer pipe lengths with complex configurations. Wysocki and Christensen (Wysocki et al., 1996) adapted the work of Hesson for use with single-phase compressible gases. Inert gas discharge from a cylinder into a pipe and nozzle network involves the following three stages:

- (1) 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.
- (2) 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.
- (3) Final transient condition, during which the storage container and pipeline empty. 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 necessitates 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 ~~are on~~ 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 limits
- (7) Maximum and minimum storage container fill density limits
- (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.

5.2.1*

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.~~

A.5.2.1

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:

- (1) 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 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.
- (2) 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.
- (3) The average nozzle pressures predicted by the flow calculation method should agree with the actual nozzle pressures by ± 10 percent of the predicted value.
- (4) 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 that the nozzle's discharge is to protect.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

5.2.1.1

The system design shall be within the manufacturer's listed limitations.

5.2.1.4-2

Designs involving pre-engineered systems shall not be required to be provided with flow calculations in accordance with 5.1.2.5-7 where used within their listed limitations.

5.2.2

Valves and fittings shall be rated for equivalent length in terms of pipe or tubing sizes with which they will be used.

5.2.2.1

The equivalent length of the container valve shall be listed.

5.2.2.2

The equivalent length of the container valve and shall include the siphon tube, valve, discharge head, and flexible connector.

5.2.3

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

5.2.4

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

Chapter 7 Total Flooding Systems

5.9.7.1* Enclosure.

A.5.9.7.1

NFPA 75, 6.1.3.3, offers clear guidance on the construction of an enclosure being protected by clean agent fire extinguishing systems, specifically that "the fire-resistant-rated enclosures shall extend from the structural floor to the structural floor above or to the roof." Proper room construction will ensure that the integrity of the room will be maintained and that the extinguishing agent concentration will be held for the required duration.

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.

Commented [CB2]: NEW chapter to be located after chapter titled 'System Design' and before 'Local Application Systems'

Commented [CB3]: Moved from A.1.4.2.3

5.9.7.1.1

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

5.9.7.1.2

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

5.9.7.1.3

The authority having jurisdiction shall be permitted to require pressurization/depressurization of the protected enclosure or other tests to ensure performance that meets the requirements of this standard. (See Annex C.)

5.9.7.1.4

To prevent loss of agent through openings to adjacent hazards or work areas, openings shall be permanently sealed or equipped with automatic closures.

7.1.5

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.

5.9.5.7.1.6

Where a clean agent total flooding system is being provided for the protection of a room with a raised or sunken floor, the room and raised or sunken floor shall be simultaneously protected.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

5.3.57.1.6.1*

If only the space under the raised floor is to be protected by a total flooding system, an inert gas shall be used to protect that space.

A.5.3.57.1.6.1

NFPA 75, 9.1.1.3, requires an automatic fire suppression system to be installed for the protection of the area below the raised floor in an information technology equipment room or information technology equipment area containing combustible material. NFPA 75, A.9.1.1.3, notes that halocarbon agents should not be used to protect the space below a raised floor unless the space above the raised floor is likewise protected by the system and the system is designed to discharge simultaneously into both the space below the raised floor and the room above the raised floor. During and after a discharge, some of the agent from the space under the raised floor will migrate into the room above the raised floor. If any fire exists in the equipment above the raised floor, the agent at a concentration below the extinguishing concentration may be exposed to the fire. If the agent is a halocarbon, considerable decomposition of the agent could occur. Note that NFPA 12A, in 5.3.1.2, also prohibits the use of Halon 1301 for flooding the space under a raised floor if the room above the raised floor is not simultaneously protected by the Halon 1301 total flooding system.

5.3.57.1.6.2

Each volume, room, and raised or sunken floor to be protected shall be provided with detectors, piping network, and nozzles.

5.3.67.1.7*

Other than the ventilation systems identified in 5.3.6.2, forced-air ventilating systems, including self-contained air recirculation 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.

A.5.3.67.1.7

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. Where recirculating ventilation is not shut off, additional agent could be needed to compensate for room leakage during the hold time.

5.3.67.1.7.1

If not shut down or closed automatically, the volume of the self-contained recirculating undamped ventilation system ducts and components mounted below the ceiling height of the protected space shall be considered as part of the total hazard volume when determining the quantity of agent.

5.3.67.1.7.2

Ventilation systems necessary to ensure safety shall not be required to be shut down upon activation of the fire suppression system.

7.1.7.3

Where a ventilation system is permitted to remain in operation in accordance with 7.1.7.2, An-an extended agent discharge shall be provided to maintain the design concentration for the required duration of protection.

5.3.77.1.8*

The protected enclosure shall have the structural strength and integrity necessary to contain the agent discharge.

7.1.8.1

If the developed pressures present a threat to the structural strength of the enclosure, venting shall be provided to prevent excessive pressures.

7.1.8.2

Designers shall consult the system manufacturer's recommended procedures relative to enclosure venting. *[For pressure relief vent area or equivalent leakage area, see 5.1.2.2(28).]*

A.5.3.77.1.8

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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.

5.4.2.2 Design Concentration Requirements. **5.4.2.2.1**

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.

5.4.2.2.2 Flame Extinguishment. **5.4.2.2.2.1***

The flame extinguishing concentration for Class B fuels shall be determined by the cup burner method described in Annex 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.

A.5.4.2.2.2.1

This standard requires that the flame extinguishing concentration of a gaseous agent for a Class B fuel be determined by the cup burner method. Cup burner testing in the past has involved a variety of techniques, apparatus, and investigators. It was reported by Senecal (2005) that significant inconsistencies are apparent in Class B flame extinguishing data for inert gases currently in use in national and international standards. In 2003, the Technical Committee for NFPA 2001 appointed a task group to develop an improved cup burner test method. Through this effort, the degree of standardization of the cup burner test method was significantly improved. A standard cup burner test procedure with defined apparatus has now been established and is outlined in Annex B. Values for minimum flame extinguishing concentration (MEC) for gaseous agents addressed in this standard, as determined by the revised test method, are given in Table A.5.4.2.2.1. Values for MEC that were determined by the 2004 test method are retained in this edition for the purpose of providing an MEC reference where data obtained by the revised test method were not available. It is intended that in subsequent editions the 2004 MEC data can be deleted.

Table A.5.4.2.2.1 Minimum Flame Extinguishing Concentration (Fuel: n-heptane)

Agent	MEC (vol %)	
	2004 Test Method	2008 Test Method**
FIC-13I1	3.2*	
FK-5-1-12	4.5	
HCFC Blend A	9.9	
HCFC-124	6.6	
HFC-125	8.7	
HFC-227ea	6.6†	6.62
HFC-23	12.9	
HFC-236fa	6.3	
HFC Blend B	11.3	
IG-01	42	
IG-100	31*	32.2
IG-541	31	
IG-55	35	

*Not derived from standardized cup burner method.

†A value of cup burner extinguishing concentration of 6.7 percent for HCF-227ea for commercial heptane fuel.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

**A working group appointed by the then NFPA 2001 technical committee revised Annex B to include a refinement of the method reported in the 2004 and earlier editions.

5.47.2.2.1.1

Measurement equipment used in applying the cup burner method shall be calibrated.

5.47.2.2.2*

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 ANSI/UL 2127 or ANSI/UL 2166 or equivalent.

A.5.47.2.2.2

The following steps detail the fire extinguishment/area coverage fire test procedure for engineered and pre-engineered clean agent extinguishing system units:

- (1) The general requirements are as follows:
 - (a) 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.5.47.2.2.2(1)(c) through A.5.47.2.2.2(6)(f) under the maximum design limitations and most severe installation instructions. See also A.5.47.2.2.2(1)(b).
 - (b) When tested as described in A.5.47.2.2.2(2)(a) through A.5.47.2.2.2(5)(b), an extinguishing system unit should extinguish all fires within 30 seconds after the end of system discharge. When tested as described in A.5.47.2.2.2(2)(a) through A.5.47.2.2.2(3)(c) and A.5.47.2.2.2(6)(a) through A.5.47.2.2.2(6)(f), an extinguishing system should prevent reignition of the wood crib after a 10 minute soak period.
 - (c) The tests described in A.5.47.2.2.2(2)(a) through A.5.47.2.2.2(6)(f) should be carried out. Consider the intended use and limitations of the extinguishing system, with specific reference to the following:
 - i. The area coverage for each type of nozzle
 - ii. The operating temperature range of the system
 - iii. Location of the nozzles in the protected area
 - iv. Either maximum length and size of piping and number of fittings to each nozzle or minimum nozzle pressure
 - v. Maximum discharge time
 - vi. Maximum fill density
 - (2) The test enclosure construction is as follows:
 - (a) 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.
 - (b) 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 ft³ (100 m³) in volume.
- (3) The extinguishing system is as follows:
 - (a) A pre-engineered type of 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.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

- (b) 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).
 - (c) Except for the flammable liquid fire test using the 2.5 ft² (0.23 m²) 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.
- (4) The extinguishing concentration is as follows:
- (a) The extinguishing agent concentration for each Class A 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.
 - (b) The extinguishing agent concentration for each Class B test is to be 76.9 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.
 - (c) The concentration for inert gas clean agents can be adjusted to take into consideration actual leakage measured from the test enclosure.
 - (d) 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.

$$W = \frac{V}{s} \left(\frac{C}{100 - C} \right) \quad [\text{A.5-42.2.2a}]$$

where:

- W = weight of clean agents [lb (kg)]
- V = volume of test enclosure [ft³ (m³)]
- s = specific volume of clean agent at test temperature [ft³/lb (m³/kg)]
- C = concentration (vol %)

- (5) The flammable liquid extinguishment tests are as follows:
- (a) Steel test cans having a nominal thickness of 0.216 in. (5.5 mm) (such as 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 the 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, closable 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 2.5 ft² (0.23 m²) 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, at 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 percent.
 - (b) The heptane is to be commercial grade having the following characteristics:

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

- i. Initial boiling point: 194°F (90°C) minimum
 - ii. Dry point: 212°F (100°C) maximum
 - iii. Specific gravity: 0.69–0.73
- (6) The wood crib extinguishment tests are as follows:
 - (a) 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.
 - (b) The wood crib is to consist of four layers of six, trade size 2 by 2 (1½ by 1½ in.) by 18 in. long, kiln spruce or fir lumber having a moisture content between 9 percent 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.
 - (c) Ignition of the crib is to be achieved by the burning of commercial grade heptane in a square steel pan 2.5 ft² (0.23 m²) 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 in. 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.
 - (d) 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 3½ minutes. Approximately ¼ gal (0.95 L) of heptane will provide a 3 to 3½ minute burn time. Just prior to the end of the pre-burn 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 in. and 28 in. (508 mm and 711 mm) above the floor. The closure is then to be sealed.
 - (e) After the crib is allowed to burn for 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 percent.
 - (f) After the end of system discharge, the enclosure is to remain sealed for 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 re-ignition.
- (7) The following is a schematic of the process to determine the design quantity:
 - (a) Determine hazard features, as follows:
 - i. Fuel type: Extinguishing concentration (EC) per ~~5.47.2.2~~ or inerting concentration (IC) per ~~5.47.2.3~~
 - ii. Enclosure volume
 - iii. Enclosure temperature
 - iv. Enclosure barometric pressure
 - (b) Determine the agent minimum design concentration (MDC) by multiplying EC or IC by the safety factor (SF):
$$MDC = (EC \text{ or } IC) SF \quad [A.5.47.2.2.2b]$$
 - (c) Determine the agent minimum design quantity (MDQ) by referring to 5.5.1 for halocarbons or 5.5.2 for inert gases
 - (d) Determine whether design factors (DF) apply. See 5.5.3 to determine individual DF [DF(i)] and then determine sum:
$$DF = \sum DF(i) \quad [A.5.47.2.2.2c]$$
 - (e) Determine the agent adjusted minimum design quantity (AMDQ):
$$AMDQ = MDQ (1 + DF) \quad [A.5.47.2.2.2d]$$
 - (f) Determine the pressure correction factor (PCF) per 5.5.3.3

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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

$$FDQ = AMDQ \times PCF [A.5.47.2.2.2e]$$

Where any of the following conditions exist, higher extinguishing concentrations might be required:

- (1) Cable bundles greater than 4 in. (100 mm) in diameter
- (2) Cable trays with a fill density greater than 20 percent of the tray cross section
- (3) Horizontal or vertical stacks of cable trays less than 10 in. (250 mm) apart
- (4) Equipment energized during the extinguishment period where the collective power consumption exceeds 5 kW

Fire extinguishment tests for (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 3530 ft³ (100 m³) and a minimum height of 11.5 ft (3.5 m) and each wall at least 13.1 ft (4 m) long. Provisions should be made for relief venting if required.

The test objects are as follows:

- (1) The polymer fuel array consists of four sheets of polymer, $\frac{3}{8}$ in. (9.53 mm) thick, 16 in. (406 mm) tall, and 8 in. (203 mm) wide. Sheets are spaced and located per Figure A.5.47.2.2.2(a). The bottom of the fuel array is located 8 in. (203 mm) from the floor. The fuel sheets should be mechanically fixed at the required spacing.
- (2) A fuel shield is provided around the fuel array as indicated in Figure A.5.47.2.2.2(a). The fuel shield is 15 in. (381 mm) wide, 33.5 in. (851 mm) high, and 24 in. (610 mm) deep. The 24 in. (610 mm) wide $\times$ 33.5 in. (851 mm) high sides and the 24 in. (610 mm) $\times$ 15 in. (381 mm) top are sheet metal. The remaining two sides and the bottom are open. The fuel array is oriented in the fuel shield such that the 8 in. (203 mm) dimension of the fuel array is parallel to the 24 in. (610 mm) side of the fuel shield.
- (3) Two external baffles measuring 40 in. $\times$ 40 in. (1 m $\times$ 1 m) and 12 in. (0.3 m) tall are located around the exterior of the fuel shield as shown in Figure A.5.47.2.2.2(a) and Figure A.5.47.2.2.2(b). The baffles are placed 3.5 in. (0.09 m) above the floor. The top baffle is rotated 45 degrees with respect to the bottom baffle.
- (4) Tests are conducted for three plastic fuels — polymethyl methacrylate (PMMA), polypropylene (PP), and acrylonitrile-butadiene-styrene (ABS) polymer. Plastic properties are given in Table A.5.47.2.2.2(a).
- (5) The ignition source is a heptane pan 2 in. $\times$ 2 in. $\times$ $\frac{1}{8}$ in. deep (51 mm $\times$ 51 mm $\times$ 22 mm deep) centered $\frac{1}{2}$ in. (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.
- (6) 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:

- (1) The procedures for ignition are as follows:
 - (a) The heptane pan is ignited and allowed to burn for 90 seconds.
 - (b) The agent is discharged 210 seconds after ignition of heptane.
 - (c) 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 of agent discharge, a higher minimum extinguishing concentration must be utilized.
 - (d) 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.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

- (e) 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 affecting the extinguishment process.
 - (f) 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.
 - (g) During the post-discharge period, the oxygen concentration should not fall below 0.5 percent by volume of the oxygen level measured at the end of agent discharge.
- (2) The observation and recording procedures are as follows:
- (a) The following data must be recorded continuously during the test:
 - i. Oxygen concentration (± 0.5 percent)
 - ii. Fuel mass loss (± 5 percent)
 - iii. Agent concentration (± 5 percent) (Inert gas concentration can be calculated based on oxygen concentration.)
 - (b) The following events are timed and recorded:
 - i. Time at which heptane is ignited
 - ii. Time of heptane pan burnout
 - iii. Time of plastic sheet ignition
 - iv. Time of beginning of agent discharge
 - v. Time of end of agent discharge
 - vi. Time all visible flame is extinguished

The minimum extinguishing concentration is determined by all of the following conditions:

- (1) All visible flame is extinguished within 600 seconds of agent discharge.
- (2) The fuel weight loss between 10 seconds and 600 seconds after the end of discharge does not exceed 0.5 oz (15 g).
- (3) There is no ignition of the fuel at the end of the 600 second soak time and subsequent test compartment ventilation.

Figure A.5-47.2.2(a) Four-Piece Modified Plastic Setup.

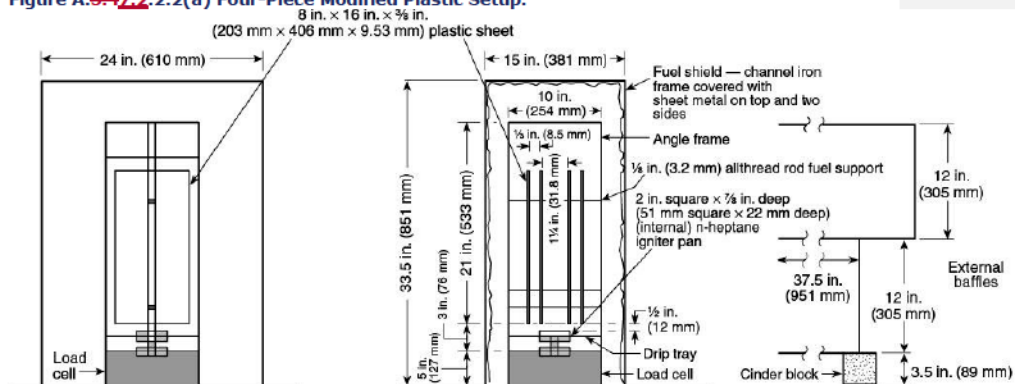
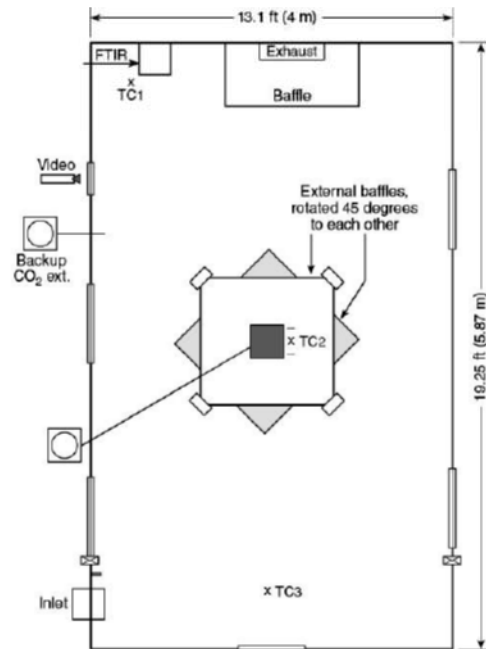


Figure A.5-47.2.2(b) Chamber Plan View.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.



x TC1—0 in. (0 mm), 12 in. (305 mm), 24 in. (610 mm), 48 in. (1220 mm), 72 in. (1.8 m), 96 in. (2.4 m), 120 in. (3 m) from ceiling
 x TC2—0 in. (0 mm), 12 in. (305 mm), 24 in. (610 mm), 48 in. (1220 mm), 72 in. (1.8 m), 96 in. (2.4 m), 120 in. (3 m) from ceiling
 x TC3—0 in. (0 mm), 12 in. (305 mm), 24 in. (610 mm), 48 in. (1220 mm), 72 in. (1.8 m), 96 in. (2.4 m), 120 in. (3 m) from ceiling
 ODM—12 in. (305 mm) down from ceiling
 → FTIR—27 in. (686 mm) up from floor
 = Noise meter—12 in. (305 mm) down from ceiling
 FTIR—Fourier transform infrared (spectrometer)
 ODM—Oxygen deficiency monitor
 TC—Thermocouple

Table A.5-47.2.2(a) Plastic Fuel Properties

25 kW/m ² Exposure in Cone Calorimeter — ASTM E1354								
Fuel	Color	Density (g/cm ³)	Ignition Time		180-Second Average Heat Release Rate		Effective Heat of Combustion	
			sec	Tolerance	kW/m ²	Tolerance	MJ/kg	Tolerance
PMMA	Black	1.19	77	±30%	286	25%	23.3	±15%
PP	Natural (white)	0.905	91	±30%	225	25%	39.8	±15%
ABS	Natural (cream)	1.04	115	±30%	484	25%	29.1	±15%

Table A.5-47.2.2(b) Class A Flame Extinguishing and Minimum Design Concentrations Tested to UL 2166 and UL 2127

Agent	Class A MEC	Class A Minimum Design Concentration	Class C Minimum Design Concentration
FK-5-1-12	3.3	4.5	4.5
HFC-125	6.7	8.7	9.0

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Agent	Class A MEC	Class A Minimum Design Concentration	Class C Minimum Design Concentration
HFC-227ea	5.2	6.7	7.0
HFC-23	15.0	18.0	20.3
IG-541	28.5	34.2	38.5
IG-55	31.6	37.9	42.7
IG-100	31.0	37.2	41.9

Note: Concentrations reported are at 70°F (21°C). Class A design values are the greater of (1) the Class A extinguishing concentration, determined in accordance with 5-47.2.2.2, times a safety factor of 1.2; or (2) the minimum extinguishing concentration for heptane as determined from 5-47.2.2.1. 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. Wood crib and polymeric sheet Class A fire tests may not adequately indicate extinguishing concentrations suitable for the protection of certain plastic fuel hazards (e.g., electrical- and electronic-type hazards involving grouped power or data cables such as computer and control room underfloor voids and telecommunication facilities). The values in Table A.5-47.2.2.2(b) are representative of the minimum extinguishing concentrations and design concentrations for various agents. The concentrations required can vary by equipment manufacturer. Equipment manufacturers should be contacted for the concentration required for their specific system.

5-47.2.2.3

The minimum design concentration for a Class B fuel hazard shall be the extinguishing concentration, as determined in 5-47.2.2.1, times a safety factor of 1.3.

5-47.2.2.4*

The minimum design concentration for a Class A surface-fire hazard shall be determined by the greater of the following:

- (1) The extinguishing concentration, as determined in 5-47.2.2.2, times a safety factor of 1.2
- (2) Equal to the minimum extinguishing concentration for heptane as determined from 5-47.2.2.1

A.5-47.2.2.4

Hazards containing both Class A and Class B fuels should be evaluated on the basis of the fuel requiring the highest design concentration.

5-47.2.2.5

The minimum design concentration for a Class C hazard shall be the extinguishing concentration, as determined in 5-47.2.2.2, times a safety factor of 1.35.

5-47.2.2.5.1

The minimum design concentration for spaces containing energized electrical hazards supplied at greater than 480 volts that remain powered during and after discharge shall be determined by testing, as necessary, and a hazard analysis.

5-47.2.2.6*

The minimum design concentration for a smoldering combustion hazard (deep-seated fire hazard) shall be determined by an application-specific test.

A.5-47.2.2.6

Two types of fires can occur in solid fuels: (1) one in which volatile gases resulting from heating or decomposition of the fuel surface are the source of combustion and (2) one in which oxidation occurs at the surface of or in the mass of fuel. The first type of fire is commonly referred to as "flaming" combustion, while the second type is often called "smoldering" or "glowing" combustion. The two types of fires frequently occur concurrently, although one type of burning can precede the other. For example, a wood fire can start as flaming combustion and become smoldering as burning progresses.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Conversely, spontaneous ignition in a pile of oily rags can begin as a smoldering fire and break into flames at some later point. Flaming combustion, because it occurs in the vapor phase, can be extinguished with relatively low levels of clean agents. In the absence of smoldering combustion, it will stay out.

Unlike flaming combustion, smoldering combustion is not subject to immediate extinguishment. Characteristic of this type of combustion is the slow rate of heat losses from the reaction zone. Thus, the fuel remains hot enough to react with oxygen, even though the rate of reaction, which is controlled by diffusion processes, is extremely slow. Smoldering fires can continue to burn for many weeks, for example, in bales of cotton and jute and heaps of sawdust. A smoldering fire ceases to burn only when either all the available oxygen or fuel has been consumed or the fuel surface is at too low a temperature to react. Smoldering fires usually are extinguished by reducing the fuel temperature, either directly by application of a heat-absorbing medium, such as water, or by blanketing with an inert gas. The inert gas slows the reaction rate to the point where heat generated by oxidation is less than heat losses to surroundings. This causes the temperature to fall below the level necessary for spontaneous ignition after removal of the inert atmosphere.

For the purposes of this standard, smoldering fires are divided into two classes: (1) where the smoldering is not "deep seated" and (2) deep-seated fires. Whether a fire will become deep seated depends, in part, on the length of time it has been burning before application of the extinguishing agent. This time is usually called the "preburn" time.

Another important variable is the fuel configuration. While wood cribs and pallets are easily extinguished with Class A design concentrations, vertical wood panels closely spaced and parallel can require higher concentrations and long hold times for extinguishment. Fires in boxes of excelsior and in piles of shredded paper also can require higher concentrations and long hold times for extinguishment. In these situations, heat tends to be retained in the fuel array rather than being dissipated to the surroundings. Radiation is an important mechanism for heat removal from smoldering fires.

5.4.7.2.3* Inerting.

A.5.4.7.2.3

The following paragraphs summarize 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. Flammability diagram data (Dalzell, 1975, and Coll, 1976) on ternary systems can be found in NFPA 12A. The procedures used to generate those data 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 in the more recent work was 2.1 gal (7.9 L) versus the 1.5 gal (5.6 L) used previously. The igniter type — carbon rod corona discharge spark — was the same, but the capacitor-stored energy levels in the later studies were higher, approximately 68 J (16.2 cal) versus 6 or 11 J (1.4 or 2.6 cal) in 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 2.1 gal (7.9 L) spherical test vessel (see Figure A.5.4.7.2.3) by the partial pressure method. The vessel was fitted with inlet and vent ports, a thermocouple, and a pressure transducer. First, the test vessel was evacuated, then agent was admitted; if the agent was 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 any pressure rise that occurred on actuation of the igniter.

Figure A.5.4.7.2.3 Spherical Test Vessel.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

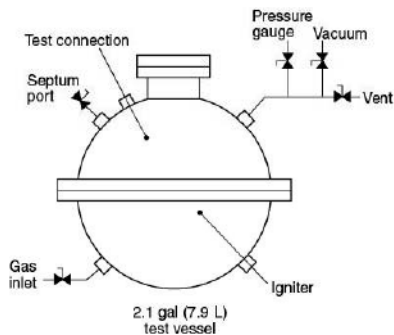


Table A.5-47.2.3 Inerting Concentrations for Various Agents

Fuel	Agent	Inerting Concentration (vol %)	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
	HFC-227ea	8.6	Robin
1,1-difluoroethane (HFC-152a)	HCFC Blend A	13.6	Moore
	HFC-227ea	3.5	Robin
Difluoromethane (HFC-32)	HCFC Blend A	8.6	Moore
	IG-100	44	Zabetakis
Ethane	HFC-227ea	13.6	Robin
Ethylene oxide	IG-100	42	Zabetakis
Methane	FK-5-1-12	8.8	Schmeer
	HFC-125	14.7	Senecal
	HFC-227ea	8	Robin
	HFC-23	20.2	Senecal
	HCFC Blend A	18.3	Moore
	IG-100	37	Zabetakis
	IG-541	43	Tamanini
Pentane	HFC-227ea	11.6	Robin
	IG-100	42	Zabetakis
Propane	FK-5-1-12	8.1	Schmeer
	FC-5-1-14	7.3	Senecal
	FIC-13I1	6.5	Moore
	HFC-125	15.7	Senecal
	HFC-227ea	11.6	Robin

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Fuel	Agent	Inerting Concentration (vol %)	Reference
	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

The igniter employed consisted of a bundle of four graphite rods ("H" pencil leads) held together by two wire or metal band wraps on either end of the bundle, leaving a gap between the wraps of about 0.12 in. (3 mm). The igniter was wired in series with two 525 mF 450 V capacitors. The capacitors were charged to a potential of 720 to 730 V dc. 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; in principle, however, stored capacitor energy 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 between tests with a cloth damp with either water or a solvent to avoid buildup of decomposition residues, which 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.5.47.2.3.

5.47.2.3.1

The inerting concentration shall be determined by test.

5.47.2.3.2*

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

A.5.47.2.3.2

These conditions exist where both the following occur:

- (1) The types and quantity of fuel permitted in the enclosure have 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.
- (2) 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.

5.47.2.3.3

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.

5.57.3 Total Flooding Quantity.

5.57.3.1*

The quantity of halocarbon agent required to achieve the design concentration shall be calculated from the following equation:

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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

[5.5.1]

where:

W = quantity 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 [ft³ (m³)]

C = agent design concentration (vol %)

s = specific volume of the superheated agent vapor at 1 atm and the minimum anticipated temperature [°F (°C)] of the protected volume [ft³/lb (m³/kg)]

A.5.5.3.1

The quantity of clean agent required to develop a given concentration will be greater than the final quantity 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 nonideal discharge arrangements.

Table A.5.5.3.1(a) through Table A.5.5.3.1(r) provide the quantity of clean agent needed to achieve design concentration.

Table A.5.5.3.1(a) FK-5-1-12 Total Flooding Quantity (U.S. 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
−20	0.93678	0.0330	0.0445	0.0562	0.0681	0.0803	0.0928	0.1056	0.1186
−10	0.96119	0.0322	0.0433	0.0548	0.0664	0.0783	0.0905	0.1029	0.1156
0	0.9856	0.0314	0.0423	0.0534	0.0648	0.0764	0.0882	0.1003	0.1127
10	1.01001	0.0306	0.0413	0.0521	0.0632	0.0745	0.0861	0.0979	0.1100
20	1.03442	0.0299	0.0403	0.0509	0.0617	0.0728	0.0841	0.0956	0.1074
30	1.05883	0.0292	0.0394	0.0497	0.0603	0.0711	0.0821	0.0934	0.1049
40	1.08324	0.0286	0.0385	0.0486	0.0589	0.0695	0.0803	0.0913	0.1026
50	1.10765	0.0279	0.0376	0.0475	0.0576	0.0680	0.0785	0.0893	0.1003
60	1.13206	0.0273	0.0368	0.0465	0.0564	0.0665	0.0768	0.0874	0.0981
70	1.15647	0.0267	0.0360	0.0455	0.0552	0.0651	0.0752	0.0855	0.0961
80	1.18088	0.0262	0.0353	0.0446	0.0541	0.0637	0.0736	0.0838	0.0941
90	1.20529	0.0257	0.0346	0.0437	0.0530	0.0624	0.0721	0.0821	0.0922
100	1.22970	0.0252	0.0339	0.0428	0.0519	0.0612	0.0707	0.0804	0.0904
110	1.25411	0.0247	0.0332	0.0420	0.0509	0.0600	0.0693	0.0789	0.0886
120	1.27852	0.0242	0.0326	0.0412	0.0499	0.0589	0.0680	0.0774	0.0869

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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
130	1.30293	0.0237	0.0320	0.0404	0.0490	0.0578	0.0667	0.0759	0.0853
140	1.32734	0.0233	0.0314	0.0397	0.0481	0.0567	0.0655	0.0745	0.0837
150	1.35175	0.0229	0.0308	0.0389	0.0472	0.0557	0.0643	0.0732	0.0822
160	1.37616	0.0225	0.0303	0.0382	0.0464	0.0547	0.0632	0.0719	0.0807
170	1.40057	0.0221	0.0297	0.0376	0.0456	0.0537	0.0621	0.0706	0.0793
180	1.42498	0.0217	0.0292	0.0369	0.0448	0.0528	0.0610	0.0694	0.0780
190	1.44939	0.0213	0.0287	0.0363	0.0440	0.0519	0.0600	0.0682	0.0767
200	1.47380	0.0210	0.0283	0.0357	0.0433	0.0511	0.0590	0.0671	0.0754
210	1.49821	0.0206	0.0278	0.0351	0.0426	0.0502	0.0580	0.0660	0.0742
220	1.52262	0.0203	0.0274	0.0346	0.0419	0.0494	0.0571	0.0650	0.0730

^aThe manufacturer's listing specifies the temperature range for the operation.

