OPTIONS FOR AIRCRAFT CARGO COMPARTMENT FIRE PROTECTION

(PREPARED BY INTERNATIONAL AIRCRAFT SYSTEM FIRE PROTECTION WORKING GROUP, SEPTEMBER 2000)

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EXECUTIVE SUMMARY

An advisory team, sponsored by the International Aircraft System Fire Protection Working Group, prepared this report. The team considered available options for fire protection in the cargo compartment. The team recommends that FAA conduct tests of

Water mist and inert gas system, and
Pentafluoroethane [HFC-125, FE-25, CHF2CF3] systems.

The above two systems are team's first and second preferences respectively. The process used to arrive at the above recommendation and the details of options evaluated are presented in the document.

1.0 Introduction

Mr. Richard Hill (FAA Technical Center, NJ), Chairman of the International Aircraft Systems Fire Protection Working Group (IASFPWG), sponsored a Team to evaluate available options to halon and recommend agents for test to the FAA. The Team was charged to make recommendations for (1) Aircraft Engine Fire Protection and (2) Cargo Bay Fire Protection.

The team, consisting of 15 members, met on May 4, 2000. The available options to halon were reviewed and <u>six options for cargo compartment fire suppression</u> selected for review and evaluation. Sub-teams were formed to prepare a report that explains the reasons each agent should be tested. The Team reviewed the proposals and team members added comments, concerns and other relevant data as appropriate to the proposals. Next, the team resolved concerns to the extent possible with available data. The six proposals are presented in this document.

The team's recommendation for engine fire protection is defined in Options for Aircraft Engine Fire Protections.

1.1 Recommendation

The team recommends, by consensus, the following two systems for FAA tests.

1. Water mist and inert gas system, and

2. Pentafluoroethane [HFC-125, FE-25, CHF2CF3]

2.0 Options

The Team selected the following options for review and evaluation. The sub-team members that voluntarily agreed to conduct the review and evaluation of the agent are identified below.

1 ENVIROGE ® [HEXAFLUOROPROPANE (CF3CF2CF3) SUPPLEMENTED WITH AMMONIUM PHOSPHATE]
Proposed by Harry Stewart (Lead), Douglas Ferguson

2. FM-200 [HFC-227ea, HEPTAFLUOROPROPANE, CF_3CHFCF_3]
Proposed by Robert Glaser (Lead), P.E

3. PENTAFLUOROETHANE [HFC-125, FE-25] Proposed by Sham Hariram (Lead)

4. INERT GASES (CO_2 OR N_2)
Proposed BY Eric Lyon (Lead) and Konstantin Kallergis

5. WATER (MIST OR FOG)
Proposed by – Sir John J. O’Sullivan (Lead) & Dr. Panos Papavergos

6. WATER-MIST AND INERT GAS
Proposed by Konstantin Kallergis (Lead) & Bernard Finck

3.0 Envirogel® [Hexafluoropropane ($CF_3CF_2CF_3$) supplemented with Ammonium Phosphate]

The United States Environmental Protection Agency (USEPA) Significant New Alternatives Policy (SNAP) list gives a variety of formulations under the category “gelled halocarbon/ dry chemical suspension” developed for particular markets. The materials that are marketed under the Trade name “Envirogel” by Powsus Inc., have been tested in a number of applications, including tracked vehicles [reference 1, 2]. Testing to date indicates that at least some formulations have effectiveness similar to that of Halon 1301 on either a weight basis or a volume basis [reference 3]. Each blend contains one or more halocarbons, a dry chemical, and a gel that keeps the powder and gas uniform.

Envirogel® is a proprietary mixture of Hexafluoropropane ($CF_3CF_2CF_3$, commonly referred to as FE-36 or HFC-236fa) and Ammonium poly phosphate (APP) powder. It behaves like a gas. The powder enhances the fire suppression capability of FE-36 and reduces toxic byproducts during fire suppression. The agent has proven to be safer and more effective than Halons in total flood systems for Class B fires. The agent is SNAP approved by the EPA for use in unoccupied areas. It is not listed in National fire Protection Association Standard 2001, Standard on Clean agent Fire Extinguishing Systems.

3.1 Features

Envirogel® is an effective fire suppression agent. In FAA tests on lavatory trash container (open, Class A fire) it proved equivalent (on agent weight basis) to halon 1301. It demonstrated equivalent performance to halon 1211when challenged by “hidden” and “seat” fire threats of the Hand-held fire-extinguisher Minimum Performance Standard, Reference 4.   In air cargo container test, conducted for Federal Express, it provided superior performance to halon 1211 on weight and volume basis, Reference 5. In tests conducted at Aberdeen test center it was found to generate lower levels hydrogen fluoride than FE-36 and FM-200, Reference 6.

3.2 Advances to date

The agent, Envirogel, when used in unoccupied space, consists of 40% powder, APP, and 60% gas FE-36. It is available for use in portable extinguishers, Halon flooding type canisters or fire (heat) sensitive tubes for local applications. The agent can be filled in a container locally adding gas to pre-gelled powder or filled premixed at factory locations. The product is priced to compete with HFC gases in use. Since Envirogel is a new product, its distribution is presently being negotiated with several companies in the aerospace industry. Outside of aerospace, the fire tubes are being introduced to the automobile engine, inboard boat engine, school bus, and hazardous transportation vehicle industries. The agent is being offered in Halon replacement situations

3.3 Concerns and benefits

Ammonium poly phosphate is non-corrosive and non-conductive, Reference 7. Clean up will be required after suppression system activation. It is not a "Clean Agent". FE-36 has a Global Warming Potential like all HFC gases. Its production and use may be phased out in the future. The system can be designed using the present halon system design concept, The will be compatible with existing fire (smoke) detection system. These features may provide non-recurring cost benefit.

3.4 Team submitted comments, concerns and other data

1. Material compatibility will be required on the unidentified gel. It will need to be tested against a wide variety of materials, hot, cold, salt/fog, high humidity, etc. including metals, composites, elastomers, etc.
   [Compatibility with materials will be required for all agents.]

