UPDATE ON NFPA 2001 AND ISO/fDIS 14520 STANDARDS

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INTRODUCTION

The NFPA 2001 Standard for Clean Agent Fire Extinguishing Systems [1] and the ISO/fDIS 14520 [2] Gaseous Fire Extinguishing Systems Standard contain the minimum requirements for total-flooding clean agent fire extinguishing systems. The 2000 edition of NFPA 2001 was issued as a standard in January of 2000, and the ISO document is expected to be issued later this year. This paper details the revisions to NFPA 2001 since the publication of the 1996 edition, and also discusses the current status of the ISO document.

NFPA 2001: 2000 EDITION

The National Fire Protection Association (NFPA) has completed revision of its NFPA 2001 Standard for Clean Agent Fire Extinguishing Systems [3], and the 2000 edition [1] was issued as a standard on January 14, 2000. Revisions to the standard since the 1996 edition include the following:

- Addition of two agents
- Revision of exposure limits
- Introduction of PBPK methodology
- Revision of minimum design concentrations
- Introduction of design factors
- Introduction of a Marine Section
- Miscellaneous revisions

NEW AGENTS

Section 1.5 of the 2000 edition of NFPA 2001 includes two new agents: nitrogen (IG-100) and Octafluoropropane (Perfluoropropane, FC-2-14), Table 1 lists the agents addressed in the 2000 edition of NFPA 2001 [1].

EXPOSURE LIMITS

Inert Gas Agents

The 2000 edition of NFPA 2001 [1] contains revised exposure limits for inert gas agents. In the previous (1996) edition [3], design concentrations for inert gases in normally occupied areas were limited to 43% v/v. An exception was made for Class B hazards where design concentrations up to 53% v/v were allowed if predischarge alarm and time delays were provided.

The revised 2000 edition of NFPA 2001 allows design concentrations of inert gases up to 43% v/v in normally occupied spaces if means are provided to limit the exposure to 5 min (Section 1-6.1.3a). For normally unoccupied areas, inert gas design concentrations between 43 and 52%

TABLE 1. AGENTS ADDRESSED IN NFPA 2001: 2000 EDITION.

Agent Designation	Composition	%	Chemical Formula
FC-2-1-8	Perfluoropropane		C_3F_8
FC-3-1-10	Perfluorohutane		C_4F_{10}
HCFC Blend A	HCFC-I23	4.75	CF_3CHCl_2
	HCFC-22	x2	CF_2HCl
	HCFC-I24	9.5	CF_3CHFCl
	d-limonene	3.75	
HCFC-I24	Chlorotetrafluoroethane		CF_3CHFCl
HFC-I25	Pentafluoroethane		CF_3CF_2H
HFC-227ea	Heptafluoropropane		CF_3CHFCF_3
HFC-23	Trifluoromethane		CHF_3
HFC-236fa	Hexafluoropropane		$CF_3CH_2CF_3$
FIC-13I1	Trifluoroiodide		CF_3I
IG-01	Argon		Ar
IG-100	Nitrogen		N_2
IG-541	Nitrogen	52	N_2
	Argon	40	Ar
	Carbon dioxide	8	CO_2
16-55	Nitrogen	50	N_2
	Argon	50	Ar

v/v are allowed it' means are provided to limit exposure to 3 min (Section 1-6.1.3b), and inert gas design concentrations between 52 and 63% v/v are allowed if means are provided to limit exposure to 30 sec (Section 1-6.1.3c). Inert gas design concentrations above 62% are allowed only in unoccupied areas (Section 1-6.1.3d). The exact language regarding exposure limits for inert gases is as follows [1]:

> 1-6.1.3 Inert Gas Clean Agents. Unnecessary exposure to inert gas systems resulting in low oxygen atmospheres shall be avoided. The requirement for pre-discharge alarms and time delays is intended to prevent human exposure to agents. The following additional provisions shall apply in order to account for failure of these safeguards:
>
> (a) Inert gas systems designed to concentrations below 43% (corresponding to an oxygen concentration of 12%, sea level equivalent of oxygen) shall be permitted, given the following:
>
> (1) The space is normally occupied.
>
> (2) Means are provided to limit exposure to no longer than 5 min.
>
> (b) Inert gas systems designed to concentrations between 43 and 52% (corresponding to between 12 and 10% oxygen, sea level equivalent of oxygen) shall he permitted given the following:
>
> (1) The space is normally unoccupied.
>
> (2) Means are provided to limit exposure to no longer than 3 min.

