The Adequacy of Guidance on Agent Concentrations in Standards for Gaseous Fire Extinguishing Systems

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1.0 INTRODUCTION

In the process of transitioning from the use of halon 1301 systems to the gaseous alternatives to halons, two standards were developed to guide users in the application of these alternative agents: (1) NFPA 2001[1] which is the U.S. National Standard and (2) ISO 14520[2] which is often used as a model in the international arena. There are many similarities in these two standards, but there are also important differences.

In the design of a total flooding gaseous fire extinguishing system, two critical decisions are made: which agent to use and at what concentration to use that agent. There are three main considerations in selecting this concentration: (1) the type of fire expected in the hazard; (2) the extinguishing concentration of the agent for that type of fire; and (3) the safety factor to apply over and above the extinguishing concentration to arrive at a reasonable use or design concentration.

This paper will address how these three subjects are treated in ISO 14520 and NFPA 2001 and make recommendations, both short term and longer term, to preclude vagaries and inconsistent design approaches at this crucial step in the system design. The use of design concentrations that do not produce the desired and believed fire extinguishing capabilities would have a devastating affect on the use of the halon alternative clean agents. A loss in confidence with the clean agents from system failures may result in increased resistance to move away from halon 1301 (and CO_2), both with long demonstrated records of fire protection success.

This paper is addressed to system specifiers, designers, and owners to provide information to base design concentration decisions (rather then simply relying on the minimum allowed) to ensure system performance. The clean agent industry is highly cost competitive between agents, and between system manufacturers with the same agent, and the lowest cost system, utilizing the lowest design concentration, will garner the most business. The paper is also addressed to the code generating and enforcing community to provide a technical basis for improving the current deficiencies in the standards.

While the issue of establishing acceptable design concentrations has been around since the first utilization of the clean agents, it has become of more serious concern recently for several reasons. First, Class A minimum extinguishing concentrations (MEC) derived from standard tests have been lowered for some agents; second, the cost competitive nature of the business has reduced the design concentrations to the absolute minimum allowed; third, is the recognition that the Class A MEC test standards may be inadequate; and fourth, energized electrical hazards are commonly being protected and often at only Class A minimum concentrations.

2.0 OBJECTIVE OF THE PAPER

The objective of this paper is to provide information and guidance on the technical basis for the selection of fire extinguishing system concentrations for gaseous alternatives to halons in current standards and to make recommendations for changes where the current guidance is considered inadequate to assure a reasonable level of fire protection.

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[1] "NFPA 2001 - Standard on Clean Agent Fire Extinguishing Systems - 2008 Edition," National Fire Protection Association, Quincy, MA: 2007.

[2] "Gaseous Fire Extinguishing Systems - Physical Properties and System Design - Part 1: General Requirements, ISO 14520-1:2006(E).

Specific goals of the paper are to:

- Outline the relevant standards that provide guidance on the selection of design concentrations for gaseous fire extinguishing systems.
- Describe the differences between the ISO 14520 series and NFPA 2001 standards with respect to recommended extinguishing concentrations and safety factors for fires involving Class A materials and electrically energized equipment.
- Describe and compare the technical bases for the extinguishing concentrations and safety factors recommended in ISO 14520 series and NFPA 2001 standards for fires involving Class A materials and energized electrical equipment.
- Provide specific recommendations on the way forward in dealing consistently with both energized electrical fires and normal Class A concentrations in ISO 14520 and in NFPA 2001.

3.0 CURRENT REQUIREMENTS

3.1 Comparison of Standards

It is not possible to directly compare ISO 14520 and NFPA 2001. NFPA 2001 is known as an installation standard and only refers to product approval requirements and testing. NFPA 2001 includes by reference the requirements of UL 2127[3] and / or UL 2166[4] which describe product approval testing. The scope of ISO 14520 includes both installation and product approval testing requirements.

The two standards are slightly different in describing the types of fires. NFPA 2001 categorizes the fires into Class A, Class B and Class C with the following definitions:

- Class A Fire. A fire in ordinary combustible materials, such as wood, cloth, paper, rubber, and many plastics.
- Class B Fire. A fire in flammable liquids, combustible liquids, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols, and flammable gases.
- Class C Fire. A fire that involves energized electrical equipment.

In addition to Class B, ISO 14520 provides guidance on "Class A surface fires" and other Class A fires it defines as "certain plastic fuel hazards (e.g. electrical and electronic type hazards involving grouped power or data cables such as computer and control room under-floor voids, telecommunication facilities, etc.)".

3.2 Minimum Extinguishing Concentration

In the process of determining minimum extinguishing concentrations, it is essential that measures be taken to assure that the values determined are scalable. That is to say that the minimum extinguishing concentration should be based on the results of a series of confirming experiments. In the case of Class B fuels, work has been done to (1) determine extinguishing

[3] "Standard for Inert Gas Clean Agent Extinguishing System Units, UL 2127," Underwriters Laboratories Inc., Northbrook, IL.

[4] "Standard for Halocarbon Clean Agent Extinguishing System Units, UL 2166," Underwriters Laboratories Inc., Northbrook, IL.

concentrations at a laboratory scale, (2) confirm those concentrations in an intermediate scale and (3) to further confirm those concentrations on large scale testing. However, Class A extinguishing concentrations are determined at an intermediate scale fire testing program without confirmation at either a smaller or larger scale. Table 1 is an illustration of the different approaches in establishing and confirming minimum extinguishing concentrations in Class A and Class B fuels.