2. "Clean-Up" issues will need to be considered.
   [Envirogel contains Ammonium poly phosphate (APP) powder. Clean up following inadvertent discharge or discharge in response to a false fire alarm will be required. The 'degree' and urgency of cleaning will depend on the effects of APP powder on materials of cargo compartment construction and the equipment therein. According to reference 7 ammonium poly phosphate is non-corrosive and non-conductive. Cleaning/ maintenance following a fire is required and clean up of envirogel residue will be part of this action.]

3. The data contained in this paper make Envirogel a viable suppression agent in some local fire applications onboard aircraft (lavatory trash containers and portable fire extinguishers). Although the halocarbon component (HFC 236fa) possesses a high GWP, its environmental impact should be weighted taking into consideration that the halocarbon component represents only 60% in weight of the blend. The resulting GWP would be therefore 5580 (100 year time horizon). Some residue is left upon discharge and the physical properties that this extinguishing agent features are not particularly suitable for total flooding systems protecting low temperature enclosures.

[Cargo compartments are typically maintained above freezing temperature to allow for shipment of live animals and other temperature sensitive items. The agent may have to withstand low temperatures but may not have to perform at extremely low temperature. Withstand and operating temperatures will depend on the airplane installation and the recommended cold weather operating procedures. FedEx cargo containers were successfully flooding at temperatures from 5 to 135 degrees F, Reference 5. Additional tests at specification low/high temperatures may be necessary to resolve this concern.]

4. This application is for non-occupied areas but toxic is still of some concern. No mention of toxicity was made. Has any stability testing been performed and what are the results

[Agents and or products of combustion can leak out of the cargo compartment and enter the passenger compartment during some failure conditions. Toxicity of the agent and its products of decomposition should be of concern for all agents. NFPA Standard 2000 identifies LC_{50} (the concentration lethal to 50% of a rat population during a four hour exposure) for neat HFC-236fa as >18.9%, NOAEL (No Observable Adverse Effect Level) 10%, and LOAEL (Lowest Observable Adverse Effect Level 15%. These values are higher than expected design values and substantially greater than what one may reasonably expect in occupied areas during failure conditions. APP passed an acute inhalation toxicity study conducted under the auspices of the EPA, Reference, 8. The synergist effects of HFC-236fa and APP has been studied at Aberdeen Test Center where reduction of HF to acceptable EPA levels was accomplished with the addition of 15% APP or more, Reference 6. It should be noted Envirogel is SNAP approved for use in unoccupied space (industrial and residential) and is being "looked upon favorably" by the EPA for use in occupied space, Reference 9. HF levels in the cargo compartment and the passenger compartment should be monitored and evaluated during FAA tests to resolve the concerns.]

5. The agent leaves a residue of Ammonium Phosphate that is 40% of the agent. This would be detrimental during inadvertent discharges and false alarms. The residue will require cleanup including cleaning of smoke detectors! Combining with FE-36 which has its own disadvantages such as performance at low temperatures and low vapor pressures will need to be addressed.

[Clean up will be required in the event of inadvertent discharge or discharge in response to false alarm. See comments 2 and 3 above.]

3.5 References

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7 Corrosion Testing Laboratories, Inc., 60 Blue hen Drive, Newark, DE (USA) – ASTM F 1110-90 Sandwich Corrosion Test, CTL Ref # 12227, Oct. 9, 1995

8. Roger Hilaski, Associate Director, Inhalation Toxicology, MPI Reasearch, Mahzwan, Michigan Study Number S 19-001

9. Meg Victor, Halon Alternatives Manager, EPA Washington, DC

4.0 FM-200 [HFC-227ea, Heptafluoropropane, CF_3CHFCF_3]

FM-200 is a halocarbon.

4.1 Technical rationale

The following gives a summary of the currently available alternate agents and the rationale for recommending HFC-227ea for consideration in this application.

Walter Kidde Aerospace has tested all the currently available vaporizing liquid agents for use in the cargo bay applications. The studies identified the currently available vaporizing liquid agents as viable candidates for further study. The vaporizing liquid agents are environmentally friendly, are clean agents (i.e. leave no residue after discharge) and are non-conductive. These properties are in common with Halon 1301 and were considered favorable in the search for a replacement agent.

The IHRWG originally selected halocarbons for testing in the cargo at the FAA technical center. Table 4.1-1 lists the properties of candidate agents. The Table was derived from the FAA technical working group report "Halon Replacement Options for Use in Aviation Fire Suppression Systems" and agent suppliers' literature. The Table will be used to show HFC-227ea is an appropriate agent for aircraft cargo fire protection.

Considering environmental properties first, Table 4.1-1 shows all of the alternatives are SNAP approved and have lower ozone depletion potentials than Halon 1301. When atmospheric lifetimes and global warming potentials are considered, it can be seen that HFC-125 and HFC-227ea are very similar with FIC-13I1 having the lowest value.

Moving on to toxicity data, it can be seen that HFC-227ea causes cardio-sensitization responses at higher concentrations than its extinguishing concentration. HFC-227ea is the least toxic vaporizing liquid agent currently under consideration. This data is of importance for the cargo bay application as it is in the pressurized shell and leakage from the cargo bay may enter the passenger and crew compartments under certain failure conditions. Based on NOAEL and LOAEL values HFC-236fa is less toxic than HFC-227ea.

Evaluating the physical properties of HFC-227ea it can be seen that this agent has a high enough vapor pressure at low temperatures to generate a fire extinguishing concentration. In addition, the density of HFC-227ea is higher than that of HFC-125 allowing an improvement in storage efficiency i.e. for the same weight of agent, HFC-227ea will need a smaller extinguisher than HFC-125. This is a valid comparison as the fire suppression capabilities in terms of mass of agent required to extinguish a fire are comparable. According to NFPA tables HFC-236fa is more weight efficient than HFC-227ea.

Of equal importance is the pressure/density/temperature relationship for HFC-227ea/nitrogen mixtures. The vapor pressure of HFC-227ea is far less than that of HFC-125 at high temperature. In terms of extinguisher design, this allows lighter, thinner walled vessels to be used for HFC-227ea compared to HFC-125. In addition, the maximum allowable fill density of HFC-227ea is far higher than that of HFC-125. Superpressurization with nitrogen may override any advantage attributable to the lower vapor pressure of HFC-227ea.