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

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

^ct [temperature (°F)] = design temperature in the hazard area.

^ds [specific volume (ft³/lb)] = specific volume of FK-5-1-12 vapor can be approximated by $s = 0.9856 + 0.002441t$, where t is the temperature (°F).

^eC [concentration (%)] = volumetric concentration of FK-5-1-12 in air at the temperature indicated.

Table A.5.57.3.1(b) FK-5-1-12 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
-20	0.0609140	0.5077	0.6840	0.8640	1.0479	1.2357	1.4275	1.6236	1.8241
-15	0.6022855	0.4965	0.6690	0.8450	1.0248	1.2084	1.3961	1.5879	1.7839
-10	0.0636570	0.4859	0.6545	0.8268	1.0027	1.1824	1.3660	1.5337	1.7455
-5	0.0650285	0.4756	0.6407	0.8094	0.9816	1.1575	1.3372	1.5209	1.7087
0	0.0664000	0.4658	0.6275	0.7926	0.9613	1.1336	1.3096	1.4895	1.6734
5	0.0677715	0.4564	0.6148	0.7766	0.9418	1.1106	1.2831	1.4593	1.6395
10	0.0691430	0.4473	0.6026	0.7612	0.9232	1.0886	1.2576	1.4304	1.6070
15	0.0705145	0.4386	0.5909	0.7464	0.9052	1.0674	1.2332	1.4026	1.5757
20	0.0718860	0.4302	0.5796	0.7322	0.8879	1.0471	1.2096	1.3758	1.5457
25	0.0732575	0.4222	0.5688	0.7184	0.8713	1.0275	1.1870	1.3500	1.5167
30	0.0746290	0.4144	0.5583	0.7052	0.8553	1.0086	1.1652	1.3252	1.4888
35	0.0760005	0.4069	0.5482	0.6925	0.8399	0.9904	1.1442	1.3013	1.4620
40	0.0773720	0.3997	0.5385	0.6802	0.8250	0.9728	1.1239	1.2783	1.4361
45	0.0787435	0.3928	0.5291	0.6684	0.8106	0.9559	1.1043	1.2560	1.4111
50	0.0801150	0.3860	0.5201	0.6570	0.7967	0.9395	1.0854	1.2345	1.3869
55	0.0814865	0.3795	0.5113	0.6459	0.7833	0.9237	1.0671	1.2137	1.3636
60	0.0828580	0.3733	0.5029	0.6352	0.7704	0.9084	1.0495	1.1936	1.3410
65	0.0842295	0.3672	0.4947	0.6249	0.7578	0.8936	1.0324	1.1742	1.3191

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a							
		3	4	5	6	7	8	9	10
70	0.0856010	0.3613	0.4868	0.6148	0.7457	0.8793	1.0158	1.1554	1.2980
75	0.0869725	0.3556	0.4791	0.6052	0.7339	0.8654	0.9998	1.1372	1.2775
80	0.0883440	0.3501	0.4716	0.5958	0.7225	0.8520	0.9843	1.1195	1.2577
85	0.0897155	0.3447	0.4644	0.5866	0.7115	0.8390	0.9692	1.1024	1.2385
90	0.0910870	0.3395	0.4574	0.5778	0.7008	0.8263	0.9547	1.0858	1.2198
95	0.0924585	0.3345	0.4507	0.5692	0.6904	0.8141	0.9405	1.0697	1.2017
100	0.0938300	0.3296	0.4441	0.5609	0.6803	0.8022	0.9267	1.0540	1.1842

^aThe manufacturer's listing specifies the temperature range for operation.

^bW/V [agent weight requirements (kg/m³)] = kilograms of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

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

^ct [temperature (°C)] = design temperature in the hazard area.

^ds [specific volume (m³/kg)] = specific volume of FK-5-1-12 vapor can be approximated by $s = 0.0664 + 0.0002741t$, where t is the temperature (°C).

^eC [concentration (%)] = volumetric concentration of FK-5-1-12 in air at the temperature indicated.

Table A.5.5.3.1(c) HCFC Blend A Total Flooding Quantity (U.S. 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) ^a							
		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	0.0300	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	0.0261	0.0280	0.0314	0.035	0.0386	0.0423	0.0461	0.0499
0	3.6121	0.0260	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	0.0250	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	0.0240	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	0.0340	0.0373	0.0406	0.0441
60	4.0835	0.0230	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	0.0310	0.0340	0.0370	0.0401
110	4.4764	0.0210	0.0221	0.0248	0.0276	0.0305	0.0334	0.0364	0.0394
120	4.5550	0.0207	0.0217	0.0244	0.0271	0.0299	0.0328	0.0357	0.0387
130	4.6336	0.0203	0.0213	0.0240	0.0267	0.0294	0.0322	0.0351	0.0381
140	4.7121	0.0200	0.0210	0.0236	0.0262	0.0289	0.0317	0.0345	0.0375

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a							
		8.6	9	10	11	12	13	14	15
150	4.7907	0.0196	0.0206	0.0232	0.0258	0.0285	0.0312	0.0340	0.0368
160	4.8693	0.0193	0.0203	0.0228	0.0254	0.0280	0.0307	0.0334	0.0362
170	4.9479	0.0190	0.0200	0.0225	0.0250	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	5.1050	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	0.0340

^aThe manufacturer's listing specifies the temperature range for operation.

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

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

^ct [temperature (°F)] = design temperature in the hazard area.

^ds [specific volume (ft³/lb)] = specific volume of HCFC Blend A vapor can be approximated by $s = 3.612 + 0.0079t$, where t = temperature (°F).

^eC [concentration (%)] = volumetric concentration of HCFC Blend A in air at the temperature indicated.

Table A.5-57.3.1(d) HCFC Blend A 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) ^a							
		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	0.6350	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	0.2280	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	0.3900	0.4100	0.4606	0.5123	0.5652	0.6194	0.6748	0.7315
5	0.2457	0.3830	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	0.3820	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	0.5010	0.5490	0.5981	0.6484
40	0.2766	0.3402	0.3576	0.4017	0.4469	0.4930	0.5403	0.5886	0.6381
45	0.2810	0.3349	0.3520	0.3954	0.4399	0.4853	0.5318	0.5793	0.6280

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Temp(t) (°C) ^c	Specific Vapor Volume(s) (m ³ /kg) ^d	Weight Requirements of Hazard Volume, <i>W/V</i> (kg/m ³) ^b Design Concentration (% by Volume) ^a							
		8.6	9	10	11	12	13	14	15
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	0.4930	0.5371	0.5823
75	0.3075	0.3060	0.3216	0.3614	0.4020	0.4435	0.4860	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

^aThe 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)] = design temperature in the hazard area.

^d*s* [specific volume (m³/kg)] = specific volume of HCFC Blend A vapor can be approximated by *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.5-5.7.3.1(e) HCFC-124 Total Flooding Quantity (U.S. Units)^a

Temp(t) (°F) ^c	Specific Vapor Volume(s) (ft ³ /lb) ^d	Weight Requirements of Hazard Volume, <i>W/V</i> (lb/ft ³) ^b Design Concentration (% by Volume) ^a							
		5	6	7	8	9	10	11	12
20	2.4643	0.0214	0.0259	0.0305	0.0353	0.0401	0.0451	0.0502	0.0553
30	2.5238	0.0209	0.0253	0.0298	0.0345	0.0392	0.0440	0.0490	0.0540
40	2.5826	0.0204	0.0247	0.0291	0.0337	0.0383	0.0430	0.0479	0.0528
50	2.6409	0.0199	0.0242	0.0285	0.0329	0.0374	0.0421	0.0468	0.0516
60	2.6988	0.0195	0.0237	0.0279	0.0322	0.0366	0.0412	0.0458	0.0505
70	2.7563	0.0191	0.0232	0.0273	0.0315	0.0359	0.0403	0.0448	0.0495
80	2.8136	0.0187	0.0227	0.0268	0.0309	0.0352	0.0395	0.0439	0.0485
90	2.8705	0.0183	0.0222	0.0262	0.0303	0.0345	0.0387	0.0431	0.0475
100	2.9272	0.0180	0.0218	0.0257	0.0297	0.0338	0.0380	0.0422	0.0466
110	2.9837	0.0176	0.0214	0.0252	0.0291	0.0331	0.0372	0.0414	0.0457
120	3.0400	0.0173	0.0210	0.0248	0.0286	0.0325	0.0365	0.0407	0.0449
130	3.0961	0.0170	0.0206	0.0243	0.0281	0.0319	0.0359	0.0399	0.0440
140	3.1520	0.0167	0.0203	0.0239	0.0276	0.0314	0.0353	0.0392	0.0433
150	3.2078	0.0164	0.0199	0.0235	0.0271	0.0308	0.0346	0.0385	0.0425
160	3.2635	0.0161	0.0196	0.0231	0.0266	0.0303	0.0340	0.0379	0.0418
170	3.3191	0.0159	0.0192	0.0227	0.0262	0.0298	0.0335	0.0372	0.0411

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a							
		5	6	7	8	9	10	11	12
180	3.3745	0.0156	0.0189	0.0223	0.0258	0.0293	0.0329	0.0366	0.0404
190	3.4298	0.0153	0.0186	0.0219	0.0254	0.0288	0.0324	0.0360	0.0398
200	3.4850	0.0151	0.0183	0.0216	0.0250	0.0284	0.0319	0.0355	0.0391

^aThe manufacturer's listing specifies the temperature range for operation.

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

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

^ct [temperature (°F)] = design temperature in the hazard area.

^ds [specific volume (ft³/lb)] = specific volume of HCFC-124 vapor can be approximated by $s = 2.3580 + 0.0057t$ where t = temperature in (°F).

^eC [concentration (%)] = volumetric concentration of HCFC-124 in air at the temperature indicated.

Table A.5-57.3.1(f) 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) ^a							
		5	6	7	8	9	10	11	12
-10	0.1516	0.3472	0.4210	0.6524	0.5736	0.6524	0.7329	0.8153	0.1346
-5	0.1550	0.3396	0.4119	0.6382	0.5612	0.6382	0.7170	0.7976	0.1317
0	0.1583	0.3325	0.4032	0.6248	0.5493	0.6248	0.7019	0.7808	0.1289
5	0.1616	0.3257	0.3950	0.6120	0.5381	0.6120	0.6876	0.7649	0.1263
10	0.1649	0.3192	0.3872	0.5999	0.5274	0.5999	0.6739	0.7497	0.1238
15	0.1681	0.3131	0.3797	0.5883	0.5172	0.5883	0.6609	0.7352	0.1214
20	0.1714	0.3071	0.3725	0.5772	0.5074	0.5772	0.6484	0.7213	0.1191
25	0.1746	0.3015	0.3656	0.5665	0.4981	0.5665	0.6364	0.7080	0.1169
30	0.1778	0.2960	0.3590	0.5563	0.4891	0.5563	0.6250	0.6952	0.1148
35	0.1810	0.2908	0.3527	0.5465	0.4805	0.5465	0.6140	0.6830	0.1128
40	0.1842	0.2858	0.3466	0.5371	0.4722	0.5371	0.6034	0.6712	0.1108
45	0.1873	0.2810	0.3408	0.5280	0.4642	0.5280	0.5932	0.6598	0.1089
50	0.1905	0.2763	0.3351	0.5192	0.4565	0.5192	0.5833	0.6489	0.1071
55	0.1936	0.2718	0.3296	0.5108	0.4491	0.5108	0.5738	0.6383	0.1054
60	0.1968	0.2675	0.3244	0.5026	0.4419	0.5026	0.5646	0.6281	0.1037
65	0.1999	0.2633	0.3193	0.4947	0.4350	0.4947	0.5558	0.6183	0.1021
70	0.2030	0.2592	0.3144	0.4871	0.4283	0.4871	0.5472	0.6087	0.1005
75	0.2062	0.2553	0.3096	0.4797	0.4218	0.4797	0.5390	0.5995	0.0990
80	0.2093	0.2515	0.3050	0.4726	0.4155	0.4726	0.5309	0.5906	0.0975
85	0.2124	0.2478	0.3005	0.4657	0.4094	0.4657	0.5231	0.5819	0.0961
90	0.2155	0.2442	0.2962	0.4589	0.4035	0.4589	0.5156	0.5735	0.0947
95	0.2186	0.2408	0.2920	0.4524	0.3978	0.4524	0.5083	0.5654	0.0934

^aThe manufacturer's listing specifies the temperature range for operation.

^bW/V [agent weight requirements (kg/m³)] = kilograms of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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

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

^s [specific volume (m³/kg)] = specific volume of HCFC-124 vapor can be approximated by $s = 0.1585 + 0.0006t$, where t is the temperature (°C).

^C [concentration (%)] = volumetric concentration of HCFC-124 in air at the temperature indicated.

Table A.5-57.3.1(g) HFC-125 Total Flooding Quantity (U.S. Units)^a

Temp(<i>t</i>) (°F) ^c	Specific Vapor Volume(<i>s</i>) (ft ³ /lb) ^d	Weight Requirements of Hazard Volume, <i>W/V</i> (lb/ft ³) ^b									
		Design Concentration (% by Volume) ^e									
		7	8	9	10	11	12	13	14	15	16
-50	2.3902	0.0315	0.0364	0.0414	0.0465	0.0517	0.0571	0.0625	0.0681	0.0738	0.0797
-40	2.4577	0.0306	0.0354	0.0402	0.0452	0.0503	0.0555	0.0608	0.0662	0.0718	0.0775
-30	2.5246	0.0298	0.0344	0.0392	0.0440	0.0490	0.0540	0.0592	0.0645	0.0699	0.0754
-20	2.5909	0.0291	0.0336	0.0382	0.0429	0.0477	0.0526	0.0577	0.0628	0.0681	0.0735
-10	2.6568	0.0283	0.0327	0.0372	0.0418	0.0465	0.0513	0.0562	0.0613	0.0664	0.0717
0	2.7222	0.0276	0.0319	0.0363	0.0408	0.0454	0.0501	0.0549	0.0598	0.0648	0.0700
10	2.7872	0.0270	0.0312	0.0355	0.0399	0.0443	0.0489	0.0536	0.0584	0.0633	0.0683
20	2.8518	0.0264	0.0305	0.0347	0.0390	0.0433	0.0478	0.0524	0.0571	0.0619	0.0668
30	2.9162	0.0258	0.0298	0.0339	0.0381	0.0424	0.0468	0.0512	0.0558	0.0605	0.0653
40	2.9803	0.0253	0.0292	0.0332	0.0373	0.0415	0.0458	0.0501	0.0546	0.0592	0.0639
50	3.0441	0.0247	0.0286	0.0325	0.0365	0.0406	0.0448	0.0491	0.0535	0.0580	0.0626
60	3.1077	0.0242	0.0280	0.0318	0.0358	0.0398	0.0439	0.0481	0.0524	0.0568	0.0613
70	3.1712	0.0237	0.0274	0.0312	0.0350	0.0390	0.0430	0.0471	0.0513	0.0556	0.0601
80	3.2344	0.0233	0.0269	0.0306	0.0344	0.0382	0.0422	0.0462	0.0503	0.0546	0.0589
90	3.2975	0.0228	0.0264	0.0300	0.0337	0.0375	0.0414	0.0453	0.0494	0.0535	0.0578
100	3.3605	0.0224	0.0259	0.0294	0.0331	0.0368	0.0406	0.0445	0.0484	0.0525	0.0567
110	3.4233	0.0220	0.0254	0.0289	0.0325	0.0361	0.0398	0.0436	0.0476	0.0515	0.0556
120	3.4859	0.0216	0.0249	0.0284	0.0319	0.0355	0.0391	0.0429	0.0467	0.0506	0.0546
130	3.5485	0.0212	0.0245	0.0279	0.0313	0.0348	0.0384	0.0421	0.0459	0.0497	0.0537
140	3.6110	0.0208	0.0241	0.0274	0.0308	0.0342	0.0378	0.0414	0.0451	0.0489	0.0527
150	3.6734	0.0205	0.0237	0.0269	0.0302	0.0336	0.0371	0.0407	0.0443	0.0480	0.0519
160	3.7357	0.0201	0.0233	0.0265	0.0297	0.0331	0.0365	0.0400	0.0436	0.0472	0.0510
170	3.7979	0.0198	0.0229	0.0260	0.0293	0.0325	0.0359	0.0393	0.0429	0.0465	0.0502
180	3.8600	0.0195	0.0225	0.0256	0.0288	0.0320	0.0353	0.0387	0.0422	0.0457	0.0493
190	3.9221	0.0192	0.0222	0.0252	0.0283	0.0315	0.0348	0.0381	0.0415	0.0450	0.0486
200	3.9841	0.0189	0.0218	0.0248	0.0279	0.0310	0.0342	0.0375	0.0409	0.0443	0.0478

^aThe 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.

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

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

^s [specific volume (ft³/lb)] = specific volume of HFC-125 vapor can be approximated $s = 2.7208 + 0.0064t$, where t = temperature (°F).

^C [concentration (%)] = volumetric concentration of HFC-125 in air at the temperature indicated.

Table A.5-57.3.1(h) HFC-125 Total Flooding Quantity (SI Units)^a

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a									
		7	8	9	10	11	12	13	14	15	16
-45	0.1496	0.5030	0.5811	0.6609	0.7425	0.8260	0.9113	0.9986	1.0879	1.1793	1.2729
-40	0.1534	0.4906	0.5668	0.6446	0.7242	0.8055	0.8888	0.9739	1.0610	1.1502	1.2415
-35	0.1572	0.4788	0.5532	0.6292	0.7069	0.7863	0.8675	0.9506	1.0356	1.1227	1.2118
-30	0.1609	0.4677	0.5404	0.6146	0.6905	0.7681	0.8474	0.9286	1.0116	1.0966	1.1837
-25	0.1646	0.4572	0.5282	0.6007	0.6749	0.7507	0.8283	0.9076	0.9888	1.0719	1.1570
-20	0.1683	0.4472	0.5166	0.5876	0.6602	0.7343	0.8102	0.8878	0.9672	1.0485	1.1317
-15	0.1720	0.4377	0.5056	0.5751	0.6461	0.7187	0.7930	0.8689	0.9466	1.0262	1.1076
-10	0.1756	0.4286	0.4952	0.5632	0.6327	0.7038	0.7765	0.8509	0.9270	1.0049	1.0847
-5	0.1792	0.4199	0.4851	0.5518	0.6199	0.6896	0.7608	0.8337	0.9082	0.9845	1.0627
0	0.1829	0.4116	0.4756	0.5409	0.6077	0.6759	0.7458	0.8172	0.8903	0.9651	1.0417
5	0.1865	0.4037	0.4664	0.5304	0.5959	0.6629	0.7314	0.8014	0.8731	0.9465	1.0216
10	0.1900	0.3961	0.4576	0.5204	0.5847	0.6504	0.7176	0.7863	0.8566	0.9286	1.0023
15	0.1936	0.3888	0.4491	0.5108	0.5739	0.6384	0.7043	0.7718	0.8408	0.9115	0.9838
20	0.1972	0.3817	0.4410	0.5016	0.5635	0.6268	0.6916	0.7578	0.8256	0.8950	0.9660
25	0.2007	0.3750	0.4332	0.4927	0.5535	0.6157	0.6793	0.7444	0.8110	0.8791	0.9489
30	0.2043	0.3685	0.4257	0.4841	0.5439	0.6050	0.6675	0.7315	0.7969	0.8639	0.9324
35	0.2078	0.3622	0.4184	0.4759	0.5347	0.5947	0.6562	0.7190	0.7833	0.8492	0.9165
40	0.2114	0.3561	0.4114	0.4679	0.5257	0.5848	0.6452	0.7070	0.7702	0.8349	0.9012
45	0.2149	0.3503	0.4047	0.4603	0.5171	0.5752	0.6346	0.6954	0.7576	0.8213	0.8864
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	0.3918	0.4457	0.5007	0.5569	0.6145	0.6733	0.7336	0.7952	0.8583
60	0.2254	0.3339	0.3857	0.4387	0.4929	0.5483	0.6049	0.6628	0.7221	0.7828	0.8449
65	0.2289	0.3288	0.3798	0.4320	0.4853	0.5399	0.5957	0.6527	0.7111	0.7708	0.8320
70	0.2324	0.3238	0.3741	0.4255	0.4780	0.5318	0.5867	0.6429	0.7004	0.7592	0.8195
75	0.2359	0.3190	0.3686	0.4192	0.4709	0.5239	0.5780	0.6333	0.6900	0.7480	0.8073
80	0.2394	0.3144	0.3632	0.4131	0.4641	0.5162	0.5696	0.6241	0.6799	0.7371	0.7956
85	0.2429	0.3099	0.3580	0.4072	0.4574	0.5088	0.5614	0.6151	0.6702	0.7265	0.7841
90	0.2464	0.3055	0.3529	0.4014	0.4509	0.5016	0.5534	0.6064	0.6607	0.7162	0.7730
95	0.2499	0.3012	0.3480	0.3958	0.4447	0.4946	0.5457	0.5980	0.6515	0.7062	0.7623

^aThe manufacturer's listing specifies the temperature range for operation.

^bW/V [agent weight requirements (kg/m³)] = kilograms required per cubic meter of protected volume to produce indicated concentration at temperature specified.

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

^ct [temperature (°C)] = design temperature in the hazard area.

^ds [specific volume (m³/kg)] = specific volume of HFC-125 vapor can be approximated $s = 0.1826 + 0.0007t$, where t = temperature (°C).

^eC [concentration (%)] = volumetric concentration of HFC-125 in air at the temperature indicated.

Table A.5-57.3.1(i) HFC-227ea Total Flooding Quantity (U.S. Units)^a

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a									
		6	7	8	9	10	11	12	13	14	15
10	1.9264	0.0331	0.0391	0.0451	0.0513	0.0570	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

^aThe manufacturer's listing specifies the temperature range for operation.

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

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

^ct [temperature (°F)] = design temperature in the hazard area.

^ds [specific volume (ft³/lb)] = specific volume of HFC-227ea vapor can be approximated by $s = 1.885 + 0.0046t$, where t = temperature (°F).

^eC [concentration (%)] = volumetric concentration of HFC-227ea in air at the temperature indicated.

Table A.5-5.2.3.1(j) 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) ^a									
		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	0.7800	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	0.9550	1.0537	1.1546	1.2579	1.3636
10	0.1320	0.4834	0.5700	0.6585	0.7490	0.8414	0.9360	1.0327	1.1316	1.2328	1.3264
15	0.1347	0.4740	0.5589	0.6457	0.7344	0.8251	0.9178	1.0126	1.1096	1.2089	1.3105
20	0.1373	0.4650	0.5483	0.6335	0.7205	0.8094	0.9004	0.9934	1.0886	1.1859	1.2856

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a									
		6	7	8	9	10	11	12	13	14	15
25	0.1399	0.4564	0.5382	0.6217	0.7071	0.7944	0.8837	0.9750	1.0684	1.1640	1.2618
30	0.1425	0.4481	0.5284	0.6104	0.6943	0.7800	0.8676	0.9573	1.0490	1.1428	1.2388
35	0.1450	0.4401	0.5190	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	0.4250	0.5012	0.5790	0.6586	0.7399	0.8230	0.9080	0.9950	1.0840	1.1751
50	0.1527	0.4180	0.4929	0.5694	0.6476	0.7276	0.8093	0.8929	0.9784	1.0660	1.1555
55	0.1553	0.4111	0.4847	0.5600	0.6369	0.7156	0.7960	0.8782	0.9623	1.0484	1.1365
60	0.1578	0.4045	0.4770	0.5510	0.6267	0.7041	0.7832	0.8641	0.9469	1.0316	1.1183
65	0.1604	0.3980	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	0.4550	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	0.5890	0.6617	0.7360	0.8120	0.8898	0.9694	1.0509
85	0.1704	0.3745	0.4416	0.5102	0.5803	0.6519	0.7251	0.8000	0.8767	0.9551	1.0354
90	0.1730	0.3690	0.4351	0.5027	0.5717	0.6423	0.7145	0.7883	0.8638	0.9411	1.0202

^aThe manufacturer's listing specifies the temperature range for operation.

^bW/V [agent weight requirements (kg/m³)] = kilograms of agent per cubic meter of protected volume to produce indicated concentration at temperature specified.

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

^ct [temperature (°C)] = design temperature in the hazard area.

^ds [specific volume (m³/kg)] = specific volume of HFC-227ea vapor can be approximated by $s = 0.1269 + 0.0005t$, where t = temperature (°C).

^eC [concentration (%)] = volumetric concentration of HFC-227ea in air at the temperature indicated.

Table A-5.5.2.3.1(k) HFC-23 Total Flooding Quantity (U.S. 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) ^a									
		10	12	14	15	16	17	18	19	20	22
-70	3.9636	0.0280	0.0344	0.0411	0.0445	0.0481	0.0517	0.0554	0.0592	0.0631	0.0712
-60	4.0752	0.0273	0.0335	0.0399	0.0433	0.0467	0.0503	0.0539	0.0576	0.0613	0.0692
-50	4.1859	0.0265	0.0326	0.0389	0.0422	0.0455	0.0489	0.0524	0.0560	0.0597	0.0674
-40	4.2959	0.0259	0.0317	0.0379	0.0411	0.0443	0.0477	0.0511	0.0546	0.0582	0.0657
-30	4.4053	0.0252	0.0310	0.0370	0.0401	0.0432	0.0465	0.0498	0.0532	0.0567	0.0640
-20	4.5151	0.0246	0.0302	0.0361	0.0391	0.0422	0.0454	0.0486	0.0520	0.0554	0.0625
-10	4.6225	0.0240	0.0295	0.0352	0.0382	0.0412	0.0443	0.0475	0.0507	0.0541	0.0610
0	4.7305	0.0235	0.0288	0.0344	0.0373	0.0403	0.0433	0.0464	0.0496	0.0528	0.0596
10	4.8383	0.0230	0.0282	0.0336	0.0365	0.0394	0.0423	0.0454	0.0485	0.0517	0.0583
20	4.9457	0.0225	0.0276	0.0329	0.0357	0.0385	0.0414	0.0444	0.0474	0.0505	0.0570
30	5.0529	0.0220	0.0270	0.0322	0.0349	0.0377	0.0405	0.0434	0.0464	0.0495	0.0558
40	5.1599	0.0215	0.0264	0.0315	0.0342	0.0369	0.0397	0.0425	0.0455	0.0485	0.0547
50	5.2666	0.0211	0.0259	0.0309	0.0335	0.0362	0.0389	0.0417	0.0445	0.0475	0.0536

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a									
		10	12	14	15	16	17	18	19	20	22
60	5.3733	0.0207	0.0254	0.0303	0.0328	0.0354	0.0381	0.0409	0.0437	0.0465	0.0525
70	5.4797	0.0203	0.0249	0.0297	0.0322	0.0348	0.0374	0.0401	0.0428	0.0456	0.0515
80	5.5860	0.0199	0.0244	0.0291	0.0316	0.0341	0.0367	0.0393	0.0420	0.0448	0.0505
90	5.6922	0.0195	0.0240	0.0286	0.0310	0.0335	0.0360	0.0386	0.0412	0.0439	0.0496
100	5.7983	0.0192	0.0235	0.0281	0.0304	0.0329	0.0353	0.0379	0.0405	0.0431	0.0486
110	5.9043	0.0188	0.0231	0.0276	0.0299	0.0323	0.0347	0.0372	0.0397	0.0423	0.0478
120	6.0102	0.0185	0.0227	0.0271	0.0294	0.0317	0.0341	0.0365	0.0390	0.0416	0.0469
130	6.1160	0.0182	0.0223	0.0266	0.0289	0.0311	0.0335	0.0359	0.0384	0.0409	0.0461
140	6.2217	0.0179	0.0219	0.0262	0.0284	0.0306	0.0329	0.0353	0.0377	0.0402	0.0453
150	6.3274	0.0176	0.0216	0.0257	0.0279	0.0301	0.0324	0.0347	0.0371	0.0395	0.0446
160	6.4330	0.0173	0.0212	0.0253	0.0274	0.0296	0.0318	0.0341	0.0365	0.0389	0.0438
170	6.5385	0.0170	0.0209	0.0249	0.0270	0.0291	0.0313	0.0336	0.0359	0.0382	0.0431
180	6.6440	0.0167	0.0205	0.0245	0.0266	0.0287	0.0308	0.0330	0.0353	0.0376	0.0424
190	6.7494	0.0165	0.0202	0.0241	0.0261	0.0282	0.0303	0.0325	0.0348	0.0370	0.0418

^aThe 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)] = design temperature in the hazard area.

^d s [specific volume (ft³/lb)] = specific volume of HFC-23 vapor can be approximated by $s = 4.7264 + 0.0107t$, where t = temperature (°F).

^e C [concentration (%)] = volumetric concentration of HFC-23 in air at the temperature indicated.