Table 1.
Differences in the Extent of Testing to Establish Minimum Extinguishing Concentrations

Scale	Class A Fire Testing	Class B Fire Testing
Laboratory	None	Cup burner
Intermediate	UL and ISO room scale tests	UL and ISO room scale tests
Large	None	Application specific such as: US Navy shipboard large scale testing USCG IMO machinery space fire testing US Air Force jet engine nacelle testing

Class B: The two standards treat Class B extinguishing concentrations in a nearly similar manner. ISO 14520 requires "The extinguishing concentration used shall be that demonstrated by the cup burner test, carried out in accordance with the method set out in Annex B that has been verified with the heptane pan tests detailed in C.5.2." NFPA 2001 states "The flame extinguishing concentration for Class B fuels shall be determined by the cup burner method described in Annex B." The requirements of UL 2127 and UL 2166 (referenced by NFPA 2001) provide for the verification of the cup burner value by heptane pan testing. Table 2 is a summary of the heptane extinguishing concentrations for both the cup burner and room tests for the agents described in ISO 14520. There are fire test reports in the public domain that support the ISO 14520 fire test data. Further, all the fire test data included in ISO 14520 has been reviewed by a technical working group charged with assuring the reasonableness of the data.

Table 3 contains the same type of information that is now published in the Annex of NFPA 2001. The data source used in NFPA 2001 is not provided but the fire test reports are believed to reflect current UL listing concentrations. Fire test reports supporting the data in NFPA 2001 are considered proprietary information between UL and the listed manufacturer and thus are not in the public domain.

Table 2.
ISO 14520 Heptane Flame Extinguishing Concentrations (vol %)

Heptane Fire Test	FK-5-1-12	HFC-125	HFC-227ea	HFC-23	IG-01	IG-100	IG-55	IG-541
Cup burner	4.5	9.3	6.7	12.6	39.2	33.6	36.5	31.7
Room test	4.4	9.3	6.9	12.3	33.7	33.6	30.2	29.6

Table 3.
NFPA 2001 Heptane Flame Extinguishing Concentrations (vol %)

Heptane Fire Test	FK-5-1-12	HFC-125	HFC-227ea	HFC-23	IG-01	IG-100	IG-55	IG-541
Cup burner	4.5	8.7	6.7	12.9	42	31	35	31
Room test	4.5	8.7	6.7				30.1	31.3

<u>Class A</u>: ISO 14520 refers to "Class A surface fires" and NFPA 2001 describes the "flame extinguishing concentration for Class A." For all practical purposes, these distinctions are synonymous in that they both intend to exclude Class A fires that are more difficult to extinguish than the surface fires specified by the standards. The Class A surface fires required by NFPA 2001 are incorporated by reference to UL 2127 and 2166 with the following statement: "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 or UL 2166 or equivalent." ISO 14520 requires "The extinguishing concentration for Class A surface fires shall be the greater of the values determined by the wood crib and polymeric sheet fire tests described in Annex C." Both standards (NFPA via the UL references) rely on fire testing on a room scale of four Class A test fuels: a wood crib and three separate tests involving different polymeric sheet arrays of polypropylene (PP), acrylonitrile butadiene styrene (ABS) and polymethyl methacrylate (PMMA). Table 4 is an illustration of the two most significant differences in the test configurations and protocols between the ISO and UL Class A fire testing. These differences in the ignition pan size and the allowable extinguishing time can cause significantly different results in determining the minimum extinguishing concentration for the following reasons:

- Both the UL and ISO protocols require an ignition pan preburn time of 90 seconds. The larger size ignition pan for ISO uses about 50% more heptane which produces a more intense fire and more heating of the plastic sheets and test fixtures, thus making the ISO fire more difficult to extinguish (i.e. requiring a higher agent concentration).
- The shorter time allowed for extinguishment in the ISO standard also leads to a higher extinguishing concentration. The longer allowable extinguishing time in the UL requirements permits small "candle" flames to continue until the plastics and test rig ultimately cool and the fire is extinguished. The UL requirements do include a maximum weight loss for the fuel package during the test, which does limit any residual fire for 10 minutes to small candle type flames.

Table 4.
Differences in ISO and UL Testing for Surface Class A Fires

	ISO	UL
Ignition pan size	51 mm x 112 mm x 21 mm deep	51 mm x 51 mm x 22 mm deep
Allowable extinguishing time	3 minutes	10 minutes

Table 5 is a compilation of the Class A surface fire extinguishing concentrations for all four test fuels (wood crib, PMMA, PP and ABS) for the most commercially significant agents in ISO 14520. There are fire test reports in the public domain that support the ISO 14520 fire test data.

Further, all of the fire test data included in ISO 14520 has been reviewed by a technical working group charged with assuring the reasonableness of the data.

Table 5.
ISO 14520 Flame Extinguishing Concentrations for Class A Surface Fire Test Fuels (vol %)

Fuel Type	FK-5-1-12	HFC-125	HFC-227ea	HFC-23	IG-01	IG-100	IG-55	IG-541
Wood Crib	3.4	6.7	4.9	10.5	30.7	30.0	28.7	28.2
PMMA	4.1	8.6	6.1	12.5	31.6	28.8	30.7	30.7
PP	4.0	8.6	6.1	12.5	31.6	30.0	29.3	30.6
ABS	4.0	8.6	6.1	12.4	32.2	31.0	31.0	30.7

Table 6 contains summary information for Class A fire tests as found in the Annex of NFPA 2001. The approval process requires that the minimum extinguishing concentration is the highest concentration required to extinguish the four Class A test fuels. The NFPA 2001 data source is not provided but it is believed to reflect current UL listing concentrations. Fire test reports supporting the data in NFPA 2001 are considered proprietary information between UL and the listed manufacturer and thus are not in the public domain.

