Clean Agent Systems

Continued Evolution

Presented by:
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For:
SFPE - Greater Atlanta Chapter
9th Annual Fire Safety Conference
March 11-13, 2013

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Clean Agents Evolution

- Electric actuator placement supervision
- Historical review of design concentration safety factors
- Class A – safety factor revisions
- Class C – safety factor revisions

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Actuator Supervision

- **New Requirement:**
  - Supervise in place electric actuators on agent storage containers and selector valves
  - Sections 4.3.4.1 and 4.3.4.2
  - Audible and visible indication at system control panel
  - In effect January 1, 2016

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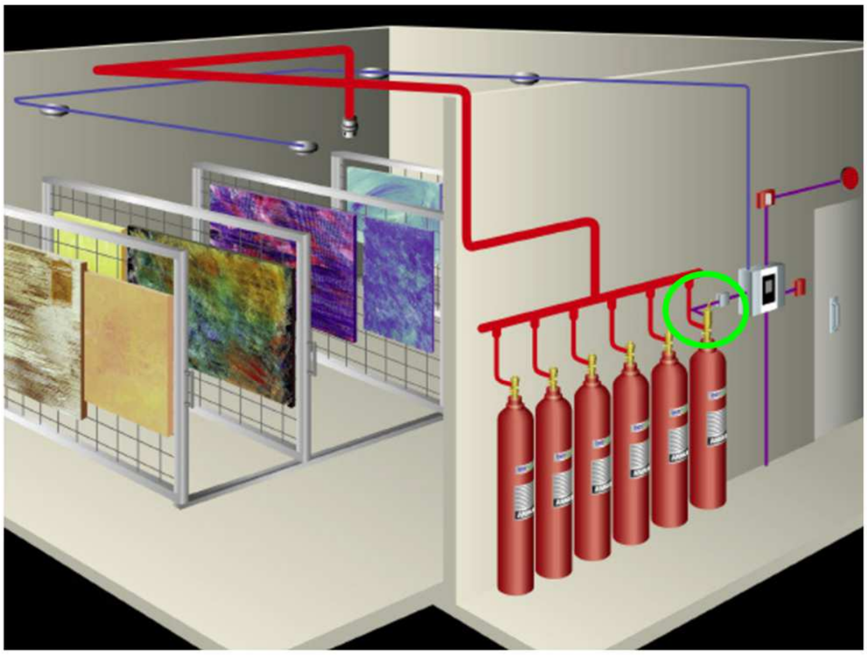

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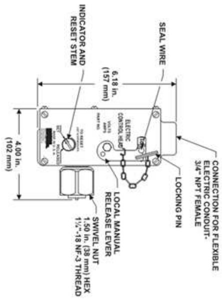
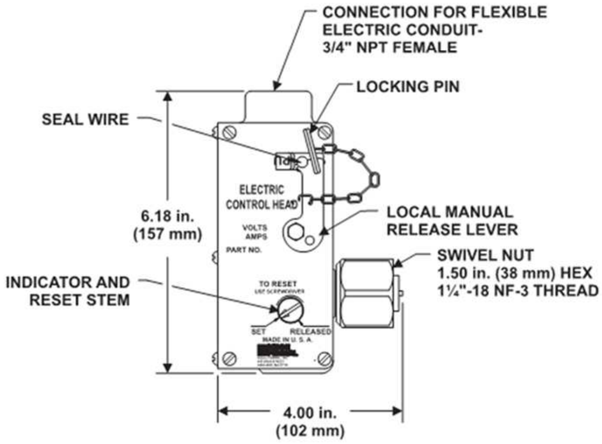
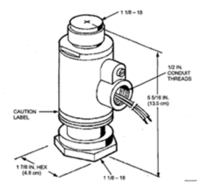
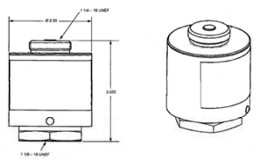
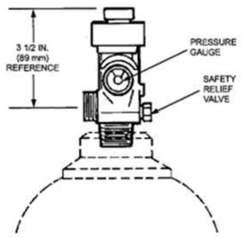


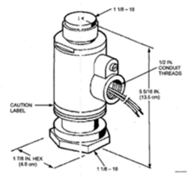

CONNECTION FOR FLEXIBLE
ELECTRIC CONDUIT-
3/4" NPT FEMALE
LOCKING PIN
SEAL WIRE
ELECTRIC
CONTROL HEAD
VOLTS
AMPS
PART NO.
6.18 in.
(157 mm)
LOCAL MANUAL
RELEASE LEVER
SWIVEL NUT
1.50 in. (38 mm) HEX
1¼"-18 NF-3 THREAD
INDICATOR AND
RESET STEM
TO RESET
SET
RELEASED
MADE IN U. S. A.
4.00 in.
(102 mm)





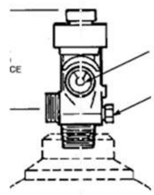


CV 98
Electric
Actuator



Booster
Actuator

CV 98
Discharge
Valve



Inergen Cylinder Valve & Electric Actuator Assembly

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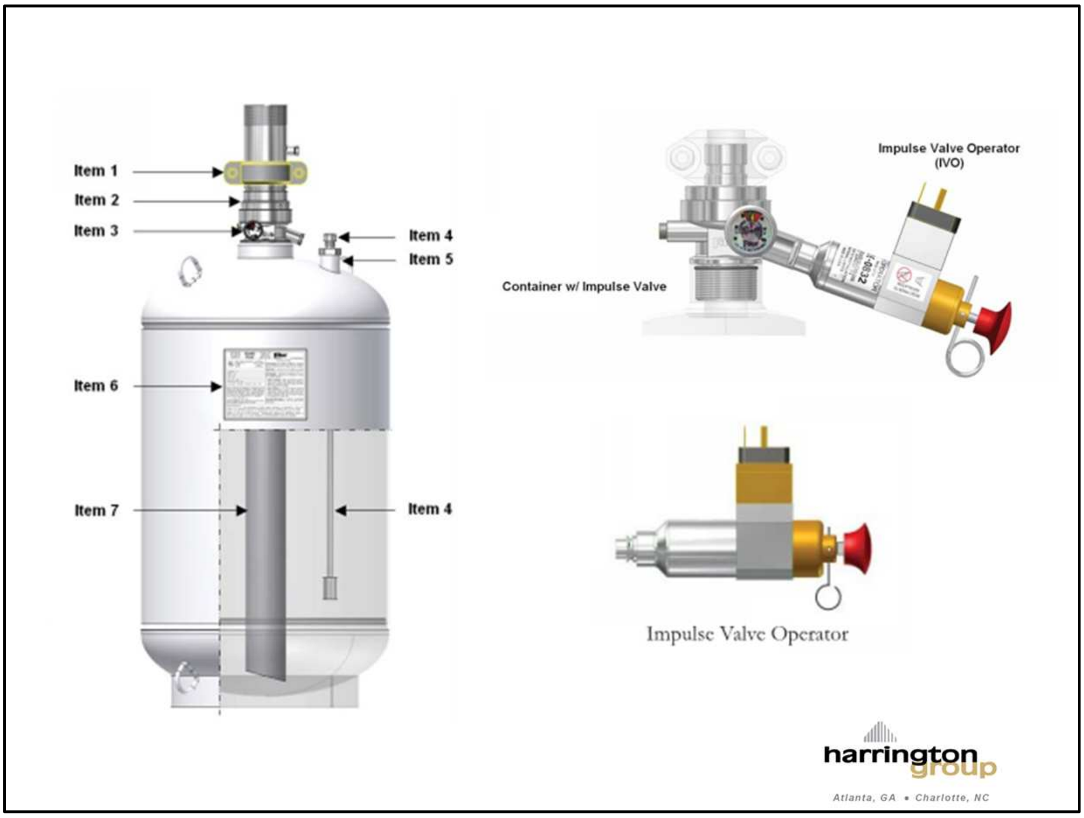
Item 1
Item 2
Item 3
Item 4
Item 5
Item 6
Item 7
Item 4
Impulse Valve Operator
(IVO)
Container w/ Impulse Valve
Impulse Valve Operator
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Actuator Supervision