Table 4.1-1: Alternate Agent Comparison

AGENT	HALON 1301	HFC-125	HFC-227ea	FIC-13I1
Manufacturer	None	DuPont	Great Lakes	AJAY
Chemical Formula	CF_3Br	C_2F_5H	C_3F_7H	CF_3I
Molecular Weight	149	120	170	196
Boiling Point @ 1 Atmosphere (°F)	-72	-55	2.6	-8.5
Density @ 25°C (lb/cu.ft	96.8	74.2	87.1	131
Vapor pressure @ 7 °F (psia)	214	182	58.8	69.5
Vapor pressure @ -6 °F (psia)	31.9	21.5	2.44	6.64
Fire Extinguishing Design Concentration (volume %)	5	10.5	8	3.6
Fire extinguishing mass performan rati	1.0	2.2	2.3	1.3
Fire extinguishing volum performance ratio	1.0	2.8	2.5	0.9
ODP (rel. CFC-11	12	0	0	0.0001
GWP (rel. CO_2)	5400	2800	2900	< 1
Atmospheric Lifetime (yrs	65	33	37	< 0.005
Cardio-sensitization LOAEL (vol.	10.0	10.0	10.5	0.4
Cardio-sensitization NOAEL (vol.%)	7.0	7.5	9.0	0.2
EPA SNAP Approved	NO	YES	YES	YES

Combining these useful features, for the same mass of agent, smaller volume, lighter weight bottles can be used for HFC-227ea compared to HFC-125. Trade studies performed for cargo bay fire protection systems show a 17%-20% volume reduction and a 10%-13% weight reduction in container weldment weight. Therefore, HFC-227ea can offer a benefit in terms of fire extinguisher weight and volume when compared to HFC-125.

4.2 Commercial rationale

HFC-227ea is the most successful environmentally friendly clean agent used in the fire protection industry. In excess of 40,000 HFC-227ea fire protection systems have been installed world wide since its introduction into the market in 1993. The common use of this agent ensures access to a world wide distribution base and a reasonable cost. In addition, HFC-227ea systems have demonstrated their effectiveness by extinguishing fires in actual installations on numerous occasions.

Therefore, this agent has a proven service record, is commercially available in large quantities, is widely used and would be a good candidate for use in this application.

4.3 Concerns and benefits

HFC-227ea is a viable candidate for use in cargo bay fire protection systems as it is environmentally friendly (zero ODP), clean, has favorable physical properties to allow weight and volume efficient storage, has proven fire suppression performance in installed systems and is widely available. No concern is identified.

4.4 Team submitted comments, concerns and other data

1. This agent will generate HF at about 10 times the rate of HALON. The impact of HF generation on materials, cargo, and "Clean-UP' will need to be addressed.

[All Hydrofluorocarbons (HFCs) generate hydrofluoric (HF) acid on thermal decomposition. The HF is corrosive and toxic. The production rate depends on agent application rate, and the fire characteristics. HF levels in the cargo compartment and the passenger compartment must be monitored during test to resolve the concern.]

2. The impact of the +3 F boiling point (vs -70 F for HALON 1301) will also need to be considered.

[Cargo compartments are typically maintained at above freezing temperature for animal and produce shipment. The +3F boiling temperature may not be a problem. Test/analysis/similarity may be required to show compliance with withstand and operating temperature requirements. In addition, the vapor pressure of the agent should be high enough to generate the required fire extinguishing concentration. Agents with higher boiling points than HFC-227ea have been successfully used in the aviation industry for fire protection.

3. If the new cup burner data for HFC 227ea (6.5%) and the other halocarbon agents included in the NFPA 2001 Standard, Edition 2000, are taken as a reference for comparison, there would be no advantage in terms of weight and space compared to HFC 125. In fact, although due to its physical characteristics HFC 227ea features a fill density of system cylinders 30% higher than HFC 125, it should be noted that HFC 125 requires about 30% less agent by weight to achieve an equivalent extinguishing concentration. Moreover, the cylinder construction requirements depend on the working pressure of the system and not on the physical characteristics of the contained agent.

[Fire tests are difficult and different laboratories use different cup burners. This causes variation in the test results. Heptane flame extinguishing concentrations reported for HFC-227ea in NFPA Std 2000 (1996 Edition) are 6.6% (Naval Research Laboratory), 6.3% (New Mexico Engineering Research Institute), 5.8% (Fenwal Safety Systems Company), 5.9% (Great Lakes Chemical Corporation) and 6.2% (National Institute for Standards and Technology. The minimum design concentration data in Table 4.1-1 is from FAA International Halon Replacement Working Group report "Halon Replacement Options for Use in Aviation Fire Suppression Systems". The data for other agents is also from this report. The cup burner data is intended to serve as a guide. Full-scale tests are required to establish the design concentration. You are right the cylinder construction depends on the working pressure. However, for fire protection systems that employ vaporizing liquid agents the maximum operating pressure of the container is directly related to the agent fill density, agent temperature-pressure relationship and nitrogen pressure.]

4. Full scale testing should be carried out in order to determine the suitability of this halocarbon and its thermodynamic characteristics for cargo bay fire protection systems under real fire scenarios. Although at normal ambient temperatures HFC 227ea possesses sufficient vapor pressure to generate a homogeneous extinguishing concentration in the protected enclosure, cargo bays of liners reach temperatures well below zero (- 40°C). In addition, cargo bay enclosures are normally full of obstacles (baggage and various items) that would render at low temperatures the distribution of this gas even more difficult, usually resulting in longer extinguishing times and higher formation of decomposition by-products. Only very low boiling point halocarbons, such as Halon 1301 and HFC 125, would overcome this problem.

[The tests will determine the unknowns. The MPS defines the fire suppression tests and the pass /fail criteria for performance equivalent to that provided by present halon 1301 system. Cargo compartments are generally above freezing temperature (by design or by supplemental heat) for animal, produce and temperature sensitive equipment transport. Monitoring of toxic gases (HF) in the cargo compartment and the passenger compartment should form an important part of the test. Also see comment 2, above.