Table 6.
NFPA 2001 Flame Extinguishing Concentrations for Class A Surface Fire Test Fuels (vol %)

Fuel Type	FK-5-1-12	HFC-125	HFC-227ea	HFC-23	IG-01	IG-100	IG-55	IG-541
Unspecified	3.5	6.7	5.2 to 5.8	-	-	-	31.6	28.5

In comparing the data in Tables 5 and 6, it can be seen that in most cases the extinguishing concentrations found in ISO 14520 are higher than those contained in NFPA 2001. Many ask the question "which results are 'right'" when they should be asking "which results most closely represent the fire hazards one would expect in actual applications." The answer is that at this time no one knows. Of real concern is that such small changes in the two testing methods (i.e., the ignition pan size and allowable extinguishment time) cause such large variations in the minimum extinguishing concentration. That behavior clearly suggests that there are circumstances where the minimum extinguishing concentrations for Class A surface fires described in NFPA 2001 would be found inadequate.

The differences between the ISO fire test results and those described in NFPA 2001 for Class A surface fires can also be attributed, at least in part, to fire testing techniques developed through repetition. The minimum extinguishing concentration testing has been conducted repeatedly for some of the agents, in the process of striving to achieve lower and lower extinguishing concentrations. Over the course of this testing, several conditions or techniques have been identified that contribute to improved performance (a lower extinguishing concentration). Some of these conditions/techniques are:

- Testing at elevations above sea level,
- Testing on days with low atmospheric pressure and/or high humidity,

- Removing the metal rods used to hold the plastic sheets,
- Configuring the enclosure leakage to optimize extinguishment, and
- Using nozzle styles and locations in the testing enclosure to optimize extinguishment.

While each of these conditions or techniques may cause only a slight change to the extinguishing concentration, taken together, they may significantly affect the test results. When purposely employed, some consider this approach as unrealistic in portraying real world applications and could actually see this as “gaming” the testing protocol. Nevertheless, these conditions / techniques are not prohibited by the test protocol and are allowed by some testing laboratories.

The NFPA 2001 process requires the testing to be conducted to UL 2166 or UL 2127. These tests standards allow the testing to be repeated as many times as desired, as long as three tests in a row can be passed for each fuel. With each success at a lower concentration, that concentration becomes the MEC, even if that same concentration may have repeatedly failed with different hardware, a different enclosure, or even on just a different day. Thus, in theory, if three laboratories tested the same agent, and each succeeded at different concentrations, the lowest of the three concentrations could ultimately be utilized by the standard.

Taking another look at the credibility of the Class A design concentrations, Table 7 is a comparison of the ISO 14520 and NFPA 2001 data using the minimum heptane extinguishing concentration for each agent as a baseline. In addition, data for carbon dioxide and halon 1301 are presented for comparison. Technical experts believe that the minimum extinguishing concentration (MEC) for heptane can be used as a baseline for the following reasons:

- The value is independent of system delivery hardware. Class A fire test results are often claimed to be dependent on the delivery hardware (nozzle design and location, nozzle pressure, etc.) and the results optimized for a particular hardware set. Significant changes to the Class A MEC test protocol may be required to remove this delivery hardware dependence.
- The heptane MEC can be, and has been, determined for each agent by numerous laboratories with only slight differences between laboratories. The heptane MEC is reasonably repeatable between laboratories. However, the repeatability of Class A MEC has not been demonstrated. Rather, there have been significant differences between MEC values from various laboratories.
- The use of a liquid fuel is a reasonable <u>worst-case</u> approximation of a diffusion flame over a solid surface.
- Comparison data exists for halon 1301 and carbon dioxide which forms the basis of historical experience with gaseous total flooding agents.

Table 7.
Comparison of Design Concentrations for Class A Fires

Agent	Heptane (MEC) (NFPA 2001) %	Class A Design Concentration (NFPA, 20% Safety Factor)* %	Ratio Class A Design Concentration to Heptane MEC (NFPA)	Class A Design Concentration (ISO 14520, 30% Safety Factor) %	Ratio Class A Design Concentration to MEC (ISO 14520)	Ratio Class A Design NFPA 2001 to ISO 14520
Halon 1301	3	5	1.67			
CO_2	20	> 35	1.75			
FK-5-1-12	4.5	4.2	0.93	5.3	1.17	0.79
HFC-125	8.7	8.0	0.92	11.2	1.3	0.71
HFC-227ea	6.6	6.2–6.5	0.94–0.99	7.9	1.2	0.78–0.82
HFC-23	12.9	16.8–18	1.3–1.4	16.3	1.26	1.03–1.1
IG-01	42			41.9	1.0	—
IG-100	31			40.3	1.3	—
IG-55	35			40.3	1.15	—
IG-541	31	34.2	1.1	36.5	1.17	0.94

*Note: Halon 1301 from NFPA 12A. CO_2 from NFPA 12, others from NFPA 2001. Safety Factor not established with equivalent fire tests for halon 1301 and CO_2.