- **Reasons for changes:**
  - Field technicians disconnect and remove electric actuators from equipment during regular performance testing to prevent accidental agent discharge
  - …and too frequently fail to re-install one or more actuators after completion of regular performance testing

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Actuator Supervision

- **Reasons for changes:**
  - As a result of regular testing designed to maintain system reliability, a hidden impairment results, destroying system reliability
  - Many of these systems protect mission critical facilities where such hidden impairments can have catastrophic results

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Actuator Supervision

- **Case Study 1:**
  - Inert clean agent system protecting mission critical facility
  - Service Call No. 1:
    - After regular functional testing, 1 out of 10 electric actuators were not reinstalled – resulting in hidden impairment
    - This was not discovered right away

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Actuator Supervision

- **Case Study 2:**
  - Service Call No. 2:
    - Prior to regular functional testing, 9 out of 10 electric actuators were properly removed – 1 was not - resulting in release of agent from an entire bank of agent storage containers
    - This discharge event damaged HDDs, erased data, and resulted in extensive service interruption
    - Legal case has settled

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Actuator Supervision

Extinguishing

SIEMENS

White Paper

Potential problems with computer hard disks when fire extinguishing systems are released

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Actuator Supervision

- **Siemens Study – 2010 Report**
  - Investigation into relationship between inert agent discharge and damage to HDDs or loss of data
  - Did reproduce some harmful effects
  - Ruled out pressure changes as cause
  - Confirmed that high sound pressure levels can cause harmful effects under certain conditions

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Actuator Supervision

A white paper issued by: Siemens Switzerland Ltd. Building Technologies

Conclusion: Noise levels created by the warning and / or the extinguishing process may have negative effects on typical HDDs, one effect could be a possible reduction in performance.

http://www.industry.siemens.co.uk/buildingtechnologies/uk/en/firesafety/technology/extinguishing/about-sinorix/latest-technical-findings/Documents/White%20Paper%20potential%20problems%20with%20computer%20hard%20disks%20V1.1.pdf

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Clean Agents Evolution

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Historical Review-Safety Factors

- **The first Clean Agent**
  - Halon 1301 (not carbon dioxide
    - Not harmful to humans at design concentrations
    - Gained wide favor in normally occupied spaces

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Historical Review-Safety Factors

- **Halon 1301**
  - Montreal Protocol ended its career
  - New NFPA TC was called: TC on Halon Alternative Options
    - Alternatives called "Clean Agents"
    - Thus Halon 1301 was really the first

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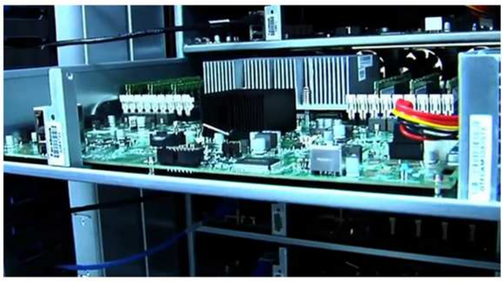
Historical Review-Safety Factors

- **NFPA 12A (1968) – Halon 1301**
  - How did it deal with safety margins?
    - Class A
    - Class B
    - Class C



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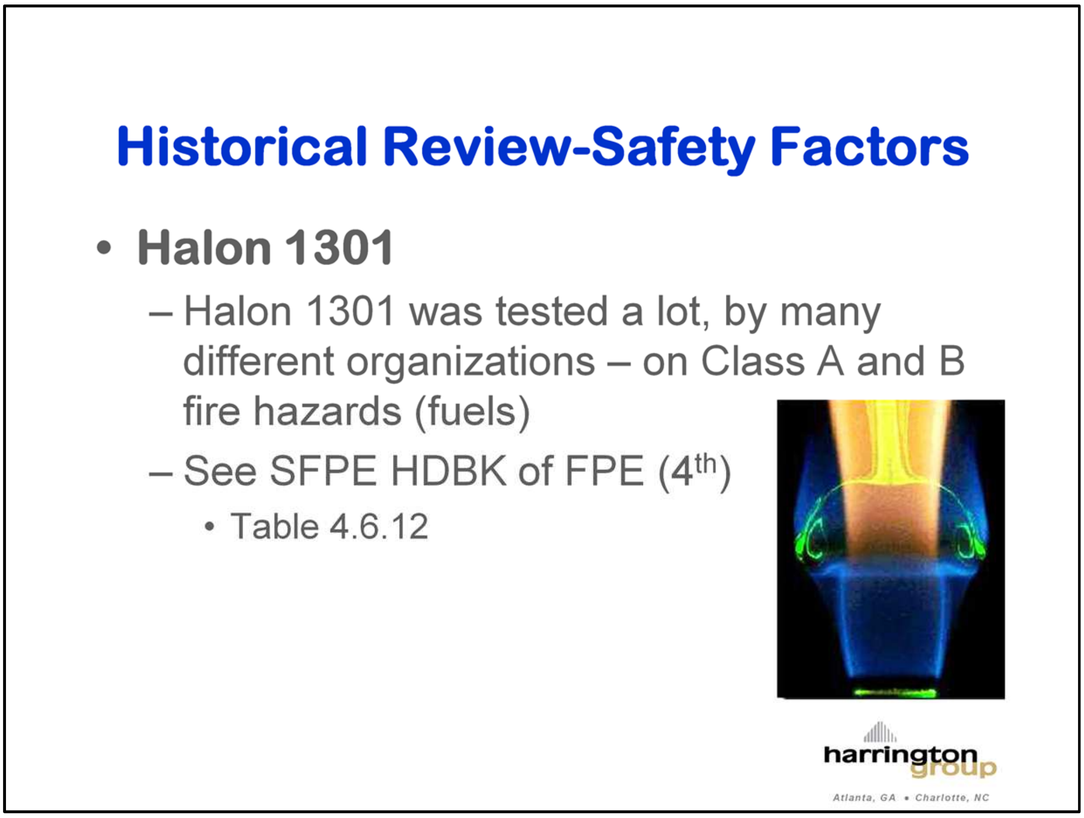
NFPA created the new technical committee on halogenated fire extinguishing systems in 1966. NFPA 12A was written and adopted by NFPA in 1968, thus helping to usher in wide-spread adoption of halon 1301 fire extinguishing systems, particularly, total flooding systems in normally occupied spaces.

Development work on halon 1301 as a fire extinguishant actually started in 1947. Production of halon 1301 in the US was ceased in 1993. During the more than 45 years of its use, many experimental tests were conducted to measure the extinguishing effectiveness on fire hazards and fuel configurations.



The SFPE Handbook, Table 4-6-12, presents halon 1301 fire extinguishing concentration data from numerous tests performed by several organizations including Factory Mutual, Fenwal, Ansul, DuPont, Safety First, and Underwriters Laboratories. The data for surface fires (Class A) range from 2.0% for polyvinyl chloride (Fenwal) to 3.88% for a wood crib (1A 50 pcs. By UL). Fenwal results for polystyrene and polyethylene were 3.0%. The data from this table was reported by Ford

The SFPE Handbook of Fire Protection Engineering, Fourth Edition, Copyright © 2008 by the Society of Fire Protection Engineers, Published by the National Fire Protection Association, Quincy, MA.

C. Ford, “Extinguishment of Surface and Deep-Seated Fires with Halon 1301,” *Symposium of an Appraisal of Halogenated Fire Extinguishing Agents*, National Academy of Sciences, Washington, DC (1972).