5. As far as the comparison between acute toxicity of HFC 125 and HFC 227ea is concerned, according to the recently adopted PBPK (physiologically based pharmacokinetic) modeling both agents - at concentrations corresponding to the

heptane cup burner data plus 20% or 30% (design concentrations) - feature a safe exposure time of 5 minutes. In any case, cargo compartments are not normally occupied areas and this aspect would not represent a concern.

[Agent of low toxicity should be used as animals are transported in the cargo compartments. The animals can be exposed to long periods (30 – 180 minutes) to the agent in the event of suppression system activation (inadvertent or in response to a false alarm). Also, reduction in oxygen partial pressure occurs when agent is released.]

6. HFC 227ea systems are widely used in normally "ground" applications, but so far they have never been used for the protection of aircraft cargo bays.

[Halon 1301 is the only agent that is used for the protection of aircraft cargo bays.]

7. It was mention that trade studies show volume and weight reductions. Should not the source of these studies be reference.

[DOT/FAA/AR-98/XX Halon Options for Aircraft Fire Suppression Systems- 1999 Update, prepared by a Team of the International halon Replacement Working Group compared the performance of total flood replacements (N-Heptane Fuel). The data for the four agents in this report is as follows:

Agent	*Cup Burner Extinguishment Concentration, Vol %*	*Weight Equivalent*	*Volume Equivalent*
Halon 1301	*3.3*	*1.00*	*1.00*
HFC-125	*8.9*	*2.17*	*2.83*
HFC-227ea	*6.6*	*2.28*	*2.54*
FIC-13I1	*3.2*	*1.28*	*0.94*

It should be noted that the above data is for N- Heptane fuel.]

8. High boiling point and low vapor pressure are impediments in low temperature environments. The agent also produces HF acid in quantities greater than any other proposed agent and this may affect other parts of the aircraft during or after a fire.

[See comments 1, 2 and 4 above.]

5.0 Pentafluoroethane [HFC-125, FE-25, CHF_2CF_3]

Pentafluoroethane, C_2F_5H, Molecular weight 120, Commercial name HFC-125 is produced by the Dupont Co. This agent is a halocarbon that leaves no residue, has a Zero Ozone Depletion Potential (ODP) and has a Global Warming Potential and atmospheric lifetime about half of Halon 1301.

The agent's cardio-sentization LOAEL (vol. %) and cardio-sensitization NOAE (vol. %) are equal to or better that Halon 1301. The agent is accepted and listed in the U.S.E.P.A. Significant New Alternatives Policy (SNAP) list.

Alternative Agent Comparison

Agent	Halon 1301	HFC-125	FM-200	Triodide
Manufacturer	Dupont *	Dupont	Great Lakes	AJAY
Chemical formula	CF_3Br	C_2F_5H	C_3F_7H	CF_3I
Molecular Weight	149	120	170	196
Boiling Point @ 1 Atm. (^oF)	-72	-55	2.6	-8.5
Density #/cu ft	96.8	74.2	87.1	131
Vapor Pressure 70^{o}F	214	182	58.8	69.5
Vapor Pressure –65^{o}F	31.9	21.5	2.44	6.64
Fire extinguishing design conc. (vol. %)	5	10.5	8	3.6
Fire ext. mass perf. ratio	1.0	2.2	2.3	1.3
Fire ext. vol. perf ratio	1.0	2.8	2.5	0.9
ODP (rel. CFC-11)	12	0	0	0.0001
GWP (rel. CO_2)	5400	2800	2900	<1
LOAEL (vol. %)	10.0	10.0	10.5	0.4
NOAEL (vol. %)	7.0	7.5	9.0	0.2
EPA SNAP Approved	NO	YES	YES	YES

* No longer produces Halon 1301 since the production is banned.

5.1 Features

The agent has chemical and physical properties that when compared to other Halocarbons make it a very attractive alternative to Halon 1301.

Some of the notable properties and their assessment are as follows:

Low molecular weight: 120 for HFC-125 compared to 149 for Halon 1301, 170 for FM-200, 196 for Triodide and 152 for FE-36. The low molecular weight helps keep the agent weight relatively low even though the design concentration (vol. %) for extinguishing or suppressing fires is high.

For example,
FM-200, mw 170, DC = 8% by vol. requires 13.5 gms of FM-200 per 1 gm mole of agent/air mixture.

HFC-125, mw 120, DC =10.5% by vol. requires 12.5 gms of HFC-125 per 1 gm/mole of agent air mixture.

Low molecular weight also provides higher buoyancy of agent when compared to other Halocarbons and also to Halon 1301. This is a distinct advantage for cargo compartment applications where the agent will remain at higher cargo compartment heights, even as compared to Halon 1301. This is a definite plus during point to point concentration measurements.

Low boiling point: -55 ^{o}F for HFC-125 when compared to -72 ^{o}F for Halon 1301, 2.6 ^{o}F for FM-200, -8.5 ^{o}F for Triodide and 29.3 ^{o}F for FE-36. Boiling point is a very important property of an extinguishing agent especially for installations where the bottle environmental temperatures can be lower than the boiling point of some agents. The boiling point is also critical when long runs of delivery pipe that may be subjected to low environmental temperatures are involved and for Low rate discharge (metered) systems. The -55 ^{o}F boiling point of HFC-125 is better than all other Halocarbons currently being considered.

High vapor pressure compared to other Halocarbons: 182 psia at 70^{o}F for HFC-125 compared to 214 psia for Halon 1301; 58.8 psia for FM-200 and 69.5 psia for Triodide. Vapor pressure is an important property of extinguishing agents. Although almost all of the cargo compartment extinguishing agent bottles are pressurized with Nitrogen, delivery of the agent from installations with low environmental temperatures could create difficulties. Bottle pressure indication is also affected. Low bottle pressures at low temperatures could pose problems for pressure regulators that are used in Low rate discharge (metered) systems including the effects of change of state during pressure reduction.

5.2 Advances to date

HFC-125 is currently available. It is proposed for use as a substitute for Halon 1301 during cargo compartment concentration measurements. The United States Air Force has tested the agent at the Wright Patterson Air Force base and verified its performance over a wide range of operating conditions. The Air Force has specified its use on F/A-18 E/F, the V-22 and the F-22 for engine fire protection.