Table A.5-5.2.3.1(I) HFC-23 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) ^a										
		10	12	14	15	16	17	18	19	20	22	24
−60	0.2432	0.4568	0.5606	0.6693	0.7255	0.7831	0.8421	0.9025	0.9644	1.0278	1.1596	1.2983
−55	0.2495	0.4453	0.5465	0.6524	0.7072	0.7633	0.8208	0.8797	0.9400	1.0018	1.1303	1.2655
−50	0.2558	0.4344	0.5331	0.6364	0.6899	0.7446	0.8007	0.8581	0.9170	0.9773	1.1026	1.2345
−45	0.2620	0.4241	0.5205	0.6213	0.6735	0.7270	0.7817	0.8378	0.8953	0.9542	1.0765	1.2053
−40	0.2682	0.4143	0.5085	0.6070	0.6580	0.7102	0.7637	0.8185	0.8746	0.9322	1.0517	1.1775
−35	0.2743	0.4050	0.4971	0.5934	0.6433	0.6943	0.7466	0.8002	0.8551	0.9113	1.0281	1.1511
−30	0.2805	0.3962	0.4862	0.5805	0.6292	0.6792	0.7303	0.7827	0.8364	0.8914	1.0057	1.1260
−25	0.2866	0.3878	0.4759	0.5681	0.6158	0.6647	0.7148	0.7661	0.8186	0.8724	0.9843	1.1020
−20	0.2926	0.3797	0.4660	0.5563	0.6031	0.6509	0.6999	0.7502	0.8016	0.8544	0.9639	1.0792
−15	0.2987	0.3720	0.4566	0.5450	0.5908	0.6377	0.6857	0.7349	0.7853	0.8370	0.9443	1.0573
−10	0.3047	0.3646	0.4475	0.5342	0.5791	0.6251	0.6721	0.7203	0.7698	0.8204	0.9256	1.0363
−5	0.3108	0.3575	0.4388	0.5238	0.5679	0.6129	0.6591	0.7064	0.7548	0.8045	0.9076	1.0162
0	0.3168	0.3508	0.4305	0.5139	0.5571	0.6013	0.6466	0.6929	0.7405	0.7892	0.8904	0.9969

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a										
		10	12	14	15	16	17	18	19	20	22	24
5	0.3228	0.3442	0.4225	0.5043	0.5467	0.5901	0.6345	0.6800	0.7267	0.7745	0.8738	0.9783
10	0.3288	0.3379	0.4147	0.4951	0.5367	0.5793	0.6229	0.6676	0.7134	0.7604	0.8578	0.9605
15	0.3348	0.3319	0.4073	0.4863	0.5271	0.5690	0.6118	0.6557	0.7007	0.7468	0.8425	0.9433
20	0.3408	0.3261	0.4002	0.4777	0.5179	0.5590	0.6011	0.6442	0.6884	0.7337	0.8277	0.9267
25	0.3467	0.3204	0.3933	0.4695	0.5089	0.5493	0.5907	0.6331	0.6765	0.7210	0.8134	0.9107
30	0.3527	0.3150	0.3866	0.4616	0.5003	0.5401	0.5807	0.6224	0.6651	0.7088	0.7997	0.8953
35	0.3587	0.3098	0.3802	0.4539	0.4920	0.5311	0.5711	0.6120	0.6540	0.6970	0.7864	0.8804
40	0.3646	0.3047	0.3740	0.4465	0.4840	0.5224	0.5617	0.6020	0.6433	0.6856	0.7735	0.8661
45	0.3706	0.2998	0.3680	0.4393	0.4762	0.5140	0.5527	0.5923	0.6330	0.6746	0.7611	0.8521
50	0.3765	0.2951	0.3622	0.4323	0.4687	0.5059	0.5440	0.5830	0.6230	0.6640	0.7491	0.8387
55	0.3825	0.2905	0.3565	0.4256	0.4614	0.4980	0.5355	0.5739	0.6133	0.6536	0.7374	0.8257
60	0.3884	0.2861	0.3511	0.4191	0.4543	0.4904	0.5273	0.5652	0.6039	0.6436	0.7262	0.8130
65	0.3944	0.2818	0.3458	0.4128	0.4475	0.4830	0.5194	0.5566	0.5948	0.6340	0.7152	0.8008
70	0.4003	0.2776	0.3407	0.4067	0.4409	0.4759	0.5117	0.5484	0.5860	0.6246	0.7046	0.7889

^aThe manufacturer's listing specifies the temperature range for operation.

^bW/V [agent weight requirements (kg/m³)] = kilograms required per cubic meter of protected volume to produce indicated concentration at temperature specified.

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

^ct [temperature (°C)] = design temperature in the hazard area.

^ds [specific volume (m³/kg)] = specific volume of HFC-23 vapor can be approximated by $s = 0.3164 + 0.0012t$, where t = temperature (°C).

^eC [concentration (%)] = volumetric concentration of HFC-23 in air at the temperature indicated.

Table A.5-5.2.3.1(m) HFC-236fa Total Flooding Quantity (U.S. 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) ^a									
		5	6	7	8	9	10	11	12	13	14
30	2.2454	0.0234	0.0284	0.0335	0.0387	0.0440	0.0495	0.0550	0.0607	0.0665	0.0725
40	2.2997	0.0229	0.0278	0.0327	0.0378	0.0430	0.0483	0.0537	0.0593	0.0650	0.0708
50	2.3533	0.0224	0.0271	0.0320	0.0370	0.0420	0.0472	0.0525	0.0579	0.0635	0.0692
60	2.4064	0.0219	0.0265	0.0313	0.0361	0.0411	0.0462	0.0514	0.0567	0.0621	0.0676
70	2.4591	0.0214	0.0260	0.0306	0.0354	0.0402	0.0452	0.0503	0.0555	0.0608	0.0662
80	2.5114	0.0210	0.0254	0.0300	0.0346	0.0394	0.0442	0.0492	0.0543	0.0595	0.0648
90	2.5633	0.0205	0.0249	0.0294	0.0339	0.0386	0.0433	0.0482	0.0532	0.0583	0.0635
100	2.6150	0.0201	0.0244	0.0288	0.0333	0.0378	0.0425	0.0473	0.0521	0.0571	0.0623
110	2.6663	0.0197	0.0239	0.0282	0.0326	0.0371	0.0417	0.0464	0.0511	0.0560	0.0611
120	2.7174	0.0194	0.0235	0.0277	0.0320	0.0364	0.0409	0.0455	0.0502	0.0550	0.0599
130	2.7683	0.0190	0.0231	0.0272	0.0314	0.0357	0.0401	0.0446	0.0493	0.0540	0.0588
140	2.8190	0.0187	0.0226	0.0267	0.0308	0.0351	0.0394	0.0438	0.0484	0.0530	0.0577
150	2.8695	0.0183	0.0222	0.0262	0.0303	0.0345	0.0387	0.0431	0.0475	0.0521	0.0567

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a									
		5	6	7	8	9	10	11	12	13	14
160	2.9199	0.0180	0.0219	0.0258	0.0298	0.0339	0.0381	0.0423	0.0467	0.0512	0.0558
170	2.9701	0.0177	0.0215	0.0253	0.0293	0.0333	0.0374	0.0416	0.0459	0.0503	0.0548
180	3.0202	0.0174	0.0211	0.0249	0.0288	0.0327	0.0368	0.0409	0.0452	0.0495	0.0539
190	3.0702	0.0171	0.0208	0.0245	0.0283	0.0322	0.0362	0.0403	0.0444	0.0487	0.0530
200	3.1201	0.0169	0.0205	0.0241	0.0279	0.0317	0.0356	0.0396	0.0437	0.0479	0.0522

^aThe manufacturer's listing specifies the temperature range for operation.

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

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

^ct [temperature (°F)] = design temperature in the hazard area.

^ds [specific volume (ft³/lb)] = specific volume of HFC-236fa vapor can be approximated by $s = 2.0983 + 0.0051t$, where t = temperature (°F).

^eC [concentration (%)] = volumetric concentration of HFC-236fa in air at the temperature indicated.

Table A.5-57.3.1(n) HFC-236fa Total Flooding Quantity (SI Units)^a

Temp (t) (°C)	Specific Vapor Volume (s) (m ³ /kg) ^d	Weight Requirements of Hazard Volume, W/V (kg/m ³) ^b Design Concentration (% by volume) ^a									
		5	6	7	8	9	10	11	12	13	14
0	0.1409	0.3736	0.4531	0.5344	0.6173	0.7021	0.7888	0.8774	0.9681	1.0608	1.1557
5	0.1439	0.3658	0.4436	0.5231	0.6043	0.6873	0.7721	0.8589	0.9476	1.0384	1.1313
10	0.1469	0.3583	0.4345	0.5123	0.5919	0.6732	0.7563	0.8413	0.9282	1.0171	1.1081
15	0.1499	0.3511	0.4258	0.5021	0.5801	0.6598	0.7412	0.8245	0.9097	0.9968	1.0860
20	0.1529	0.3443	0.4176	0.4924	0.5689	0.6470	0.7269	0.8086	0.8921	0.9775	1.0650
25	0.1558	0.3378	0.4097	0.4831	0.5581	0.6348	0.7131	0.7932	0.8752	0.9590	1.0448
30	0.1587	0.3316	0.4021	0.4742	0.5478	0.6231	0.7000	0.7787	0.8591	0.9414	1.0256
35	0.1616	0.3256	0.3949	0.4657	0.5380	0.6119	0.6874	0.7646	0.8436	0.9244	1.0071
40	0.1645	0.3199	0.3880	0.4575	0.5285	0.6011	0.6753	0.7512	0.8288	0.9082	0.9894
45	0.1674	0.3144	0.3813	0.4496	0.5194	0.5908	0.6637	0.7383	0.8145	0.8926	0.9724
50	0.1703	0.3091	0.3749	0.4420	0.5107	0.5808	0.6525	0.7258	0.8008	0.8775	0.9560
55	0.1731	0.3040	0.3687	0.4347	0.5022	0.5712	0.6417	0.7138	0.7876	0.8630	0.9402
60	0.1760	0.2991	0.3627	0.4277	0.4941	0.5620	0.6313	0.7023	0.7748	0.8491	0.9250
65	0.1788	0.2943	0.3569	0.4209	0.4863	0.5531	0.6214	0.6912	0.7626	0.8356	0.9104
70	0.1817	0.2897	0.3514	0.4143	0.4787	0.5444	0.6116	0.6804	0.7507	0.8226	0.8961
75	0.1845	0.2853	0.3460	0.4080	0.4714	0.5361	0.6023	0.6700	0.7392	0.8100	0.8824
80	0.1873	0.2810	0.3408	0.4019	0.4643	0.5280	0.5932	0.6599	0.7280	0.7978	0.8691
85	0.1901	0.2768	0.3358	0.3959	0.4574	0.5202	0.5845	0.6501	0.7173	0.7860	0.8563
90	0.1929	0.2728	0.3309	0.3902	0.4508	0.5127	0.5760	0.6407	0.7069	0.7746	0.8439
95	0.1957	0.2689	0.3261	0.3846	0.4443	0.5053	0.5677	0.6315	0.6968	0.7635	0.8318

^aThe manufacturer's listing specifies the temperature range for operation.

^bW/V [agent weight requirements (kg/m³)] = kilograms of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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

^at [temperature (°C)] = design temperature in the hazard area.

^ds [specific volume (m³/kg)] = specific volume of HFC-236fa vapor can be approximated by $s = 0.1413 + 0.0006t$, where t = temperature (°C).

^eC [concentration (%)] = volumetric concentration of HFC-236fa in air at the temperature indicated.

Table A.5-57.3.1(o) FIC-1311 Total Flooding Quantity (U.S. 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	0.0386	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

^aThe manufacturer's listing specifies the temperature range for operation.

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

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

^ct [temperature (°F)] = design temperature in the hazard area.

^ds [specific volume (ft³/lb)] = specific volume of FIC-1311 vapor can be approximated by $s = 1.683 + 0.0044t$, where t = temperature (°F).

^eC [concentration (%)] = volumetric concentration of FIC-1311 in air at the temperature indicated.

Table A.5-57.3.1(p) FIC-1311 Total Flooding Quantity (SI Units)^a

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a							
		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

^aThe manufacturer's listing specifies the temperature range for operation.

^bW/V [agent weight requirements (kg/m³)] = kilograms required per cubic meter of protected volume to produce indicated concentration at temperature specified.

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

^ct [temperature (°C)] = design temperature in the hazard area.

^ds [specific volume (m³/kg)] = specific volume of FIC-1311 vapor can be approximated by $s = 0.1138 + 0.0005t$, where t = temperature (°C).

^eC [concentration (%)] = volumetric concentration of FIC-1311 in air at the temperature indicated.

Table A.6.5.2.3.1(q) HFC Blend B Total Flooding Quantity Table (U.S. Units)^a

Temp(t) (°F) ^c	Specific Vapor Volume(s) (ft³/lb) ^d	Weight Requirement of Hazard Volume W/V (lb/ft³) ^b Concentration (% by volume) ^a								
		8	9	10	11	12	13	14	15	16
-40	2.9642	0.0293	0.0334	0.0375	0.0417	0.0460	0.0504	0.0549	0.0595	0.0643
-30	3.0332	0.0287	0.0326	0.0366	0.0407	0.0450	0.0493	0.0537	0.0582	0.0628
-20	3.1022	0.0280	0.0319	0.0358	0.0398	0.0440	0.0482	0.0525	0.0569	0.0614
-10	3.1712	0.0274	0.0312	0.0350	0.0390	0.0430	0.0471	0.0513	0.0556	0.0601
0	3.2402	0.0268	0.0305	0.0343	0.0381	0.0421	0.0461	0.0502	0.0545	0.0588
10	3.3092	0.0263	0.0299	0.0336	0.0373	0.0412	0.0452	0.0492	0.0533	0.0576
20	3.3782	0.0257	0.0293	0.0329	0.0366	0.0404	0.0442	0.0482	0.0522	0.0564
30	3.4472	0.0252	0.0287	0.0322	0.0359	0.0396	0.0433	0.0472	0.0512	0.0553
40	3.5162	0.0247	0.0281	0.0316	0.0352	0.0388	0.0425	0.0463	0.0502	0.0542
50	3.5852	0.0243	0.0276	0.0310	0.0345	0.0380	0.0417	0.0454	0.0492	0.0531
60	3.6542	0.0238	0.0271	0.0304	0.0338	0.0373	0.0409	0.0445	0.0483	0.0521
70	3.7232	0.0234	0.0266	0.0298	0.0332	0.0366	0.0401	0.0437	0.0474	0.0512
80	3.7922	0.0229	0.0261	0.0293	0.0326	0.0360	0.0394	0.0429	0.0465	0.0502

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Temp(t) (°F) ^c	Specific Vapor Volume(s) (ft ³ /lb) ^d	Weight Requirement of Hazard Volume W/V (lb/ft ³) ^b Concentration (% by volume) ^a								
		8	9	10	11	12	13	14	15	16
90	3.8612	0.0225	0.0256	0.0288	0.0320	0.0353	0.0387	0.0422	0.0457	0.0493
100	3.9302	0.0221	0.0252	0.0283	0.0314	0.0347	0.0380	0.0414	0.0449	0.0485
110	3.9992	0.0217	0.0247	0.0278	0.0309	0.0341	0.0374	0.0407	0.0441	0.0476
120	4.0682	0.0214	0.0243	0.0273	0.0304	0.0335	0.0367	0.0400	0.0434	0.0468
130	4.1372	0.0210	0.0239	0.0269	0.0299	0.0330	0.0361	0.0393	0.0427	0.0460
140	4.2062	0.0207	0.0235	0.0264	0.0294	0.0324	0.0355	0.0387	0.0420	0.0453
150	4.2752	0.0203	0.0231	0.0260	0.0289	0.0319	0.0350	0.0381	0.0413	0.0446
160	4.3442	0.0200	0.0228	0.0256	0.0285	0.0314	0.0344	0.0375	0.0406	0.0438
170	4.4132	0.0197	0.0224	0.0252	0.0280	0.0309	0.0339	0.0369	0.0400	0.0432
180	4.4822	0.0194	0.0221	0.0248	0.0276	0.0304	0.0333	0.0363	0.0394	0.0425
190	4.5512	0.0191	0.0217	0.0244	0.0272	0.0300	0.0328	0.0358	0.0388	0.0419
200	4.6202	0.0188	0.0214	0.0240	0.0268	0.0295	0.0323	0.0352	0.0382	0.0412

^aThe manufacturer's listing specifies the temperature range for operation.

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

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

^ct [temperature (°F)] = the design temperature in the hazard area.

^ds [specific volume (ft³/lb)] = specific volume of HFC Blend B vapor can be approximated by s = 3.2402 + 0.0069t, where t = temperature (°F).

^eC [concentration (%)] = volumetric concentration of HFC Blend B in air at the temperature indicated.

Table A.5.52.3.1(r) HFC Blend B Total Flooding Quantity Table (SI Units)^a

Temp (t) (°C) ^c	Specific Vapor Volume (s) (m³/kg) ^d	Weight Requirement of Hazard Volume W/V (kg/m³) ^b Concentration (% by volume) ^a								
		8	9	10	11	12	13	14	15	16
−40	0.1812	0.4799	0.5458	0.6132	0.6821	0.7526	0.8246	0.8984	0.9739	1.0512
−30	0.1902	0.4572	0.5200	0.5842	0.6498	0.7169	0.7856	0.8559	0.9278	1.0015
−20	0.1992	0.4365	0.4965	0.5578	0.6205	0.6846	0.7501	0.8172	0.8859	0.9562
−10	0.2082	0.4177	0.4750	0.5337	0.5936	0.6550	0.7177	0.7819	0.8476	0.9149
0	0.2172	0.4004	0.4553	0.5116	0.5690	0.6278	0.6880	0.7495	0.8125	0.8770
10	0.2262	0.3844	0.4372	0.4912	0.5464	0.6028	0.6606	0.7197	0.7802	0.8421
20	0.2352	0.3697	0.4205	0.4724	0.5255	0.5798	0.6353	0.6921	0.7503	0.8098
30	0.2442	0.3561	0.4050	0.4550	0.5061	0.5584	0.6119	0.6666	0.7226	0.7800
40	0.2532	0.3434	0.3906	0.4388	0.4881	0.5386	0.5901	0.6429	0.6970	0.7523
50	0.2622	0.3316	0.3772	0.4238	0.4714	0.5201	0.5699	0.6209	0.6730	0.7265
60	0.2712	0.3206	0.3647	0.4097	0.4557	0.5028	0.5510	0.6003	0.6507	0.7023
70	0.2802	0.3103	0.3530	0.3965	0.4411	0.4867	0.5333	0.5810	0.6298	0.6798
80	0.2892	0.3007	0.3420	0.3842	0.4274	0.4715	0.5167	0.5629	0.6102	0.6586
90	0.2982	0.2916	0.3317	0.3726	0.4145	0.4573	0.5011	0.5459	0.5918	0.6388
100	0.3072	0.2831	0.3219	0.3617	0.4023	0.4439	0.4864	0.5299	0.5744	0.6200
110	0.3162	0.2750	0.3128	0.3514	0.3909	0.4313	0.4726	0.5148	0.5581	0.6024

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Temp (t) (°C) ^c	Specific Vapor Volume (s) (m ³ /kg) ^d	Weight Requirement of Hazard Volume W/V (kg/m ³) ^b									
		Concentration (% by volume) ^a									
		8	9	10	11	12	13	14	15	16	
120	0.3252	0.2674	0.3041	0.3417	0.3801	0.4193	0.4595	0.5006	0.5427	0.5857	
130	0.3342	0.2602	0.2959	0.3325	0.3698	0.4080	0.4471	0.4871	0.5280	0.5699	
140	0.3432	0.2534	0.2882	0.3238	0.3601	0.3973	0.4354	0.4743	0.5142	0.5550	
150	0.3522	0.2469	0.2808	0.3155	0.3509	0.3872	0.4243	0.4622	0.5011	0.5408	
160	0.3612	0.2407	0.2738	0.3076	0.3422	0.3775	0.4137	0.4507	0.4886	0.5273	
170	0.3702	0.2349	0.2672	0.3001	0.3339	0.3684	0.4036	0.4397	0.4767	0.5145	
180	0.3792	0.2293	0.2608	0.2930	0.3259	0.3596	0.3941	0.4293	0.4654	0.5023	
190	0.3882	0.2240	0.2548	0.2862	0.3184	0.3513	0.3849	0.4193	0.4546	0.4907	
200	0.3972	0.2189	0.2490	0.2797	0.3112	0.3433	0.3762	0.4098	0.4443	0.4795	

^aThe manufacturer's listing specifies the temperature range for operation.

^bW/V [agent weight requirement (kg/m³)] = kilograms of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

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

^ct [temperature (°C)] = design temperature in the hazard area.

^ds [specific volume (m³/kg)] = specific volume of HFC Blend B vapor can be approximated by $s = 0.2172 + 0.0009t$, where t = temperature (°C).

^eC [concentration (%)] = volumetric concentration of HFC Blend B in air at the temperature indicated.

5.5.7.3.1.1

The concentration of halocarbon clean agent that will be developed in the protected enclosure shall be calculated at both the minimum and maximum design temperature using the following equation:

$$C = 100 \frac{\left(\frac{W \times s}{V} \right)}{\left(\frac{W \times s}{V} \right) + 1} \quad [5.5.7.3.1.1]$$

where:

C = agent concentration [vol %]

W = installed quantity of agent [lb (kg)]

s = specific volume of the gaseous agent at the minimum/maximum design temperature of the hazard [ft³/lb (m³/kg)]

V = volume of the as-built enclosure [ft³ (m³)]

5.5.7.3.1.2

Agent concentrations calculated based on as-built and as-installed data and the lowest and highest design temperatures of the protected space shall be recorded in accordance with the requirements of 5.1.2.4 and 5.2.4.

5.5.7.3.2*

The quantity of inert gas agent required to achieve the design concentration shall be calculated using Equation 5.5.7.3.2, 5.5.7.3.2.1a, or 5.5.7.3.2.1b:

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100 - C} \right) \quad [5.5.7.3.2]$$

where:

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

- X = volume of inert gas added at standard conditions of 14.7 psi absolute, 70°F (1.013 bar absolute, 21°C) per volume of hazard space [ft³/ft³ (m³/m³)]
- s_0 = specific volume of inert gas agent at 70°F (21°C) and 14.7 psi absolute (1.013 bar absolute)
- s = specific volume of inert gas at 14.7 psi absolute and the minimum design temperature [°F (°C)] of the protected volume [ft³/lb (m³/kg)]
- C = inert gas design concentration (vol %)

A.5-57.3.2

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 one of the following equations:

$$e^x = \frac{100}{100 - \% \text{ IG}} \quad [\text{A.5-57.3.2a}]$$

or

$$X = 2.303 \log_{10} \frac{100}{100 - \% \text{ IG}} \quad [\text{A.5-57.3.2b}]$$

where:

% IG = volume percent of inert gas

X = volume of inert gas added per volume of space

Table A.5-57.3.2(a) through Table A.5-57.3.2(h) provide the quantity of clean agent needed to achieve design concentration.

Table A.5-57.3.2(a) IG-01 Total Flooding Quantity (U.S. Units)*

Temp (t) (°F) ^c	Specific Vapor Volume (s) (ft ³ /lb) ^d	Volume Requirements of Agent per Unit Volume of Hazard ($V_{\text{agent}}/V_{\text{enclosure}}$) ^b Design Concentration (% by Volume) ^a							
		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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Temp (t) (°F) ^c	Specific Vapor Volume (s) (ft ³ /lb) ^d	Volume Requirements of Agent per Unit Volume of Hazard ($V_{\text{agent}}/V_{\text{enclosure}}$) ^b Design Concentration (% by Volume) ^a							
		34	37	40	42	47	49	58	62
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	0.566	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

^aThe manufacturer's listing specifies the temperature range for operation.

^b X [agent volume requirements (ft³/ft³)] = volume of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s_0 [specific volume (ft³/lb)] = specific volume of inert gas agent at 70°F and 14.7 psi absolute

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

^d s [specific volume (ft³/lb)] = specific volume of IG-01 vapor can be approximated by $s = 8.514 + 0.0185t$, where t = temperature (°F).

^c C [concentration (%)] = volumetric concentration of IG-01 in air at the temperature indicated.

Table A.5-5.7.3.2(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 ($V_{\text{agent}}/V_{\text{enclosure}}$) ^b Design Concentration (% by Volume) ^a							
		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	0.6303	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	0.4654	0.5424	0.5752	0.7411	0.8200
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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a							
		34	37	40	42	47	49	58	62
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	0.3908	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

^aThe manufacturer's listing specifies the temperature range for operation.

^bX [agent volume requirements (m³/m³)] = volume of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s₀ [specific volume (m³/kg)] = specific volume of inert gas agent at 21°C and 1.013 bar absolute

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

^ds [specific volume (m³/kg)] = specific volume of IG-01 vapor can be approximated by $s = 0.5685 + 0.00208t$, where t = temperature (°C).

^cC [concentration (%)] = volumetric concentration of IG-01 in air at the temperature indicated.

Table A.5.5.3.2(c) IG-100 Total Flooding Quantity (U.S. 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) ^a							
		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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a							
		34	37	40	42	47	49	58	62
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

^aThe manufacturer's listing specifies the temperature range for operation.

^bX [agent volume requirements (ft³/ft³)] = volume of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s₀ [specific volume (ft³/lb)] = specific volume of inert gas agent at 70°F and 14.7 psi absolute

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

^ds [specific volume (ft³/lb)] = specific volume of IG-100 vapor can be approximated by s = 11.976 + 0.02606t, where t = temperature (°F).

^cC [concentration (%)] = volumetric concentration of IG-100 in air at the temperature indicated.

Table A.5-5.2.2(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) ^a							
		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

^aThe manufacturer's listing specifies the temperature range for operation.

^bX [agent volume requirements (m³/m³)] = volume of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s₀ [specific volume (m³/kg)] = specific volume of inert gas agent at 21°C and 1.013 bar absolute

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

^ds [specific volume (m³/kg)] = specific volume of IG-100 vapor can be approximated by s = 0.7997 + 0.00293t, where t = temperature (°C).

^cC [concentration (%)] = volumetric concentration of IG-100 in air at the temperature indicated.

Table A.5-5.2.2(e) IG-541 Total Flooding Quantity (U.S. Units)^a

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Temp (t) (°F) ^c	Specific Vapor Volume (s) (ft ³ /lb) ^d	Volume Requirements of Agent per Unit Volume of Hazard ($V_{\text{agent}}/V_{\text{enclosure}}$) ^b Design Concentration (% by Volume) ^e							
		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
200	14.144	0.334	0.384	0.437	0.495	0.557	0.624	0.697	0.777

^aThe manufacturer's listing specifies the temperature range for operation.

^b X [agent volume requirements (ft³/ft³)] = volume of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s_0 [specific volume (ft³/lb)] = specific volume of inert gas agent at 70°F and 14.7 psi absolute

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

s [specific volume (ft³/lb)] = specific volume of IG-541 vapor can be approximated by $s = 9.8579 + 0.02143t$, where t = temperature (°F).

C [concentration (%)] = volumetric concentration of IG-541 in air at the temperature indicated.

Table A.5.5.7.3.2(f) IG-541 Total Flooding Quantity (SI Units)^a

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Temp (t) (°C) ^c	Specific Vapor Volume (s) (m³/kg) ^d	Volume Requirements of Agent per Unit Volume of Hazard (V _{agent} /V _{enclosure}) ^b Design Concentration (% by Volume) ^a							
		34	38	42	46	50	54	58	62
-40	0.562	0.524	0.602	0.686	0.776	0.873	0.978	1.093	1.219
-30	0.586	0.502	0.578	0.658	0.745	0.838	0.938	1.048	1.169
-20	0.610	0.482	0.555	0.633	0.716	0.805	0.902	1.007	1.124
-10	0.634	0.464	0.534	0.609	0.689	0.775	0.868	0.969	1.081
0	0.659	0.447	0.515	0.587	0.664	0.746	0.836	0.934	1.042
10	0.683	0.432	0.497	0.566	0.640	0.720	0.807	0.901	1.005
20	0.707	0.417	0.480	0.547	0.619	0.696	0.780	0.871	0.971
30	0.731	0.403	0.464	0.529	0.598	0.673	0.754	0.842	0.940
40	0.755	0.391	0.449	0.512	0.579	0.652	0.730	0.816	0.910
50	0.779	0.379	0.436	0.496	0.562	0.632	0.708	0.791	0.882
60	0.803	0.367	0.423	0.482	0.545	0.613	0.687	0.767	0.855
70	0.827	0.357	0.410	0.468	0.529	0.595	0.667	0.745	0.831
80	0.851	0.347	0.399	0.455	0.514	0.578	0.648	0.724	0.807
90	0.875	0.337	0.388	0.442	0.500	0.563	0.630	0.704	0.785
100	0.900	0.328	0.378	0.430	0.487	0.548	0.613	0.685	0.764

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

^b X [agent volume requirements (m³/m³)] = volume of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s₀ [specific volume (m³/kg)] = specific volume of inert gas agent at 21°C and 1.013 bar absolute

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

^d s [specific volume (m³/kg)] = specific volume of IG-541 vapor can be approximated by $s = 0.65799 + 0.00239t$, where t = temperature (°C).

^c C [concentration (%)] = volumetric concentration of IG-541 in air at the temperature indicated.

Table A.5-57.3.2(g) IG-55 Total Flooding Quantity (U.S. Units)^a

Temp (t) (°F) ^c	Specific Vapor Volume (s) (ft³/lb) ^d	Volume Requirements of Agent per Unit Volume of Hazard (V _{agent} /V _{enclosure}) ^b Design Concentration (% by Volume) ^a							
		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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Temp (t) (°F) ^c	Specific Vapor Volume (s) (ft ³ /lb) ^d	Volume Requirements of Agent per Unit Volume of Hazard ($V_{\text{agent}}/V_{\text{enclosure}}$) ^b Design Concentration (% by Volume) ^a							
		34	38	42	46	50	54	58	62
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

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 ft³.

^aThe manufacturer's listing specifies the temperature range for operation.

^b X [agent volume requirements (lb/ft³)] = volume of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100 - C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100 - C} \right)$$

where:

s_0 [specific volume (ft³/lb)] = specific volume of inert gas agent at 70°F and 14.7 psi absolute

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

^d s [specific volume (ft³/lb)] = specific volume of IG-55 vapor can be approximated by $s = 9.8809 + 0.0215t$, where t = temperature (°F).

^e C [concentration (%)] = volumetric concentration of IG-55 in air at the temperature indicated.

Table A.5-57.3.2(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 ($V_{\text{agent}}/V_{\text{enclosure}}$) ^b Design Concentration (% by Volume) ^a							
		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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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) ^a							
		34	38	42	46	50	54	58	62
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

^aThe manufacturer's listing specifies the temperature range for operation.

^bX [agent volume requirements (m³/m³)] = volume of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

^s₀ [specific volume (m³/kg)] = specific volume of inert gas agent at 21°C and 1.013 bar absolute

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

^s [specific volume (m³/kg)] = specific volume of IG-55 vapor can be approximated by $s = 0.6598 + 0.00242t$, where t = temperature (°C).

^C [concentration (%)] = volumetric concentration of IG-55 in air at the temperature indicated.

Commented [CB4]: Revised separately

5-52.3.2.1*

An alternative equation for calculating the inert gas clean agent concentrations shall be permitted, as follows:

$$X = 2.303 \left(\frac{530}{460+t} \right) \log_{10} \left(\frac{100}{100-C} \right) \quad [5-52.3.2.1a]$$

where:

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

$$X = 2.303 \left(\frac{294}{273+t} \right) \log_{10} \left(\frac{100}{100-C} \right) \quad [5-52.3.2.1b]$$

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

where:

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

A.5.57.3.2.1

Total flooding quantities based on Equations 5.57.3.2.1a and 5.57.3.2.1b are given in Table A.5.57.3.2(a) through Table A.5.57.3.2(h).

5.57.3.2.2

The design quantity of inert gas agent in mass units shall be calculated as follows:

$$W = 2.303 \left(\frac{V}{s} \right) \log_{10} \left(\frac{100}{100 - C} \right) \quad [5.57.3.2.2a]$$

or

$$W = \left(\frac{V}{s} \right) \ln \left(\frac{100}{100 - C} \right) \quad [5.57.3.2.2b]$$

where:

W = quantity of inert gas agent [lb (kg)]

V = volume of the hazard [ft³ (m³)]

s = specific volume of the gaseous agent at the temperature of the hazard [ft³/lb (m³/kg)]

C = inert gas agent concentration [vol %]

5.57.3.2.3

The concentration of an inert gas clean agent that will be developed in the protected enclosure shall be calculated at both the minimum and maximum design temperature, using one of the following equations:

$$C = 100 \frac{10^{\left(\frac{W \cdot s}{2.303 \cdot V} \right)} - 1}{10^{\left(\frac{W \cdot s}{2.303 \cdot V} \right)}} \quad [5.57.3.2.3a]$$

or

$$C = 100 \frac{e^{\left(\frac{W \cdot s}{V} \right)} - 1}{e^{\left(\frac{W \cdot s}{V} \right)}} \quad [5.57.3.2.3b]$$

where:

C = agent concentration [vol %]

W = installed quantity of agent [lb (kg)]

s = specific volume of the gaseous agent at the minimum/maximum design temperature of the hazard [ft³/lb (m³/kg)]

V = volume of the as-built enclosure [ft³ (m³)]

5.57.3.3* Design Factors.