An analysis of the data in Table 7 indicates the following:

- The NFPA 2001 design concentration differences for Class A surface fires for clean agents are as much as 47% (for HFC-125) lower than the equivalent concentration for carbon dioxide relative to a cup burner baseline.
- The design concentration for HFC-125 is approximately 47% of the value one would expect for carbon dioxide if applying the same safety factors and design concentrations (0.92 vs. 1.75). Similarly, the design concentration for HFC-125 is 45% of that expected for halon 1301 (0.92 vs. 1.67).
- The agent faring the best in comparison to halon 1301 and carbon dioxide is HFC-23.
- Design values contained in ISO 14520 are much more reasonable in comparison with the NFPA 2001 values. This is due to a higher safety factor and more demanding extinguishing concentration tests for Class A fuels in ISO 14520.

The last column in Table 7 shows the weakness of NFPA 2001 when compared to ISO 14520. The design value for HFC-125 used by NFPA 2001 is only 71% of the value used in ISO 14520. The design concentration used in NFPA 2001 is lower than the ISO concentration for all agents, except HFC-23.

The analysis presented in Table 7 indicates that the Class A extinguishing concentrations used in NFPA 2001 for clean agents are significantly lower (approximately 50%) than the equivalent values for halon 1301 and carbon dioxide, relative to a common baseline. It is important to note that these differences do not exist between halon 1301 and the clean agents for liquid Class B fuels. In addition, the NFPA 2001 values for Class A design concentrations are as much as 30% lower than the equivalent design value under ISO 14520.

From both an historical perspective and current international practice, the design concentrations for Class A surface fires as described in NFPA 2001 appear too low.

Class C: NFPA 2001 provides the following guidance for the protection of Class C: "The minimum design concentration for Class C hazards shall be at least that for Class A surface fire." On the other hand, ISO 14520 provides some measurable guidance given that energized electrical equipment and cabling are recognized by technical experts as much more challenging fire threats than a simple Class A surface fire:

> "It is recognized that the 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 under-floor voids, telecommunication facilities, etc.). An extinguishing concentration not less than that determined in accordance with 7.5.1.3, or not less than 95% of that determined from the heptane fire test described in C.6.2, whichever is the greater, should be used under certain conditions. These conditions may include:
>
> 1) Cable bundles greater than 100 mm in diameter;
> 2) Cable trays with a fill density greater than 20% of the tray cross-section;
> 3) Horizontal or vertical stacks of cable trays (closer than 250mm);
> 4) Equipment energized during the extinguishment period where the collective power consumption exceeds 5kW."

Some limited testing with HFC-227ea on low energy single wire and small cable bundles indicated that concentrations between 6.5% and 6.8% were necessary to extinguish these small cable bundles or arrays with PVC/PE or PE insulation. These values exceed the minimum Class A extinguishing concentration for HFC-227ea of between 5.2 and 5.4%, and the *design* concentration of 6.2 to 6.5% which is supposed to include a 20% safety factor.

This dangerous situation has arisen, in part, because the Class A extinguishing concentration for HFC-227ea has been reduced from 5.8% to 5.2% over time by re-conducting the test protocol. This further illustrates the weakness of the test method used to determine Class A extinguishing concentrations. A situation now exists where small energized electrical fires would not be extinguished at either the extinguishing concentration or the design concentration. These same fires would have been expected to be extinguished at the design concentration in 1996 when the most often used concentration of HFC-227ea was 7.0%.

These very limited results on small electrically energized conductors are not applicable to large diameter high voltage and high power rated cables, particularly in large cable bundles and arrays. Such cables in these arrays have historically required much higher extinguishing concentrations than Class A surface values. For example, Sandia Laboratories and the Nuclear Regulatory Commission required design concentrations of 40% for carbon dioxide and 6% for halon 1301. NFPA 12 requires a carbon dioxide design concentration of > 40% for energized electrical equipment. These values represent increases of at least 20% (for halon 1301) over the Class A design value. As indicated in previous discussions, the Class A design value for halon 1301 is in the range of 80% higher than HFC-125 for a comparable Class A fire scenario.

3.3 Safety Factor

The most obvious difference between the ISO and NFPA standards is the safety factor. Both standards require a 30% safety factor for Class B fires. For Class A fires, ISO 14520 also requires a 30% safety factor while NFPA 2001 allows a 20% safety factor. The potential weakness of a 20% safety factor has been examined.[5,6] It is incongruous that the NFPA 2001 standard with the testing protocol yielding the lowest minimum extinguishing concentration also allows the lowest (20%) safety factor.

The adequacy of a 20% safety factor as a means of assuring fire extinguishment is questionable. For engineered systems, the listing/approval of the flow calculation design software – under laboratory controlled test conditions – is required to have an accuracy of plus/minus 10% of agent mass. It is difficult to believe the current extinguishment concentration determinations are accurate to better then 10%. Thus, for any engineered system with nozzles remote from each other (either in separate enclosures are with more then three in a row), the entire 20% safety factor could be "used." This would not include any needed safety factor for cylinder leakage (allowed to be 5%), incomplete vaporization and mixing, uncloseable openings/enclosure leaks, obstructions, etc. The expectation could certainly be that some systems, even though designed to NFPA 2001, would fail because of inadequacy in the design itself.

4.0 THE EVOLUTION FROM HALON 1301 TO THE ALTERNATIVES

During the development of these standards, many of the practices adopted over the years for halon 1301 were incorporated and, over time, many of these practices extrapolated from halon 1301 experience have been validated. Among these is the use of the cup burner, a laboratory instrument, for determining the extinguishing concentration of gaseous and liquid Class B fuels. The laboratory equipment and test procedures related to the cup burner have been continually refined to a point where we have a high degree of confidence in the results generated. Much of that confidence came from the requirements to confirm the laboratory cup burner test results with room scale fire testing where the highest concentration of the laboratory and room testing was selected as the minimum extinguishing concentration for heptane. This approach is nearly identical in NFPA 2001 and ISO 14520 as far as Class B applications are concerned. Also, both use a safety factor of 30% (1.3 times the extinguishing concentration) in determining a minimum design concentration for an agent / Class B fuel combination. The validity of extinguishing agent concentrations for some agents has been confirmed in full scale testing on several Class B applications ranging from shipboard machinery spaces, armored vehicle engine and crew compartments to engine nacelles on high performance military aircraft.