Historical Review-Safety Factors

- **NFPA 12A (2009)**
  - Class A
    - Minimum Design Conc: ≥ 5%
    - Minimum Extinguishing Conc:
      - 3.88% for UL wood crib
      - 2.0% for polyvinyl chloride (PVC)
    - Safety Factors:
      - 1.3 for UL wood crib
      - 2.5 for PVC

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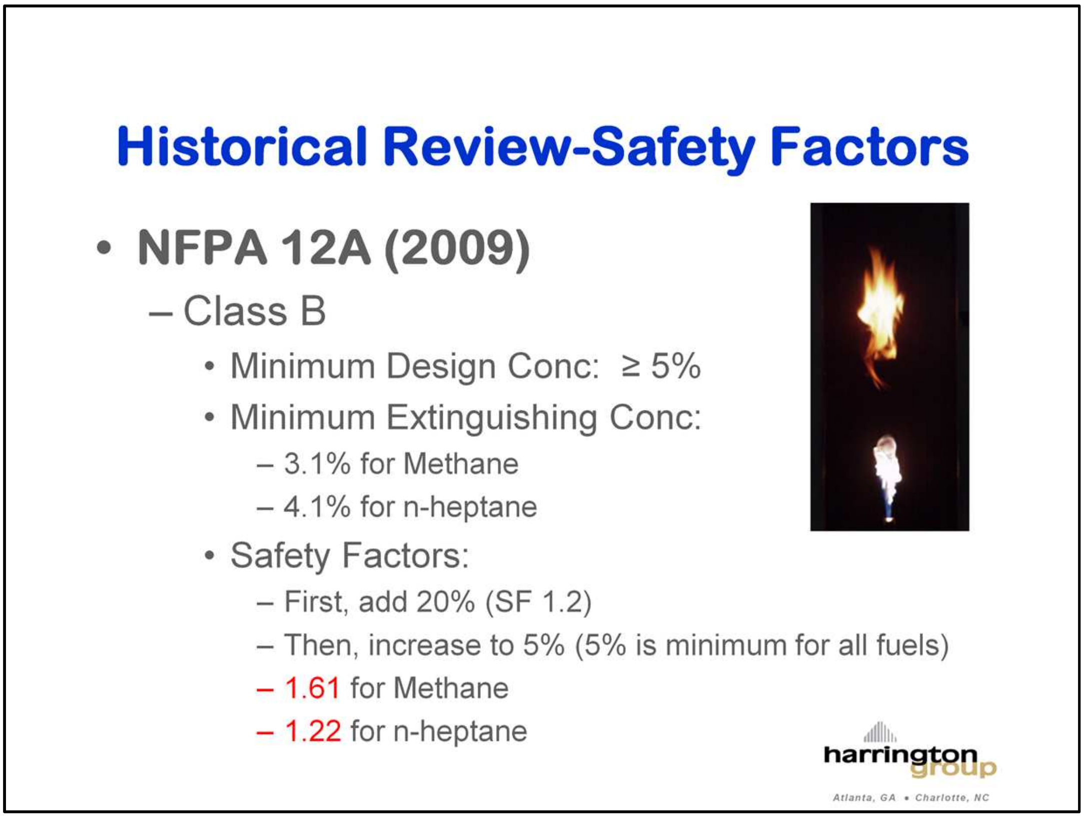
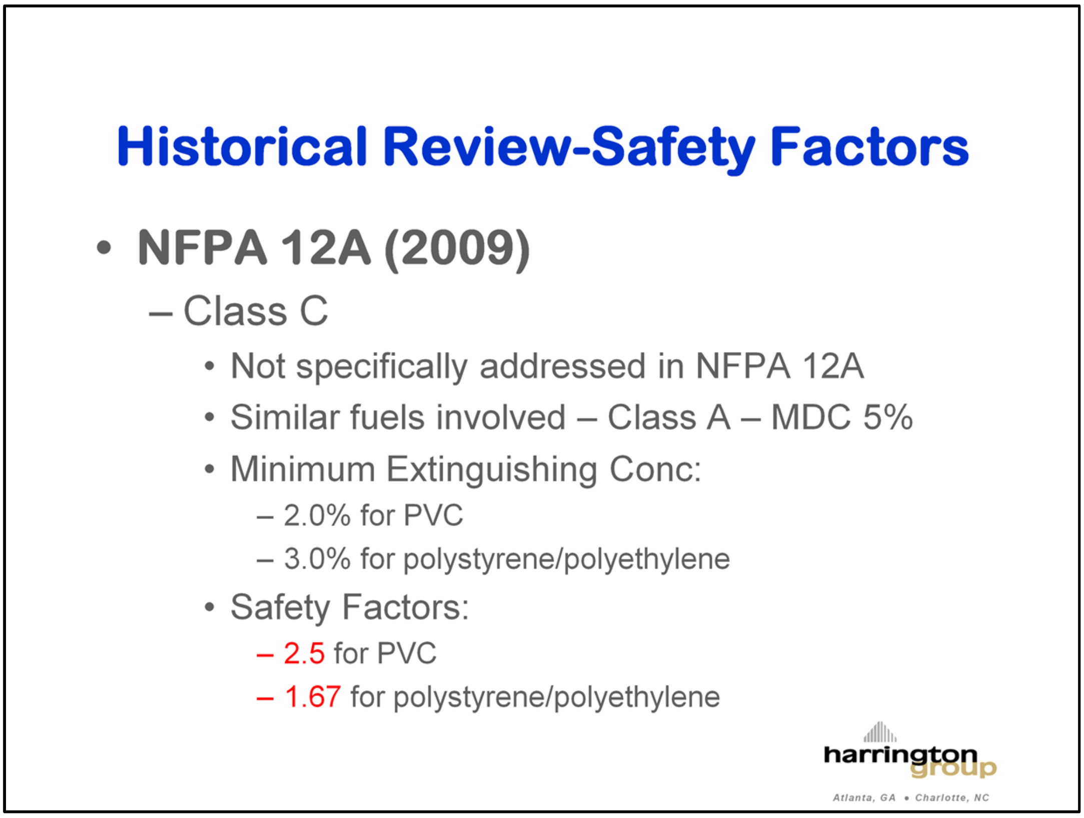


The requirement of a minimum 5% design concentration for all flammable liquids and gases (Class B), and all surface fires (Class A) has the result of requiring that a safety margin be added to the minimum extinguishing concentration for these hazards. In the case of methane, for example, the minimum extinguishing concentration is listed as 3.1% and the required design concentration is 5%. This results in a margin of safety of 61%, which can also be referred to as a safety factor (multiplier) of 1.61. As another example, the minimum extinguishing concentration of polystyrene and polyethylene is 3.0%. The required safety factor is, therefore, 1.67. The minimum extinguishing concentration for n-heptane, as a final example, is 4.1%, resulting in a required safety factor of 1.22. As can be seen, the margin of safety requirements in NFPA 12A result in widely varying margins of safety for various fire hazards.



NFPA 12A does not specifically address minimum extinguishing concentrations or minimum design concentrations for Class C fire hazards, which are fires in continuously energized electrical equipment. Such fires hazards have been traditionally classified as surface fires by the halon 1301 industry and protected by a minimum design concentration of 5%. If one were to compare the fuel involved in Class C fires to polyvinyl chloride (2% minimum extinguishing concentration) or polystyrene/polyethylene (3% minimum extinguishing concentration), with a required minimum design concentration of 5%, one would conclude that the required safety factor for a Class C fire could range between 1.67 and 2.5.

A significant percentage of all halon 1301 total flooding systems installed in the US, and elsewhere, were designed according to NFPA 12A to protect surface fires in Class A and Class C configurations. At a 5% minimum design concentration, these systems employed a safety factor of between 1.3 (wood crib, UL) and 2.5 (polyvinyl chloride, Fenwal). Under these conditions, halon 1301 enjoyed a strong reputation for fire extinguishing effectiveness in real-world fire conditions.

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Historical Review-Safety Factors

- **NFPA 12A (2009)**
  - Safety Factor Justifications
    - Class A fire hazards
      - to account for real world complexities (Annex J)
    - Class B fire hazards
      - No explanation for the base 1.2 safety factor
      - No explanation for the minimum 5% threshold
    - Class C
      - Not addressed

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The rationale for applying the initial 20% safety margin for flammable liquid and gases is not explained in NFPA 12A, nor is the additional margin of safety beyond 20% to reach the minimum 5% design concentration.

For surface fires, the additional margin of safety required to reach the minimum design concentration of 5% is explained in Annex J, *Surface Fires*, which states, *"…because the potential array of fuels likely to be involved in every real fire requires the higher concentration.*"

Perhaps, this means that, according to the committee, fuel arrays in the real world are likely to be more complex that those tested, and the complexity of the real world arrays could require higher agent concentrations to extinguish, so an added margin of safety is warranted to cover the unknown factors.