Where special conditions could affect the extinguishing efficiency, the minimum quantity of agent shall be increased through the use of design factors.

A.5.57.3.3

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

The minimum design concentration based either on the cup burner extinguishing concentration plus 30 percent or on 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 quantity of agent used:

- (1) *Unclosable openings* (see also 5.7.2). Special considerations should be taken into account in the design of 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 Annex C. When agent is applied 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 5.7.1.1.1 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.
- (2) *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 Sheinson et al., 1994, and Sheinson et al., 1995.)
- (3) *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 [850 m³(30,000 ft³)] 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 Naval Research Laboratory Report Ser 6180/0049.2.
- (4) *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 cannot be adequately addressed through nozzle placement, additional concentration should be considered. An example of such applications could be enclosures having very high or very low aspect ratios (length/width).
- (5) *Obstructions within the enclosure*. The following three considerations should be given to enclosure obstructions:
 - (a) Room volume should be calculated considering the room empty. Exceptions can be made only for structural components or shafts that pass through the room.
 - (b) For small room volumes, consideration should be given to equipment/storage that take up a considerable percentage of the room volume, specifically, whether 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.
 - (c) 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 middle or upper elevations. Certainly, uniform dispersion and concentration will not be achieved.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Other than as identified in 5.5.7.3.3.1.3, where a single agent supply is used to protect multiple hazards, a design factor from Table 5.5.7.3.3.1 shall be applied.

Table 5.5.7.3.3.1 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

A.5.5.7.3.3.1

The tee 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 (two to four). If the number of tees in a system is greater, additional agent is required to compensate for the uncertainty at the tee splits and 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 for the halocarbons because it is believed that the flow of inert gases can be more accurately predicted and that inert gases are less sensitive to pipe variability.

The following two examples illustrate the method for determining the design factor tee count (note that these examples might not represent good design practice):

(1) **Example 1**[see Figure A.5.5.7.3.3.1(a)]

Hazard	Design Factor Tee Count
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 uses a halocarbon agent, the design factor is 0.05, and if the system uses an inert gas agent, the design factor is 0.01.

Figure A.5.5.7.3.3.1(a) Piping for Design Factor Tee Count for Example 1.

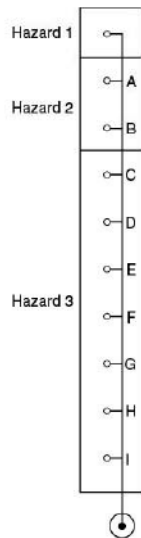
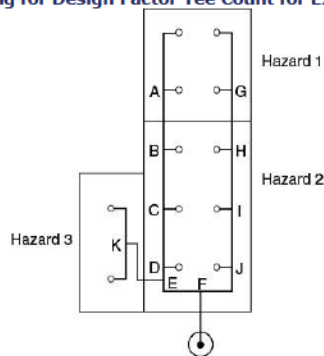


Figure A.5-57.3.3.1(b) Piping for Design Factor Tee Count for Example 2.



(2) Example 2[see Figure A.5-57.3.3.1(b)]

Hazard	Design Factor Tee Count
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 uses a halocarbon agent, the design factor is 0.01, and if the system uses an inert gas agent, the design factor would be 0.00.

5-57.3.3.1.1

For the application of Table 5-57.3.3.1, the design factor tee count shall be determined for each hazard the system protects, using the following guidelines:

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

- (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.

5-57.3.3.1.2

The hazard with the greatest design factor tee count shall be used in Table 5-57.3.3.1 to determine the design factor.

5-57.3.3.1.3

For systems that pass a discharge test, this design factor shall not apply.

5-57.3.3.2* Additional Design Factors.

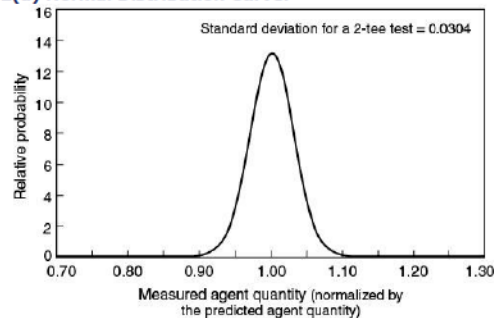
The designer shall assign and document additional design factors for each of the following:

- (1) Unclosable openings and their effects on distribution and concentration (*see also 5.8.2*)
- (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

A.5-57.3.3.2

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 that can be represented statistically by a normal (Gaussian) distribution. A normal distribution curve is shown in Figure A.5-57.3.3.2(a), with the measured mass normalized by the predicted value. The resulting standard deviation is 0.0304 from standard tables. These systems generally have two tees and three nozzles.

Figure A.5-57.3.3.2(a) Normal Distribution Curve.



For a system that utilizes more than two 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. For example, the standard deviation for a system with eight 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.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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 should be used in the system, which would move the entire probability curve up. The quantity of agent that would need to be added is as follows:

$0.90 - 0.859 = 0.041$, or 4.1 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 5-57.3.3.1 was performed for up to 19 tees, 20 nozzles, in a system. [See

Figure A-57.3.3.2(b) through Figure A-57.3.3.2(g).]

Figure A-57.3.3.2(b) Distribution Curve No. 1.

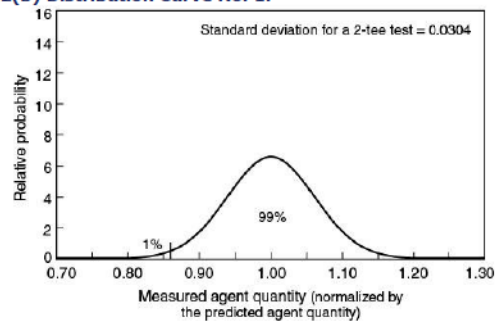


Figure A-57.3.3.2(c) Distribution Curve No. 2.

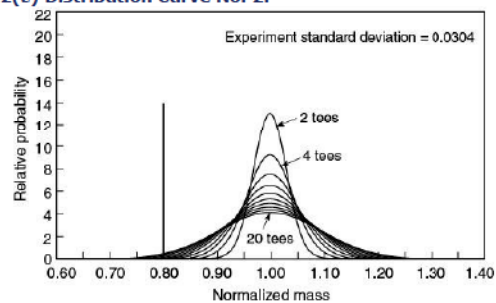


Figure A-57.3.3.2(d) Distribution Curve No. 3.

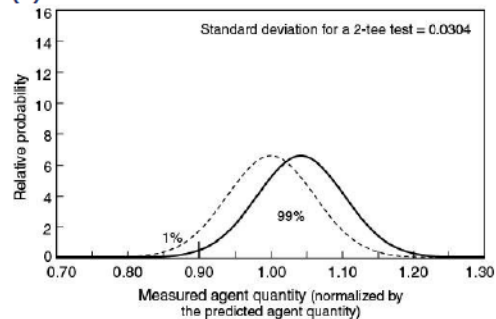


Figure A-57.3.3.2(e) Distribution Curve No. 4.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

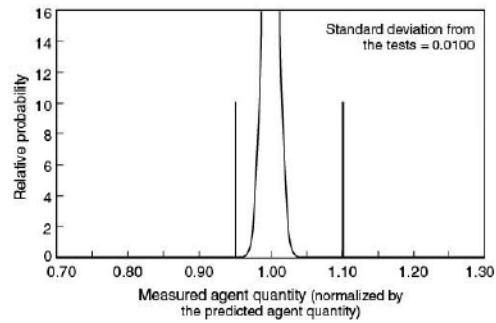


Figure A-5.57.3.3.2(f) Distribution Curve No. 5.

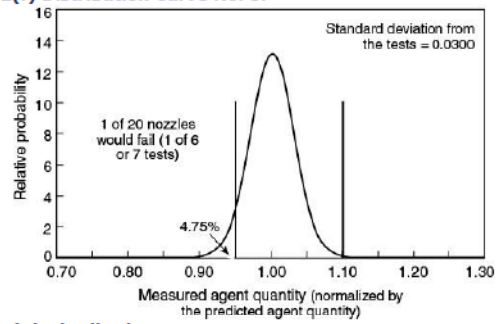
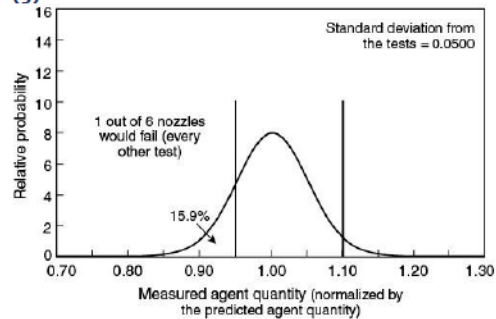


Figure A-5.57.3.3.2(g) Distribution Curve No. 6.



5.57.3.3.3* 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 5.57.3.3.3.)

Table 5.57.3.3.3 Atmospheric Correction Factors

Equivalent Altitude		Enclosure Pressure (Absolute)		Atmospheric Correction Factor
ft	km	psi	mm Hg	
-3,000	-0.92	16.25	840	1.11

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Equivalent Altitude		Enclosure Pressure (Absolute)		Atmospheric Correction Factor
ft	km	psi	mm Hg	
-2,000	-0.61	15.71	812	1.07
-1,000	-0.30	15.23	787	1.04
0	0.00	14.70	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	678	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

A.5.5.7.3.3.3

Some areas affected 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:

$$Y = (-0.000036 \times X) + 1 \quad \text{[A.5.5.7.3.3.3a]}$$

For 5501 ft to 10,000 ft of equivalent altitude:

$$Y = (-0.00003 \times X) + 0.96 \quad \text{[A.5.5.7.3.3.3b]}$$

where:

Y = correction factor

X = altitude (ft)

For SI units, 1 ft = 0.305 m.

The increase, from the 1996 edition to this edition, in safety factor for manually actuated systems and systems protecting Class B hazards, 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 pre-burn times can 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. Field experience indicates that any existing system designed with a 20 percent safety factor will perform as intended.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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)].

Commented [CB5]: Revised separately

5-67.4* Duration of Protection.

A minimum concentration of 85 percent of the adjusted minimum design concentration shall be held at the highest height of protected content within the hazard for a period of 10 minutes or for a time period sufficient to allow for response by trained personnel.

A.5-67.4

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) Winddown 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 agent 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.

5-67.4.1*

It is important that the adjusted minimum design concentration of agent not only shall be achieved but also shall be maintained for the specified period of time to allow effective emergency action by trained personnel.

A.5-67.4.1

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.

Commented [CB6]: Revised separately

5-77.5 Distribution System.

5-77.5.1 Rate of Application.

5-77.5.1.1* Discharge Time.

A.5-77.5.1.1

The optimum discharge time is a function of many variables, five of which 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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

It is essential for the end user to understand that both the products of combustion and the decomposition products formed from the suppression agent contribute to the total threat to life or assets associated with a fire.

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 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 (e.g., HCl, HBr, HF, HCN, CO).

The halogenated hydrocarbon fire extinguishing agents described in this standard will break down into their decomposition products when they are exposed to a fire. It is essential that the end user understand this process, since the selection of the discharge time and other design factors will be affected by the amount of decomposition products the protected hazard can tolerate.

The concentration of thermal decomposition products from a halogenated fire suppression agent is dependent on 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, because 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, 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 pre-burn time, the presence of hot surfaces or deep-seated fires, and the suppression agent concentration.

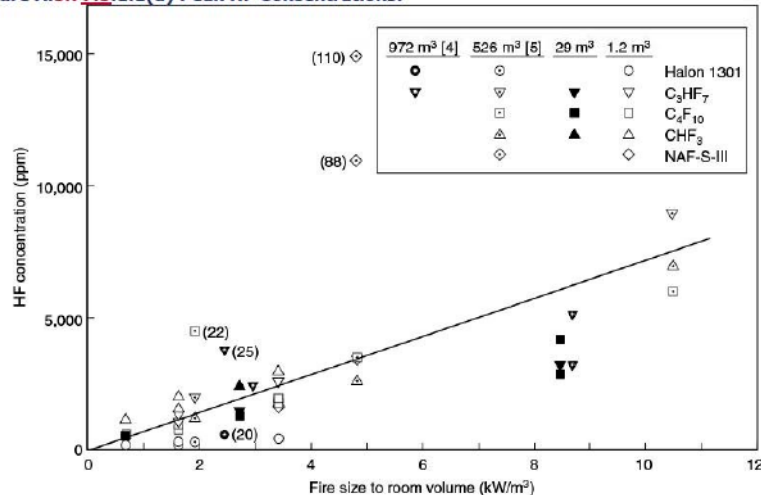
This decomposition issue is not unique to the new clean halogenated agents. The thermal decomposition products resulting from the extinguishment of fires with Halon 1301 have been investigated by numerous authors (e.g., Ford, 1972, and Cholin, 1972), and it is well established that the most important 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 parts per million 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 (COF₂), carbonyl bromide (COBr₂), and bromine (Br₂), 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 and Wilkinson, 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 (COF₂). HCFC agents can potentially produce carbonyl fluoride (COF₂), carbonyl chloride (COCl₂), and elemental chlorine (Cl₂), and I-containing compounds can potentially produce carbonyl fluoride (COF₂) and elemental iodine (I₂). All of these products are subject to relatively rapid hydrolysis (Cotton and Wilkinson, 1980) to produce the associated halogen acid (HF, HCl, or HI); hence, 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.5.7.5.1.1(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 m³ (42 ft³) to 972 m³ (34,326 ft³). The 526 m³ results are from U.S. Coast Guard (USCG) testing; the 972 m³ 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; Halon 1301 will yield bromine and hydrogen bromide in addition to HF.

Figure A.5-77.5.1.1(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 for all the halocarbon agents tested is approximately three to eight times higher than that formed for Halon 1301 (which also forms bromine and hydrogen bromide). It is important to note that as pointed out by Peatross and Forssell (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 CF₃I was not tested in the USCG or NRL studies, but other data available on CF₃I indicate that its production of HF is comparable to that of Halon 1301. In addition, elemental iodine (I₂) is formed from CF₃I.

There might be differences between the various HFC/HCFC compounds tested, but it is not clear from these data whether such differences exist. 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 on 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, 1993). In many cases in the telecommunication industry, detection at fire sizes of 1 kW is desired (Grosshandler, 1998). Skaggs and Moore (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 indicates that thermal decomposition product concentrations from the halogenated agents would be comparable to that from Halon 1301.

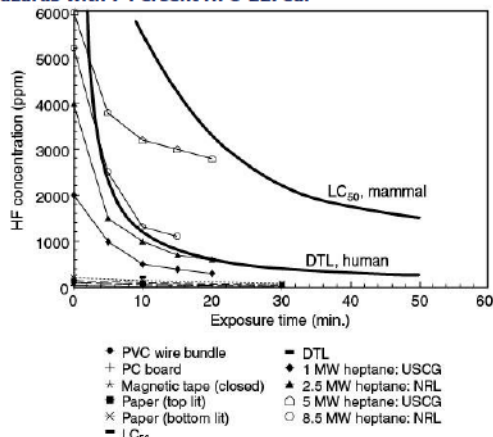
Tests by Hughes Associates, Inc. (1995) evaluated the thermal decomposition products resulting from the extinguishment of Class A fires typical of those encountered in telecommunication and electronic data processing (EDP) facilities by HFC-227ea. The test fuels included shredded paper, PC boards, PVC-coated 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.5-77.5.1.1(b) (Peatross and Forssell, 1996) shows the HF concentration resulting from these tests. Also shown in Figure A.5-77.5.1.1(b) is the approximate mammalian median lethal concentration (LC₅₀) (Sax, 1984) and the dangerous toxic load (DTL) for humans based on the analysis of Meldrum (1993). As seen in Figure A.5-77.5.1.1(b), the HF levels produced in the computer room were below both the estimated mammalian LC₅₀ and DTL curves. Peatross and Forssell (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.5-77.5.1.1(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 (1996), in many of these large fire scenarios the levels of combustion products (e.g., CO) and the high temperatures

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

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 that basis. However, the increased combustion products and oxygen level reduction associated with longer discharge times should be considered.

Figure A.5-7.2.5.1.1(b) Hazard Assessment of HF Concentrations. Extinguishment of Typical EDP and Class B Hazards with 7 Percent HFC-227ea.



Agent mass flow rates should 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 also should 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, among others. The likelihood of these effects increases 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 previously described.

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, on detection of some specified fraction of the lower flammable limit of the flammable vapors present.

5-7.2.5.1.1.1*

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.

A.5-7.2.5.1.1.1

The minimum design concentration for flame extinguishment is defined in 5-4.2.2.2 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 and thus prevent re-ignition
- (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

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

In the examples cited in A.5-72.5.1.1.1(1) through A.5-72.5.1.1.1(4), it is the intent of 5-72.5.1.1 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; as an alternative, separate piping networks with different flow rates can be used.

5-72.5.1.1.2*

For inert gas agents, the discharge time required to achieve 95 percent of the minimum design concentration for flame extinguishment shall not exceed 60 seconds for Class B fuel hazards, 120 seconds for Class A surface-fire hazards or Class C hazards, or as otherwise required by the authority having jurisdiction.

A.5-72.5.1.1.2

See A.5-72.5.1.1.1.

5-72.5.1.1.3*

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 a 20 percent safety factor for flame extinguishment.

A.5-72.5.1.1.3

For third-party listing or approval of pre-engineered systems or flow calculation software for engineered systems (see 5.2.1), direct measurement of the point in time at which 95 percent of the agent mass is discharged from the nozzle is not necessary to satisfy compliance with the intent of 5-72.5.1.1.3. For some agents, the point in time at which 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 in which 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 at which 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 at which the agent discharge changes from predominately liquid to gas to calculate an agent mass balance in the network of cylinders and pipes. The experimental discharge time is taken as the point at which the summed calculated mass discharged from all nozzles equals 95 percent of the agent required to achieve minimum design concentration.

5-72.5.1.1.4

Flow calculations performed in accordance with Section 5.2 or in accordance with the listed pre-engineered systems instruction manuals shall be used to demonstrate compliance with 5-72.5.1.1.

5-72.5.1.1.5

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.

5-72.5.2* Extended Discharge.

When an extended discharge is necessary to maintain the design concentration for the specified period of time, additional agent quantities ~~can~~ shall be permitted to be applied at a reduced rate.

7.5.2.1

The initial discharge shall be completed within the limits specified in 5-72.5.1.1.

7.5.2.2

The performance of the extended discharge system shall be confirmed by test.

A.5-72.5.2

Special attention should be paid to safety and health issues when extended discharge systems are being considered.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

The effect of decomposition products on electronic equipment is a potential area of concern. Sufficient data at present are not available to predict the effects of a given HF exposure scenario on all electronic equipment. Several evaluations of the effect 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 in which the space shuttle *Orbiter's* electronics were exposed to 700, 7000, and 70,000 ppm HF and HBr (Pedley, 1995). In those tests, exposures up to 700 ppm HF and HBr caused no failures. At 7000 ppm, severe corrosion was noted, and there were some operating failures. 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 the boards following a 15-minute exposure to post-fire 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. (1994) exposed multifunction boards for 30 minutes in the post-fire extinguishment environment; no failures were reported up to 90 days post-test. 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 to accomplish mixing of the additional agent throughout the enclosure. To accomplish this, the extended discharge probably will need to be performed 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.

~~5-8.7.6~~ Nozzle Choice and Location.

~~5-8.7.6.1~~

Nozzles shall be of the type listed for the intended purpose.

~~7.6.2~~

~~and~~ **Nozzles** shall be placed within the protected enclosure in compliance with listed limitations with regard to spacing, floor coverage, and alignment.

~~5-8.27.6.3~~

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.



First Revision No. 6-NFPA 2001-2019 [Global Input]

(1) Insert a new annex chapter, titled "Storage Containers for Vaporizing-liquid Agents," in accordance with the attached file. This annex should be placed after the annex titled "Enclosure Evaluation."

(2) Revise 4.1.4.1, as follows:

4.1.4.1* 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. [\(See Annex F.\)](#)

Supplemental Information

File Name	Description Approved
2001_FR6_AnnexF.docx	STAFF USE
2001_Global_FR-6_New_Annex_F.pdf	For ballot

Submitter Information Verification

Committee:

Submittal Date: Wed Apr 24 15:45:35 EDT 2019

Committee Statement

Committee Statement: Nitrogen-pressurized storage containers of vaporizing-liquid agents are at risk of developing high non-equilibrium pressures upon temperature swings from low to high temperatures. Such temperature changes are common and, could be of large magnitude, as in shipment of containers in very cold weather followed by off-loading and storage in warm facilities. Under certain conditions, though uncommon, container pressure could exceed the pressure rating of a container's safety rupture disc. This revision creates a new annex that contains technical information that could be helpful in estimating non-equilibrium pressures under stated temperature change scenarios.

Response Message: FR-6-NFPA 2001-2019

[Public Input No. 61-NFPA 2001-2018 \[Section No. 4.1.4.1\]](#)

Annex F Storage Containers for Vaporizing-liquid Agents

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

F.1 Introduction.

Containers of vaporizing-liquid agents are usually pressurized with nitrogen or other gases, which facilitates liquid discharge. Some of the nitrogen dissolves in the agent liquid phase, in accordance with Henry's law, which has the effect of decreasing the liquid density and increasing its volume. Changes in storage temperature cause the container pressure, the liquid- and gas-phase volumes, and the amount of nitrogen in each phase to change.

Figure F.1 depicts how temperature changes can affect container contents. Here, the estimated relative volumes of gas and liquid are shown at three temperatures for HFC-227ea pressurized to 360 psi (2480 kPa) at 70°F (21°C) at a fill density of 70 lb/ft³ (1121 kg/m³), cooled to 32°F (0°C), followed by heating to 100°F (38°C). After initial container fill and equilibration, the estimated relative liquid and gas volumes are about 87 percent and 13 percent, respectively. On cooling to 32°F (0°C), say during transport in the winter, the liquid density increases and its volume decreases. The new relative liquid and gas volumes change to about 81 percent and 19 percent, a relative gas volume increase of 46 percent. The pressure in the expanded gas volume decreases and is initially no longer in pressure-equilibrium with the liquid phase. Pressure equilibrium between the phases is restored by nitrogen bubbling out of solution (i.e., effervescence) to achieve a new equilibrium pressure of about 310 psi (2140 kPa). In this example, it is estimated that the amount of nitrogen in the gas phase increases about 48 percent. Removal of the cooled container to a warm storage space causes liquid expansion and gas phase contraction. In this example, the storage area is assumed to be at 100°F (38°C) and that the container and contents heat rapidly without agitation. The new estimated relative liquid and gas volumes are 92.1 percent and 7.9 percent. Gas-phase pressure increases significantly due to (a) the volume reduction of 58 percent from the cooled state and (b) very slow transport of nitrogen back to the liquid phase. In the limit of negligible nitrogen movement to the liquid, it is estimated that the pressure in the warmed container could exceed 850 psi (5860 kPa). It is feasible that there are scenarios where non-equilibrium pressures could exceed the pressure rating of the container burst disc.

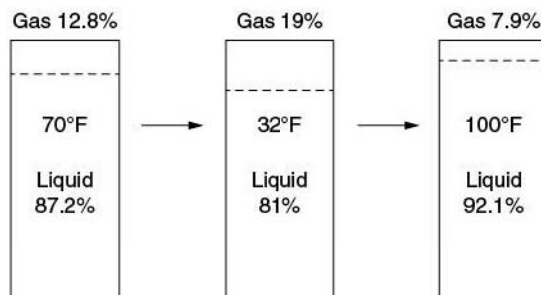
The intent of this annex is to present information, where available, that could be useful in estimating non-equilibrium pressures in storage containers subject to rapid temperature rise. Agent property data is given in Section F.2 for HFC-125 and HFC-227ea over a range of temperatures, including:

- (1) Agent liquid density and vapor pressure
- (2) Henry's law constant for nitrogen solubility in agent liquid
- (3) Nitrogen-to-agent fill quantities over a range of cylinder fill densities

Additionally, an important property of nitrogen-pressurized agent is the density of the nitrogen-saturated liquid phase, a metric necessary for estimating the volume of the vapor space in a container at different storage temperatures. Density of nitrogen-saturated liquid can be estimated from calibration charts developed by system manufacturers for use in measuring liquid-level in system containers.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Figure F.1 Estimated Volumes of Liquid and Gas Phases of HFC-227ea at a Fill Density of 70 lb/ft³ (1121 kg/m³) Pressurized with Nitrogen to 360 psi (2480 kPa) at 70°F (21°C).



F.2 Agent Properties.

The agent property values given in this section are derived from manufacturer's data provided in the references identified in Section F.3.

F.2.1 HFC-125 Properties.

F.2.1.1 HFC-125: Vapor Pressure and Liquid Density.

Table F.2.1.1(a) and Table F.2.1.1(b) give the vapor pressure and liquid density of HFC-125 at various temperatures. Equations F.2.1.1(a) through (d) can be used to approximate values at other temperatures.

$$P_v = (3.781 \times 10^{-5})t^3 + (7.878 \times 10^{-3})t^2 + (1.060)t + 53.69 \quad \text{[F.2.1.1(a)]}$$

where:

$$P_v \equiv \text{Vapor pressure [psi]}$$

$$t \equiv \text{Temperature [°F]}$$

$$P_v = (1.774 \times 10^{-5})t^3 + (2.381 \times 10^{-3})t^2 + (2.101 \times 10^{-1})t + 6.730 \quad \text{[F.2.1.1(b)]}$$

where:

$$P_v \equiv \text{Vapor pressure [bar]}$$

$$t \equiv \text{Temperature [°C]}$$

$$\rho_L = (-1.020 \times 10^{-7})t^4 + (1.149 \times 10^{-5})t^3 + (-1.719 \times 10^{-4})t^2 + (-1.710 \times 10^{-1})t + 87.26 \quad \text{[F.2.1.1(c)]}$$

where:

$$\rho_L \equiv \text{Liquid density [lb/ft}^3\text{]}$$

$$t \equiv \text{Temperature [°F]}$$

$$\rho_L = (-3.419 \times 10^{-5})t^4 + (1.686 \times 10^{-3})t^3 + (-1.948 \times 10^{-2})t^2 + (-5.336)t + 1321 \quad \text{[F.2.1.1(d)]}$$

where:

$$\rho_L \equiv \text{Liquid density [kg/m}^3\text{]}$$

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

$t \equiv$ Temperature [$^{\circ}\text{C}$]

Table F.2.1.1(a) HFC-125: Vapor Pressure and Liquid Density, US Units

<u>Temperature</u>	<u>Vapor Pressure</u>	<u>Liquid Density</u>
<u>$^{\circ}\text{F}$</u>	<u>Psi</u>	<u>lb/ft³</u>
<u>0</u>	<u>53.15</u>	<u>87.24</u>
<u>10</u>	<u>64.83</u>	<u>85.79</u>
<u>20</u>	<u>78.36</u>	<u>84.29</u>
<u>30</u>	<u>93.91</u>	<u>82.73</u>
<u>40</u>	<u>111.70</u>	<u>81.10</u>
<u>50</u>	<u>131.80</u>	<u>79.39</u>
<u>60</u>	<u>154.60</u>	<u>77.59</u>
<u>70</u>	<u>180.10</u>	<u>75.69</u>
<u>80</u>	<u>208.70</u>	<u>73.65</u>
<u>90</u>	<u>240.60</u>	<u>71.44</u>
<u>100</u>	<u>276.00</u>	<u>69.03</u>
<u>110</u>	<u>315.30</u>	<u>66.32</u>
<u>120</u>	<u>358.70</u>	<u>63.2</u>
<u>130</u>	<u>406.70</u>	<u>59.42</u>
<u>140</u>	<u>459.90</u>	<u>54.33</u>
<u>150</u>	<u>519.40</u>	<u>43.07</u>

Table F.2.1.1(b) HFC-125: Vapor Pressure and Liquid Density, SI Units

<u>Temperature</u>	<u>Vapor Pressure</u>	<u>Liquid Density</u>
<u>$^{\circ}\text{C}$</u>	<u>bar</u>	<u>kg/m³</u>
<u>-20</u>	<u>3.38</u>	<u>1407</u>
<u>-15</u>	<u>4.05</u>	<u>1386</u>
<u>-10</u>	<u>4.83</u>	<u>1365</u>
<u>-5</u>	<u>5.71</u>	<u>1343</u>
<u>0</u>	<u>6.71</u>	<u>1320</u>
<u>5</u>	<u>7.83</u>	<u>1296</u>
<u>10</u>	<u>9.09</u>	<u>1272</u>
<u>15</u>	<u>10.49</u>	<u>1246</u>
<u>20</u>	<u>12.05</u>	<u>1219</u>
<u>25</u>	<u>13.78</u>	<u>1190</u>
<u>30</u>	<u>15.68</u>	<u>1159</u>

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

<u>Temperature</u>	<u>Vapor Pressure</u>	<u>Liquid Density</u>
<u>°C</u>	<u>bar</u>	<u>kg/m³</u>
<u>35</u>	<u>17.78</u>	<u>1126</u>
<u>40</u>	<u>20.08</u>	<u>1089</u>
<u>45</u>	<u>22.60</u>	<u>1048</u>
<u>50</u>	<u>25.37</u>	<u>1001</u>
<u>55</u>	<u>28.39</u>	<u>945</u>
<u>60</u>	<u>31.71</u>	<u>870</u>
<u>65</u>	<u>35.38</u>	<u>730</u>

F.2.1.2 HFC-125: Henry's Law Constant for Nitrogen Solubility.