During the development of halon 1301 systems there was much full-scale testing to understand the behavior of the agent, including the extinguishing concentrations necessary for numerous applications. The military was at the forefront of most of the testing to understand the use of halon 1301 on Class B type fires. However, the greatest need for halon 1301 systems was for the protection of essential electronic equipment and their immediate surroundings. An industry-wide testing program was initiated with several participants including testing laboratories, agent manufacturers, system manufacturers, computer manufacturers, insurance companies and

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[5] "Considerations for Achieving Extinguishing Concentrations," C. Hanauska, Halon Options Technical Working Conference, 1996.

[6] "Aspects of Clean Agent Fire Extinguishing System Reliability" C. Hanauska, Halon Options Technical Working Conference, 1997.

engineering firms. The program tested to find extinguishing concentration requirements for fuel types ranging from electrical cable and circuit boards up through and including cellulosic materials such as printout paper and shredded paper. In the end, the industry agreed that a nominal 5% agent concentration was a reasonable level to protect this type of equipment and immediate surroundings. It was on the basis of this industry program that the use of halon 1301 systems for the protection of essential electronic equipment became widespread.

No testing of that scale has been done to validate the use of the alternatives to halons in these essential electronic applications. Indeed, it is impossible to locate a technical paper for the halon alternatives that directly addresses the most fundamental questions the industry was pursuing with the halon 1301 testing program. Instead of directly addressing the technical issues facing the application of alternatives to this huge market, the industry chose to employ surrogate measures to establish a technical basis for many of its practices, not the least of which was / is the technical basis for the extinguishing concentration for this type of application.

In the case of Class A fuels with surface burning characteristics, the standards initially required a minimum design concentration of the cup burner value for heptane plus a safety factor. Many opposed this approach arguing that heptane and the cup burner have nothing to do with typical Class A applications. They worked to disassociate design concentrations for Class A applications from both heptane and the cup burner. Since Class A fuels do not lend themselves to laboratory type testing, it was necessary to develop a test protocol involving a series of room size tests to determine the minimum extinguishing concentration for each of four Class A test fuels. The highest extinguishing concentration determined from the testing on these multiple fuels was then deemed to be the Class A extinguishing concentration for the agent. At the same time, the NFPA 2001 standard chose to require only a 20% safety factor whereas the ISO standard chose to use a more conservative 30%.

The fundamental principle of a gaseous total flooding system is that an adequate extinguishing concentration evenly distributed throughout a hazardous volume will extinguish and keep extinguished any and all fires in that space. With Class B hazards where there is sufficient cup burner data confirmed by room scale testing and further confirmed by specialized testing in hazards such as shipboard machinery spaces, it is not difficult to technically defend the practice of extrapolating to larger and larger spaces. This is not the case in the so-called Class A surface fires testing where our collective knowledge of the agent concentration requirements have been based on very small room tests with preset fuel loads of a wood crib and three polymeric materials. Further, as evidenced in Table 8, it is possible to have enormous data ranges between two recognized testing protocols with the difference for one agent actually exceeding the 20% safety factor required by NFPA 2001.

Table 8.
Comparison of Class A Extinguishing Concentrations
ISO and UL Results

	ISO 14520 Testing	UL 2166 Testing	Difference
HFC-227ea	6.1	5.2	14.75%
HFC-125	8.6	6.7	24.42%

5.0 THE PROBLEM(S) TODAY

There are two major problems that need to be resolved:

- The surface Class A testing protocols in both NFPA 2001 (via UL 2127 and UL 2166) and ISO 14520 are inadequate. These testing protocols serve as the means for determining the extinguishing concentration requirements for broad market applications where the suitability of the testing protocol is questionable, the scalability of the results are unproven and, at least in the case of NFPA 2001, the safety factor can be consumed by the difference in results of the two recognized test protocols.
- NFPA 2001 is, for all practical purposes, silent on the agent concentration requirements for the protection of energized electrical equipment which is the broadest application of the gaseous halon alternatives. ISO 14520 recognizes the potential difficulty by tying the minimum concentration to 95% of the heptane cup burner but stops short of complete advice on the matter.

6.0 EFFORTS TO CHANGE NFPA 2001

During the last cycle for the revision of NFPA 2001, efforts to improve the standard in several areas were unsuccessful due principally to opposition from those with a commercial stake in the existing agents and systems. The technical committee for gaseous fire extinguishing systems was presented with several proposals to address extinguishing concentration issues. These proposals sought:

1) To establish a "floor" based on a percentage of the heptane cup burner value below which an agent's Class A surface fire extinguishing concentration would not be allowed;
2) To increase the safety factor to 30% (1.2 to 1.3) for Class A surface fires; and
3) To modify the standard to provide some meaningful guidance on the protection of energized electrical equipment.

The proposal to establish the "floor" for the Class A surface fire concentration is shown below and was initially acted on favorably by the technical committee.