Clean Agents Evolution

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Class A Safety Factor Revisions

- **NFPA 2001 (2012) – Roots**
  - First edition developed using NFPA 12A as a starting point
  - New and different concerns about new clean agents at the time:
    - More agent required
    - Higher agent and overall system cost
    - Preservation of the market during transition

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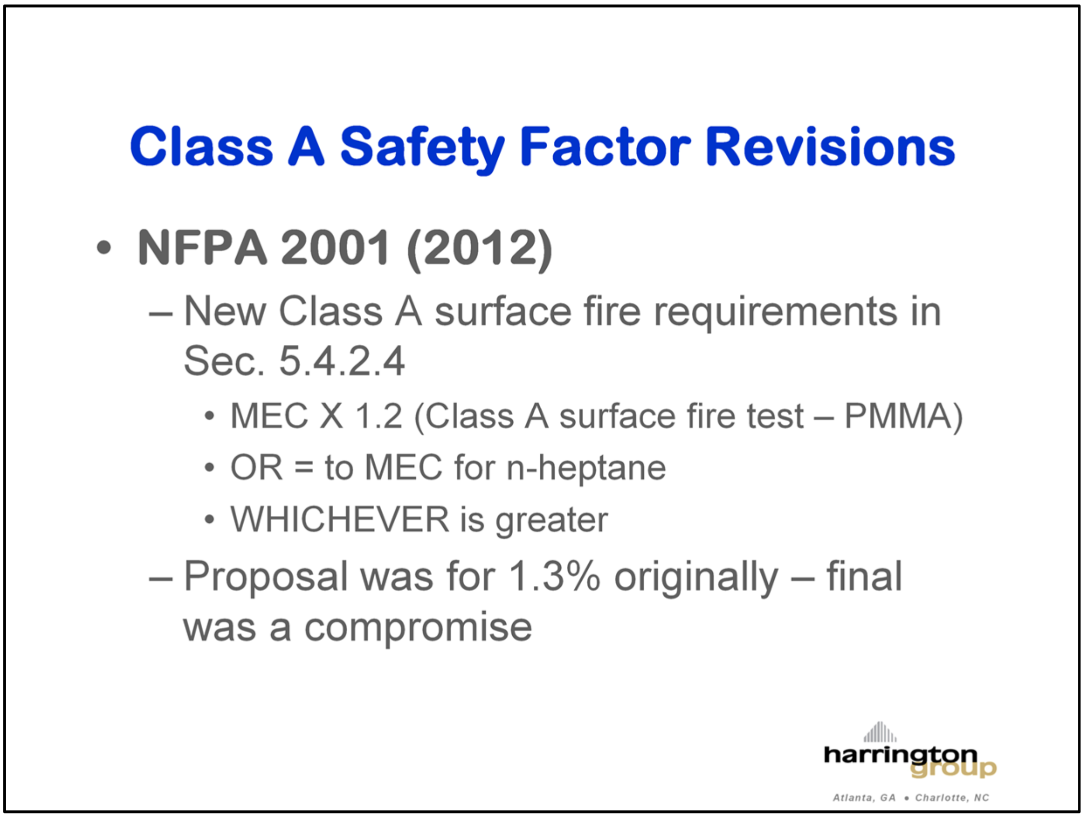
During the development of NFPA 2001, NFPA 12A was used as a starting point. On the subject of margin of safety between the minimum extinguishing concentration as determined by test and the minimum design concentration, the committee decided to require a safety factor of only 1.2 for Class A surface-type and B fire hazards. Class C fire hazards were addressed, but the minimum design concentration was pinned to that for Class A surface-type fires. No specific technical justification was presented for the requirement of a 20% margin of safety. This value was chosen because it was used in NFPA 12A, also without any specific technical justification or explanation.

Underlying the committee's interest in modest safety factor of 1.2 were: more agent was going to be required, more equipment, higher overall system cost – leading to concerns about preserving the clean agent market established by Halon 1301 during the transition period. Desire to keep cost increases as minimal as possible – but also to provide reasonable extinguishing performance and system reliability.



Over the years, the blanket use of a 1.2 safety factor in NFPA 2001 has come under scrutiny, in part because it is significantly lower than the effective safety factors used for most fire hazards in NFPA 12A, and in part due to the influence of work done internationally by the committee responsible for writing the ISO clean agent standard, ISO 14520. Eventually, the safety factor for Class B fire hazards was raised from 1.2 to 1.3. Also, in the latest edition of NFPA 2001, a revision to the safety factor requirements for Class A fire hazards was implemented, which raised the required margin of safety for some clean agents. The following changes were incorporated into Section 5.4.2.4.

The minimum design concentration for any clean agent shall be the GREATER of:
The MEC determined by the Class A surface fire tests as part of the listing program, as a minimum, UL 2127 or UL 2166, multiplied by a safety factor of 1.2
Equal to the MEC for heptane as determined by the cup burner test method

For certain listed system and agent combinations, there is virtually not change (still SF of 1.2):
All inert agent systems
Some HFC-227ea systems

For certain other listed system and agent combinations, there is an increase in the required minimum design concentration, and hence an increase in the

effective safety factor (new SF of about 1.3)
All FK-5-1-12 systems
All HFC-125 systems
Some HFC-227ea systems

Class A Safety Factor Revisions

Clean Agent	Class A MEC	Class A Safety Factor	Class A Design	Class A Safety Factor	Class A Design	Class B MEC	Effective Class A Safety Factor	Class B Design	NOAEL	LOAEL	5 minute limit
FK-5-1-12	3.50	1.20	4.2	1.30	4.6	4.5	1.29	5.9	10.0	>10.0	10.0
HFC-125	6.70	1.20	8.0	1.30	8.7	8.7	1.30	11.3	7.5	10.0	11.5
HFC-227ea	5.20	1.20	6.25	1.30	6.8	6.7	1.29	8.7	9	10.5	10.5
HFC-227ea	5.80	1.20	7.0	1.30	7.5	6.7	1.16	8.7	9	10.5	10.5
IG-541	28.50	1.20	34.2	1.30	37.05	31.25	1.10	40.6	43	52	43.0
IG-55	31.60	1.20	37.9	1.30	41.1	30.1	0.95	39.1	43	52	43.0

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All FK-5-1-12 systems
All HFC-125 systems
Some HFC-227ea systems

Class A Safety Factor Revisions

- **Catalyst for Change**
  - Class B raised to 1.3
  - Halon 1301 historically in 1.6+ range
  - Ingeborg Schlosser risk study (17.5% to 10% reduction in failures predicted)
  - International consensus that 1.3 is best
  - Uncertainty in measuring MEC values

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<u>Support for this change:</u>

The safety factor of 1.2 applied to the minimum extinguishing concentration as determined by test, to determine the minimum design concentration, has long been a matter of debate within the TC. There has never been a detailed scientifically-based understanding of what risks or errors this 20% safety factor addresses, and what it does not include.

The public proposal (Log #30) recommended a blanket increase in the safety factor for Class A hazards from 1.2 to 1.3, and presented 5 reasons.

Class B hazards currently require a safety factor of 1.3, and there is no practical or theoretical reason for the safety factor for Class A hazards to be less than this.
Historical safety factors for Halon 1301 and CO2 in range of 1.5 to 1.6, and there is no demonstrated reason for clean agents to have a substantially lower safety factor.
Probability of failure calculations performed by Ingeborg Schlosser[1] of VdS indicate a decrease in probability of system failure from 17.5% to 10% as safety factor is increased from 1.2 to 1.3.
The international consensus view is that a minimum safety factor of 1.3 is required, including the view of USTAG as reflected in ISO Standard 14520.
Uncertainty in minimum extinguishing concentration values for Class A fuels

provides an additional argument for a higher safety factor

[1]Study by Ingeborg Schlosser: “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.