Figure F.2.1.2(a) and Figure F.2.1.2(b) can be used to determine the Henry's law constant for nitrogen solubility in HFC-125 at various temperatures. Equations F.2.1.2(a) and (b) can be used to approximate values at other temperatures.

$$H_x = (-7.138 \times 10^{-2})t^2 + (-1.170)t + 4384 \quad \text{[F.2.1.2(a)]}$$

where:

$H_x \equiv$ Henry's law constant [psi/mole fraction]

$t \equiv$ Temperature [°F]

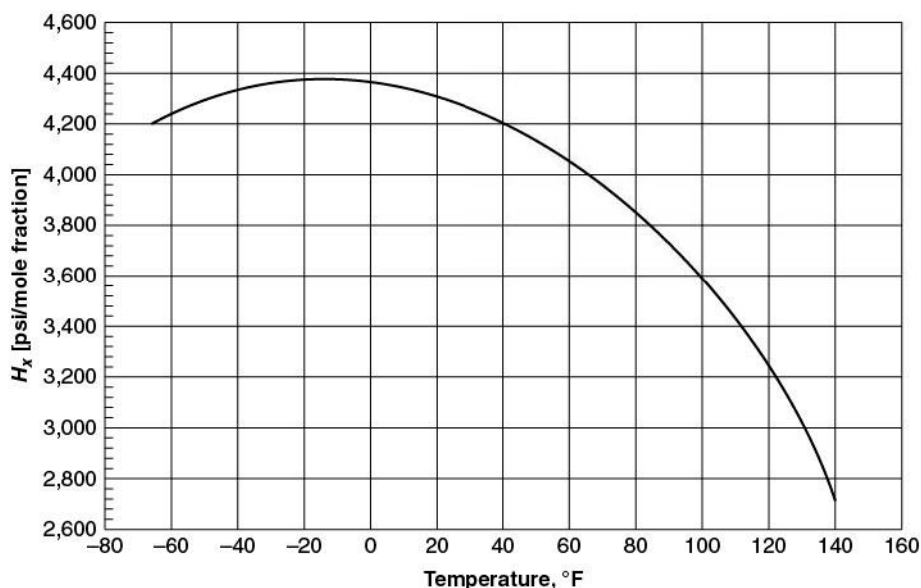
$$H_x = (-1.595 \times 10^{-2})t^2 + (-7.124 \times 10^{-2})t + 294.7 \quad \text{[F.2.1.2(b)]}$$

where:

$H_x \equiv$ Henry's law constant [bar/mole fraction]

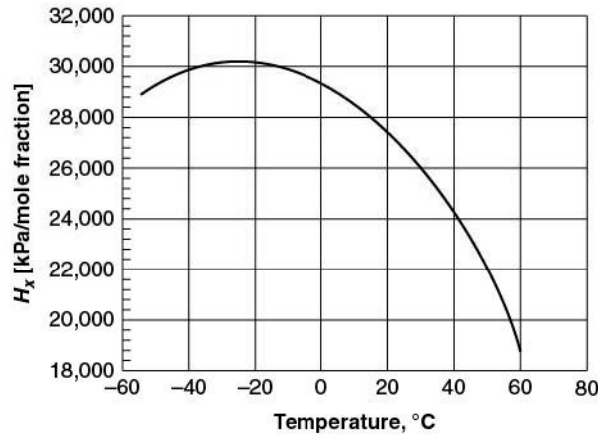
$t \equiv$ Temperature [°C]

Figure F.2.1.2(a) HFC-125: Henry's Law Constant, H_x , for Nitrogen Solubility, U.S. Units.



Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

Figure F.2.1.2(b) HFC-125: Henry's Law Constant, H_x , for Nitrogen Solubility, SI Units.



F.2.1.3 HFC-125: Nitrogen Required for Cylinder Pressurization at Temperature and Fill Density.

Table F.2.1.3(a) and Table F.2.1.3(b) give the nitrogen-to-agent ratio that results in the specified cylinder pressure at the given temperature and HFC-125 fill density. Equations F.2.1.3(a) through (d) can be used to approximate values at other fill densities.

$$n_{\{\text{HFC-125;360 psi;70°F}\}} = (7.320 \times 10^{-6}) \rho_{\text{fill}}^2 + (-1.130 \times 10^{-3}) \rho_{\text{fill}} + 0.0552 \quad \text{[F.2.1.3(a)]}$$

where:

$$n_{\{\text{HFC-125;360 psi;70°F}\}} \equiv \text{Nitrogen-to-agent mass fraction for HFC-125 pressurized to 360 psi at 70°F [lb/lb]}$$

$$\rho_{\text{fill}} \equiv \text{Cylinder agent fill density [lb/ft}^3\text{]}$$

$$n_{\{\text{HFC-125;600 psi;70°F}\}} = (1.750 \times 10^{-5}) \rho_{\text{fill}}^2 + (-2.660 \times 10^{-3}) \rho_{\text{fill}} + 0.127 \quad \text{[F.2.1.3(b)]}$$

where:

$$n_{\{\text{HFC-125;600 psi;70°F}\}} \equiv \text{Nitrogen-to-agent mass fraction for HFC-125 pressurized to 600 psi at 70°F [lb/lb]}$$

$$\rho_{\text{fill}} \equiv \text{Cylinder agent fill density [lb/ft}^3\text{]}$$

$$n_{\{\text{HFC-125;25 bar;21°C}\}} = (2.642 \times 10^{-8}) \rho_{\text{fill}}^2 + (-6.864 \times 10^{-5}) \rho_{\text{fill}} + 0.05521 \quad \text{[F.2.1.3(c)]}$$

where:

$$n_{\{\text{HFC-125;41.5 bar;21°C}\}} \equiv \text{Nitrogen-to-agent mass fraction for HFC-125 pressurized to 25 bar at 21°C [kg/kg]}$$

$$\rho_{\text{fill}} \equiv \text{Cylinder agent fill density [kg/m}^3\text{]}$$

$$n_{\{\text{HFC-125;41.5 bar;21°C}\}} = (6.357 \times 10^{-8}) \rho_{\text{fill}}^2 + (-1.606 \times 10^{-4}) \rho_{\text{fill}} + 0.1258 \quad \text{[F.2.1.3(d)]}$$

where:

$$n_{\{\text{HFC-125;41.5 bar;21°C}\}} \equiv \text{Nitrogen-to-agent mass fraction for HFC-125 pressurized to 41.5 psi at 21°C [lb/lb]}$$

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

$$\rho_{fill} \equiv \text{Cylinder agent fill density [kg/m}^3\text{]}$$

Table F.2.1.3(a) HFC-125: Nitrogen Required, US Units

<u>Cylinder Fill Density</u>	<u>Nitrogen Required to Pressurize to 360 psi at 70°F</u>	<u>Nitrogen Required to Pressurize to 600 psi at 70°F</u>
<u>lb/ft³</u>	<u>lb nitrogen / lb agent</u>	<u>lb nitrogen / lb agent</u>
<u>40</u>	<u>0.0216</u>	<u>0.0486</u>
<u>45</u>	<u>0.0189</u>	<u>0.0425</u>
<u>50</u>	<u>0.0168</u>	<u>0.0376</u>
<u>55</u>	<u>0.015</u>	<u>0.0337</u>
<u>60</u>	<u>0.0136</u>	<u>0.0303</u>
<u>65</u>	<u>0.0123</u>	<u>0.0276</u>
<u>70</u>	<u>0.0119</u>	<u>0.0265</u>
<u>75</u>	<u>0.0113</u>	<u>=</u>

Table F.2.1.3(b) HFC-125: Nitrogen Required, SI Units

<u>Cylinder Fill Density</u>	<u>Nitrogen Required to Pressurize to 25 bar at 21°C</u>	<u>Nitrogen Required to Pressurize to 41.5 bar at 21°C</u>
<u>kg/m³</u>	<u>kg nitrogen / kg agent</u>	<u>kg nitrogen / kg agent</u>
<u>600</u>	<u>0.0237</u>	<u>0.0526</u>
<u>700</u>	<u>0.0199</u>	<u>0.0442</u>
<u>800</u>	<u>0.0171</u>	<u>0.0379</u>
<u>900</u>	<u>0.0149</u>	<u>0.0330</u>
<u>1000</u>	<u>0.0132</u>	<u>0.0291</u>
<u>1100</u>	<u>0.0117</u>	<u>0.0259</u>
<u>1150</u>	<u>0.0111</u>	<u>=</u>

F.2.2 HFC-227ea Properties.

F.2.2.1 HFC-227ea: Vapor Pressure and Liquid Density.

Table F.2.2.1(a) and Table F.2.2.1(b) give the vapor pressure and liquid density of HFC-227ea at various temperatures. Equations F.2.1.1(a) through (d) can be used to approximate values at other temperatures.

$$P_v = (2.394 \times 10^{-5})t^3 + (1.727 \times 10^{-3})t^2 + (4.161 \times 10^{-1})t + 12.72$$

[F.2.2.1(a)]

where:

$$P_v \equiv \text{Vapor pressure [psi]}$$

$$t \equiv \text{Temperature [°F]}$$

$$P_v = (8.161 \times 10^{-6})t^3 + (1.020 \times 10^{-3})t^2 + (7.282 \times 10^{-2})t + 1.958$$

[F.2.2.1(b)]

where:

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

P_V = Vapor pressure [bar]

t = Temperature [°C]

$$\rho_L = (-3.786 \times 10^{-6})t^3 + (6.235 \times 10^{-4})t^2 + (-1.656 \times 10^{-1})t + 97.40$$

[F.2.2.1(c)]

where:

ρ_L = Liquid density [lb/ft³]

t = Temperature [°F]

$$\rho_L = (-1.281 \times 10^{-4})t^3 + (-5.744 \times 10^{-3})t^2 + (-3.684)t + 1486$$

[F.2.2.1(d)]

where:

ρ_L = Liquid density [kg/m³]

t = Temperature [°C]

Table F.2.2.1(a) HFC-227ea: Vapor Pressure and Liquid Density, US Units

Temperature	Vapor Pressure	Liquid Density
°F	Psi	lb/ft³
<u>10</u>	<u>17.50</u>	<u>95.51</u>
<u>20</u>	<u>21.93</u>	<u>94.28</u>
<u>30</u>	<u>27.18</u>	<u>93.02</u>
<u>40</u>	<u>33.35</u>	<u>91.73</u>
<u>50</u>	<u>40.55</u>	<u>90.41</u>
<u>60</u>	<u>48.88</u>	<u>89.05</u>
<u>70</u>	<u>58.45</u>	<u>87.64</u>
<u>80</u>	<u>69.38</u>	<u>86.19</u>
<u>90</u>	<u>81.79</u>	<u>84.64</u>
<u>100</u>	<u>95.80</u>	<u>83.11</u>
<u>110</u>	<u>111.54</u>	<u>81.46</u>
<u>120</u>	<u>129.15</u>	<u>79.73</u>
<u>130</u>	<u>148.77</u>	<u>77.90</u>
<u>140</u>	<u>170.55</u>	<u>75.94</u>
<u>150</u>	<u>194.65</u>	<u>73.84</u>
<u>160</u>	<u>221.26</u>	<u>71.54</u>

Table F.2.2.1(b) HFC-227ea: Vapor Pressure and Liquid Density, SI Units

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

<u>Temperature</u>	<u>Vapor Pressure</u>	<u>Liquid Density</u>
<u>°C</u>	<u>bar</u>	<u>kg/m³</u>
<u>-15</u>	<u>1.073</u>	<u>1540</u>
<u>-10</u>	<u>1.322</u>	<u>1522</u>
<u>-5</u>	<u>1.614</u>	<u>1504</u>
<u>0</u>	<u>1.954</u>	<u>1486</u>
<u>5</u>	<u>2.346</u>	<u>1467</u>
<u>10</u>	<u>2.796</u>	<u>1448</u>
<u>15</u>	<u>3.309</u>	<u>1429</u>
<u>20</u>	<u>3.891</u>	<u>1408</u>
<u>25</u>	<u>4.547</u>	<u>1388</u>
<u>30</u>	<u>5.284</u>	<u>1366</u>
<u>35</u>	<u>6.108</u>	<u>1344</u>
<u>40</u>	<u>7.025</u>	<u>1321</u>
<u>45</u>	<u>8.041</u>	<u>1297</u>
<u>50</u>	<u>9.164</u>	<u>1271</u>
<u>55</u>	<u>10.401</u>	<u>1245</u>
<u>60</u>	<u>11.759</u>	<u>1217</u>
<u>65</u>	<u>13.247</u>	<u>1186</u>

F.2.2.2 HFC-227ea: Henry's Law Constant for Nitrogen Solubility.

Figure F.2.2.2(a) and Figure F.2.2.2(b) can be used to determine the Henry's law constant for nitrogen solubility in HFC-227ea at various temperatures. Equations F.2.2.2(a) and (b) can be used to approximate values at other temperatures.

$$H_x = (-4.912 \times 10^{-2})t^2 + (2.386)t + 4234 \quad \text{[F.2.2.2(a)]}$$

where:

H_x = Henry's law constant [psi/mole fraction]

t = Temperature [°F]

$$H_x = (-1.098 \times 10^{-2})t^2 + (-9.940 \times 10^{-2})t + 293.8 \quad \text{[F.2.2.2(b)]}$$

where:

H_x = Henry's law constant [bar/mole fraction]

t = Temperature [°C]

Figure F.2.2.2(a) HFC-227ea: Henry's Law Constant, H_x , for Nitrogen Solubility, US Units.

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

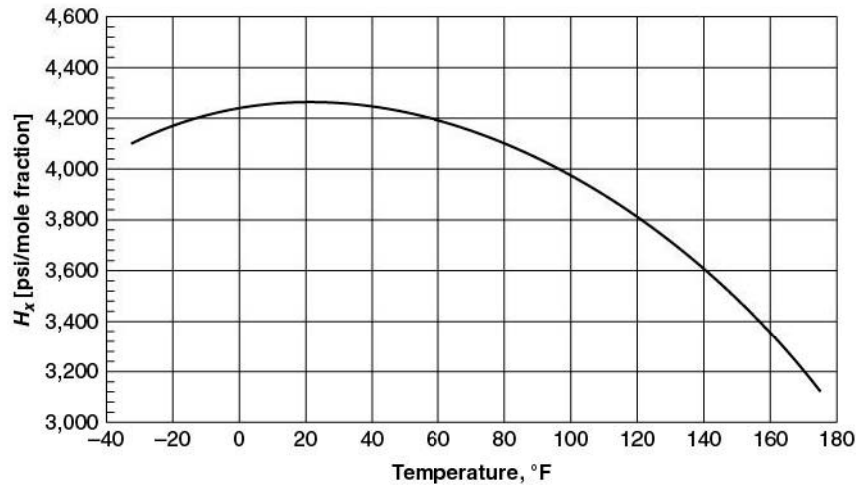
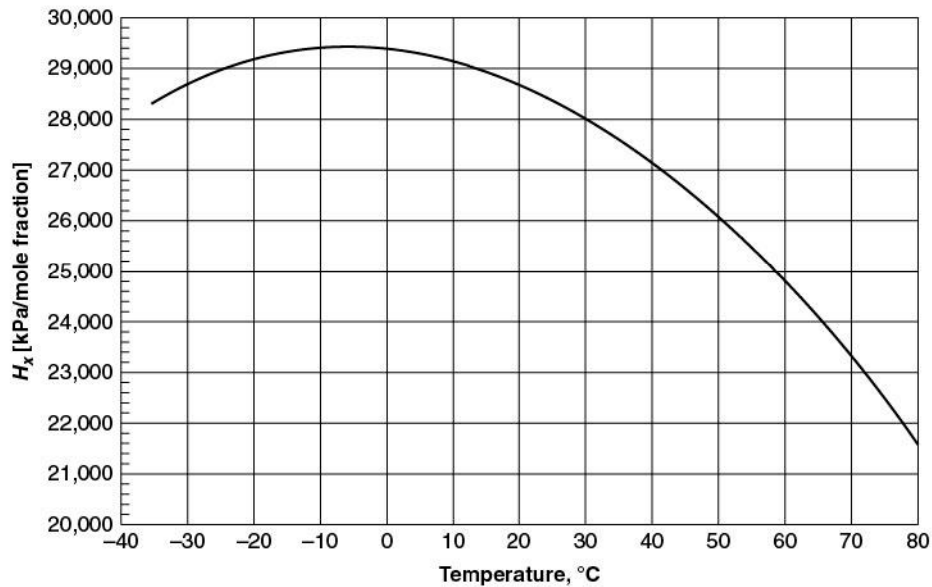


Figure F.2.2.2(b) HFC-227ea: Henry's Law Constant, H_x , for Nitrogen Solubility, SI Units.



F.2.2.3 HFC-227ea: Nitrogen Required for Cylinder Pressurization at Temperature and Fill Density.

Table F.2.2.3(a) and Table F.2.2.3(b) give the nitrogen-to-agent ratio that results in the specified cylinder pressure at the given temperature and HFC-227ea fill density. Equations F.2.2.3(a) through (d) can be used to approximate values at other fill densities.

$$n_{\{\text{HFC-227 ea}; 360 \text{ psi}; 70^\circ\text{F}\}} = (9.270 \times 10^{-6}) \rho_{\text{fill}}^2 + (-1.580 \times 10^{-3}) \rho_{\text{fill}} + 0.0815 \quad \text{[F.2.2.3(a)]}$$

where:

$$\frac{n_{\{\text{HFC-125}; 360 \text{ psi}; 70^\circ\text{F}\}}}{\text{psi}; 70^\circ\text{F}} \equiv \text{Nitrogen-to-agent mass fraction for HFC-227ea pressurized to 360 psi at } 70^\circ\text{F [lb/lb]}$$

$$\rho_{\text{fill}} \equiv \text{Cylinder agent fill density [lb/ft}^3\text{]}$$

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

$$n_{\{HFC-227ea;600\text{ psi};70^{\circ}F\}} = (1.650 \times 10^{-5}) \rho_{fill}^2 + (-2.810 \times 10^{-8}) \rho_{fill} + 0.145 \quad \text{[F.2.2.3(b)]}$$

where:

$$\frac{n_{\{HFC-227ea;600\text{ psi};70^{\circ}F\}}}{\text{psi at } 70^{\circ}F} = \frac{\text{Nitrogen-to-agent mass fraction for HFC-227ea pressurized to 600 psi at } 70^{\circ}F \text{ [lb/lb]}}{\text{psi at } 70^{\circ}F \text{ [lb/lb]}}$$

$$\rho_{fill} = \text{Cylinder agent fill density [lb/ft}^3 \text{]}$$

$$n_{\{HFC-227ea;25\text{ bar};21^{\circ}C\}} = (3.330 \times 10^{-8}) \rho_{fill}^2 + (-9.530 \times 10^{-5}) \rho_{fill} + 0.0812 \quad \text{[F.2.2.3(c)]}$$

where:

$$\frac{n_{\{HFC-227ea;25\text{ bar};21^{\circ}C\}}}{\text{bar at } 21^{\circ}C} = \frac{\text{Nitrogen-to-agent mass fraction for HFC-227ea pressurized to 25 bar at } 21^{\circ}C \text{ [kg/kg]}}{\text{bar at } 21^{\circ}C \text{ [kg/kg]}}$$

$$\rho_{fill} = \text{Cylinder agent fill density [kg/m}^3 \text{]}$$

$$n_{\{HFC-227ea;41.5\text{ bar};21^{\circ}C\}} = (5.730 \times 10^{-8}) \rho_{fill}^2 + (-1.730 \times 10^{-4}) \rho_{fill} + 0.147 \quad \text{[F.2.2.3(d)]}$$

where:

$$\frac{n_{\{HFC-227ea;41.5\text{ bar};21^{\circ}C\}}}{\text{bar at } 21^{\circ}C} = \frac{\text{Nitrogen-to-agent mass fraction for HFC-227ea pressurized to 41.5 bar at } 21^{\circ}C \text{ [lb/lb]}}{\text{bar at } 21^{\circ}C \text{ [lb/lb]}}$$

$$\rho_{fill} = \text{Cylinder agent fill density [kg/m}^3 \text{]}$$

Table F.2.2.3(a) HFC-227ea: Nitrogen Required, US Units.

<u>Cylinder Fill Density</u> <u>lb/ft³</u>	<u>Nitrogen Required to Pressurize to 360 psi at 70°F</u> <u>lb nitrogen / lb agent</u>	<u>Nitrogen Required to Pressurize to 600 psi at 70°F</u> <u>lb nitrogen / lb agent</u>
<u>40</u>	<u>0.0334</u>	<u>0.0590</u>
<u>45</u>	<u>0.0289</u>	<u>0.0512</u>
<u>50</u>	<u>0.0254</u>	<u>0.0449</u>
<u>55</u>	<u>0.0226</u>	<u>0.0398</u>
<u>60</u>	<u>0.0202</u>	<u>0.0355</u>
<u>65</u>	<u>0.0182</u>	<u>0.0319</u>
<u>70</u>	<u>0.0164</u>	<u>0.0288</u>
<u>75</u>	<u>0.0149</u>	<u>0.0261</u>

Table F.2.2.3(b) HFC-227ea: Nitrogen Required, SI Units

<u>Cylinder Fill Density</u> <u>kg/m³</u>	<u>Nitrogen Required to Pressurize to 25 bar at 21°C</u> <u>kg nitrogen / kg agent</u>	<u>Nitrogen Required to Pressurize to 41.5 bar at 21°C</u> <u>kg nitrogen / kg agent</u>
<u>600</u>	<u>0.0364</u>	<u>0.0638</u>
<u>700</u>	<u>0.0303</u>	<u>0.0531</u>
<u>800</u>	<u>0.0257</u>	<u>0.0451</u>

Important Notice: This document has been provided for NFPA technical committee member use only. This document is the copyright property of the National Fire Protection Association (NFPA), Copyright © 2019 NFPA, and may not be used for any other purpose or distributed to any other persons or parties outside of the technical committee.

<u>Cylinder Fill</u>	<u>Nitrogen Required to Pressurize</u>	<u>Nitrogen Required to Pressurize</u>
<u>Density</u>	<u>to 25 bar at 21°C</u>	<u>to 41.5 bar at 21°C</u>
<u>kg/m3</u>	<u>kg nitrogen / kg agent</u>	<u>kg nitrogen / kg agent</u>
<u>900</u>	<u>0.0229</u>	<u>0.0388</u>
<u>1000</u>	<u>0.0193</u>	<u>0.0297</u>
<u>1100</u>	<u>0.0170</u>	<u>0.0263</u>
<u>1150</u>	<u>0.0151</u>	<u>=</u>

F.3 References.

FE-25™ Fire Extinguishing Agent — Properties, Uses, Storage, and Handling, The Chemours Company, Wilmington, DE, June 2017.

FM-200™ Fire Extinguishing Agent — Properties, Uses, Storage, and Handling, The Chemours Company, Wilmington, DE, June 2017.



First Revision No. 11-NFPA 2001-2019 [Detail]

Add new annex material for 8.3 [11.3 after reorg] Semiannual Service and Inspection:

A.11.3

To determine the quantity of halocarbon agent in a cylinder, the cylinder can be weighed, or a dedicated in-place weighing system or a listed device, such as a liquid-level indicator, can be used. Cylinders can be heavy and bulky so proper precautions must be taken to avoid personal injury if cylinders are to be weighed.

Submitter Information Verification

Committee:

Submittal Date: Wed Apr 24 17:39:17 EDT 2019

Committee Statement

Committee Statement: Agent cylinders can weigh 1000 pounds or more. Moving or lifting such large heavy cylinders presents the potential for injury to service personnel. The suggested addition to the Annex highlights some options to moving and lifting cylinders for the purpose of determining the quantity of agent in the cylinder.

Response FR-11-NFPA 2001-2019

Message:

Public Input No. 63-NFPA 2001-2018 [New Section after 8.3]



First Revision No. 15-NFPA 2001-2019 [Detail]

Add new annex material to Section 1.2 Purpose:

The Fire Suppression Systems Association (FSSA) has published a *Guide to Clean Fire Extinguishing Agents and Their Use in Fixed Systems*, which offers a user-friendly presentation of the essential properties of the agents.

Submitter Information Verification

Committee:

Submittal Date: Thu Apr 25 10:23:18 EDT 2019

Committee Statement

Committee The FSSA guide serves to compliment the the NFPA 2001 Standard and is intended to assist
Statement: the designer and end user to better understand the concepts of the Clean Agents.

Response FR-15-NFPA 2001-2019

Message:

Public Input No. 69-NFPA 2001-2018 [Section No. 1.4]



First Revision No. 2-NFPA 2001-2019 [Detail]

Insert a new section and associated annex material after 1.4.2.4 [4.2.4 after reorg]:

4.2.4* Potential Effects of Acoustical Noise.

The potential effects of acoustical noise produced by activation of a clean agent fire-extinguishing system shall be considered where such systems are used in an occupancy containing noise-sensitive equipment.

A.4.2.4

Information can be found in the following references:

- (1) Brian P. Rawson and Kent C. Green. "Inert Gas Data Center Fire Protection and Hard Disk Drive Damage." Data Center Journal, August 27, 2012
(<http://www.datacenterjournal.com/it/inert-gas-data-center-fire-protection-and-hard-disk-drive-damage/>).
- (2) Eurofeu, "Fixed Extinguishing Installation Section, Guidance paper on Impact of noise on Computer hard drives", October 2012.
- (3) FSSA White Paper, "Fire Safety Systems Protecting Data Centers," Fire Suppression Systems Association, Baltimore, MD, 2018.
- (4) Juan Jose Merlo Latorre., "Hard Drive Damage", Industrial Fire Journal, Autumn 2013, issue no. 93, pp 12-14.
- (5) Sandahl, D., A. Elder, and A. Barnard, "Impact of Sound on Computer Hard Disk Drives and Risk Mitigation Measures," Johnson Controls Form No. T-2016367-01, 2018.
- (6) Section D.3 of NFPA 75
- (7) Siemens White Paper, "Potential damage to hard disk drives during discharges of dry extinguishing systems", Siemens, September 2012.

Submitter Information Verification

Committee:

Submission Date: Wed Apr 24 14:19:52 EDT 2019

Committee Statement

Committee Statement: New text is added to bring awareness on protecting noise sensitive equipment with clean agent systems.

Response Message: FR-2-NFPA 2001-2019

Public Input No. 42-NFPA 2001-2018 [New Section after 1.4.2.4]

Public Input No. 43-NFPA 2001-2018 [New Section after A.1.4.2.4]



First Revision No. 40-NFPA 2001-2019 [Detail]

C.2.2 Equipment ~~Required~~ .

The equipment identified in C.2.2.1 and C.2.2.2 is ~~required~~ necessary to test an enclosure using fan pressurization technology.

Submitter Information Verification

Committee:

Submittal Date: Fri Jun 14 15:17:31 EDT 2019

Committee Statement

Committee Statement: The word "required" is eliminated from the title and text because annexes cannot contain requirements. See FR 27 for additional changes on this section.

Response Message: FR-40-NFPA 2001-2019

**First Revision No. 38-NFPA 2001-2019 [Section No. 1.4.2.2]****4.2.2 Incompatible Hazards.**

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

- (1) Certain chemicals or mixtures of chemicals, such as cellulose nitrate and gunpowder, which 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, pyrophoric materials, and hydrazine
- (5) Class A fuels subject to smoldering (deep-seated) combustion *[see 3.3.38, Smoldering (Deep-Seated) Combustion]*

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Fri May 10 13:56:26 EDT 2019

Committee Statement

Committee Statement: Protection of smoldering (deep-seated) combustion hazards is deleted from 5.4.2 (see FR-25), since minimum extinguishing concentrations have not been established by test for any clean agent.

Addressing this type of hazard in 5.4.2 could lead to confusion over the applicability of clean agent systems to deep-seated hazards. Therefore, "Class A materials subject to smoldering (deep-seated) combustion" is added to the list in 1.4.2.2, which identifies materials that cannot be protected with a clean agent without testing. This is a more appropriate location for this requirement. A new definition (see FR-39) of 'smoldering (deep-seated) combustion' is added for clarification.

Response FR-38-NFPA 2001-2019

Message:

**First Revision No. 3-NFPA 2001-2019 [Section No. 2.3.9]****2.3.9** UL Publications.

Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096.

ANSI/ UL 2127, ~~Standard for Inert Gas Clean Agent Extinguishing System Units, 2012 (revised 2015)~~ 2018 .

ANSI/ UL 2166, ~~Standard for Halocarbon Clean Agent Extinguishing System Units, 2012 (revised 2015)~~ 2018 .

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Wed Apr 24 15:04:22 EDT 2019

Committee Statement

Committee Statement: Update of references.

Response Message: FR-3-NFPA 2001-2019

Public Input No. 65-NFPA 2001-2018 [Section No. 2.3.9]

**First Revision No. 4-NFPA 2001-2019 [Section No. 2.3.10]****2.3.10** ULC Publications.

~~Underwriters Laboratories of Canada, 7 Underwriters Road, Toronto, ON M1R 3B4, Canada~~ ULC Standards, 171 Nepean Street, Suite 400, Ottawa, ON K2P 0B4 Canada .

CAN/ULC S524-14, ~~Standard for the~~ *Installation of Fire Alarm Systems*, 2014.

CAN/ULC S529-16, *Smoke Detectors for Fire Alarm Systems*, 2016.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Wed Apr 24 15:04:55 EDT 2019

Committee Statement

Committee Statement: A new address for ULC was provided to reflect the company location change.

Response Message: FR-4-NFPA 2001-2019

Public Input No. 66-NFPA 2001-2018 [Section No. 2.3.10]

**First Revision No. 28-NFPA 2001-2019 [Section No. 3.3.16]****3.3.16** Inert Gas Agent.

An agent that contains ~~as primary components~~ one or more of the following gases as components: helium, neon, argon, or nitrogen. ~~Inert gas agents that are blends of gases , and that~~ can also contain carbon dioxide as a ~~secondary~~ minor component.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Fri Apr 26 18:49:57 EDT 2019

Committee Statement

Committee The definition is revised to meet the Manual of Style, which does not permit more than one **Statement:** sentence in a definition.

Response FR-28-NFPA 2001-2019

Message:

**First Revision No. 31-NFPA 2001-2019 [Section No. 3.3.26]****3.3.26** No Observed Adverse Effect Level (NOAEL).

The highest concentration at which no adverse physiological or toxicological ~~or physiological~~ effect has been observed.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Tue Apr 30 18:54:11 EDT 2019

Committee Statement

Committee The order of words is reversed to match the order used in the definition for Lowest Observed
Statement: Adverse Effect Level (LOAEL)

Response FR-31-NFPA 2001-2019

Message:



First Revision No. 29-NFPA 2001-2019 [New Section after 3.3.27]

3.3.28 Normally Unoccupied Enclosure or Space.

An enclosure or space not normally occupied but one that could be entered occasionally by one or more persons for brief periods.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Tue Apr 30 18:48:30 EDT 2019

Committee Statement

Committee The definitions of Normally Unoccupied Enclosure or Space is added from NFPA 12, as this
Statement: term is used in several paragraphs of this document.

Response FR-29-NFPA 2001-2019

Message:

**First Revision No. 39-NFPA 2001-2019 [New Section after 3.3.36]****3.3.38* Smoldering (Deep-Seated) Combustion.**

A form of combustion without flame that occurs in fuel that is comprised of finely divided fibers or particles that have a relatively large surface area-to-mass ratio.

A.3.3.38 Smoldering (Deep-Seated) Combustion.

Two types of fires can occur in solid fuels: (1) one in which volatile gases resulting from heating or decomposition of the fuel surface are the source of combustion and (2) one in which oxidation occurs at the surface of or in the mass of fuel. The first type of fire is commonly referred to as "flaming" combustion, while the second type is often called "smoldering" or "glowing" combustion. The two types of fires frequently occur concurrently, although one type of burning can precede the other. For example, a wood fire can start as flaming combustion and become smoldering as burning progresses. Conversely, spontaneous ignition in a pile of oily rags can begin as a smoldering fire and break into flames at some later point. Flaming combustion, because it occurs in the vapor phase, can be extinguished with relatively low levels of clean agents. In the absence of smoldering combustion, it will stay out.

Unlike flaming combustion, smoldering combustion is not subject to immediate extinguishment. Characteristic of this type of combustion is the slow rate of heat losses from the reaction zone. Thus, the fuel remains hot enough to react with oxygen, even though the rate of reaction, which is controlled by diffusion processes, is extremely slow. Smoldering fires can continue to burn for many weeks, for example, in bales of cotton and jute and heaps of sawdust. A smoldering fire ceases to burn only when either all the available oxygen or fuel has been consumed or the fuel surface is at too low a temperature to react. Smoldering fires usually are extinguished by reducing the fuel temperature, either directly by application of a heat-absorbing medium, such as water, or by blanketing with an inert gas. The inert gas slows the reaction rate to the point where heat generated by oxidation is less than heat losses to surroundings. This causes the temperature to fall below the level necessary for spontaneous ignition after removal of the inert atmosphere.