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Submitter: Philip J. DiNenno, Hughes Associates, Inc.
Recommendation: Add a new sentence to the end of 5.4.2.2 to read:
The Class A flame extinguishing concentration shall not be less than 85 percent of the minimum extinguishing concentration for Heptane as determined in accordance with 5.4.2.1.
Substantiation: Apparent weaknesses in the test procedure for Class A fuel extinguishing concentration have resulted in the use of unacceptably low extinguishing concentrations for Class A fuels obtained from listing tests. For example, over the past several years the minimum extinguishing concentration for HFC-227ea has decreased from 5.8 to 5.25 percent, while the Class A extinguishing concentration value for HFC 227ea in ISO 15420 is 6.1 percent. This is a range of 16 percent for the same agent in the same application. (See Table below)
One way to evaluate the consistency of the Class A EC values is by comparison with Class B values for various agents is shown in Table 1. Extinguishment of a Heptane flame is a reasonable approximation of extinguishing a flame above a thermoplastic polymer surface fire, (not electrically energized, heated in depth or charring). Further, the Heptane cup burner EC has shown reasonable agreement with full scale data and there is excellent reproducibility of the test method and its results.

The Heptane cup burner EC and the Class A EC value from ISO 15420 and the ratio of the Class A to Class B EC is shown.

Agent	Cup Burner Heptane Extinguishing Concentration	Class A Extinguishing Concentration(1)	Ratio Class A/Class B
Halon 1301	3	5	1.69
CO2	20	~35	1.75
HFC-227	6.7	6.1/6.8/5.25(2)	0.91/0.87/0.78
HFC-125	9.3	8.6	0.925
HFC-23	12.6	12.5	0.99
IG-541	31.7	30.7	0.97
IG-01	39.2	32.2	0.82
IG-100	33.6	31.0	0.9226
IG-55	36.5	31.0	0.85
FK-5-1-12	4.5	4.1	0.911

Notes: (1) All values except as noted from ISO 15420
(2) 5.8 and 5.25 values are UL/FM listing values in U.S.

Historically the Class A extinguishing concentration has been greater than the Heptane cup burner extinguishing concentration by at least 50 percent (see CO2 and Halon 1301). The initial recommendation in NFPA 2001 was to use the Heptane EC value for Class A fuels. This requirement was modified with the introduction of the Class A polymeric sheet test, primarily to resolve a conflict with the data for HFC Blend A. As of the last edition of the standard, the worst case ratio of Class A EC to Class B EC was .87 for HFC 227ea. It is now as low as .78. This proposed change returns the design of systems to a reasonable minimum value and avoids future problems associated with listing test method variability, and/or hardware/enclosure effects. Establishing minimum Class A concentrations based on in part Heptane cup burner values is further supported by a wide range of full scale testing performed with a range of fuel packages and arrangements. A partial review of this data, contained in the 19th edition of the NFPA Fire Protection Handbook shows at least 7 failed extinguishing tests at concentrations above 85 percent of the Heptane cup burner values for energized electrical wire fires. By contrast all of the successful extinguishing test data we have for Class A fuels is at an extinguishing concentration greater than 85 percent of the Heptane cup burner value. Tests conducted at the Loss Prevention Council (UK) indicated that an extinguishing concentration of 85 percent Heptane cup burner gave marginal to good performance on Class A fuels for a range of agents.

Committee Meeting Action: Accept in Principle

Add a new sentence to the end of 5.4.2.2 to read: The Class A flame extinguishing concentration shall not be less than 77 percent of the minimum extinguishing concentration for Heptane as determined in accordance with 5.4.2.1.

Committee Statement: Data supports a 77 percent minimum threshold.

Within months, the technical committee reversed itself after receiving six opposing comments, all from agent or system manufacturers or installers. The comment the committee acted upon is shown below.

2001-48 Log #24

Submitter: Howard S. Hammel, DuPont Fluoroproducts
Comment on Proposal No: 2001-35
Recommendation: Reject the proposal.
Substantiation: There is no data or substantiation to justify linking the Class A minimum extinguishing concentration to the Class B minimum extinguishing concentration or the heptane

cup burner value. The industry standard is UL 2166/UL 2127, which contains Class A minimum extinguishing concentration fire testing. This test procedure was revised to account for plastics through significant research and testing.
Committee Meeting Action: Accept

The technical committee initially acted favorably on two proposals to change the safety factor from 1.2 to 1.3.

<u>2001-37 Log #11</u>

Submitter: Robert T. Wickham, Wickham Associates
Recommendation: Revise as follows: 5.4.2.4* The minimum design concentration for a Class A surface fire hazard shall be the extinguishing concentration, as determined in 5.4.2.2 times a safety factor of ~~1.2~~1.3.
Substantiation: There is no technical basis for employing a safety factor of 1.3 for Class B fires and a safety factor of 1.2 for Class A fires. Both types of fires are equally serious, can be equally intense and can be equally difficult to extinguish. Further, both types of hazards are protected by systems made up of identical components with identical reliability characteristics. In addition, systems for Class A and Class B applications are both designed with the same calculation methods and thus share identical uncertainties with regard to predicted performance.
Committee Meeting Action: Accept