The committee was divided and there was much debate. Ultimately, a compromise was agreed upon, which resulted in the new language in the standard stated previously. As a result:

The system using HFC-227ea that was re-listed by UL at a lower MEC of 5.2% now has to use a minimum design concentration of 6.7% rather than 6.25%, resulting in a safety factor of 1.3, while the systems using HFC-227ea that did not re-list by UL remain at 7.0%, which is a safety factor of 1.2.
No change for the inert agents
All FK-5-1-12 and HFC-125 systems now have to use a minimum design concentration that is higher than before, corresponding to a safety factor of approximately 1.3

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Class C Safety Factor Revisions

- **NFPA 2001 (2012) – Roots**
  - NFPA 12A did not address Class C
  - NFPA 2001 did, but tied the design concentration to Class A
    - In application, the same result as in NFPA 12A
  - Committee worked toward an indeptendent approach for Class C

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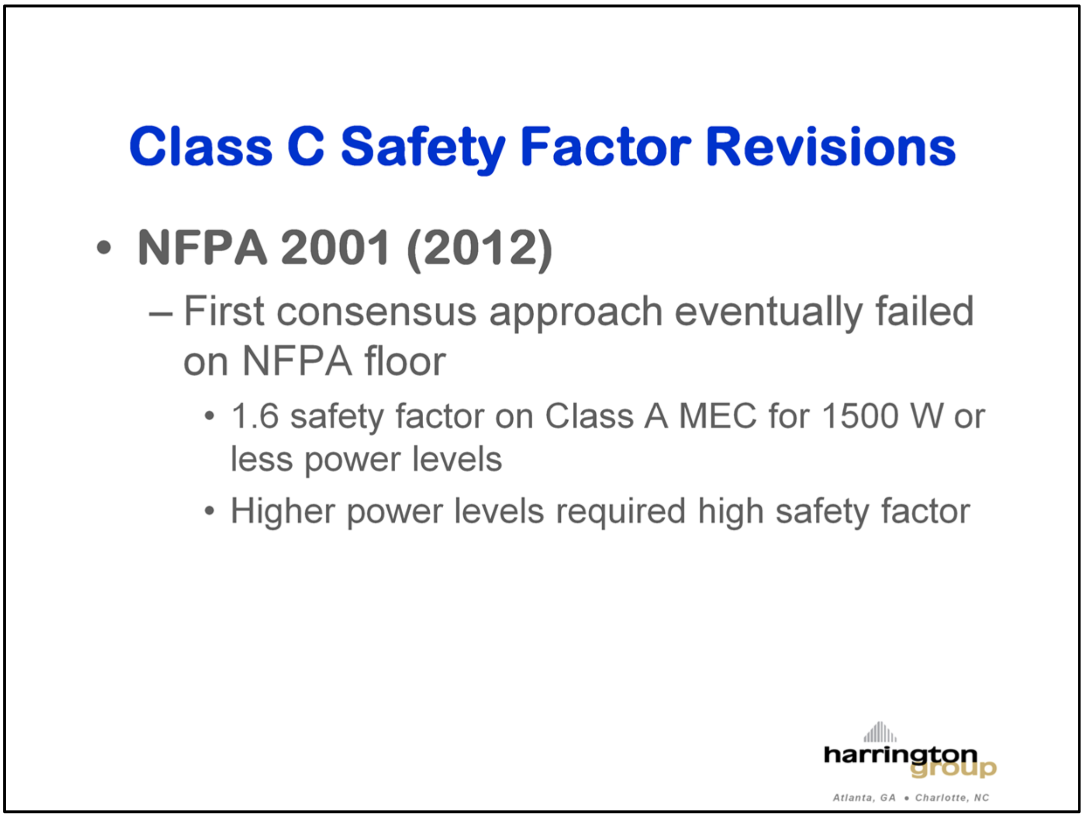
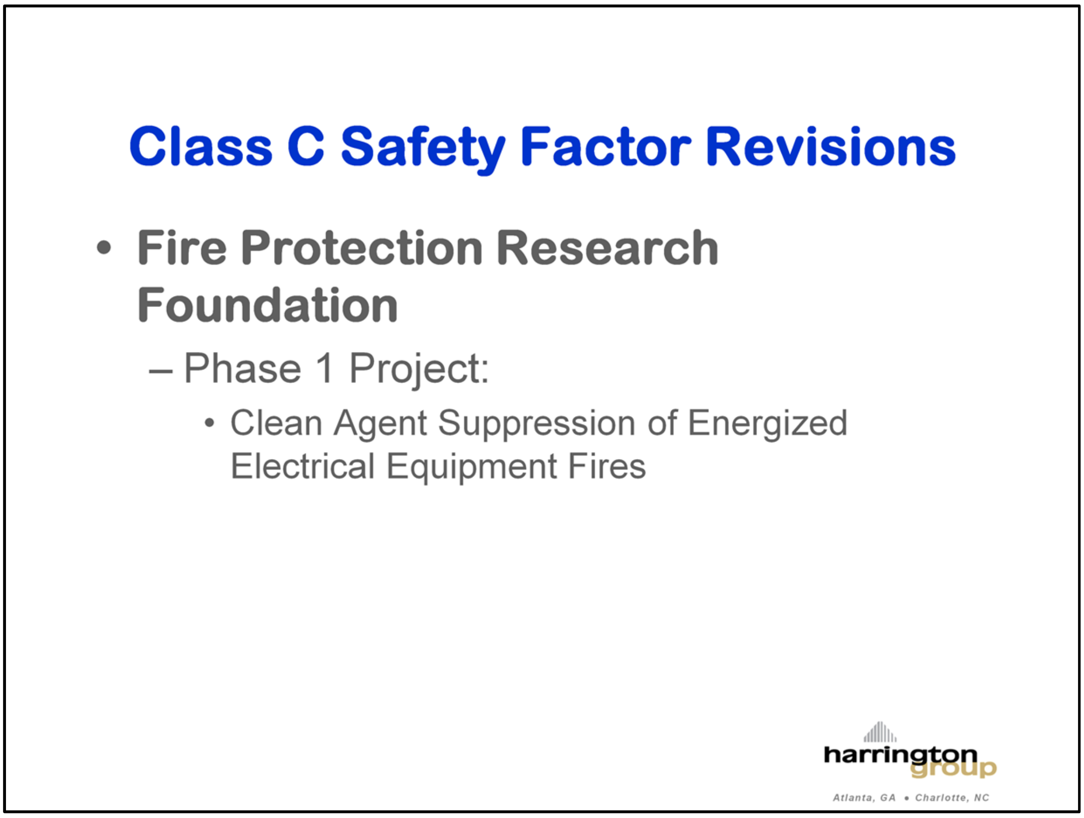
Eventually, the committee became uncomfortable with the fact that the Class C design concentration had never been independently validated. Pinning it to the Class A design concentration was not justifiable and should be replaced with Class C fire extinguishment fundamental knowledge.