For the purposes of this standard, smoldering fires are divided into two classes: (1) where the smoldering is not "deep seated" and (2) deep-seated fires. Whether a fire will become deep seated depends, in part, on the length of time it has been burning before application of the extinguishing agent. This time is usually called the "preburn" time.

Another important variable is the fuel configuration. While wood cribs and pallets are easily extinguished with Class A design concentrations, vertical wood panels closely spaced and parallel can require higher concentrations and long hold times for extinguishment. Fires in boxes of excelsior and in piles of shredded paper also can require higher concentrations and long hold times for extinguishment. In these situations, heat tends to be retained in the fuel array rather than being dissipated to the surroundings. Radiation is an important mechanism for heat removal from smoldering fires.

Smoldering combustion is commonly referred to as deep-seated combustion. The fuel aggregate must be permeable to allow oxygen transport to the combustion reaction zone below the surface of the fuel. The fuel aggregate must also be dense enough to form an effective insulation layer that slows down heat losses from the reaction zone. Smoldering combustion can occur only in solid fuels.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Fri May 10 14:02:44 EDT 2019

Committee Statement

Committee Protection of smoldering (deep-seated) combustion hazards is deleted from 5.4.2 (see FR-25), since
Statement: minimum extinguishing concentrations have not been established by test for any clean agent.

Addressing this type of hazard in 5.4.2 could lead to confusion over the applicability of clean agent systems to deep-seated hazards. Therefore, "Class A materials subject to smoldering (deep-seated) combustion" is added to the list in 1.4.2.2 (see FR-38), which identifies materials that cannot be protected with a clean agent without testing. This is a more appropriate location for this requirement. A new definition of 'smoldering (deep-seated) combustion' is added for clarification.

Response FR-39-NFPA 2001-2019

Message:



First Revision No. 30-NFPA 2001-2019 [New Section after 3.3.39]

3.3.42 Unoccupiable Enclosure or Space.

An enclosure or space that has dimensions and physical characteristics such that it could not be entered by a person.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Tue Apr 30 18:52:29 EDT 2019

Committee Statement

Committee The definition of Unoccupiable Enclosure or Space is added from NFPA 12, as this term is
Statement: used in several paragraphs of this document.

Response FR-30-NFPA 2001-2019

Message:



First Revision No. 16-NFPA 2001-2019 [New Section after 4.1.4.4]

5.1.4.5*

Where a liquid-level indicator (LLI) is provided as a component of the container assembly, the LLI and method of measuring the agent quantity shall be listed.

A.5.1.4.5

For refillable halocarbon agent containers, an LLI can be considered, where available from the system manufacturer. The LLI provides the means to safely determine the quantity of halocarbon agent in accordance with the requirements of 11.3.1 without lifting or moving the container.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 11:09:52 EDT 2019

Committee Statement

Committee Statement: Most manufacturers of refillable halocarbon agent containers offer an optional liquid level device (LLI), in at least part of the product line, to assist the servicing personnel to determine the quantity of halocarbon agent in the storage container without the need to lift or move the container. This allows for additional safe handling practices to avoid injury to the service personnel. Where available, this liquid level indicator (LLI) must be listed to meet the requirement in 8.3.6 for special measuring devices.

Response FR-16-NFPA 2001-2019
Message:

Public Input No. 62-NFPA 2001-2018 [New Section after A.4.1.4.2]



First Revision No. 7-NFPA 2001-2019 [Section No. 4.2.1.1.1]

5.2.1.1.1

In no case shall the value used for the minimum pipe design pressure be less than that specified in Table 5.2.1.1.1(a) and Table 5.2.1.1.1(b) for the conditions shown. For inert gas clean agents that employ the use of a pressure-reducing device, Table 5.2.1.1.1(a) shall be used for piping upstream of the pressure reducer, and 5.2.1.1.2 shall be used to determine minimum pipe design pressure for piping downstream of the pressure reducer. The pressure-reducing device shall be readily identifiable. For halocarbon clean agents, Table 5.2.1.1.1(b) shall be used. If different fill densities, pressurization levels, or higher storage temperatures from those shown in Table 5.2.1.1.1(a) or Table 5.2.1.1.1(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 5.2.1.1(1) and 5.2.1.1(2).

Table 5.2.1.1.1(a) Minimum Design Working Pressure for Inert Gas Clean Agent System Piping

Agent	Agent Container Gauge Pressure at 70°F (21°C)		Agent Container Gauge Pressure at 130°F (55°C)		Minimum Design Pressure of Piping Upstream of Pressure Reducer	
	psi	kPa	psi	kPa	psi	kPa
IG-01	2370	16,341	2650	18,271	2370	16,341
	2964	20,436	3304	22,781	2964	20,436
	4510	31,097	5402	37,244	4510	31,097
IG-541	2175	14,997	2575	17,755	2175	14,997
	2900	19,996	3433	23,671	2900	19,996
	4351	30,000	5150	35,500	4351	30,000
IG-55	2175	15,000	2541	17,600	2175	15,000
	2900	20,000	3434	23,700	2900	20,000
	4350	30,000	5222	36,100	4350	30,000
IG-100	2404	16,575	2799	19,299	2404	16,575
	3236	22,312	3773	26,015	3236	22,312
	4061	28,000	4754	32,778	4061	28,000

Table 5.2.1.1.1(b) Minimum Design Working Pressure for Halocarbon Clean Agent System Piping

Agent	Agent Container Maximum Fill Density		Agent Container Charging Pressure at 70°F (21°C)		Agent Container Pressure at 130°F (55°C)		Minimum Piping Design Pressure	
	lb/ft ³	kg/m ³	psi	bar	psi	bar	psi	bar
HFC-227ea	79	1265	44*	3	135	9	416	29
	75	1201	150	10	249	17	200	14
	72	1153	360	25	520	36	416	29
	72	1153	600	41	1025	71	820	57
HCFC Blend A	56.2	900	600	41	850	59	680	47
	56.2	900	360	25	540	37	432	30
HFC 23	54	865	608.9†	42	2182	150	1746	120
	48	769	608.9†	42	1713	118	1371	95
	45	721	608.9†	42	1560	108	1248	86
	40	641	608.9†	42	1382	95	1106	76
	35	561	608.9†	42	1258	87	1007	69
	30	481	608.9†	42	1158	80	927	64
HCFC-124	74	1185	240	17	354	24	283	20
HCFC-124	74	1185	360	25	580	40	464	32
HFC-125	54	865	360	25	615	42	492	34

Agent	Agent Container Maximum Fill Density		Agent Container Charging Pressure at 70°F (21°C)		Agent Container Pressure at 130°F (55°C)		Minimum Piping Design Pressure	
	lb/ft ³	kg/m ³	psi	bar	psi	bar	psi	bar
HFC 125	56	897	600	41	1045	72	836	58
HFC-236fa	74	1185	240	17	360	25	280	19
HFC-236fa	75	1201	360	25	600	41	480	33
HFC-236fa	74	1185	600	41	1100	76	880	61
HFC Blend B	58	929	360	25	586	40	469	32
	58	929	600	41	888	61	710	50
FK-5-1-12	90	1442	150	10	175	12	150	10
	90	1442	195	13	225	16	195	13
	90	1442	360	25	413	28	360	25
	75	1201	500	34	575	40	500	34
	90	1442	610	42	700	48	610	42
	<u>70</u>	<u>1121</u>	<u>870</u>	<u>60</u>	<u>975</u>	<u>67</u>	<u>870</u>	<u>60</u>

*Nitrogen delivered to agent cylinder through a flow restrictor upon system actuation. Nitrogen supply cylinder pressure is 1800 psi (124 bar) at 70°F (21°C).

†Not superpressurized with nitrogen.

5.2.1.1.1.1

For inert gas clean agents that employ the use of a pressure-reducing device, and both of the following shall apply:

- (1) Table 5.2.1.1.1(a) shall be used for piping upstream of the pressure reducer.
- (2) Subparagraph 5.2.1.1.2 shall be used to determine minimum pipe design pressure for piping downstream of the pressure reducer.

5.2.1.1.1.2

The pressure-reducing device shall be readily identifiable.

5.2.1.1.1.3

For halocarbon clean agents, Table 5.2.1.1.1(b) shall be used.

5.2.1.1.1.4

If different fill densities, pressurization levels, or higher storage temperatures from those shown in Table 5.2.1.1.1(a) or Table 5.2.1.1.1(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 5.2.1.1(1) and 5.2.1.1(2).

Supplemental Information

File Name	Description Approved
2001_FR7_4.2.1.1.1.docx	STAFF USE

Submitter Information Verification

Committee: GFE-AAA

Submission Date: Wed Apr 24 15:51:13 EDT 2019

Committee Statement

Committee Statement: A system is commercialized that incorporated FK-5-1-12 at a charge pressure of 60 Bar. Table 4.2.1.1.1(b) is revised to include the working pressures for this system.

Response FR-7-NFPA 2001-2019

Message:

[Public Input No. 18-NFPA 2001-2018 \[Section No. 4.2.1.1.1\]](#)



First Revision No. 9-NFPA 2001-2019 [Section No. 4.2.1.6]

5.2.1.6 Dirt Trap.

5.2.1.6.1

A dirt trap consisting of a tee with a capped nipple, at least 2 in. (50 mm) and not more than 4 pipe diameters long, shall be installed ~~at the end of~~ after the last nozzle on each pipe run.

5.2.1.6.2

Single nozzle systems with a single pipe run from a clean agent container to the nozzle shall not be required to have a dirt trap.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Wed Apr 24 16:35:27 EDT 2019

Committee Statement

Committee The revised language further details where dirt traps should be required to be installed. A **Statement:** maximum length was also added to limit the potential effects on system hydraulic performance.

Response FR-9-NFPA 2001-2019

Message:

[Public Input No. 5-NFPA 2001-2018 \[Section No. 4.2.1.6\]](#)

[Public Input No. 6-NFPA 2001-2018 \[New Section after 4.2.1.6\]](#)

**First Revision No. 25-NFPA 2001-2019 [Section No. 5.4]****7.2 Design Concentration Requirements.****7.2.1 General.****7.2.1.1**

The flame-extinguishing or inerting concentrations shall be used in determining the agent design concentration for a particular the specific fuel.

7.2.1.2

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.

7.2.2 Flame Extinguishment.**7.2.2.1 Class A Hazards.****7.2.2.1.1**

The ~~flame~~ minimum extinguishing concentration for Class A fuels shall be determined by test as part of a listing program in accordance with 7.2.2.3 .

7.2.2.1.2

The minimum design concentration for a Class A surface-fire hazard shall be determined by the greater of the following:

- (1) The extinguishing concentration, as determined in 7.2.2.1.1 , times a safety factor of 1.2 for systems with automatic detection and actuation (see 9.1.2.1) or 1.3 for systems with manual-only actuation (see 9.1.2.2)
- (2) Equal to the minimum extinguishing concentration for heptane as determined from 7.2.2.1.1 7.2.2.2.1 (2)

7.2.2.2 Class B Hazards.**7.2.2.2.1***

The flame-extinguishing concentration for Class B fuels shall be determined by the ~~cup burner method described in Annex G~~ - greater of the following:

- (1) The Class B concentration as determined by a listing program in accordance with 7.2.2.3
- (2) The flame-extinguishing concentration for the specific fuel, as determined by the cup burner method (see Annex B)

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

7.2.2.2.2

Measurement equipment used in applying the cup burner method shall be calibrated.

7.2.2.2.3

The minimum design concentration for a Class B fuel hazard shall be the extinguishing concentration, as determined in 7.2.2.2.1 , times a safety factor of 1.3.

Global FR-1

7.2.2.3* Listing Program.

As a minimum, the listing program shall conform to ANSI/ UL 2127 or ANSI/ UL 2166 or equivalent.

A.7.2.2.3

The following steps detail the fire extinguishment/area coverage fire test procedure for engineered and pre-engineered clean-agent-extinguishing-system units:

(1) The general ~~requirements~~procedures are as follows:

- (a) 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.7.2.2.3(1)(c) through A.7.2.2.3(6)(f) under the maximum design limitations and most severe installation instructions. See also A.7.2.2.3(1)(b).
- (b) When tested as described in A.7.2.2.3(2)(a) through A.7.2.2.3(5)(b), an extinguishing system unit should extinguish all fires within 30 seconds after the end of system discharge. When tested as described in A.7.2.2.3(2)(a) through A.7.2.2.3(3)(c) and A.7.2.2.3(6)(a) through A.7.2.2.3(6)(f), an extinguishing system should prevent reignition of the wood crib after a 10-minute soak period.
- (c) The tests described in A.7.2.2.3(2)(a) through A.7.2.2.3(6)(f) should be carried out. Consider the intended use and limitations of the extinguishing system, with specific reference to the following:
 - i. The area coverage for each type of nozzle
 - ii. The operating temperature range of the system
 - iii. Location of the nozzles in the protected area
 - iv. Either maximum length and size of piping and number of fittings to each nozzle or minimum nozzle pressure
 - v. Maximum discharge time
 - vi. Maximum fill density

(2) The test enclosure construction is as follows:

- (a) The enclosure for the test should be constructed of either indoor- or outdoor-grade minimum $\frac{3}{8}$ in. (9.5 mm)–thick plywood or equivalent material.
- (b) 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 335 ± 35 ft³ (100 m³) in volume.

(3) The extinguishing system is as follows:

- (a) A pre-engineered type of 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.
- (b) 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).
- (c) Except for the flammable liquid fire test using the 2.5 ft² (0.23 m²) 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.

(4) The extinguishing concentration is as follows:

- (a) The extinguishing agent concentration for each Class A 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.
- (b) The extinguishing agent concentration for each Class B test is to be 76.9 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.

- (c) The concentration for inert gas clean agents can be adjusted to take into consideration actual leakage measured from the test enclosure.
- (d) 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.

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

[A.5.4.2.2aA.7.]

where:

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

V=volume of test enclosure [ft³ (m³)]

S=specific volume of clean agent at test temperature [ft³/lb (m³/kg)]

C=concentration (vol %)

- (5) The flammable liquid extinguishment tests are as follows:

- (a) Steel test cans having a nominal thickness of 0.216 in. (5.5 mm) (such as 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 the 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, closable 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 2.5 ft² (0.23 m²) 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, at 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 percent.
- (b) The heptane is to be commercial grade having the following characteristics:
 - i. Initial boiling point: 194°F (90°C) minimum
 - ii. Dry point: 212°F (100°C) maximum
 - iii. Specific gravity: 0.69–0.73

- (6) The wood crib extinguishment tests are as follows:

- (a) 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.
- (b) The wood crib is to consist of four layers of six, trade size 2 by 2 (1½ by 1½ in.) by 18 in. long, kiln spruce or fir lumber having a moisture content between 9 percent 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.
- (c) Ignition of the crib is to be achieved by the burning of commercial-grade heptane in a square steel pan 2.5 ft² (0.23 m²) 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 in. 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.

- (d) 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 3½ minutes. Approximately ¼ gal (0.95 L) of heptane will provide a 3 to 3½ minute burn time. Just prior to the end of the pre-burn 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 in. and 28 in. (508 mm and 711 mm) above the floor. The closure is then to be sealed.
 - (e) After the crib is allowed to burn for 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 percent.
 - (f) After the end of system discharge, the enclosure is to remain sealed for 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 re-ignition.
- (7) The following is a schematic of the process to determine the design quantity:
- (a) Determine hazard features, as follows:
 - i. Fuel type: Extinguishing concentration (EC) per 7.2.2 or inerting concentration (IC) per 7.2.3
 - ii. Enclosure volume
 - iii. Enclosure temperature
 - iv. Enclosure barometric pressure

- (b) Determine the agent minimum design concentration (MDC) by multiplying EC or IC by the safety factor (SF):

$$\text{MDC} = (\text{EC or IC}) \text{ SF} \quad \text{[A.5.4.2.2b A.7]}$$

- (c) Determine the agent minimum design quantity (MDQ) by referring to 7.3.1 for halocarbons or 7.3.2 for inert gases
- (d) Determine whether design factors (DF) apply. See 7.3.3 to determine individual DF [DF(i)] and then determine sum:

$$\text{DF} = \Sigma \text{DF}(i) \quad \text{[A.5.4.2.2c A.7]}$$

- (e) Determine the agent adjusted minimum design quantity (AMDQ):

$$\text{AMDQ} = \text{MDQ} (1 + \text{DF}) \quad \text{[A.5.4.2.2d A.7]}$$

- (f) Determine the pressure correction factor (PCF) per 7.3.3.3

- (g) Determine the final design quantity (FDQ) as follows:

$$\text{FDQ} = \text{AMDQ} \times \text{PCF} \quad \text{[A.5.4.2.2e A.7]}$$

Where any of the following conditions exist, higher extinguishing concentrations might be required:

- (1) Cable bundles greater than 4 in. (100 mm) in diameter
- (2) Cable trays with a fill density greater than 20 percent of the tray cross section
- (3) Horizontal or vertical stacks of cable trays less than 10 in. (250 mm) apart

- (4) Equipment energized during the extinguishment period where the collective power consumption exceeds 5 kW

Fire extinguishment tests for (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 3530 ft³ (100 m³) and a minimum height of 11.5 ft (3.5 m) and each wall at least 13.1 ft (4 m) long. Provisions should be made for relief venting if required.

The test objects are as follows:

- (1) The polymer fuel array consists of four sheets of polymer, $\frac{3}{8}$ in. (9.53 mm) thick, 16 in. (406 mm) tall, and 8 in. (203 mm) wide. Sheets are spaced and located per [Figure A.7.2.2.3\(a\)](#). The bottom of the fuel array is located 8 in. (203 mm) from the floor. The fuel sheets should be mechanically fixed at the required spacing.
- (2) A fuel shield is provided around the fuel array as indicated in [Figure A.7.2.2.3\(a\)](#). The fuel shield is 15 in. (381 mm) wide, 33.5 in. (851 mm) high, and 24 in. (610 mm) deep. The 24 in. (610 mm) wide $\times$ 33.5 in. (851 mm) high sides and the 24 in. (610 mm) $\times$ 15 in. (381 mm) top are sheet metal. The remaining two sides and the bottom are open. The fuel array is oriented in the fuel shield such that the 8 in. (203 mm) dimension of the fuel array is parallel to the 24 in. (610 mm) side of the fuel shield.
- (3) Two external baffles measuring 40 in. $\times$ 40 in. (1 m $\times$ 1 m) and 12 in. (0.3 m) tall are located around the exterior of the fuel shield as shown in [Figure A.7.2.2.3\(a\)](#) and [Figure A.7.2.2.3\(b\)](#). The baffles are placed 3.5 in. (0.09 m) above the floor. The top baffle is rotated 45 degrees with respect to the bottom baffle.
- (4) Tests are conducted for three plastic fuels — polymethyl methacrylate (PMMA), polypropylene (PP), and acrylonitrile-butadiene-styrene (ABS) polymer. Plastic properties are given in [Table A.7.2.2.3\(a\)](#).
- (5) The ignition source is a heptane pan 2 in. $\times$ 2 in. $\times$ $\frac{7}{8}$ in. deep (51 mm $\times$ 51 mm $\times$ 22 mm deep) centered $\frac{1}{2}$ in. (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.
- (6) 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:

- (1) The procedures for ignition are as follows:
 - (a) The heptane pan is ignited and allowed to burn for 90 seconds.
 - (b) The agent is discharged 210 seconds after ignition of heptane.
 - (c) 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 of agent discharge, a higher minimum extinguishing concentration must be utilized.
 - (d) 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.
 - (e) 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 affecting the extinguishment process.
 - (f) At the beginning of the tests, the oxygen concentration must be within 2 percent (approximately 0.5 percent by volume O₂) of ambient value.
 - (g) During the post-discharge period, the oxygen concentration should not fall below 0.5 percent by volume of the oxygen level measured at the end of agent discharge.
- (2) The observation and recording procedures are as follows:
 - (a) The following data must be recorded continuously during the test:

- (b) The following events are timed and recorded:

- The minimum extinguishing concentration is determined by all of the following conditions:

- Figure A.7.2.2.3(a) Four-Piece Modified Plastic Setup.**

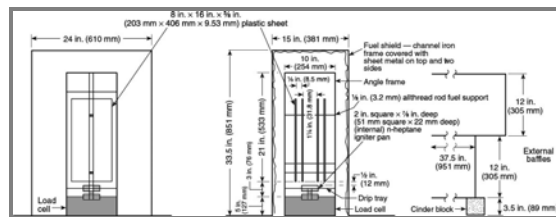


Figure A.7.2.2.3(b) Chamber Plan View.

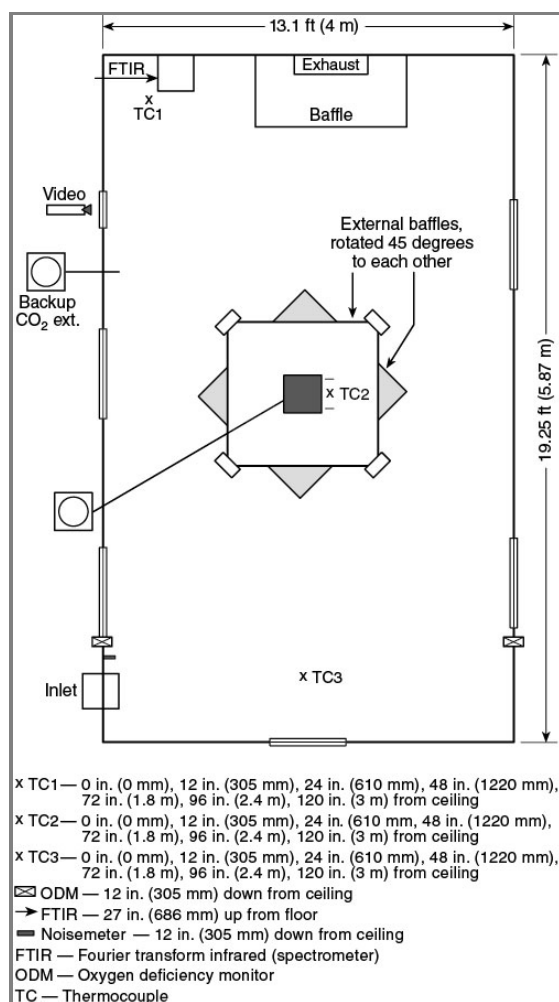


Table A.7.2.2.3(a) Plastic Fuel Properties

25 kW/m ² Exposure in Cone Calorimeter — ASTM E1354								
Fuel	Color	Density (g/cm ²)	Ignition Time		180-Second Average Heat Release Rate		Effective Heat of Combustion	
			sec	Tolerance	kW/m ²	Tolerance	MJ/kg	Tolerance
PMMABlack		1.19	77	±30%	286	25%	23.3	±15%
PP	Natural (white)	0.905	91	±30%	225	25%	39.8	±15%
ABS	Natural (cream)	1.04	115	±30%	484	25%	29.1	±15%

Table A.7.2.2.3(b) Class A Flame Extinguishing and Minimum Design Concentrations Tested to UL 2166 and UL 2127

Agent	Class A MEC	Class A Minimum Design Concentration	Class C Minimum Design Concentration
FK-5-1-12	3.3	4.5	4.5
HFC-125	6.7	8.7	9.0
HFC-227ea	5.2	6.7	7.0
HFC-23	15.0	18.0	20.3
IG-541	28.5	34.2	38.5
IG-55	31.6	37.9	42.7
IG-100	31.0	37.2	41.9

Note: Concentrations reported are at 70°F (21°C). Class A design values are the greater of (1) the Class A extinguishing concentration, determined in accordance with 5.4.2.2.2.1.1, times a safety factor of 1.2; or (2) the minimum extinguishing concentration for heptane as determined from 5.4.2.17.2.2.2.1(b).

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. Wood crib and polymeric sheet Class A fire tests ~~may~~might not adequately indicate extinguishing concentrations suitable for the protection of certain plastic fuel hazards (e.g., electrical- and electronic-type hazards involving grouped power or data cables such as computer and control room underfloor voids and telecommunication facilities).

The values in ~~Table A.7.2.2.3(b)~~this table are representative of the minimum extinguishing concentrations and design concentrations for various agents. The concentrations required can vary by equipment manufacturer. Equipment manufacturers should be contacted for the concentration required for their specific system.

7.2.2.4 Class C Hazards.

7.2.2.4.1

The minimum design concentration for a Class C hazard shall be the Class A minimum extinguishing concentration, as determined in 5.4.2.2.2.2.1.1, times a safety factor of 1.35.

7.2.2.4.2

The minimum design concentration for spaces containing energized electrical hazards supplied at greater than 480 volts that remain powered during and after discharge shall be determined by a hazard analysis and testing, as necessary, ~~and a hazard analysis~~.

7.2.3 Inerting.

7.2.3.1*

The inerting concentration shall be determined by test.

7.2.3.2*

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

7.2.3.3

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.

Supplemental Information

File Name	Description Approved
2001_FR25_5.4.docx	STAFF USE

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 15:56:35 EDT 2019

Committee Statement

Committee Section 5.4.1 is revised to comply with the Manual of Style, including a new subsection title and **Statement:** separating the requirements into individual paragraphs.

Section 5.4.2 is revised to more clearly establish the basis for minimum extinguishing concentrations and minimum design concentrations for each class of fire.

Protection of smoldering (deep-seated) combustion hazards is deleted from 5.4.2, since minimum extinguishing concentrations have not been established by test for any clean agent. Addressing this type of hazard in 5.4.2 could lead to confusion over the applicability of clean agent systems to deep-seated hazards. Therefore, "Class A materials subject to smoldering (deep-seated) combustion" is added to the list in 1.4.2.2 (see FR-38), which identifies materials that cannot be protected with a

clean agent without testing. This is a more appropriate location for this requirement. A new definition of 'smoldering (deep-seated) combustion' is added (see FR-39) as would be needed.

Response FR-25-NFPA 2001-2019

Message:

[Public Input No. 68-NFPA 2001-2018 \[Section No. 5.4\]](#)

[Public Input No. 47-NFPA 2001-2018 \[Section No. A.5.4.2.1\]](#)

**First Revision No. 10-NFPA 2001-2019 [Section No. 5.6]****7.4* Duration of Protection.****7.4.1***

~~It is important that the adjusted minimum design concentration of agent not only shall be achieved but also shall be maintained for the specified period of time to allow effective emergency action by trained personnel.~~

A.7.4.1

~~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.~~

7.4.1

A For flame-extinguishing systems, a minimum concentration of 85 percent of the adjusted minimum design concentration shall be held at the highest height of protected content within the hazard for a period of 10 minutes or for a time period sufficient to allow for response by trained personnel.

7.4.2

For inerting systems, a minimum concentration not less than the inerting concentration determined in accordance with 7.2.3.1 shall be held throughout the protected space for a time period sufficient to allow for response by trained personnel.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Wed Apr 24 17:21:47 EDT 2019

Committee Statement

Committee Statement: The section is rewritten to address systems used for inerting, which use a lower safety factor (see 5.4.3).

Existing 5.6.1 is deleted, as it was in conflict with the original requirement to maintain 85 percent of the adjusted minimum design concentration. The associated annex material is deleted, as well, as it was redundant to A.5.6.

Response Message: FR-10-NFPA 2001-2019

Public Input No. 2-NFPA 2001-2018 [Section No. 5.6]

**First Revision No. 33-NFPA 2001-2019 [Section No. 8.5.2]****11.5.2**

Actuation, impairment, and restoration of ~~this protection~~ the clean agent system shall be reported promptly to the authority having jurisdiction.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Tue Apr 30 19:13:52 EDT 2019

Committee Statement

Committee Statement: The text is revised to be more specific.

Response Message: FR-33-NFPA 2001-2019

**First Revision No. 12-NFPA 2001-2019 [Section No. 8.6.1]****11.6.1***

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~~ the requalification period specified by the regulating authority for the container has elapsed since the date of the last test and inspection.

11.6.1.1

For halocarbon agent storage containers, the retest shall be permitted to consist of a complete visual inspection as described in 49 CFR.

11.6.1.2

A cylinder shall be permitted to be requalified at any time during or before the month and year that the requalification is due.

11.6.1.3

A cylinder filled before the requalification becomes due shall be both of the following:

- (1) Permitted to remain in service
- (2) Periodically inspected in accordance with 11.6.2

11.6.1.4

A cylinder with a specified service life shall not be refilled and offered for transportation after its authorized service life has expired.

11.6.1.2

~~For inert gas agent storage containers, the retest shall be in accordance with U.S. Department of Transportation (DOT), Canadian Transport Commission (CTC), or similar design and requalification regulations.~~

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Wed Apr 24 17:52:27 EDT 2019

Committee Statement

Committee The revised section more clearly defines the requirements for requalification of cylinders. The

Statement: specific reference to a 5-year interval in 5.6.1 was removed, as some cylinder types or regulations permit different testing intervals.

Response FR-12-NFPA 2001-2019

Message:

Public Input No. 44-NFPA 2001-2018 [Section No. 8.6.1]

**First Revision No. 13-NFPA 2001-2019 [Section No. 8.6.2 [Excluding any Sub-Sections]**

]

Containers continuously in service without discharging need for refill or repair shall be given a complete external visual inspection every 5 years, or more frequently if required.

Submitter Information Verification**Committee:** GFE-AAA**Submittal Date:** Wed Apr 24 18:06:18 EDT 2019**Committee Statement**

Committee Statement: The revision addresses recharges performed for leakage and damage, as well as discharge.

Response Message: FR-13-NFPA 2001-2019Public Input No. 45-NFPA 2001-2018 [Section No. 8.6.2 [Excluding any Sub-Sections]]



First Revision No. 14-NFPA 2001-2019 [Section No. A.1.5.1.2]

B.1.1 Toxicological Effects of Halocarbon Agents.

Table A.1.5.1.2(a) Table B.1.1 provides information on the toxicological effects of halocarbon agents covered by this standard. The no observable adverse effect level (NOAEL) is the highest concentration at which no adverse physiological or toxicological effect has been observed. The lowest observable adverse effect level (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 B.1.1 Toxicity Information for Halocarbon Clean Agents

Agent	LC ₅₀ or ALC (%)	NOAEL (%)	LOAEL (%)
FIC-1311	>12.8	0.2	0.4
FK-5-1-12	>10.0	10	>10.0
HCFC Blend A	64	10	>10.0
HCFC-124	23–29	1	2.5
HFC-125	>70	7.5	10
HFC-227ea	>80	9	10.5
HFC-23	>65	30	>30
HFC-236fa	>45.7	10	15
HFC Blend B	56.7*	5.0*	7.5*

Notes:

(1) LC₅₀ 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.

*These values are for the largest component of the blend (HFCB 134A).

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 heartbeats 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 (*i.e.*, 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 its 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 concentrations 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; thus, cardiac sensitization will not occur. Accordingly, in the tables in 4.5.1.2.4 4.3.2.3, 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, 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 pre-discharge alarms and time delays is intended to prevent human exposure to agents during firefighting. 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 4.3.2.3. The concentrations and times given in the tables 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.