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

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

(d) Inert gas systems designed to concentrations above 62% (corresponding to 8% oxygen or below, sea level equivalent of oxygen) shall only be used in unoccupied areas where personnel are not exposed to such oxygen depletion.

PBPK METHODOLOGY

The revised NFPA 2001 edition incorporates the use of a physiologically based pharmacokinetic (PBPK) model to determine exposure limits for halocarbon agents. The PBPK model accounts for the time element involved in the physiological response to agent exposure, and takes into account the fact that the concentration of the agent in the blood must reach a critical value to produce a physiological effect. The PBPK methodology was introduced by the **U.S.** EPA as a more realistic measure of cardiac sensitization than the NOAEL/LOAEL concept. According to the PBPK model, the level of the agent in the blood must reach a critical value (taken as the LOAEL value found in dog studies) before a physiological response can occur; if this level is not reached during the exposure scenario, no cardiac effects occur.

Table 2 shows the results of PBPK modeling for HFC-227ea. In this case calculations were camed out for exposure scenarios lasting up to 10 hours. At exposure to concentrations of 10.5% v/v HFC-227ea or below, the amount of HFC-227ea in the blood never reaches (after 10 hours) the level required to produce a cardiac event (this level being taken as the LOAEL as determined in dog studies). Hence, exposures to HFC-227ea at concentrations up to 10.5% for a time period of 10 hours results in no cardiac sensitization according to the PBPK model. At an exposure concentration of 12.0% v/v, the level of HFC-227ea in the blood reaches the LOAEL (as measured in dogs) after 0.49 min.

TABLE 2. PBPK MODEL TIME FOR HFC-227ea LEVELS IN HUMAN BLOOD TO REACH THE LOAEL VALUE.

HFC-227ea Concentration, % v/v	X = Time for HFC-227ea level in human blood to reach the LOAEL
9.0	> 10 hrs
9.5	> 10 hrs
10.0	> 10 hrs
10.5	> 10 hrs
11.0	1.13
11.5	0.60
12.0	0.49

The revised NFPA 2001 standard provides PBPK information, in the form of tables similar to Table 2, for HFC-125, HFC-227ea, HFC-236fa, and FIC-13I1. However, in the NFPA 2001 tables an arbitrary, maximum exposure time of 5.0 min is indicated in all cases; for example. in the case of HFC-227ea, the ">10 hrs" figures (Table 2) are replaced by "5.0 min." This arbitrary cutoff at 5 min was agreed to by the NFPA 2001 committee for two reasons. First, the PBPK calculations were run to a total exposure time of only 5 min for all of the agents except HFC-227ea, for which the calculations were continued out to a total exposure of 10 hrs. Secondly, the committee did not want to encourage exposure incidents exceeding 5 min in length.

EXPOSURE LIMITS

Halocarbon Agents

In the previous (1996) edition of NFPA 2001, design concentrations of halocarbon agents were limited to the NOAEL or below, with the exception of Class B hazards where design concentrations up to the LOAEL value were allowed if pre-discharge alarms and time delays were provided. The 2000 edition of NFPA 2001 allows design concentrations of halocarbon agents in normally occupied spaces of up to the NOAEL with no restrictions on egress times (Section 1-6.1.2a). Concentrations of halocarbon agents between the NOAEL and LOAEL are allowed in normally occupied areas if the exposure can be limited to "X" min, where "X," derived from the PBPK model, is the time at which the level of the agent in the blood equals the LOAEL (Section 1-6.1.2b). For normally unoccupied areas, halocarbon design concentrations above the LOAEL are allowed if the exposure can be limited to "X" min, where "X," derived from the PBPK model, is the time at which the level of the agent in the blood equals the LOAEL (Section I-6.1.2~) In the event that PBPK data are unavailable, concentrations up to the LOAEL are allowed if egress can occur between 30 and 60 sec, and concentrations exceeding the LOAEL are allowed only in normally unoccupied areas provided that egress is possible within 30 sec (Section 1-6.1.2d). The exact language in the standard regarding exposure limits for halocarbon agents is as follows [1]:

> 1-6.1.2 Halocarbon Agents. Any unnecessary exposure to halocarbon clean agents, even at NOAEL concentrations, and halocarbon decomposition products, shall be avoided. The requirement for pre-discharge alarms and time delays are intended to prevent human exposure to agents. The following additional provisions shall apply in order to account for failure of these safeguards:
>
> (a) Halocarbon systems for spaces that are normally occupied and designed to concentrations up to the NOAEL [Table 1-6.1.2.1(a)] shall be permitted.
>
> (b) Halocarbon systems for spaces that are normally occupied and designed to concentrations above the NOAEL and up to the LOAEL [Table 1-6.1.2.1(a)] shall he permitted, given that means he provided to limit exposure to no longer than the time specified in Tables 1-6.1.2.1 (b) through 1-6.1.2.1(e) corresponding to the given design concentration.
>
> (c) In spaces that are not normally occupied and protected by a halocarbon system designed to concentrations above the LOAEL [Table 1-6.1.2.1(a)], and where personnel could possibly be exposed, means shall he provided to limit exposure times using Tables 1-6.1.2.1(b) through 1-6.1.2.1(e).
>
> (d) In the absence of the information needed to fulfill the conditions listed in 1-6.1.2.1(a) through 1-6.1.2.1(c), the following provisions shall apply:

(1) Where egress takes longer than 30 sec hut less than 1 min, the halocarbon agent shall not be used in a concentration exceeding its LOAEL.

(2) Concentrations exceeding the LOAEL are permitted only in areas not normally occupied **by** personnel provided that any personnel in the area can escape within 30 sec. No unprotected personnel shall enter the area during agent discharge.

Table **3** shows the revised maximum allowable exposures for those halocarbon agents for which PBPK data are available, for normally occupied areas, where exposures are limited to 5 min.

TABLE 3. MAXIMUM ALLOWABLE HALOCARBON AGENT CONCENTRATIONS FOR NORMALLY OCCUPIED AREAS ACCORDING TO NFPA 2001.

Agent	1996 Edition 131	2000 Edition [1]
HFC-125	***1.5***	10.0
HFC-227ea	9.0	10.5
HFC-236fa	10.0	12.5 (Exposure **at** LOAEL of 15.0% allowed for 0.49 min)
FIC-13I1	0.2	0.3 (Exposure at LOAEL of 0.4% allowed for 0.85 min)

MINIMUM DESIGN CONCENTRATIONS

Class A Surface Fires

In the previous edition of NFPA 2001 [3], the minimum design concentration for Class A surface fires was the extinguishing concentration determined by test as part of a listing program, plus a 20% safety factor, whereas a minimum the listing program conformed to the Underwriters Laboratories 1058 Standard. In the current edition, the minimum extinguishing concentrations are determined in an identical fashion, however, as a minimum the listing program shall conform to the recently issued UL 2127 or UL 2166 standards. The exact language found in the 2000 edition of NFPA 2001 is as follows [1]:

> 3-4.2.2 The flame extinguishing concentration for Class A fuels shall be determined by test as part of a listing program. As a minimum, the listing program shall conform to UL 2127, Standard for Inert Gas Clean Agent Extinguishing System Units, or UL 2166, Standard for Halocarbon Clean Agent Extinguishing System Units, or equivalent.
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> 3-4.2.4 The minimum design concentration ***for*** a Class A surface fire hazard shall be the extinguishing concentration, as determined in 3-4.2.2, times a safety factor of 1.2.