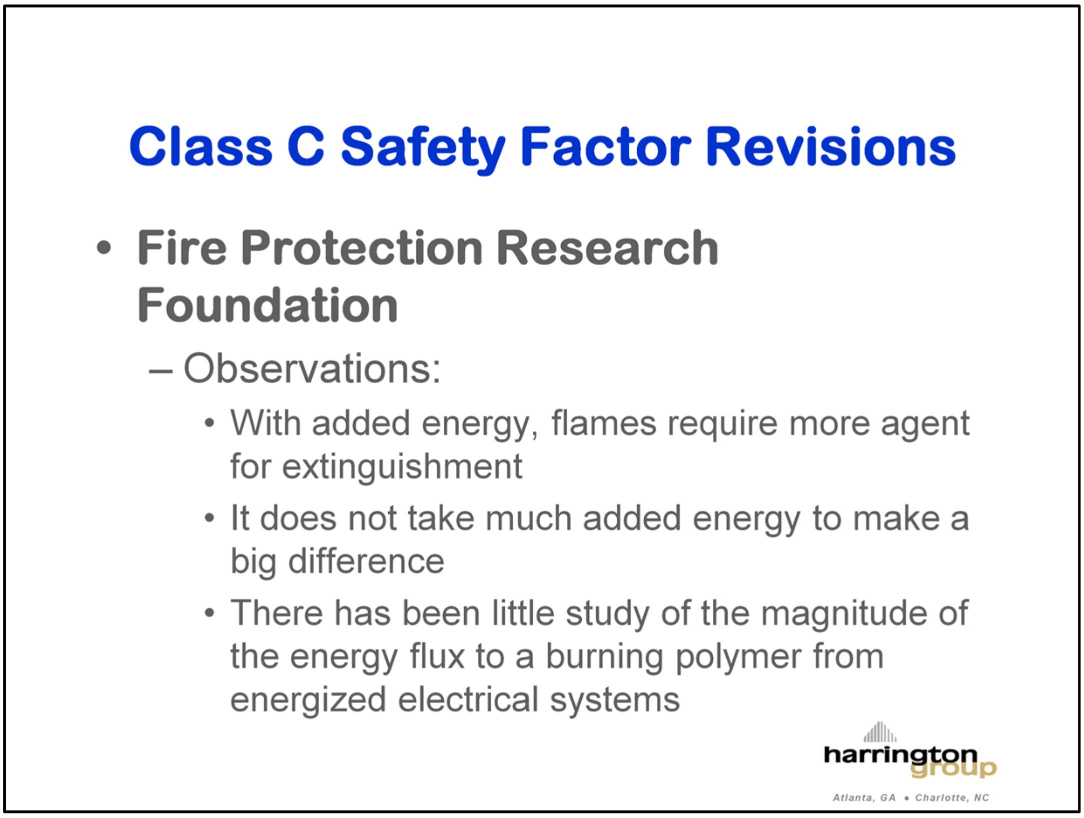


First, a literature search was done turning up about 13 or so technical papers. This information was analyzed and condensed. Initially, the committee felt that the data supported imposing a safety factor of 1.6 on Class C fire hazards for 1500 W power conditions or less. If power conditions are more than 1500 W, then higher concentrations are required. This was included in the ROC as Comment 2001-61a, and was overturned at the annual meeting, and debated some more during the subsequent cycle.



The committee requested that a project be funded through the FPRF to study Class C fires. This was done, and Dr. Gregory Linteris of NIST was contracted to perform the work. He produced a project report. Three primary conclusions were provided in this report regarding Class C fire extinguishment:
With added energy, flames require more agent for extinguishment
It does not take much added energy to make a big difference
There has been little study of the magnitude of the energy flux to a burning polymer from energized electrical systems

It was recommended that a Class C test protocol and apparatus be developed to research Class C fires further in a manner, including round robin testing, that would produce accurate and trustworthy results accepted by all of the key stakeholders.
G. Linteris, *Clean Agent Suppression of Energized Electrical Equipment Fires, Copyright © by Fire Protection Research Foundation, January 2009.*



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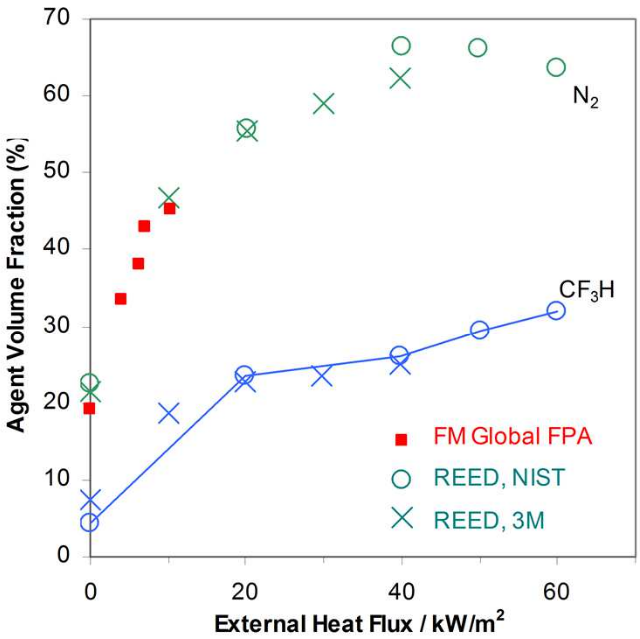

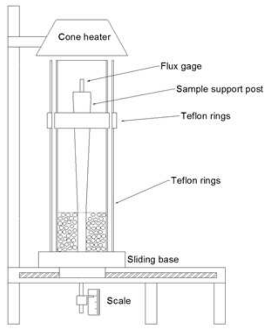

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Class C Safety Factor Revisions

- **Fire Protection Research Foundation**
  - Future Path Suggestions:
    - Develop Class C test apparatus and protocols
      - REED apparatus suggested as possibility
    - Perform round robin style testing between labs to establish technical foundation
    - Focus research on data center and telecommunications environment hazards

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Class C Safety Factor Revisions

- **NFPA 2001 (2012)**
  - New Class C requirements (5.4.2.5)
    - 1.35 safety factor on Class A MEC
    - If > 480 V, design concentration determined by testing and risk assessment

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The committee used the work of Dr. Linteris and the FPRF workshop to develop a revised approach to Class C fires, adopting the change for the 2012 edition (Section 5.4.2.5).
Class C fire hazards require a safety factor of 1.35 times the Class A surface fire minimum extinguishing concentration
Continuously energized equipment greater than 480 volts requires a minimum design concentration determined by testing and fire hazard analysis.

Class C Safety Factor Revisions

- **Continued Class C Research**
  - Two examples:
    - UMD Master's Thesis-2012+
    - Fike Protection Systems – 2012+

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Class C Safety Factor Revisions

- UMD Master's Thesis – 2012+
  - TEST VIDEO

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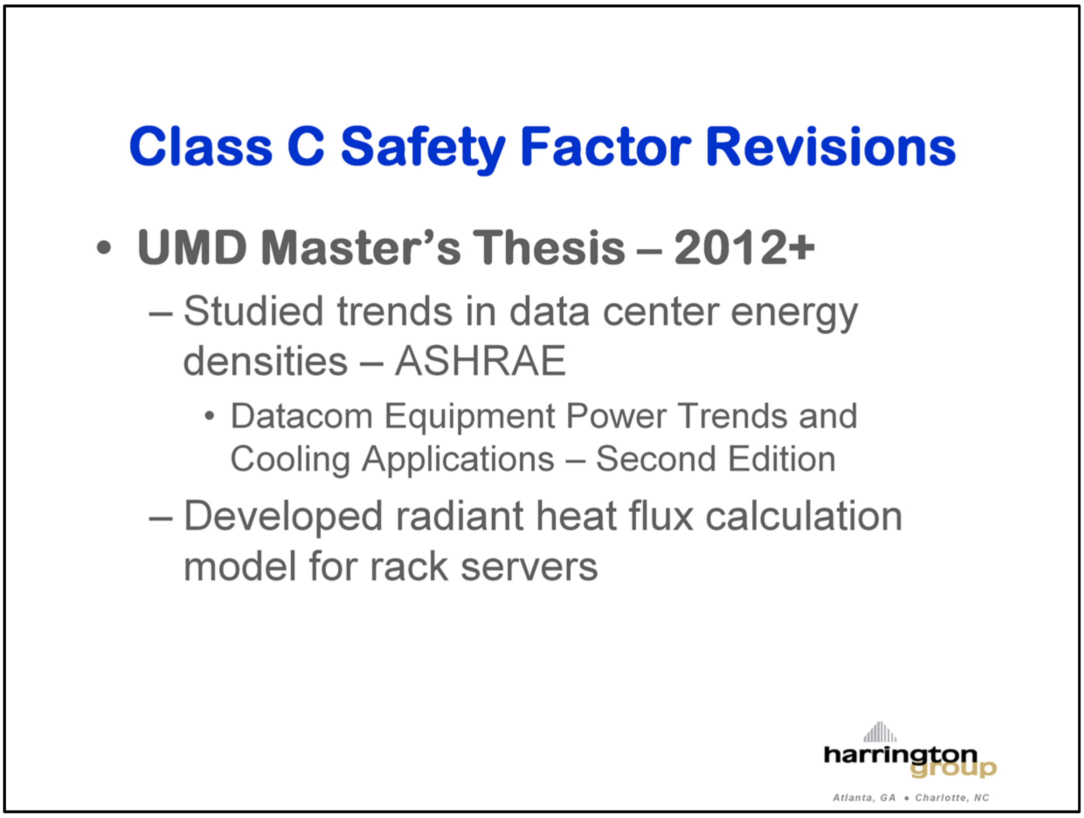

UMD master's thesis

Reports details on development of the REED test apparatus, referencing a report published by David M. Smith et al.
Reports on the development at Factory Mutual of the FM Global Flammability Apparatus
Presents graph from Linteris showing combined results of data from REED and FM Global Flammability Apparatus.