In specialized applications that require a very high rate of discharge, where agent concentration is measured at a much faster rate than human respiration periods, brief pulses of high concentration levels can be observed. In these cases, a time-weighted average of the concentration level with a period of one second can be used to compare to the safe levels given in the tables in 4.3.2.3.

B.1.2 Toxicological Effects of Hydrogen Fluoride.

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 (i.e., front part) region of the nose and extending back to the lower respiratory tract (i.e., 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 (i.e., 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 patterns would be expected to change primarily from nose breathing to primarily mouth breathing. This change in breathing pattern determines the deposition pattern of HF into the respiratory tract, either upper respiratory tract (i.e., nose breathing) or lower respiratory tract (i.e., mouth breathing). In studies conducted by Dalby (1996), rats were exposed by nose-only or mouth-only breathing. In the mouth-only breathing 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 breathe through the nose but inhale through the mouth, thereby maximizing the deposition of HF into the lower respiratory tract.

In the nose-only breathing model, 2-minute or 10-minute exposures of rats to about 6400 or 1700 ppm, respectively, produced similar effects; that is, no mortality resulted but significant cell damage in the nose was observed. In contrast, marked differences in toxicity were evident in the mouth-only 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, such as 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 was observed 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 (1993) proposed the concept of the dangerous toxic load (DTL) as a means of predicting the effects of, for example, HF in humans. Meldrum developed the argument that the toxic effects of certain chemicals tend to follow Haber's law:

$$C \times t = k$$

[A-1.5.1.2 B.1.]

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 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, such as firefighters, and those with compromised health. Exposure to higher concentrations of HF would be expected to be tolerated more in healthy individuals, whereas equal concentrations can have escape-impairing effects in those with compromised health. The following discussion assumes that the effects described at the various concentrations and durations are for the healthy individual.

Inflammation (*i.e.*, irritation) of tissues represents a continuum from “no irritation” to “severe, deep penetrating” irritation. Use of the 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 (*i.e.*, 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 (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 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.1.5.1.2(b) Table B.1.2 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 a 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 might need to be considered in clean-up procedures where high levels of HF were generated.

Table B.1.2 Potential Human Health Effects of Hydrogen Fluoride in Healthy Individuals

Exposure Time	Concentration of	
	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

Exposure Time	Concentration of	
	Hydrogen Fluoride (ppm)	Reaction
10 minutes	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 effects 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~~ The ERPG/WEEL Handbook provides a quick reference for these limits, which are established to also account for sensitive populations, such as 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. (1934) and 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.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 10:03:26 EDT 2019

Committee Statement

Committee Statement: The dosing unit in paragraph 21 (following Equation A.1.5.1.2) is corrected from ppm/min to ppm-min.

A new paragraph addresses the interpretation of very brief (sub second) excursions of agent concentration to high levels, which might not represent a failure to meet NFPA 2001 safe breathing limits.

Response Message: FR-14-NFPA 2001-2019

Public Input No. 48-NFPA 2001-2018 [Section No. A.1.5.1.2]



First Revision No. 8-NFPA 2001-2019 [Section No. A.4.1.4.1]

A.5.1.4.1

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 Figure A.5.1.4.1(a) through Figure A.5.1.4.1(m).

For halocarbon clean 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 and present a hazard to personnel and property. Therefore, it is 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.5.1.4.1](#) 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.5.1.4.1](#).

[Annex F](#) discusses the effects of temperature changes on superpressurized vaporizing-liquid agents.

Figure A.5.1.4.1(a) Isometric Diagram of FIC-131I.

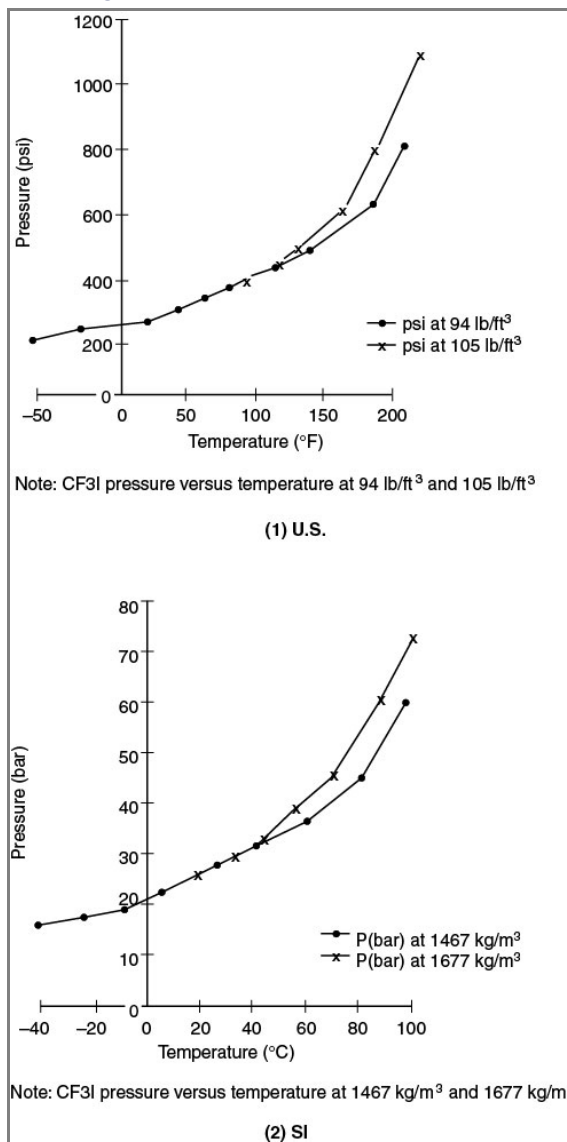


Figure A.5.1.4.1(b) Isometric Diagram of FK-5-1-12.

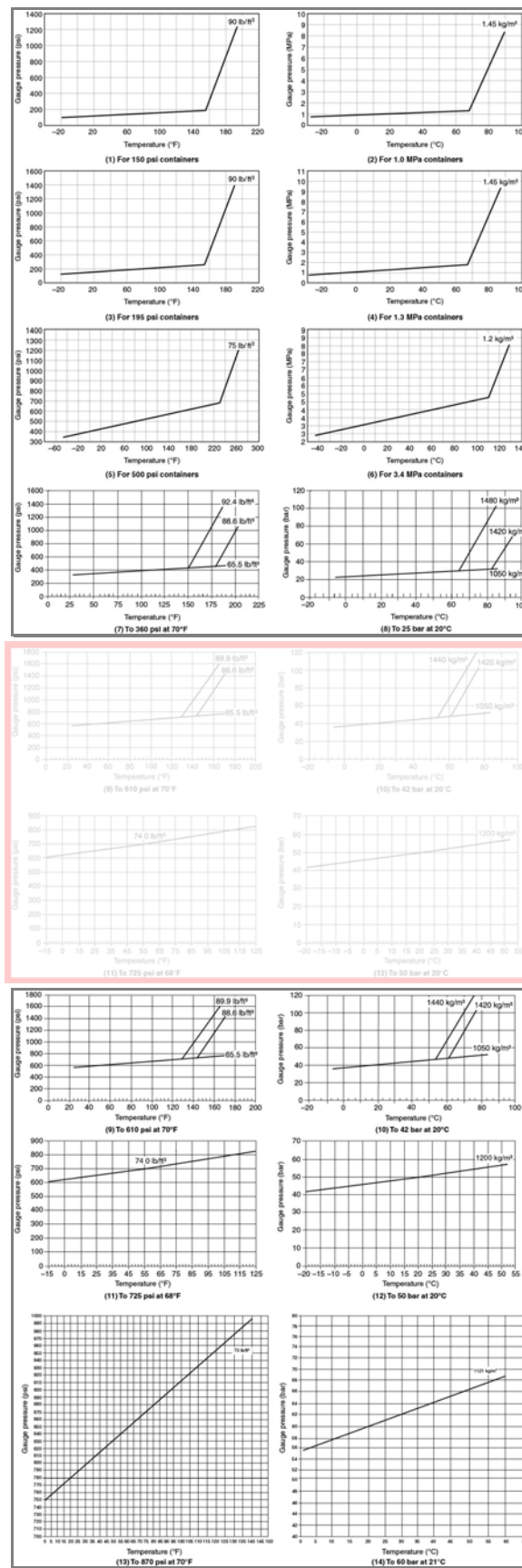


Figure A.5.1.4.1(c) Isometric Diagram of HCFC Blend A.

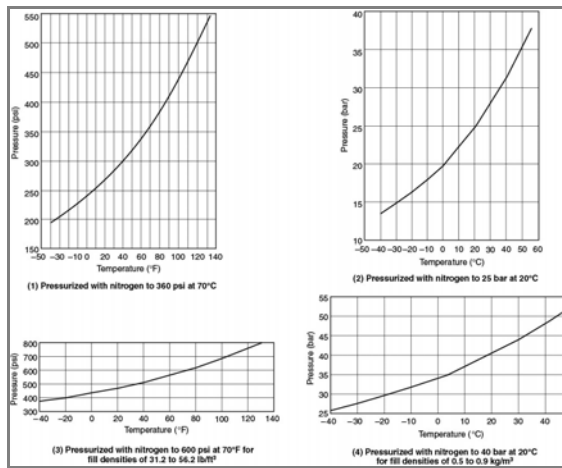


Figure A.5.1.4.1(d) Isometric Diagram of HCFC-124 Pressurized with Nitrogen.

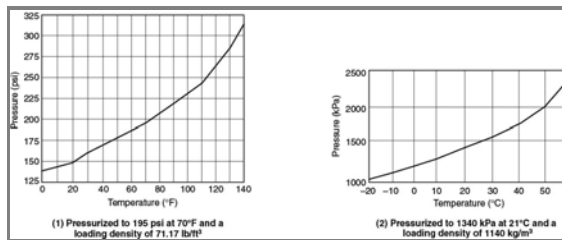
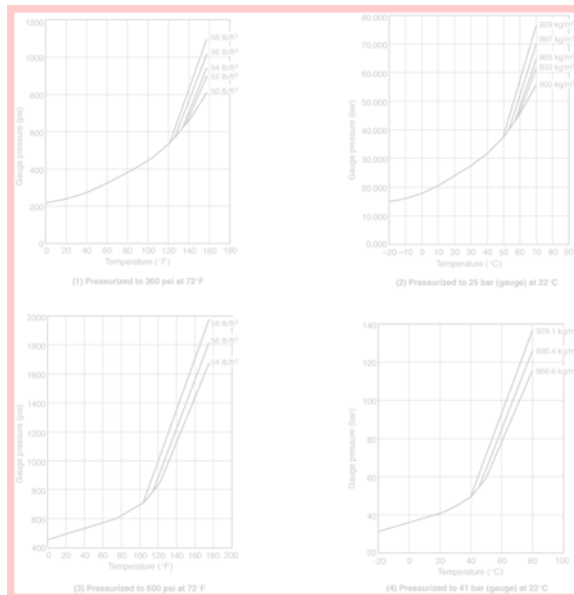


Figure A.5.1.4.1(e) Isometric Diagram of HFC-125 Pressurized with Nitrogen.



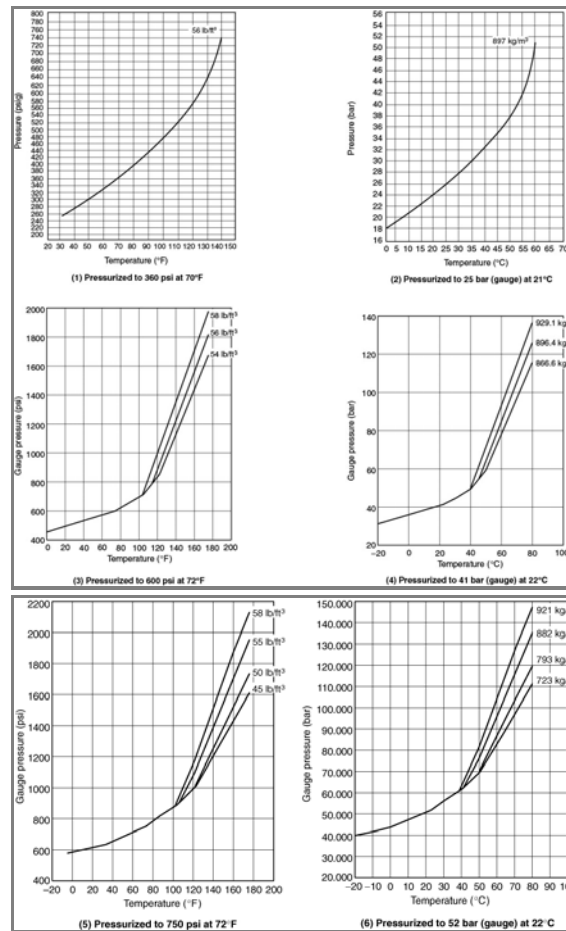
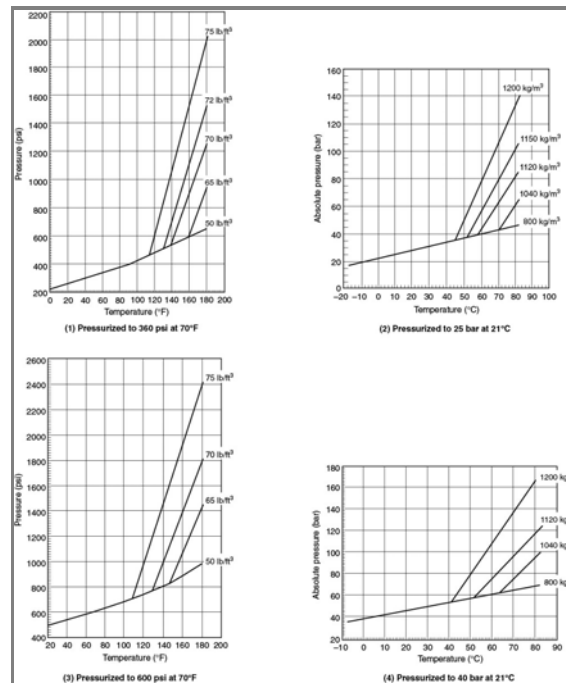


Figure A.5.1.4.1(f) Isometric Diagram of HCFC HFC -227ea Pressurized with Nitrogen.



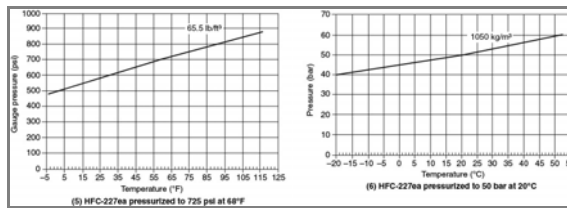


Figure A.5.1.4.1(g) Isometric Design of HFC-23.

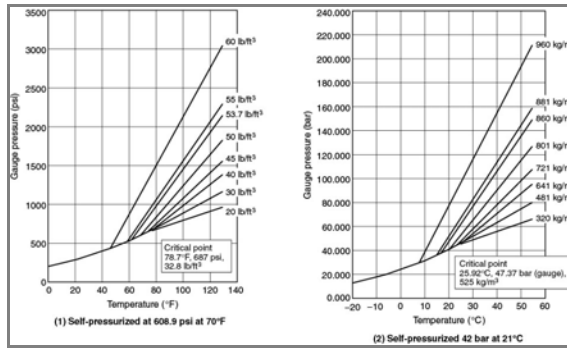


Figure A.5.1.4.1(h) Isometric Diagram of HCFC-236fa Pressurized with Nitrogen.

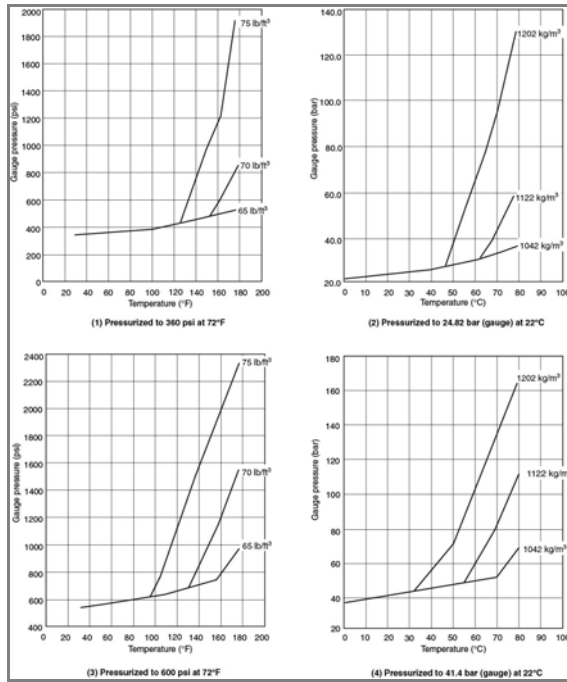


Figure A.5.1.4.1(i) Isometric Diagram of IG-01.

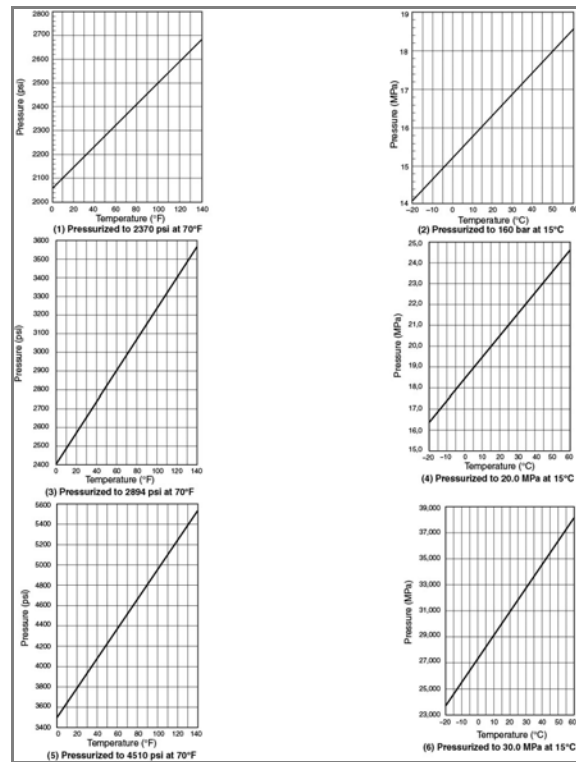


Figure A.5.1.4.1(j) Isometric Diagram of IG-100.

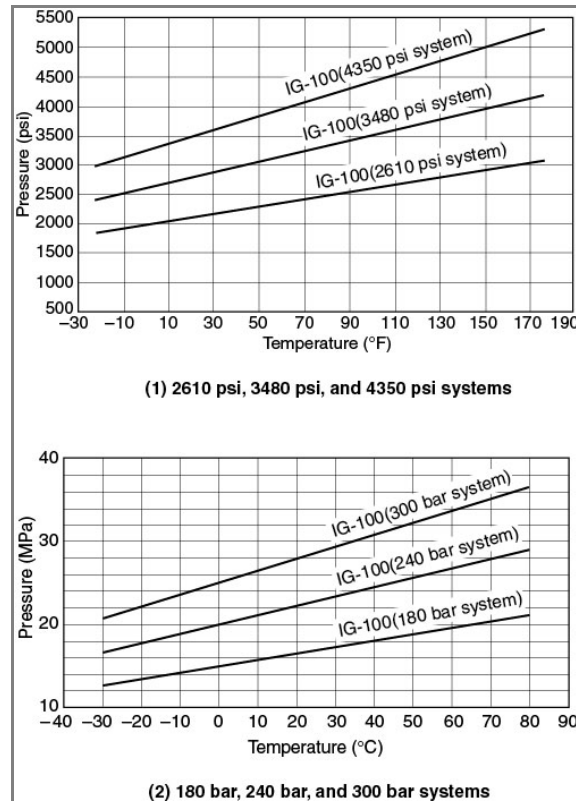


Figure A.5.1.4.1(k) Isometric Diagram of IG-541.

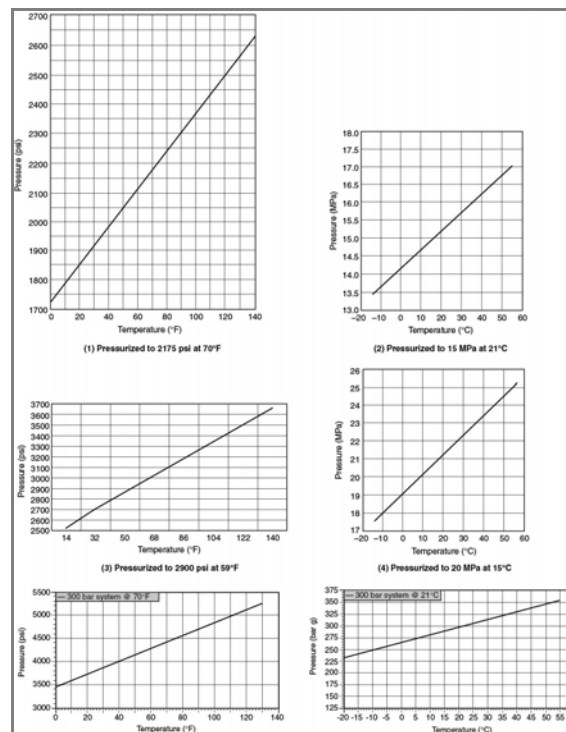


Figure A.5.1.4.1(l) Isometric Diagram of IG-55 Filled at 59°F (15°C).

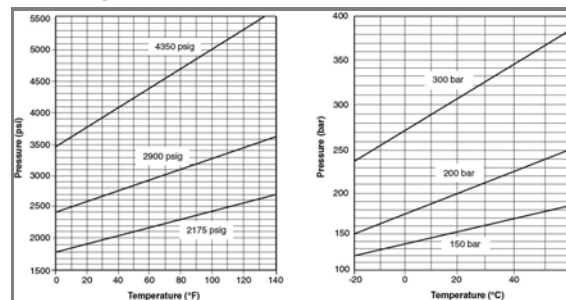
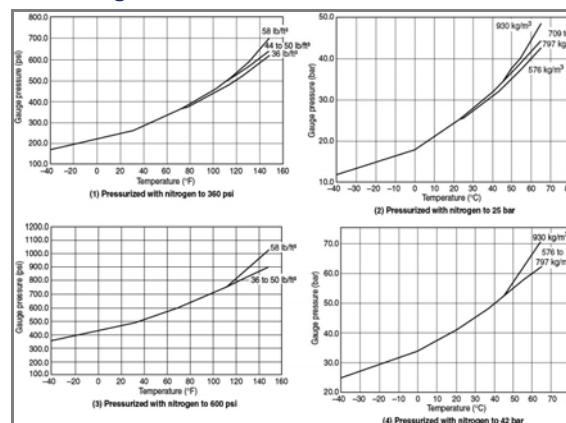


Figure A.5.1.4.1(m) Isometric Diagram of HFC Blend B.



With the exception of inert gas-type systems, all 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 and present a hazard to personnel and property. Therefore, it is 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.5.1.4.1 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.5.1.4.1.

Table A.5.1.4.1 Storage Container Characteristics

Extinguishing Agent	Maximum Fill Density for Conditions Listed (lb/ft ³)	Minimum Container Design Level Working Pressure (Gauge) (psi)	Total Gauge Pressure Level at 70°F (psi)
FK-5-1-12	90	500	360
HCFC Blend A	56.2	500	360
HCFC-124	71	240	195
HFC-125	58	320	166.4 ^a
HFC-227ea	72	500	360
HFC-23	54	1800	608.9 ^a
FIC-1311	104.7	500	360
IG-01	N/A	2120	2370
IG-100 (300)	N/A	3600	4061
IG-100 (240)	N/A	2879	3236
IG-100 (180)	N/A	2161	2404
IG-541	N/A	2015	2175
IG-541 (200)	N/A	2746	2900
IG-55 (2222)	N/A	2057	2222 ^b
IG-55 (2962)	N/A	2743	2962 ^c
IG-55 (4443)	N/A	4114	4443 ^d
HFC Blend B	58	400	195 ^e

For SI units, 1 lb/ft³ = 16.018 kg/m³; 1 psi = 6895 Pa; °C = (°F – 32)/1.8.

Notes:

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

(2) Total pressure level at 70°F (21°C) is calculated from the following filling conditions:

IG-100 (300): 4351 psi (30.0 MPa) and 95°F (35°C)

IG-100 (240): 3460 psi (23.9 MPa) and 95°F (35°C)

IG-100 (180): 2560 psi (17.7 MPa) and 95°F (35°C)

IG-55 (2222): 2175 psi (15 MPa) and 59°F (15°C)

IG-55 (2962): 2901 psi (20 MPa) and 59°F (15°C)

IG-55 (4443): 4352 psi (30 MPa) and 59°F (15°C)

^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.

^e Vapor pressure of agent.

Supplemental Information

File Name	Description Approved
2001_FR8_Fig_A.4.1.4.1b-13.png	For staff use
2001_FR8_Fig_A.4.1.4.1b-14.png	For staff use

2001_FR8_Fig_A.4.1.4.1e-1.JPG	For staff use
2001_FR8_Fig_A.4.1.4.1e-2.JPG	For staff use
2001_FR8_A.4.1.4.1.docx	STAFF USE

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Wed Apr 24 15:54:52 EDT 2019

Committee Statement

Committee Statement: A new paragraph is added to reference the new Annex F on storage containers for vaporizing-liquid agents. (See FR-6.)

New curves (13) and (14) are added to Figure A.4.1.4.1(b) for FK-5-1-12 pressurized to 870 psi and 60 bar, respectively.

Curves (1) and (2) in Figure A.4.1.4.1(e) have been updated to give better resolution for HFC-125 pressurized to 360 psi and 25 bar, respectively.

The title of Figure A.4.1.4.1(f) is revised to correct an error in the agent designation (i.e., "HCFC-227ea" should be "HFC-227ea").

The heading of the second column in Table A.4.1.4.1 is revised to remove usage of the word "listed" where the definition in 3.2.3 is not applicable.

Response Message: FR-8-NFPA 2001-2019

Public Input No. 17-NFPA 2001-2018 [Section No. A.4.1.4.1]



First Revision No. 26-NFPA 2001-2019 [Section No. A.5.5.2]

A.7.3.2

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 one of the following equations:

$$e^x = \frac{100}{100 - \% \text{ IG}} \quad [\text{A.5.5.2a A.7.3}]$$

or

$$X = 2.303 \log_{10} \frac{100}{100 - \% \text{ IG}} \quad [\text{A.5.5.2b A.7.3}]$$

where:

% IG = volume percent of inert gas

X = volume of inert gas added per volume of space

Table A.7.3.2(a) through Table A.7.3.2(h) provide the quantity of clean agent needed to achieve design concentration.

Table A.7.3.2(a) IG-01 Total Flooding Quantity (US 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})						
		Design Concentration (% by Volume) ^e						
		34	37	40	42	47	49	58
-40	7.67176 <u>7.774</u>	0.524	0.583	0.645	0.688 <u>0.687</u>	0.801	0.850	1.095
-30	7.85457 <u>7.959</u>	0.512	0.570 <u>0.569</u>	0.630	0.672 <u>0.671</u>	0.783 <u>0.782</u>	0.830	1.069
-20	8.03738 <u>8.144</u>	0.504 <u>0.500</u>	0.557 <u>0.556</u>	0.615	0.656	0.765	0.811	1.045
-10	8.22049 <u>8.329</u>	0.489	0.544	0.602	0.642	0.748	0.793	1.022
0	8.40299 <u>8.514</u>	0.479	0.532	0.589	0.628	0.732 <u>0.731</u>	0.776	1.000 <u>0.9</u>
10	8.58580 <u>8.699</u>	0.469	0.521	0.576	0.614	0.716	0.759	0.978
20	8.76864 <u>8.884</u>	0.459	0.510	0.564	0.602 <u>0.601</u>	0.701	0.744 <u>0.743</u>	0.958
30	8.95142 <u>9.069</u>	0.449	0.500	0.553	0.589	0.687	0.728	0.938
40	9.13422 <u>9.254</u>	0.440	0.490	0.541	0.577	0.673	0.714	0.920
50	9.31703 <u>9.439</u>	0.432	0.480	0.531	0.566	0.660	0.700	0.902
60	9.49984 <u>9.624</u>	0.424	0.471	0.521	0.555	0.647	0.686	0.884
70	9.68265 <u>9.809</u>	0.416	0.462	0.511	0.545	0.635	0.673	0.868
80	9.86545 <u>9.994</u>	0.408	0.453	0.501	0.535	0.623	0.661	0.851
90	10.04826 <u>10.179</u>	0.400	0.445	0.492	0.525	0.612	0.649	0.836
100	10.23107 <u>10.364</u>	0.393	0.437	0.483	0.516	0.601	0.637	0.821
110	10.41988 <u>10.549</u>	0.386	0.430	0.475	0.506 <u>0.507</u>	0.590	0.626	0.807
120	10.59668 <u>10.734</u>	0.380	0.422	0.467	0.498	0.580	0.615	0.793
130	10.77949 <u>10.919</u>	0.373	0.415	0.459	0.489	0.570	0.605	0.779
140	10.96230 <u>11.104</u>	0.367	0.408	0.451	0.481	0.561	0.595	0.766
150	11.14511 <u>11.289</u>	0.361	0.401	0.444	0.473	0.552	0.585	0.754
160	11.32794 <u>11.474</u>	0.355	0.395	0.437	0.466	0.543	0.576	0.742
170	11.51072 <u>11.659</u>	0.350	0.389	0.430	0.458	0.534	0.586 <u>0.567</u>	0.730
180	11.69353 <u>11.844</u>	0.344	0.383	0.423	0.451	0.526	0.558	0.718
190	11.87634 <u>12.029</u>	0.339	0.377	0.416 <u>0.417</u>	0.444	0.518	0.549	0.707

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
200	12.05944	0.334	0.371	0.410	0.437	0.510	0.541	0.697

^aThe manufacturer's listing specifies the temperature range for operation.

^bX [agent volume requirements (ft³/ft³)] = volume of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s_0 [specific volume (ft³/lb)] = specific volume of inert gas agent at 70°F and 14.7 psi absolute

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

s [specific volume (ft³/lb)] = specific volume of IG-01 vapor can be approximated by $s = 8.514 + 0.0185t$, where t = temperature (°F).

^eC [concentration (%)] = volumetric concentration of IG-01 in air at the temperature indicated.