5.3 Concerns and benefits

The agent is listed by SNAP, has zero ODP and has LOAEL and NOAEL equal to or better than Halon 1301. It has MW, BP and Vapor Pressures that are more readily acceptable to System Design Engineers.

HFC-125 is a halocarbon. It produces Hydrofluoric Acid (HF) as a product of decomposition however when compared to FM-200, the quantity of HF is lower. The GWP (rel. %CO_2) although half of Halon 1301 and lower than that of FM-200 and FE-36 is still a concern.

It must be noted that HFC-125 is not a drop in replacement for Halon 1301 in Cargo Compartment applications but it does have toxicity levels equal to or lower than Halon 1301 and that is a plus. Toxicity is a major concern in occupied areas or areas from which the agent can leak into occupied areas. All things considered, HFC-125 is probably a better alternative to other Halocarbons being considered at the present time.

In due time HFC-125 may also be banned with the rest of the high GWP agents, however it a better stop gap in the interim since it's testing is currently in the advanced stages. A search and acceptance of a new 0 ODP and low GWP agent may be years away.

5.4 Team submitted comments, concerns and other data

1. This agent will generate HF at about 10 times the rate of HALON. The impact of HF generation on materials, cargo, and "Clean-UP' will need to be addressed.

   [Agree with the comment. It must be noted however that decomposition occurs only when there is a fire. With a reported ratio of one fire to two hundred false alarms, cleaning will be a small price to pay to protect the aircraft. Also HFC-125 is better than FM-200 in terms of HF production and does not produce any powders.

2. In the Alternative Agent Comparison Table, if we refer to the new cup burner data included in the new edition of NFPA 2001 Standard, the design concentrations of the halocarbon products based on heptane cup burner data plus 20% safety factor would be: HFC 227ea: 8.5% (6.5% plus 20%); HFC 125: 10.5% (8.7% plus 20%); and CF_3I: 3.8% (3.2% plus 20%).

   [Agree with the comments. There are various sources of information available. The final concentration will be that which is established by the FAA Technical Center and which complies with the MPS.

3. HFC-125 may be better than other halocarbons. Like other HFCs its production may phase out. This will then require redesign or search for a drop-in agent of equivalent performance. I believe we should look for a permanent solution to the problem.

[HFC-125 is definitely better than other Halocarbons and may not require a redesign of the plumbing system but will require installation of larger containers to handle the larger volume. It has taken us eight years to get to this point. I recommend that we at least complete the testing which (can be completed in about two months when the FAA is given this direction). The data will be available for use by those who want to use an interim solution. For those who want for a permanent solution and do not mind waiting for many more years, they too will be accommodated.]

6.0 Inert Gases

Inert gases suppress fire by reducing oxygen concentration in the combustion air. Several gases are commercially available.

6.1 Carbon dioxide (CO_2)

Formula:	CO_2
Molecular Weight:	44.01
Freezing Point:	-78.5°C
Gas Density (at 0°C):	1.977 kg/m^3
Health Hazard:	9-10 Vol.% causes unconsciousness within 5 minutes
Exposure Limit (TLV-TWA):	5000 ppm

(+) CO_2 is heavier than air
(+) CO_2 is available almost everywhere
(+) CO2 can be cooled & thus can be stored at a lower pressure.
(+) Low cost
(+) 0 Ozone Depleting Potential (ODP)
(-) extinguishing capability is rather poor (numbers found between 30 and 70 Vol.%)
(-) mass: heavy installation (bottles) required
(-) CO_2 is a global warmer
(-) poor cooling capabilities (no class A fires)
(-) high rate of accidents due to electrostatic charge (further investigation required)

Pressure increase in compartment on discharge must be considered. Means to prevent CO2 infiltration into occupied areas may be necessary (perhaps a separate system to relieve compartment pressure).

6.2 Nitrogen (N_2)

Name:	Nitrogen
Formula:	N_2
Molecular Weight:	28
Boiling Point:	-195.8°C
Gas Density (at 20°C):	1,251 kg/m^3
Health Hazard:	non-toxic (minimum oxygen partial pressure, 12% sea-level equivalent, for breathing may be necessary.)

(+) N_2 is available everywhere
(+) non-toxic (12% sea-level equivalent oxygen partial pressure necessary for breathing)
(+) can be produced out of the ambient air by membranes
(+) lowers burning temperatures
(+) 0 Ozone Depleting Potential (ODP)

(-) extinguishing capability is rather poor (numbers found between 30 and 80 Vol.%)
(-) mass: heavy installation (bottles) required
N_2 is *(lighter* than air.
N_2 is used in OBIGGS Systems for military aircraft.
N_2 is uncritical concerning toxicity.
Pressure increase in compartment must be considered.

6.3 Inergen

Name:	Inergen, IG-541	
Formula:	N_2:	52 +/- 4 %
	Ar:	40 +/- 4 %
	CO_2:	8 +/- 1 %
Extinguishing Concentration (cup-burner, n-heptane):	33 Vol.%	

(+) Extinguishing concentration is breathable.
(-) poor extinguishing capabilities
(-) heavy solution
Pressure increase in compartment must be considered.

6.4. Nitrogen (N_2) and Argon (Ar) Mixture (Argonite)

Name:	IG-55	
Formula:	N_2:	50 +/- 5 %
	Ar:	50 +/- 5 %
Extinguishing Concentration (cup-burner, n-heptane):		35 Vol.%

(-) poor extinguishing capabilities
(-) heavy

Pressure increase in compartment must be considered.

6.5 Argon (Ar)

Name:	IG-01	
Formula:	Ar	
Extinguishing. Concentration (cup-burner, n-heptane):		42 Vol.%

(-) poor extinguishing capabilities
(-) heavy

Pressure increase in compartment must be considered.

6.6 Team submitted comments, concerns and other data

1. Health hazards for all these gasses will need to be evaluated for fire crews, maintenance crews, and passengers. CO2 is responsible for deaths each year and all other gasses could cause death if not properly handled.