- This combined data demonstrates sharp increase in MEC between heat fluxes of 0 and 10 kW/m^2, followed by a leveling off
- This graph shows that between 20 kW/m^2 and 50 kW/m^2 the MEC for CF3H increases by a factor of 1.45, and for N2 a factor of 1.24

Presents MEC test data obtained at UMD during this study, and compares that to same data obtained at 3M

- For HFC-227ea, the average results of the tests run at UMD are 10% higher than the average of the 3M test results
- For IG-541, the average results of the tests run at UMD are 9% lower than the average of the 3M test results

Presents table, and graphs of test data for each agent – NFPA 2001 Class C design concentration vs. UMD REED test results for MEC

- At flux of **5kW/m^2 and above**, the MEC values from the REED testing exceed the design concentration requirements currently in NFPA 2001

Presented the development of a model to approximate the power density and resulting radiant heat flux that will be emitted by two adjacent 1U blade servers on a cable positioned in the space between them

Conclusion given that 4.76 kW/m^2 is largest expected heat flux emitted from a blade server with $0.1m^2$ surface area in a 20 kW 42U server rack in the year 2012 – therefore, this study should especially look at the heat flux range of 0 to 5 kW/m^2.

The ASHRAE study suggests that server rack densities, and thus heat flux values, will continue to increase to the year 2020.

Discovered that the standard REED test protocol has a tendency to destabilize the flame prior to extinction, which may produce artificially low extinguishing concentration results

The current protocol requires 100 second waiting period between each step increase in agent concentration, until flame is extinguished – thus flame is bathed in increasing amounts of extinguishing agent which may weaken and destabilize the flame gradually until it is finally extinguished, by a lower concentration than would normally be required.

Revised protocol eliminated the 100 second delay between steps replacing it with a 2 second delay – this resulted in extinguishing concentrations that were 33% to 50% higher than the original REED test protocol.

The revised protocol may have its own inaccuracies that have to be resolved, but this is a good demonstration of the fact that the extinguishing concentration determined by any test is partially dependent on the test apparatus and protocol.

David M. Smith, et al. *Energized Fire Performance of Clean Agents: Recent Developments*, 3M Specialty Chemicals Division, NIST Building and Fire Research Laboratory

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- **ASHRAE Trend Data**

Type	Size			Range of Average Heat Loads	Heat Load/Chassis (W)			Heat Load/42U Rack (W)		
	W	H	Sockets		2010	2015	2020	2010	2015	2020
Compute Servers	17.5 in. (0.44 m)	1U	1S	±20%	255	290	330	10,710	12,180	13,860
			2S	±10%	600	735	870	25,200	30,870	36,540
			4S	±5%	1000	1100	1200	42,000	46,200	50,400
		2U	2S	±20%	750	1100	1250	15,750	23,100	26,250
			4S	±5%	1400	1800	2000	29,400	37,800	42,000
		4U	4S	±5%	2300	3100	3300	23,000	31,000	33,000
		7U (Blade)	2S	±10%	5500	6500	7500	33,000	39,000	45,000
		9U (Blade)		±10%	6500	8000	9500	36,000	32,000	38,000
		10 (Blade)		±10%	8000	9000	10,500	32,000	36,000	42,000

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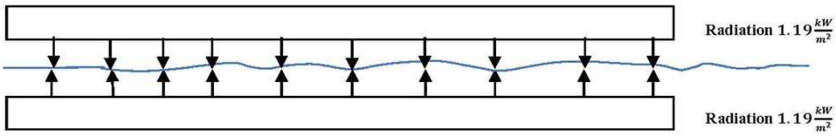
- **Heat Flux Model – Blade Server Rack**



	Typical Server Blade Area (m²)	10 kW Rack	20 kW Rack
Incident Heat Flux (kW/m²)	0.1	2.38	4.76
	0.15	1.59	3.17
	0.2	1.19	2.38
	0.25	0.95	1.90
	0.3	0.79	1.59
	0.4	0.60	1.19

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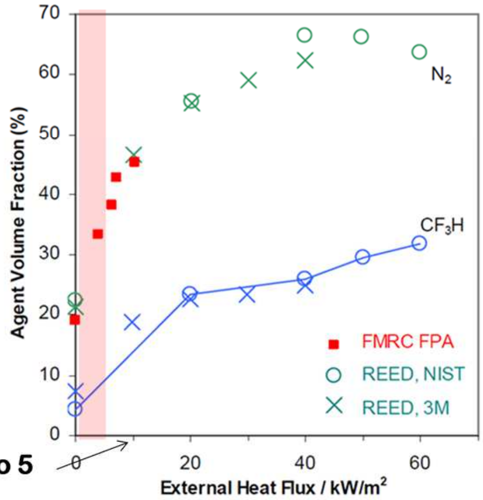
- **Heat Flux Focus Range**



Target range up to 5 kW/m²

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- **MEC Results**

Table 6: NFPA 2001 Class C Design Concentrations versus REED Apparatus Extinguishing Concentrations.

Agent	NFPA 2001	0 kW/m²	1 kW/m²	2 kW/m²	4 kW/m²	5 kW/m²	10 kW/m²	20 kW/m²	30 kW/m²	40 kW/m²
IG-100	40.5	21.8	26.4	30.5	36.8	41.0	46.8	55.5	59.0	62.3
HFC-227ea	7.0	4.7	5.7	6.7	8.0	8.5	10.3	14.4	15.1	16.2
HFC-125	9.0	3.9	5.7	7.8	11.6	12.7	16.8	19.3	22.5	25.9
IG-541	38.5	24.0	27.8	32.0	39.1	42.0	49.0	54.3	57.4	58.0
FK-5-1-12	4.7	2.9	3.0	3.8	4.8	5.4	7.6	13.2	N/A	17.1
IG-55	42.7	24.6	28.5	33.8	40.9	43.3	51.1	55.2	58.8	59.9

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- **All Test Results**

Agent	Extinguishing Concentrations								
	0 kW/m^2	1 kW/m^2	2 kW/m^2	4 kW/m^2	5 kW/m^2	10 kW/m^2	20 kW/m^2	30 kW/m^2	40 kW/m^2
Nitrogen	21.82	26.20	30.15	36.46	40.83	44.0	54.0	59.0	63.0
C.B = 32.0%	21.81	26.53	30.65	36.94	41.11	49.0	54.0	59.0	63.0
	21.81	26.51	30.69	36.98	41.08	47.0	57.0	59.0	61.0
						47.0	57.0	59.0	
Averages	21.8	26.4	30.5	36.8	41.0	46.8	55.5	59.0	62.3
HFC-227ea	4.67	6.63	7.44	9.26	9.99	9.8	13.2	13.2	14.0
C.B = 6.6%	4.71	6.74	7.47	9.17	10.31	9.8	12.4	13.2	14.9
	4.70	6.69	7.48	9.34	10.23	10.7	12.4	13.2	13.2
		5.71	6.66	7.96	8.46	10.7	12.4	17.2	16.8
		5.67	6.71	7.99	8.51	10.1	16.8	17.1	18.5
		5.68	6.67	7.94	8.49	10.8	17.6	16.7	18.0
							16.2		17.7
Averages	4.7	5.7	6.7	8.0	8.5	10.32	14.43	15.10	16.16
HFC-125	3.97	5.76	7.78	11.54	12.56	16.12	19.4	22.18	25.7
C.B = 8.7	3.89	5.64	7.73	11.61	12.73	16.73	19.2	22.43	25.9
	3.82	5.72	7.90	11.68	12.67	17.49	19.3	22.78	26.0
Averages	3.9	5.7	7.8	11.6	12.7	16.8	19.3	22.5	25.9
		25.59	26.74	29.58	32.88				
IG-541	23.78	25.53	26.90	29.58	32.93	50.0	53.0	59.0	57.0
C.B = 29.1%	24.13	25.65	26.84	29.58	32.88	48.0	56.0	57.0	59.0
	23.97	27.90	31.93	39.10	42.03	48.0	53.0	58.0	57.0
	23.94	27.80	32.02	38.99	41.96	50.0	55.0	55.0	59.0
		27.69	31.97	39.06	42.00			58.0	58.0
Averages	24.0	27.8	32.0	39.1	42.0	49.0	54.3	57.4	58.0
FK-5-1-12	2.82	2.97	3.53	4.88	4.96	7.11	12.8		15.8
C.B =4.5%	2.97	3.06	3.93	4.81	6.04	7.56	13.5		18.4
	2.78		3.98		5.28	8.21			
						7.66			
Averages	2.9	3.0	3.8	4.8	5.4	7.6	13.2		17.1
IG-55	19.03	21.32	25.42	32.06	35.52				
C.B = 31.2	20.06	21.38	25.92	31.12	35.93				
*	20.80	21.19	26.36	31.74	35.93				
	24.21								
	23.98	28.32	33.86	41.02	42.87	51.23	54.89	58.79	59.98
	24.89	28.48	33.57	40.87	43.34	51.12	55.23	58.95	60.02
	24.78	28.75	33.98	40.67	43.79	50.98	55.38	58.55	59.77
Averages	24.6	28.5	33.8	40.9	43.3	51.1	55.2	58.8	59.9