Table A.7.3.2(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	0.5269	0.4828	0.5368	0.5935	0.6329	0.7376	0.7823	1.0079	1.1242
-10	0.5477	0.4644	0.5164	0.5710	0.6089	0.7096	0.7526	0.9696	1.0815
0	0.5685	0.4474	0.4975	0.5501	0.5866	0.6837	0.7251	0.9342	1.0419
10	0.5893	0.4316	0.4800	0.5307	0.5659	0.6595	0.6995	0.9012	1.0052
15	0.6101	0.4169	0.4636	0.5126	0.5466	0.6370	0.6756	0.8705	0.9709
20	0.6309	0.4032	0.4483	0.4957	0.5286	0.616	0.6534	0.8418	0.9389
30	0.6517	0.3903	0.4340	0.4798	0.5117	0.5964	0.6325	0.8149	0.9089
35	0.6725	0.3782	0.4206	0.4650	0.4959	0.5779	0.6129	0.7897	0.8808
40	0.6933	0.3669	0.4080	0.4511	0.4810	0.5606	0.5946	0.7660	0.8544
50	0.7141	0.3562	0.3961	0.4379	0.4670	0.5443	0.5772	0.7437	0.8295
60	0.7349	0.3461	0.3849	0.4255	0.4538	0.5289	0.5609	0.7226	0.8060
70	0.7557	0.3366	0.3743	0.4138	0.4413	0.5143	0.5455	0.7027	0.7838
80	0.7765	0.3276	0.3643	0.4027	0.4295	0.5005	0.5309	0.6839	0.7628
90	0.7973	0.3190	0.3548	0.3922	0.4183	0.4875	0.5170	0.6661	0.7429
100	0.8181	0.3109	0.3457	0.3822	0.4076	0.4751	0.5039	0.6491	0.724
110	0.5269	0.4828	0.5368	0.5935	0.6329	0.7376	0.7823	1.0079	1.1242
120	0.5477	0.4644	0.5164	0.5710	0.6089	0.7096	0.7526	0.9696	1.0815

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

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
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	0.6303	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	0.4654	0.5424	0.5752	0.7411	0.8200
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	0.3908	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

^aThe manufacturer's listing specifies the temperature range for operation.

^bX [agent volume requirements (m³/m³)] = volume of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s₀ [specific volume (m³/kg)] = specific volume of inert gas agent at 21°C and 1.013 bar absolute

^ct [temperature (°C)] = design temperature in the hazard area.

^ds [specific volume (m³/kg)] = specific volume of IG-01 vapor can be approximated by s = 0.5685 + 0.00208t, where t = temperature (°C).

^eC [concentration (%)] = volumetric concentration of IG-01 in air at the temperature indicated.

Table A.7.3.2(c) IG-100 Total Flooding Quantity (U.S. 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

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
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

^aThe manufacturer's listing specifies the temperature range for operation.

^bX [agent volume requirements (ft³/ft³)] = volume of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s_0 [specific volume (ft³/lb)] = specific volume of inert gas agent at 70°F and 14.7 psi absolute

^ct [temperature (°F)] = design temperature in the hazard area.

^ds [specific volume (ft³/lb)] = specific volume of IG-100 vapor can be approximated by $s = 11.976 + 0.02606t$, where t = temperature (°F).

^eC [concentration (%)] = volumetric concentration of IG-100 in air at the temperature indicated.

Table A.7.3.2(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

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
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

^aThe manufacturer's listing specifies the temperature range for operation.

^bX [agent volume requirements (m³/m³)] = volume of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s₀ [specific volume (m³/kg)] = specific volume of inert gas agent at 21°C and 1.013 bar absolute

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

s [specific volume (m³/kg)] = specific volume of IG-100 vapor can be approximated by $s = 0.7997 + 0.00293t$, where t = temperature (°C).

C [concentration (%)] = volumetric concentration of IG-100 in air at the temperature indicated.

Table A.7.3.2(e) IG-541 Total Flooding Quantity (U.S. 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	9.001	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

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
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
200	14.144	0.334	0.384	0.437	0.495	0.557	0.624	0.697	0.777

^aThe manufacturer's listing specifies the temperature range for operation.

^bX [agent volume requirements (ft³/ft³) = volume of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s_0 [specific volume (ft³/lb)] = specific volume of inert gas agent at 70°F and 14.7 psi absolute

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

s [specific volume (ft³/lb)] = specific volume of IG-541 vapor can be approximated by $s = 9.8579 + 0.02143t$, where t = temperature (°F).

^eC [concentration (%)] = volumetric concentration of IG-541 in air at the temperature indicated.

Table A.7.3.2(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	0.602	0.686	0.776	0.873	0.978	1.093	1.219
-30	0.586	0.502	0.578	0.658	0.745	0.838	0.938	1.048	1.169
-20	0.610	0.482	0.555	0.633	0.716	0.805	0.902	1.007	1.124
-10	0.634	0.464	0.534	0.609	0.689	0.775	0.868	0.969	1.081
0	0.659	0.447	0.515	0.587	0.664	0.746	0.836	0.934	1.042
10	0.683	0.432	0.497	0.566	0.640	0.720	0.807	0.901	1.005
20	0.707	0.417	0.480	0.547	0.619	0.696	0.780	0.871	0.971
30	0.731	0.403	0.464	0.529	0.598	0.673	0.754	0.842	0.940
40	0.755	0.391	0.449	0.512	0.579	0.652	0.730	0.816	0.910
50	0.779	0.379	0.436	0.496	0.562	0.632	0.708	0.791	0.882
60	0.803	0.367	0.423	0.482	0.545	0.613	0.687	0.767	0.855
70	0.827	0.357	0.410	0.468	0.529	0.595	0.667	0.745	0.831
80	0.851	0.347	0.399	0.455	0.514	0.578	0.648	0.724	0.807
90	0.875	0.337	0.388	0.442	0.500	0.563	0.630	0.704	0.785
100	0.900	0.328	0.378	0.430	0.487	0.548	0.613	0.685	0.764

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

^bX [agent volume requirements (m³/m³) = volume of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s_0 [specific volume (m³/kg)] = specific volume of inert gas agent at 21°C and 1.013 bar absolute

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

s [specific volume (m³/kg)] = specific volume of IG-541 vapor can be approximated by $s = 0.65799 + 0.00239t$, where t = temperature (°C).

C [concentration (%)] = volumetric concentration of IG-541 in air at the temperature indicated.

Table A.7.3.2(g) IG-55 Total Flooding Quantity (U.S. 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

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 ft³.

^aThe manufacturer's listing specifies the temperature range for operation.

^b X [agent volume requirements (lb/ft³)] = volume of agent required per cubic foot of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s_0 [specific volume (ft³/lb)] = specific volume of inert gas agent at 70°F and 14.7 psi absolute

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

s [specific volume (ft³/lb)] = specific volume of IG-55 vapor can be approximated by $s = 9.8809 + 0.0215t$, where t = temperature (°F).

C [concentration (%)] = volumetric concentration of IG-55 in air at the temperature indicated.

Table A.7.3.2(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 ($V_{\text{agent}}/V_{\text{enclosure}}$) ^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

^aThe manufacturer's listing specifies the temperature range for operation.

^b X [agent volume requirements (m³/m³)] = volume of agent required per cubic meter of protected volume to produce indicated concentration at temperature specified.

$$X = 2.303 \left(\frac{s_0}{s} \right) \log_{10} \left(\frac{100}{100-C} \right) = \left(\frac{s_0}{s} \right) \ln \left(\frac{100}{100-C} \right)$$

where:

s_0 [specific volume (m³/kg)] = specific volume of inert gas agent at 21°C and 1.013 bar absolute

c_t [temperature (°C)] = design temperature in the hazard area.

d_s [specific volume (m³/kg)] = specific volume of IG-55 vapor can be approximated by $s = 0.6598 + 0.00242t$, where t = temperature (°C).

e_C [concentration (%)] = volumetric concentration of IG-55 in air at the temperature indicated.

Supplemental Information

File Name	Description Approved
2001_FR26_A.5.5.2.docx	STAFF USE

Submitter Information Verification

Committee: GFE-AAA

Submission Date: Fri Apr 26 09:09:24 EDT 2019

Committee Statement

Committee Statement: This revision corrects the values given in Tables A.5.5.2(a) and Table A.5.5.2(b) for IG-01.

Response Message: FR-26-NFPA 2001-2019



First Revision No. 20-NFPA 2001-2019 [Section No. A.5.5.3.3]

A.7.3.3.3

Some areas affected 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:

$$Y = (-0.000036 \times X) + 1 \quad [\text{A.5.5.3.3a A.7}]$$

For 5501 ft to 10,000 ft of equivalent altitude:

$$Y = (-0.00003 \times X) + 0.96 \quad [\text{A.5.5.3.3b A.7}]$$

where:

Y = correction factor

X = altitude (ft)

For SI units, 1 ft = 0.305 m.

~~The increase, from the 1996 edition to this edition, in safety factor for manually actuated systems and systems protecting Class B hazards, 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 pre-burn times can 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. Field experience indicates that any existing system designed with a 20 percent safety factor will 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)].

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 14:26:24 EDT 2019

Committee Statement

Committee The deleted paragraphs are no longer relevant since the safety factor for Class B systems

Statement: has been increased to 1.3.

Response FR-20-NFPA 2001-2019

Message:



First Revision No. 23-NFPA 2001-2019 [Section No. B.18.1]

C.18.1 Endnotes.

¹The large majority of total flooding fire-extinguishing systems are used for protection of Class A fire hazards such as data centers, clean rooms, telephone central offices, and control rooms. These occupancies do not normally contain Class B fire hazards.

²Preece, S., P. Mackay, and A. Chattaway, *The Cup Burner Method — A Parametric Analysis of the Factors Influencing the Reported Extinguishing Concentrations of Inert Gases*, Proceedings of the Halon Options Technical Working Conference. April 24–26, 2001, Albuquerque, NM.

³Senecal, J. A., *Flame Extinguishing by Inert Gases: Theoretical and Experimental Analysis*, Proceedings of the 2004 Technical Meeting of the Central States Section of the Combustion Institute, Austin, TX, March 21–22, 2004.

⁴Takahashi, F., G. T. Linteris, and V. R. Katta, *Suppression of Cup-Burner Flames*, Fourth International Symposium on Scale Modeling (ISSM-IV), Cleveland, OH, September 17–19, 2003.

⁵Flames of gaseous fuels behave differently than do flames of liquids in this test. Gaseous fuel flow is fixed at the start of the test. Liquid fuel vapor flow decreases as the extinguishing point is approached due to reduction in heat transfer rate. Also see Linteris, G. T., *Suppression of Cup-Burner Flames by Super-Effective Chemical Inhibitors and Inert Compounds*, Proceedings of the Halon Options Technical Working Conference, April 24–26, 2001, Albuquerque, NM, pp. 187–196. Figures 1 and 2 illustrate the relationship of liquid fuel consumption rate and agent concentration.

⁶CO₂ might serve well as a secondary reference agent, because it is readily available and has an extinguishing concentration approximately two-thirds that of nitrogen, thereby establishing a significant span that is useful in establishing benchmark performance.

⁷F. Takahashi commented: “Methane, a main ingredient of natural gas, is favorable because its reaction mechanism is most known and thus most widely used in combustion research. Accurate numerical predictions can be made with full chemistry. However, as Irv Glassman has frequently mentioned, methane (C₁) is unique kinetically compared to higher hydrocarbons. Ethane (C₂) represents kinetics of higher hydrocarbons more closely as they decompose to smaller HCs and the oxidation reaction pathway is ethane to ethylene then to acetylene. When I was in Dayton (UDRI, on-site at WPAFB), Sandia, NM, specifically requested us to use ethane as the fuel for the extinguishing nitrogen concentration measurement in step-stabilized flames. Propane is another popular fuel and attractive for research use, although it (C₃) is also somewhat unique kinetically. Therefore, methane and propane may be practically reasonable, but ethane may be more scientifically sound.” (July 8, 2004)

⁸The specification in Annex B of the 2004 edition of NFPA 2001 is “90 to 120 s” for liquids and 60 sec for gases. At the recommendation of the VdS (Germany), ISO TC 21/SC 8 opted, in September 2003, for a 60 s pre-burn time for liquid fuels and a 60 s pre-burn time, with no tolerance, for gaseous fuels. In technical collaboration among those experienced in performing this test it was agreed that the value of MEC for liquid fuels is not sensitive to variation in pre-burn time in the 60 to 100 s time period.

⁹It has yet to be demonstrated whether barometric pressure variation from 101.3 Pa affects results obtained in this test. A controlled experimental effort is needed.

¹⁰~~The specified chimney dimensions are standard and available in Pyrex[®] and Kimax[®] brand tubes.~~

¹¹Takahashi et al. (2003) filled the cup with 3 mm glass beads and placed two layers of 40 mesh screen on top.

¹²A systematic study showed that for one halocarbon agent, the extinguishing concentration was linearly related to the humidity of the supplied air. The MEC for 100 percent RH air (~21°C) was ~11 percent (relative) less than that determined for ~0 percent RH air. (P. Mackay memorandum, 18 May 2004.) In addition, analysis (J. A. Senecal, July 2004) of humidity effects on inert gas (i.e., nitrogen) extinguishment indicates that feasible variations in humidity of air supplied to the cup burner can affect the extinguishing concentration, X_G . Specifically, it is estimated that in the two extremes of (a) dry air and (b) 70 percent RH air at 25°C, the variation in X_G is approximately $0.313 < X_G < 0.295$, or 6 percent, which is at least twice the estimated uncertainty of the measurement. An RH correction to results may could be necessary.

¹³The air flow rate should be 40 L/min ± 2 L/min, which, for the standard chimney and cup configuration specified herein, corresponds to a superficial linear velocity in the cup-chimney annulus of 13.5 cm/sec ± 0.7 cm/sec. The air flow rate should be adjusted in consideration of the actual chimney and cup dimensions to achieve the same nominal annular air velocity.

The literature discusses a “plateau” region in the air flow rate (i.e., a range of air velocities over which the MEC value is invariant, or nearly so). Most investigators report that the plateau for halocarbon agents is

usually at or near 40 L/min. It is also reported that there is no plateau for inert gas agents and that the MEC value creeps up with increasing air velocity.

¹⁴The goal is to determine the agent concentration at the extinguishing point. Methods that do not use direct measurement of agent flow rate are permitted. For example, composition analysis of agent-air mixture is acceptable.

¹⁵Takahashi et al. (2003) studied a methane flame. They used an air flow velocity of 10.7 cm/sec (volumetric rate of ~36 L/min) and a methane cup-exit velocity of 0.92 cm/sec (flow rate ~0.34 L/min), which corresponds to an overall equivalence ratio of about 0.090 (i.e., about 900 percent excess air for complete combustion). The uninhibited flame height was ~75 mm.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 15:02:38 EDT 2019

Committee Statement

Committee Statement: Endnote No. 10 is deleted, as it contains registered trademarks.

Response Message: FR-23-NFPA 2001-2019



First Revision No. 17-NFPA 2001-2019 [Section No. B.19]

C.19 Figures.

Figure C.19(a) through Figure C.19(f) and Table C.19 illustrate critical components for use in fabricating a standard cup burner system.

Figure C.19(a) Cup Burner Assembly (Exploded View).

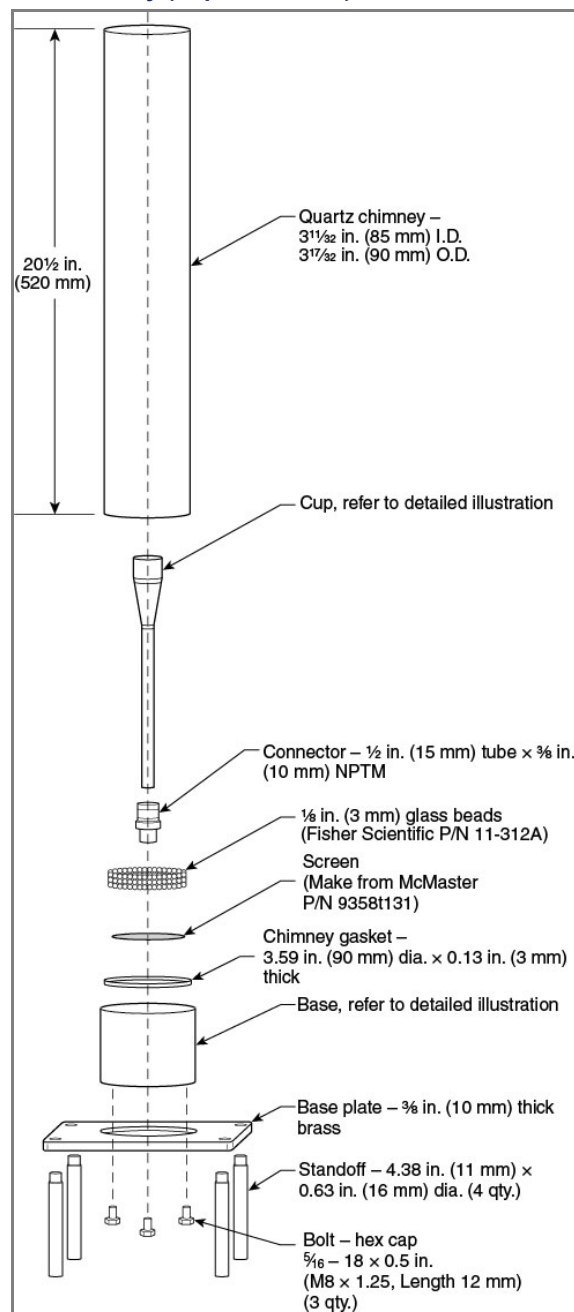


Figure C.19(b) Cup Burner Assembly (Transparent View).

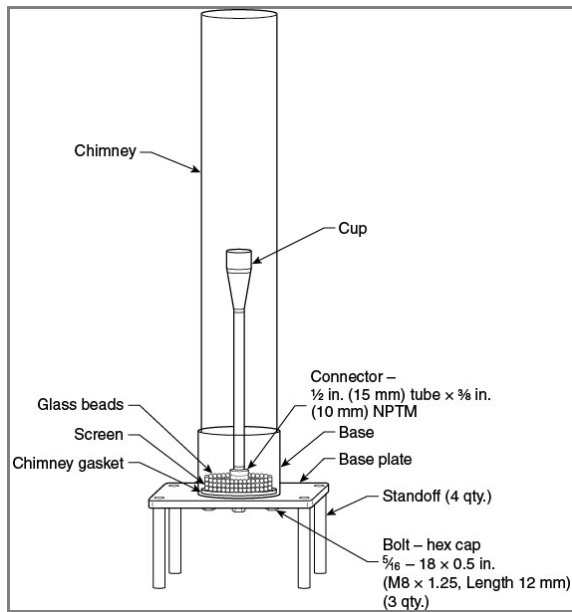


Figure C.19(c) Cup Material: Quartz [Dimensions in Inches (Millimeters)].

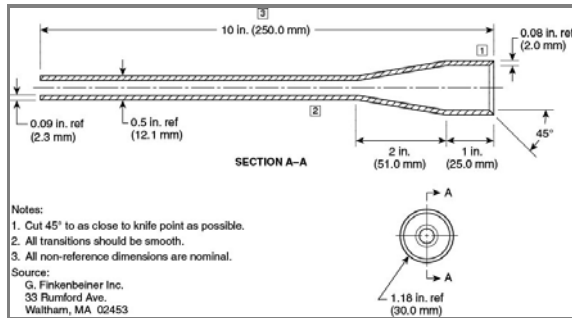
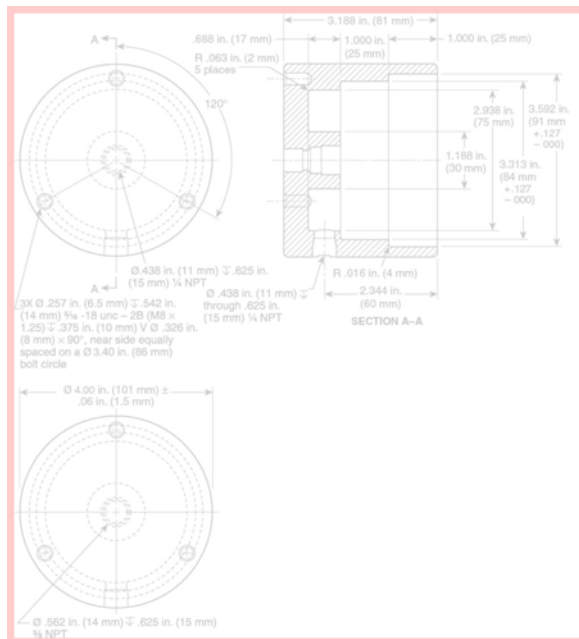


Figure C.19(d) Base, Detail.





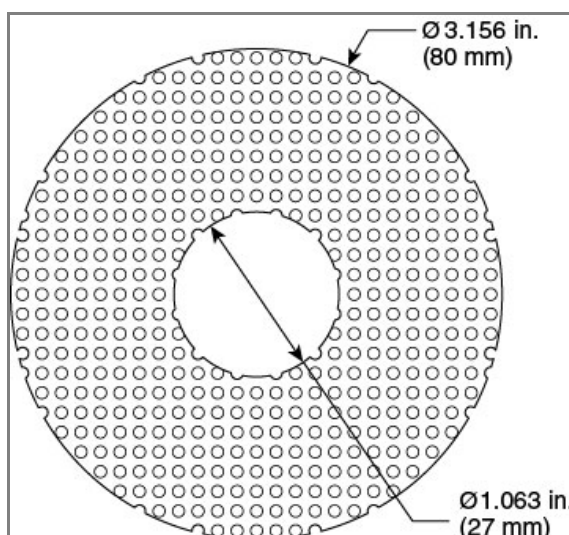


Table C.19 Cup Burner System Major Components

Component	Specifications	Supplier
Cup-burner base	Design: Per Figure B.19(d) Material: Brass	Custom fabrication
Cup-burner base support plate	Design: Per Figure Figure B.19(e) Material: Brass	Custom fabrication
Chimney	90 mm OD × 85 mm ID × 520 mm (nominal) Material: Quartz	National Scientific Company, Inc., 205 East Paletown Road, P.O. Box 498, Quakertown, PA 18951
Cup	Design: Per Figure B.19(c) Material: Quartz	G. Finkenbeiner Inc., 33 Rumford Ave., Waltham, MA 02453, or other laboratory glass fabricator
Adapter, NPT to glass tube	Swagelock p/n SS-8-UT-1-6, SS Ultra-Torr Male Connector, ½ in. female vacuum seal fitting – ¾ in. MNPT	Cambridge Valve & Fitting, Inc., 50 Manning Road, Billerica, MA 01821
Diffuser bead support screen	Design: Per Figure B.19(f) Material: McMaster-Carr p/n 9358T131. Type 304 stainless steel perforated sheet 36 in. × 40 in., 0.0625 in. hole dia, 23% open area, 22 gauge	Custom fabrication
Diffuser bed beads	Diameter: 3 mm Material: Glass	Fisher Scientific p/n 11-312A
Gasket, chimney-base	Buna-N Square O-ring cord stock, ½ in. fractional size	McMaster-Carr p/n 9700K121
Support plate legs (4)	Standoff—4.38 in. (11 mm) × 0.63 in. (16 mm) dia. ½-13 UNC	Common
Connector screws, support plate-to-base (3)	Bolt – Hex cap, ⅝-18 × 0.5 in. (M8 × 1.25, Length 12 mm)	Common
Support plate-to-base spacer sleeves	p/n M37 9 mm OD × 89 mm Material: Brass Custom cut to finish	K & S Engineering, 6917 West 59th Street, Chicago, IL 60638

Supplemental Information

File Name	Description Approved
2001_FR17_B.19.docx	STAFF USE

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 11:42:45 EDT 2019

Committee Statement

Committee Statement: The following unit conversion errors are corrected:

(1) In Figure B.19(d) Base, Detail, "R.016 in. (4mm)" should be "R.016 in. (0.4mm)".

(2) In Figure B.19(e) Base Support Plate, $\frac{3}{8}$ in. (10 mm) Thick, "7.00 in. (78 mm)" at the bottom should be "7.00 in. (178 mm)".

Response Message: FR-17-NFPA 2001-2019

Public Input No. 46-NFPA 2001-2018 [Section No. B.19]

**First Revision No. 27-NFPA 2001-2019 [Section No. C.2.2 [Excluding any Sub-Sections]**

]

The equipment listed identified in D.2.2.1 and D.2.2.2 is required necessary to test an enclosure using fan pressurization technology.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Fri Apr 26 18:42:49 EDT 2019

Committee Statement

Committee This revision eliminates the use of the word "listed" in a manner that is inconsistent with the **Statement:** definition in 3.2.3.

Response Message: FR-27-NFPA 2001-2019

**First Revision No. 32-NFPA 2001-2019 [Section No. C.2.7.1.4]****D.2.7.1.4**

Calculate the initial column pressure caused by the clean agent–air mixture in the protected enclosure using the following equation:

$$P_{mi} = (g_n)(H_0)(\rho_{mi} - \rho_a) \quad [\text{C. D. 2.7.1.4}]$$

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Tue Apr 30 19:00:06 EDT 2019

Committee Statement

Committee Statement: Editorial correction to the term "clean agent-air mixture." The hyphen was in the wrong location.

Response Message: FR-32-NFPA 2001-2019



First Revision No. 34-NFPA 2001-2019 [Section No. D.1]

E.1

The discharge of a clean agent total flooding fire-extinguishing system into a protected enclosure creates pressure fluctuations therein. Normally, for halocarbon agents, the enclosure will have enough vent area and resistive strength to moderate and resist the pressure changes so that no damage occurs. In some circumstances, however, the enclosure could be damaged by the momentary pressure change. Damaging pressure can develop if there is insufficient vent area provided by normal leakage in the enclosure boundary. Alternatively, enclosure damage might occur due to a relatively weak construction, perhaps because of design or fabrication deficiencies. Damage could occur due to a combination of these factors.

The peak pressure created in an enclosure depends on many factors, including the agent concentration and discharge time, humidity, opening characteristics of the system discharge valve, and the aggregate vent area of the enclosure. The most influential parameter is the aggregate vent area, which comprises all openings, whether unintentional or intentional.

Pressures are developed within an enclosure during the discharge of both inert and halocarbon clean agents. The discharge of an inert agent results in only a positive pressure change, as illustrated by Figure E.1(a).

On the other hand, the discharge of a halocarbon agent usually creates an initially negative pressure change followed by a positive pressure change, as illustrated by Figure E.1(b).

Figure E.1(b) shows the measured pressure changes within an enclosure during an actual discharge of halocarbon clean agent. The measured pressure within the enclosure initially dropped to a negative peak value of -387 Pa (8.1 psf), then rose to the positive peak value of $+671$ Pa (14.0 psf) before falling back down to 0, about 10 seconds after the end of the 5.5-second 5-second discharge.

Enclosures must be capable of withstanding peak pressures, whether positive in the case of the inert agents or both negative and positive in the case of the halocarbon agents. To achieve this objective, it is necessary to determine the strength of the enclosure's bounding walls, floor, and ceiling in terms of their ability to resist pressure decreases and increases as applicable to the specific agent.

The strength of the enclosure walls and ceiling usually determines the overall strength of an enclosure. The strength and physical dimensions of the construction elements and their physical dimensions play an important role. For example, a common wall construction system consists of gypsum wallboard attached to vertical studs of either metal or wood. The inherent strength of the stud system will dictate the overall strength of the wall. The stud material, physical dimensions, and spacing between studs have a significant influence on the overall strength of the stud system.

Figure E.1(a) Example of an Actual IG-541 60-Second Discharge Showing Peak Pressure.

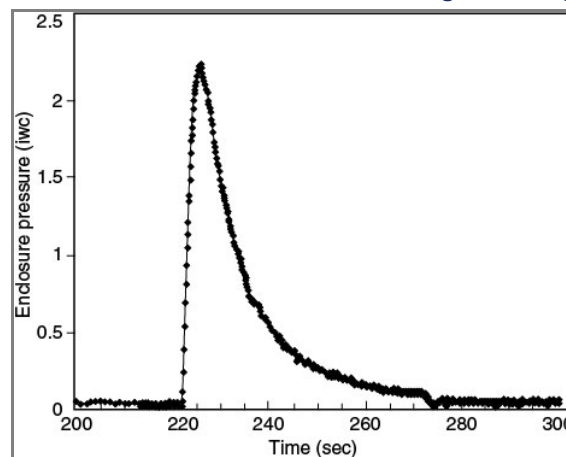
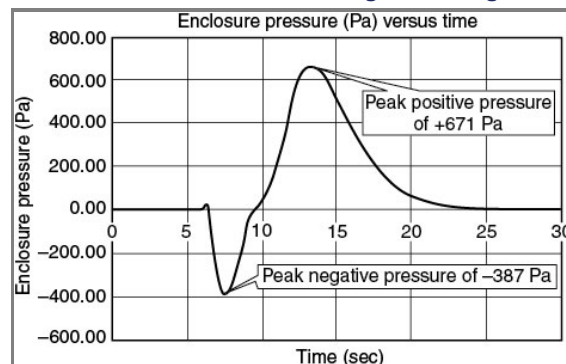


Figure E.1(b) Example of an Actual HFC-227ea Discharge Showing Peak Pressures.



Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Tue Apr 30 19:16:44 EDT 2019

Committee Statement

Committee Statement: The text is revised to fix grammatical errors.

Response Message: FR-34-NFPA 2001-2019



First Revision No. 18-NFPA 2001-2019 [Section No. E.1.2.8]

G.1.2.8 FSSA Publications.

Fire Suppression Systems Association, 3601 E. Joppa Road, Baltimore, MD 21234. www.fssa.net

FSSA Application Guide to Estimating Enclosure Pressure Relief Vent Area for Use with Clean Agent Fire Extinguishing Systems, 2nd 3rd edition, ~~revision 1~~, January 2013 October 2014 .

FSSA Design Guide for Use with Fire Protection Systems Inspection Forms, January 2012.

FSSA Pipe Design Handbook Guide for Use with Special Hazard Fire Suppression Systems, 2nd edition, 2011.

FSSA Test Guide for Use with Special Hazard Fire Suppression Systems Containers, ~~3rd~~ 4th edition, January 2012 2017 .

FSSA Application Guide Detection & Control for Fire Suppression Systems, November 2010.

FSSA White Paper, "Fire Safety Systems Protecting Data Centers," Fire Suppression Systems Association, Baltimore, MD, 2018.

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 11:45:31 EDT 2019

Committee Statement

Committee Statement: This revision updates the edition and published dates of the FSSA Publications.

Response Message: FR-18-NFPA 2001-2019

Public Input No. 72-NFPA 2001-2019 [Section No. E.1.2.8]

**First Revision No. 19-NFPA 2001-2019 [Section No. E.1.2.13]****G.1.2.13** SFPE Publications.

Society of Fire Protection Engineers, 9711 Washingtonian Blvd., Suite 380, Gaithersburg, MD 20878.
Hurley, Morgan (editors), *SFPE Handbook of Fire Protection Engineering*, fifth edition, 2015 2016 .

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Thu Apr 25 11:48:37 EDT 2019

Committee Statement

Committee Statement: This revision corrects the publication date (2016) for the SFPE Handbook.

Response Message: FR-19-NFPA 2001-2019

Public Input No. 73-NFPA 2001-2019 [Section No. E.1.2.13]

**First Revision No. 5-NFPA 2001-2019 [Section No. E.1.2.14]****G.1.2.14** UL Publications.

Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062–2096.

ANSI/ UL 2127, ~~Standard for Inert Gas Clean Agent Extinguishing System Units, 2012 (revised 2015)~~ 2018 .

ANSI/ UL 2166, ~~Standard for Halocarbon Clean Agent Extinguishing System Units, 2012 (revised 2015)~~ 2018 .

Submitter Information Verification

Committee: GFE-AAA

Submittal Date: Wed Apr 24 15:05:55 EDT 2019

Committee Statement

Committee Statement: Update of references.

Response Message: FR-5-NFPA 2001-2019

Public Input No. 67-NFPA 2001-2018 [Section No. E.1.2.14]