[Health hazards need to be evaluated for all agents. Inert gases (except carbon dioxide are non –toxic. When released in air, they reduce the partial pressure of oxygen. The reduced oxygen partial pressure causes hypoxemia (inadequate oxygenation of the blood). National Fire Protection Association (NFPA) 2001 Standard on Clean Agent Fire Extinguishing Systems (1996 Edition) states " No inert gas agent with a design concentration above 43% which corresponds to an oxygen concentration of 12 percent (sea-level equivalent) shall be permitted for use in normally occupied areas." Cargo compartments are normally <u>unoccupied</u>. Also, the cargo compartments have design features to prevent smoke and toxic fume penetration into occupied areas. Leakage into the passenger compartment requires evaluation in the presence of probable failures of 'penetration prevention feature(s)'.

2. The mass of extinguishing agent required, the number of cylinders and their weight (high pressure cylinders) would represent a burden for commercial aviation.

[Inert gas concentration required to maintain suppressed a fire to the level equivalent to present halon 1301 system is not known. It is difficult to estimate the agent mass, the number of cylinders (stored gas system) and their weight. Inert gases provide a means to suppress cargo compartment fire that is environmentally friendly and safe to humans.]

3. From a toxicity standpoint, CO_2 systems cannot operate automatically, being this gas lethal to humans.

[Presently, all cargo compartment fire suppression systems are manual. (The regulations do not mandate system type – manual or automatic). Flight crew actuates the system on annunciation of cargo compartment fire. Carbon dioxide is a toxic gas and has a higher molecular weight. Nitrogen would be a better choice based on toxicity and molecular considerations.]

4. In the designing process of N_2 and other inert gas type of systems the oxygen level is always a concern. In normal ground applications for manned areas the amount of agent required to achieved the design concentration has to be calculated <u>with extra care</u> and it is based on the net volume of the enclosure, in order to have an oxygen concentration after discharge capable of sustaining life. The net volume of cargo bays is reduced dramatically when they are loaded and the resulting oxygen concentration in case of system discharge would be dangerous to humans.

[Cargo compartments are normally unoccupied. The reduction of oxygen concentration in the cargo compartment to a level that may not sustain human life is not critical. Low oxygen concentration after an inadvertent discharge on ground, during loading/ unloading or maintenance operations, is of concern. (This condition is of concern with

all agents). The probability of inadvertent discharge on ground can be reduced by design and such design features must be included, if necessary.]

5. Both systems (CO_2 and N_2) are characterized by longer discharge times (one minute) compared to halocarbon systems (10 seconds), thus resulting in longer extinguishing times.

[Inert gas systems can be designed for shorter discharge time by selection of proper line sizes and nozzle. There is a lot of pressure in the reservoirs to provide the force necessary to expel the agent. NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems (1996 Edition) requires that the discharge time for inert gas agents shall not exceed 60 seconds to achieve 95 % of the design concentration or as otherwise required by the authority having jurisdiction. Note, the Standard does not prevent faster discharge time.]

6. In order to limit the number of bottles, inert gas system hardware manufacturers are developing very high working pressure hardware (250-300 bar systems). Although this may not be a problem on ground applications, onboard aircraft would be a concern.

[High-pressure cylinders/systems are used in commercial aviation for several purposes. Presently, reservoirs used for cargo compartment fire suppression system are charged to 360 psig (25 bar), engine fire protection system to 800 psig (55 bar), crew gaseous oxygen system to 1850 psig (128 bar) and reservoirs to inflate evacuation slides to 3000 psig (207 bar). Hydraulic systems on commercial airplanes operate at 3000 psig (207 bar); military airplanes have used higher operating pressures. High-pressure system or high-pressure reservoir is of concern in all applications. Reservoirs charged to 3600-4400 (250-300 bars approximately) can be used with proper design factors (burst and proof), safety features (pressure relief, burst disk) and other design /installation features. Such features may impose weight penalty but will reduce the installation volume requirements.]

7. It is stated that CO2 is a global warmer. The CO2 used is a byproduct of other processes, such as fermentation and would have been released anyway. No net global warming is incurred.

[No net global warming is incurred if waste carbon dioxide is used.]

8. For nitrogen, oxygen deprivation is a concern. Therefore, the addition of greater than 31% nitrogen would reduce oxygen to lower than 16%, which can impair occupants. What is meant by "N2 is uncritical concerning toxicity"

[Nitrogen is not a toxic gas. This is implied by the term "N2 is uncritical concerning toxicity". Nitrogen when added to air reduces the oxygen concentration (or partial pressure) in air. A mixture containing 30% pure nitrogen and 70% air, contains 14.7% oxygen and 85.3% nitrogen by volume. The oxygen concentration of air reduces from 21% to 14.7% and the concentration of nitrogen in air increases from 79% to 85.3% on addition of nitrogen. The reduced oxygen concentration (or reduced oxygen partial pressure) causes lower blood oxygen saturation in the lungs and thus ill effects. This phenomenon is called hypoxemia (inadequate oxygenation of the blood). Hypoxemia can

cause impairment. Individual responds differently to different levels of oxygen concentration. Cargo compartments are normally unoccupied. See also concern 1.

9. What is the EPA and NFPA status of these materials

There is no restriction on the use of carbon dioxide, nitrogen, argon and their mixtures for fire protection. NFPA 2001 Standard lists IG-01 (Argon), IG-541 (Nitrogen, Argon, Carbon dioxide), and IG-55 (Nitrogen and Argon) as acceptable Clean Agents. NFPA 12 Standard deals with carbon dioxide extinguishing systems.

10. Which substance or blend is being recommended for FAA test

[Nitrogen is recommended for FAA test. It is readily available and is non-toxic. Also, it can be generated on board. It provides greatest system design flexibility.]

11. Leakage into occupied areas (the gas is odorless). Also concentrations for fire fighting may be high.

[Fire suppression requires that the oxygen concentration in cargo compartment be reduced to a low level – 10-15%; the required concentration depends on the fuel and the inert gas. The leakage from the cargo compartment (if any) will contain 10-15% oxygen. The "leaked-air" will get diluted with clean air on its travel from the cargo compartment to the occupied areas – the effect on the oxygen concentration in the occupied areas will be minimal.