<u>2001-38 Log #21</u>

Submitter: Philip J. DiNenno, Hughes Associates, Inc.
Recommendation: Change 1.2 to 1.3.
Substantiation: The safety factor for Class A fires should be increased from 1.2 to 1.3 for the following reasons:
1. The current safety factor for Class B hazards is 1.3; there is no practical or theoretical reason for the safety factor to be different for Class A hazards.
2. The historical safety factors for total flooding gases for Class A hazards were in the range of 1.5 to 1.6 for Halon 1301 and carbon dioxide. There is no demonstrated reason for the safety factor for Class A fuels to be so much lower with these new alternative agents.
3. Probability of failure calculations performed by I. Schlosser at VdS indicate a decrease in the system failure probability from 17.5 percent to 10 percent as the safety factor is increased from 1.2 to 1.3.
Reference: Schlosser, I, "Reliability and Efficacy of Gas Extinguishing Systems with Consideration of System – Analytical Methods" Proceedings – VdS Congress on Fire Extinguishing Systems, December 1 and 2, 1998, Cologne, Germany.
4. The international consensus view including the USTAG, as reflected in ISO 15420, is that a minimum safety factor of 1.3 is required for Class A hazards.
5. Uncertainty in extinguishing concentration values (see proposals related to 5.4.2.2.) for Class A fuels provides an additional argument for a higher safety factor.
Committee Meeting Action: Accept in Principle
Committee Statement: See Committee Action on 2001-37 (Log #11).

Within months, the technical committee reversed itself after receiving seven opposing comments all from agent or system manufacturers or installers. The comment the committee acted upon is shown below.

2001-55 Log #25

Submitter: Howard S. Hammel, DuPont Fluoroproducts
Comment on Proposal: 2001-37
Recommendation: Reject the proposal.
Substantiation: There is no data or substantiation to justify increasing the Class A safety factor to 30 percent. To the contrary, there are years of installed systems that indicate the current accepted practice of a 20 percent safety factor for Class A hazards achieves the necessary margin of safety in the design of Clean Agent Systems. If accepted this action will cause a significant change in system design and will impact currently installed systems.
Committee Meeting Action: Accept

The proposal to include some useful guidance for the protection of energized electrical cable and equipment is shown below. While the submitter sought to have the recommendation incorporated in the body of the standard, the technical committee chose to place it in the annex as advisory material.

2001-36 Log #19

Submitter: Philip J. DiNenno, Hughes Associates, Inc.
Recommendation: Add a new section to read as follows:
5.4.2.2.1 The extinguishing concentration shall be the greater of 95 percent of the Heptane cup burner value as determined in 5.4.2.1 or the Class A flame extinguishing concentration as determined in 5.4.2.2, where any of the following conditions exist:
(a) cable bundles greater than 100 mm in diameter;
(b) cable trays with a fill density greater than 20 percent of the tray cross-section;
(c) horizontal or vertical stacks of cable trays (closer than 250 mm);
(d) equipment energized during the extinguishment period where the collective power consumption exceeds 5 kW.
Substantiation: The extinguishing concentration needed for extinguishing fires in cable bundles and cable tray arrays are known to require higher extinguishing concentrations than simple surface fire conditions. This is due to a number of factors including the possibility of char formation and smoldering, hot metal surfaces in close proximity to cables, as well as energized electrical equipment. This wording is extracted from ISO 15420 and represents the most recent international consensus on the subject, including the position of USTAG.
Committee Action: Accept in Principle
Add a new section to read as follows:
A.5.4.2.2 Where any of the following conditions exist higher extinguishing concentrations might be required:
(a) cable bundles greater than 100 mm in diameter;
(b) cable trays with a fill density greater than 20 percent of the tray cross-section;
(c) horizontal or vertical stacks of cable trays (closer than 250 mm);
(d) equipment energized during the extinguishment period where the collective power consumption exceeds 5 kW.
Committee Statement: More appropriate as annex material.

During a recent review cycle for NFPA 2001, the chair of the gaseous fire extinguishing systems technical committee appointed a task group on energized electrical hazards to perform a literature search on the protection of energized electrical equipment and make a recommendation on a safety factor for this Class A type application. The task group prepared a report with the following recommendation for a change to NFPA 2001:

> "A significant body of test data exist from a diverse group of researchers providing evidence through testing for fire hazards with relatively low energy added electrically, conductively or radiatively to a system, agent concentrations

required to effectively control and extinguish fires in those scenarios tend to be higher than the minimum design concentrations for Class A or B fuels without such energy added. As guidance, where the protected hazard includes continuously energized electrical equipment operating at up to 48 volts (nominal) and where the power dissipation from an electric circuit failure is not likely to exceed 1500 W (continuous) the minimum design concentration of a clean agent should be lesser of:

1) 2.0 times its listed minimum Class A extinguishing concentration; or
2) 1.5 times its minimum listed Class B extinguishing concentration for heptane."

After deliberations, the technical committee prepared a committee comment which fell short of the recommendation of the task group but which made a safety factor of 1.6 mandatory for low energy energized electrical applications and went further to suggest even higher concentrations may be required at higher power levels.