Figure A-3: REED Testing using Original Method. Data in Yellow are Results from Testing at 3M, Data in Green are Results from Testing at UMD

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	0 kW/m²	1 kW/m²	2 kW/m²	4 kW/m²	5 kW/m²	
HFC-227ea		6.63	7.44	9.26	9.99	
		6.74	7.47	9.17	10.31	
		6.69	7.48	9.34	10.23	
		5.71	6.66	7.96	8.46	
		5.67	6.71	7.99	8.51	
		5.68	6.67	7.94	8.49	
	Averages					
		6.69	7.07	8.61	9.33	
		5.69	6.68	7.96	8.49	
	Variances					Avg
		1.00	0.39	0.65	0.85	0.72
		18%	6%	8%	10%	10%

	0 kW/m²	1 kW/m²	2 kW/m²	4 kW/m²	5 kW/m²	
IG-541		25.59	26.74	29.58	32.88	
		25.53	26.90	29.58	32.93	
		25.65	26.84	29.58	32.88	
		27.9	31.93	39.10	42.03	
		27.8	32.02	38.99	41.96	
		27.69	31.97	39.06	42	
	Averages					
		26.69	29.40	34.32	37.45	
		27.80	31.97	39.05	42.00	
	Variances					Avg
		-1.10	-2.57	-4.74	-4.55	-3.24
		-4%	-8%	-12%	-11%	-9%

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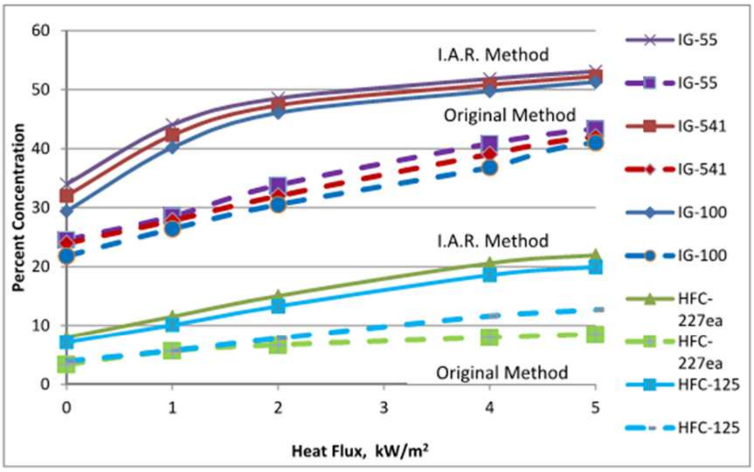

Figure 32: Original versus IAR Testing Method Extinguishing Concentrations using REED Apparatus, 0-5 kW/m^2

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- Fike Corporation – 2012+
  - TEST VIDEO

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- **Fike Corporation – 2012+**

A solid line represents a solid surface hot plate

A dashed line in a coil type heater element

The square represents our plastic test sample

And the bowtie represents a muffin fan for air movement

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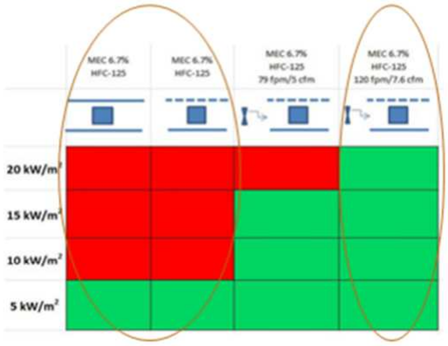
Energy augmented combustion and fire extinction tests with HFC-125



Fike

An increase in air flow from 79 to 120 fpm resulted in a 300% increase in radiant heat load extinguishment when compared to still air. The 120 fpm air flow increased the maximum extinguishment level from 5 to 20 kW/m^2. In no case did we need more than 6.5% of normal air flow required for extinguishment at MEC up to 20 kW/m^2.

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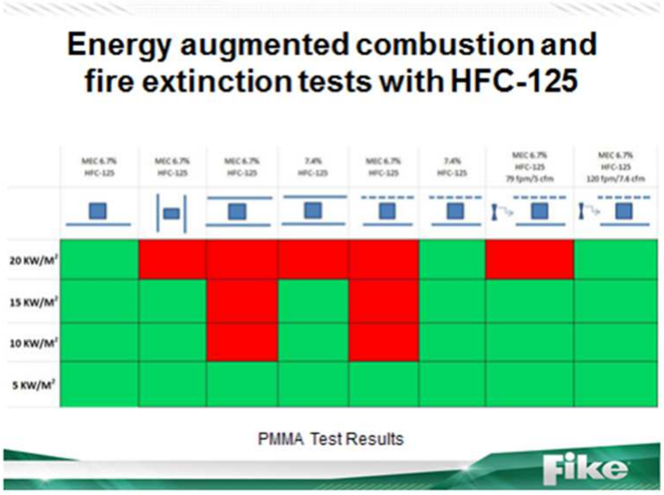

This is a quick refresher of our test results using Calrod style heating elements with emissivity of 56% over a total power range from 5 to 20 kW/m^2 both with and without air movement.

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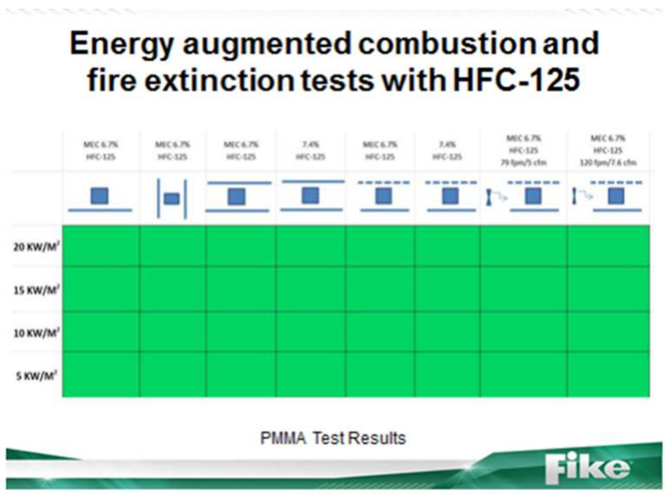

And here are the test results after skinning the Calrod style heating elements with copper to more closely match emissivity of materials found in servers. All tests passed, at all power density levels from 5 to 20 kW/m^2 , in all hot plate orientations, with and without air movement.

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In summary –

Copper and ordinary metals are poor heat radiators and usually fall in the range of 7% - 10% efficiency and this is what is found in rack equipment using forced convection cooling.

All modes of heat transfer: conduction, convection and radiation, must be considered in proper proportion to realistically assess threats.

Estimating energy augmentation onto nearby fuels requires careful analysis of real-world geometries, power densities, ***and materials*** found in datacom equipment designs.

Interaction between server chassis and server blades, by design, is minimized. Metal panels separate one from another and are not good radiators of heat.

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Questions?

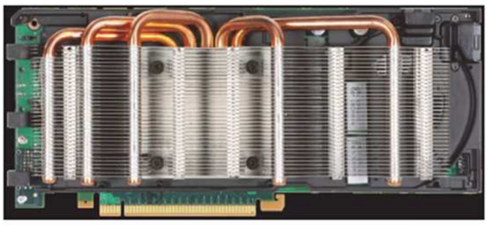

Figure 3.13 GPU with associated advanced thermal solution.

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