To reduce oxygen concentration from 21 % to 10-15% by volume, at constant pressure, would require nitrogen gas input that is 75 to 35% (approximately) of the of the compartment volume assuming homogeneous mixture during nitrogen inflow.

12. Large mass of N_2 required since concentrations for fire fighting are high.

[See comment 11, above.

7.0 Watermist fire suppression syste

Water mist is by far the most benign medium for fire protection and is ideal for cargo bays that may have animal cargo. The technology relies upon the generation and propulsion of small drops ($d_m \leq 200$ µm) in fire scenarios to bring about suppression or extinguishment.

The main fire extinguishing mechanisms are: gas phase cooling; oxygen dilution b steam expansion and wetting of fuel surfaces.

Water mist has demonstrated equivalent fire protection to chemical agents, including Halon, in a large number of tests conducted by several investigators.

The use of gaseous HCFC/HFCs is seen as a short term solution, in view of the global warming and ozone depletion problems associated with them. In addition, compartment integrity is essential for gaseous agents to perform their intended function and to retain toxic products of combustion and agent decomposition. Hence, the Chemical Options review group has considered it appropriate to investigate the use of water mist for the fire protection of cargo bays.

7.1 Features

Water mist is weight efficient due to the large number of small drops occupying large spaces. Its suppression offers: effective smoke stripping and acid gas absorption capability; temperature knock-down of environs to a survivable level without the production of toxic by-products. It uses an area coverage design concept and its performance is essentially independent of the compartment integrity. The required water does not depend on compartment volume. It is an active system; it monitors the temperatures (fire hazard) and limits the temperatures below hazardous levels. Cargo load, airplane maneuvers (descent, climb) and airplane operation (pressurized, unpressurized flight, ventilation, etc) have no effect on its peformance.

7.2 Advances to date

Watermist is an old technology, reference 1. Water systems (spray) are universally used for fire protection in occupied and non-occupied areas. National Fire Protection Association (NFPA) has published NFPA Std 750, Water Mist Protection Systems, reference 2. Underwriter's Laboratories has a listing process.

Previous water mist work in FIREDASS has shown adequate fire protection in the cargo bay of aircraft using relatively small amount of water. This has been confirmed by other investigators, Reference 3 and 4. Telecommunications industry determined water to be an efficient and safe fire fire suppressant in switch gear, Reference 5.

7.3 Concerns and benefits

Water freezing in airplanes that are unattended for long durations during cold (sub-freezing) weather is of concern. Cost effective solution to prevent water freezing will need to be put forward prior to the use of water mist in the aviation. This is not considered a show stopper.

The effect of water on electrical equipment inside the cargo compartment and on equipment that may be exposed in the event of cargo compartment liner failure is of concern. However, it is realized that such equipment will be exposed to chemical agents and products of combustion/ decomposition under similar operational/ failure conditions. Reference 5 tests have shown that equipment is not adversely effected by watermist. This is not consdered a show stopper.

However, any cost benefit of the water mist can only be realised when the cost of refilling and the cost of ownership are also considered in the cost of the package, vis-a-vis other candidate gaseous suppressant.

7.4 Team submitted comments, concerns and other data

1. There is little if any test data on "Water Mist" systems that simulate "Full-Up" aircraft installation addressing all the issues associated with the technology. These include including additives (to address flow effectiveness, corrosion, storage stability, bacterial growth, contamination, freezing, etc.), filters to protect the nozzle openings from particulate contamination, ice, etc., any relevant equipment, etc. to allow discharge at low temperatures after cold soaking to -40 F to -65 F. This data needs to be developed.

[Water systems – potable water, waste water and sewage – are exist on all commercial airplanes. Water systems have also been used for thrust augmentation (water spray in engine inlet), and equipment (radar cooling) on military airplanes. Technology to design water systems is readily available. Cold-soaked airplanes are "prepared" using cold weather maintenance procedures prior to introduction in service. Compartments are heated to temperatures above freezing for animal, produce, and temperature sensitive equipment transport. The cargo compartment fire suppression system is a manually actuated system. It requires crew action from the flight deck. Several techniques are available to minimize water freeze. These include reservoir surface area per unit volume (spherical reservoir) minimization, use of low thermal conductivity material (non-metallic reservoir), reservoir insulation to reduce heat transfer, electric blanket to keep reservoir ambient warm, immersion heater to maintain water above a design threshold, etc. The optimum solution would depend on withstand and operating temperature requirements of a particular system and cost-benefit analysis of the available options. Similarly, nozzle openings can be protected either by design or auxiliary means. These items are design details and not show stopper.]

2. "Flash Over" at marginal concentrations may also need to be addressed.
[“Flash over” requires combustible gas/air mixture, and ignition source. The water vapor will dilute the combustible gas mixture, reduce the process of fuel pyrolysis by cooling the fire, remove soluble combustible products and reduce the temperature of the products of combustion by absorbing heat. All these factors should minimize “flash over” potential. However, this concern can be best resolved by controlled tests and we recommend the tests. FAA developed Minimum Performance Standard for the cargo compartment requires an aerosol can test. All agents are required to pass this test.

3. The area coverage in water mist systems is critical to ensure the extinguishment of fires; however, the presence of many non-permeable obstacles normally encountered in this type of enclosures could cause the wetting of surfaces, a non homogeneous distribution and the impossibility for the water droplets to reach hidden fires.
[All systems are required to provide fire suppression capability equivalent to present halon system for four fire challenges – surface fire, container fire, pallet fire and aerosol can fire. Container and pallet fires simulate the fires discussed by you in your comment. Several tests, conducted by different investigators on both sides of the Atlantic, have successfully demonstrated that water mist system can suppress a fire inside a container (most critical fire) to equivalent level (maximum temperature and heat release) as the current halon system.]