MINIMUM DESIGN CONCENTRATIONS

Class B or Manual Only Systems

For Class B fuels, the previous edition of NFPA 2001 **[3]** specified a minimum design concentration determined by adding a 20% safety factor to the extinguishing value found from the cup-burner apparatus. The current edition specifies that a safety factor of 30% be added to the cup-burner extinguishing concentration to determine the minimum design concentration for Class B fuels. In addition, a 30% safety factor is applied to all systems that employ manual only actuation. The exact language in the revised NFPA 2001 edition is as follows [1]:

> 3-4.2.1 The flame extinguishing concentration for Class B fuels shall be determined by the cup-burner method described in Appendix B.
>
> 3-4.2.3 The minimum design concentration for a Class B fuel hazard or an only manually actuated system shall be the extinguishing concentration as determined in 3-4.2.1, times a safety factor of 1.3.

DESIGN FACTORS

The revised edition of NFPA 2001 includes in Section 3-5.3 a discussion of "design factors":

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

Design factors are included to compensate for multiple tee splits (Section 3-5.3.1j . and the designer shall assign additional design factors for each of the following (Section 3-5.3.2):

- Unclosable openings
- Control of acid gases
- Reignition from heated surfaces
- Fuel type, configurations, scenarios not fully accounted for in the extinguishing concentration, enclosure geometry, and obstructions and their effects on distribution

The design quantity of the clean agent must also be adjusted to compensate for ambient pressures that vary more than 11% from standard sea level pressures (Section 3-5.3.3).

MARINE CHAPTER

The revised edition of NFPA 2001 includes a separate Marine Section (Chapter 5). which outlines the deletions, modifications, and additions necessary for marine applications.

MISCELLANEOUS REVISONS

Section A-1-5 contains updated physical properties for the agents currently listed in NFPA 2001.

Section A-1-6.1.2 contains a detailed discussion of the toxicology of halocarbon agents, includeing a detailed discussion of the PBPK methodology, and the toxicology of hydrogen tluoride (HF). The section also includes a discussion of potential human health effects and risk analysis in fire scenarios.

Section A-3-7.1.2 discusses in detail the generation of HF from the halocarbon agents and its effects on personnel and equipment.

Appendix B describes the standardized cup burner apparatus and the procedure for the determination of extinguishing concentrations for Class **B** fuels.

ISO/fDIS 14520: GASEOUS FIRE EXTINGUISHNG SYSTEMS

The ISO/fDIS 14520 Standard **is** identical in many aspects to the NFPA 2001 standard. Major differences between the two standards are as follows:

- The ISO document applies a 30% safety factor to both Class A and Class B fuels
- The extinguishing concentration for Class **A** surface fires is derived solely from a wood crib test, identical to that described in UL 1058,2127 or 2166.
- Exposure levels for halocarbons based upon NOAEL/LOAEL concept.

Voting on the draft ISO/fDIS 14520 document terminated on April 17,2000. If passed, the document is expected to issue by the end of 2000.

The ISO/fDIS 14520 Class A task group met on April 27,2000 and has agreed upon a Class A test protocol that includes three tests: a wood crib test, a plastic sheet test similar to UL 2166, and a PVC cable tray test. These tests will not be included in the first edition of the ISO standard. The proposed protocols will be presented to the full ISO/fDIS 14520 committee during its September 2000 meeting for its consideration for inclusion in the second edition of the ISO/fDIS 14520 standard.

REFERENCES

1. *NFPA 2001: Standard on Clean Agent Fire Extinguishing Systems*, 2000 Edition, NFPA, Quincy, MA, 2000.

2. *ISO/fDIS 14520: Gaseous Fire Extinguishing Systems*, International Standards Organization, Homebush, New South Wales, Australia, 2000.

3. *NFPA 2001: Standard on Clean Agent Fire Extinguishing Systems,* 1996 Edition, NFPA, Quincy, MA, 1996.