2001-61a Log #CC7

Submitter: Technical Committee on Gaseous Fire Extinguishing Systems,
Comment on Proposal No: 2001-80
Recommendation: Revise text to read as follows:
5.4.2.5 Where Class C fire hazards are de-energized, the minimum design concentration shall be in accordance with either 5.4.2.3 or 5.4.2.4 depending on whether it becomes a Class A or Class B fire hazard.
5.4.2.5.1 Where electrical equipment cannot be de-energized, the design concentrations provided in 5.4.2.3 and 5.4.2.4 shall be considered to be inadequate.
5.4.2.5.2* A minimum design concentration shall be determined by multiplying the flame extinguishing concentration as determined in 5.4.2.2 times a safety factor of 1.6 where the power dissipation from an electric circuit failure is not likely to exceed 1500 W continuous.
5.4.2.5.3 Where the operating voltage or power dissipation exceeds these values, higher concentrations shall be specified.
5.4.2.5.4 A written emergency response plan based on the response time of emergency personnel shall be implemented.
Delete Annex material – 4th paragraph – A.5.6., "If electrical equipment ..."
A.5.4.2.5.2 Laboratory testing indicates that the agent concentration required to extinguish a fire in energized electrical equipment typically increases with increased electrical power input. The fire effects of continued application of electrical energy to burning materials can be uncontrollable and are not readily predicted. It is possible that fires augmented by continued addition of electrical energy may not be extinguished by the minimum concentration required by 5.4.2.5.2. When it is necessary to maintain electric power to equipment protected by a clean agent system, a contingency plan is required by 5.4.2.5.4 to account for the possibility that a fire may not be completely extinguished.
Substantiation: Laboratory testing indicates that the agent concentration required to extinguish a fire in energized electrical equipment typically increases with increased electrical power input. The committee conducted a literature search of available testing on energized electrical equipment fires and made an informed decision regarding an appropriate safety factor.
Committee Meeting Action: Accept

This language (committee comment 7) was included in the report of the committee and acted on by the association membership at the annual meeting in June 2007. After a lengthy floor discussion led by agent manufacturers, system manufacturers and installers opposing this comment, the membership acted to adopt the technical committee report without committee comment 7.

So, after three years of trying to strengthen the standard, the technical committee and NFPA have been unable (1) to put a “floor” under the uncharacteristically low Class A surface fire concentrations in use, (2) to change the Class A safety factor from 1.2 to 1.3 which would merely bring it up to the ISO 14520 level, one considered the absolute minimum in the international arena and (3) to provide any guidance in NFPA 2001 on the need for higher concentrations of agent for energized electrical circuits, cabling and equipment.

7.0 RECOMMENDED ACTIONS

It is clear that both NFPA 2001 and ISO 14520 provide different types of guidance with respect to agent concentrations in several types of applications. Of the two standards, ISO 14520 provides clearer guidance on agent concentrations across the board while NFPA 2001 provides poor guidance on Class A fires and incorrect guidance on the protection of electrical equipment. With the understanding that there are gaps in the available data and technology, and that it may take years to acquire the technology and see it embodied in standards, the following recommendations are made:

1. Professionals engaged in the design and review of clean agent systems should be made aware of the contents of this paper, especially the weak technical basis for the recommendations of extinguishing concentrations for Class A fuels in NFPA 2001.
2. Unless and until NFPA 2001 is changed to provide more credible guidance, professionals engaged in the design and review of clean agent systems would be advised to employ the following guidelines for those systems:
    - For surface Class A fires, the extinguishing concentrations specified in ISO 14520 with the 30% safety factor should be used. The values contained in NFPA 2001 with the 20% safety factor are considered inadequate.
    - For Class A fires in electrical and electronic type hazards involving grouped power or data cables (such as computer and control room under-floor voids, telecommunication facilities, etc.), the guidance of ISO 14520 should be followed. This provides for a design concentration of not less than 95% of the heptane design concentration with a 30% safety factor. The guidance provided in NFPA 2001 on this matter is considered inadequate.
    - With regard to Class B fires, the approaches of NFPA 2001 and ISO 14520 are identical and both are considered adequate.
    - With regard to Class C fires in large diameter high voltage and high power rated cables, particularly in large cable bundles and arrays, a design concentration of no less than twice the heptane extinguishing concentration should be used and even then expectations should be limited to flame extinguishment only as long as that concentration can be maintained.

Table 9 is an illustration of the design concentrations that would be employed for the various agents in the four types of applications described above.

Table 9.
Minimum Design Concentrations (vol %)

Fuel Type	FK-5-1-12	HFC-125	HFC-227ea	HFC-23	IG-01	IG-100	IG-55	IG-541
Class B*	5.9	12.1	9.0	16.4	51.0	43.7	47.5	41.2
Class A Surface**	5.3	11.2	7.9	16.3	41.9	40.3	40.3	39.9
Class A Energized Electrical Equipment***	5.6	11.5	8.5	16.3	48.4	41.5	45.1	39.9
Class C Energized Electrical****	9.0	18.6	13.8	25.2	78.2	67.2	73.0	73.4

Notes: * Values based on heptane design concentrations specified in ISO 14520.

** Values based on surface Class A design concentrations specified in ISO 14520.

*** Values based on guidance in ISO 14520 specifying at least 95% of heptane design concentration.

**** Values based on carbon dioxide and halon 1301 guidelines of twice the heptane minimum extinguishing concentration

3. Over the longer term three courses of action are recommended:
    - The fire protection industry should address the development of a strong technical link between a laboratory instrument that would be extinguishing system hardware independent and a (more) reasonable intermediate test for Class A surface fires that better reflects actual applications. The aim should be to correlate the results of the two.
    - The fire protection industry should better define the range of electrically energized hazards and do the research and testing to identify the appropriate gaseous agent concentrations necessary to control or extinguish fires in those types of hazards.
    - The fire protection industry should work with the standards making organizations to assure that the above two items are integrated into NFPA 2001, ISO 14520 and other standards as appropriate.

The consequences of the recommendations not being heeded are two-fold; first the potential exists for systems to be designed and installed with design concentrations inadequate for the hazard being protected. This could lead to the need to retro-fit some systems in the future, or the possibility of system failure in the event of a fire. A more global consequence would be an erosion in confidence with the agents and systems being installed which could lead to an increased reliance on halon 1301, CO_2, or other fire protection methods that may not provide the benefits that a properly designed and installed clean agent system provides.