4. How will the water mist cargo compartment fire suppression system, when deployed, will not endanger the continued safe flight of the airplane or the health of the occupants
[This will require a combination of careful design; detailed failure mode, effect and criticality analysis; and some change in past practices. However, it must be recognized that fire is probable in the cargo compartment and if a fire (that cause destruction) does not endanger the continued safe flight of the airplane than it is highly unlikely that water mist will prevent continued safe flight of the airplane. FAR 25.855(e) recognize damage potential of fire and cargo movement in the cargo compartment. It requires that “No compartment may contain any controls, wiring, lines, equipment, or accessories whose damage or failure would affect safe operation, unless those items are protected so that (1) they cannot be damaged by the movement of cargo in the compartment, and (2) their breakage or failure will not create a fire hazard.” JAR 25.855(e) contains similar requirement. Animals are transported in the cargo compartment. Of all available agents (inert gases, halocarbons, and halons) water is the safest agent. Inert gases cause hypoxemia; Halocarbons and halons cause hypoxemia and toxic environment.

5. How much weight will be added to protect electrical equipment from moisture incursion and how much will this cost the industry?
[This will depend on the criticality of the equipment and the effect of moisture incursion. FAR 25.855(e) requirement above.]

6 Probably the most promising <u>long term</u> alternative. Water is abundant and does not cause pollution. Challenges are going to be to design an optimum system that is zone oriented i.e., turns on in a particular zone only.

[System design will be a challenge. However, zone oriented systems that operate based on a command (generated by a sensed parameter) are common. One finds fountains in public places that operate in response to music, water misting systems in stores that periodically mist produce to keep it fresh, etc. The design of such a system is state-of-the-art technology.]

7 This will be a detection and suppression system. Weight of the complete system will be high. Issues such as freezing can be addressed by adding anti-freeze agents. A drainage system with dams and drains under the floor may be required to collect and drain the water or place it in a sump for recycling during a fire.

[Fire detection can be an independent system or the two systems can be integrated. For example, one can have an independent fire detection system that uses smoke or ionized particle detectors or an integrated system that uses heat signature for fire detection. The system will require a controller for system operation that may be temperature based. Weight is important as it represents operating cost. Cold temperature and drainage provisions will form part of the overall design. However other advantages of the system (friendly to the atmosphere, safe to humans and animals, flexibility of integration with potable water system, less dependent on cargo compartment liner integrity for performance and airplane operation (descent), less dependent on cargo compartment volume for agent weight, etc) may help in trade study of potential systems.

8. There are concerns for water mist wetting baggage and smoke detectors especially during inadvertent discharge or during false alarms.

[Valid concerns. However, wetting of baggage or smoke detectors during inadvertent discharge or during false alarm will not cause an unsafe situation. Financial loss-possibly. Inert gases and halocarbons may cause loss of animal cargo under similar conditions.]

9. The class “C” cargo compartments are sealed except for ventilation ports and drain holes in the floor. Additional water proofing may have to be specified e.g., Cargo liners be water proof in addition to being fire resistant.

[Liners will have to be compatible with the selected agent.]

10. Cargo compartments with cargo rollers that are motorized will have to have the motors and wiring water proofed.

[The equipment will have to be compatible with the selected agent.]

11. The main challenge is going to be fire suppression in cargo compartments with containers. The containers are stacked about 1.5 to 2 inches from the ceiling and it would be a challenge to suppress a fire inside a container and keep it suppressed for 3 to 3.5 hours or longer.

[Tests conducted by the FAA and FIREDASS, a European Union Consortium, have demonstrated that a fire within a container can be maintained in a suppressed condition 9equivalent to the level it is maintained by present halon system.]

12. The effects of altitude on water mist particles needs to be evaluated i.e.; does 8 to 10 thousand feet cabin pressure altitude affect the droplet size and the fire fighting efficiency?

[Yes, the effects will need evaluation. However, based on non-aviation water spray systems the effects are believed to be minimal.]

13. The system will require a long development time. Design and application on an aircraft will take a long time. Certification issues will have to be worked out with the certification authorities since there is no certification method for a water mist system at the present time and that itself will take a long time. Bottom line is it will take many years for a system to be developed, designed for a particular aircraft, implemented and certified.

[Development time, design and application on an aircraft depends on several factors, the most important is commitment. Certification issues need to be worked for all agents- there is no certification method for inert gases or halocarbons.]

7.5 References

1. The Mechanism of Extinguishment of Fire by finely Divided Water – An Investigation Conducted by Underwriter's Laboratories, Inc. for the National board of Fire Underwriters, 1955.

2. NFPA Std. 750 Water Mist Fire Suppression Systems. National Fire protection Association, 1, Batterynarch park, Quincy, MA 02269-9101 (USA)

3. CAA Paper 93007 Aircraft Cargo Bay Fire Protection by Water Sprays: A Feasibilit Study. D.P. Smith [Prepared by Fire Safety International and Published by Civil Aviation Authority, London, March 1993]

4. Evaluation and Optimization of an On-Board Water Spray Fire Suppression System in Aircraft. Richard G. Hill, Timothy P. Marker, Constantine P. Sarkos. Fire Safety Branch, Federal Aviation Administration Technical Center, Atlantic City International Airport, NJ 08405 (USA) – Presented at Water Mist Fire Suppression Workshop, national Institute of Standards and technology, Gaithersburg, Maryland 20899 (USA) march 1993

5. Water Mist Fire Protection Systems for Telecommunication Switch Gear and Other Electronic Facilities." Andrew T. Hills, Terence Simpson and David P. Smith. Fire and Safety International – Research, Mill House, Poyle Road, Colnbrook Slough, SL3 0HB, Great Britain

8.0 Watermist and Inert gas fire suppression syste

Water and nitrogen (inert gas) are readily available, safe to humans and environmentally friendly. Test of a “Zonal” system that uses

(a) water mist (for a finite time) to knockdown the fire, dampen the fuel and increase the humidity of compartment air in the vicinity of the fire; and
(b) Nitrogen to maintain the compartment air at low oxygen concentration to allow continued safe flight and landing

is recommended for test.

The nitrogen may be bottled nitrogen (small cargo compartment, low leakage) or may be generated on-board using an On-Board Inert Gas Generating system (OBIGGS)

8.1 Features

Water mist is highly efficient in absorbing heat from a fire by virtue of the large surface area per unit volume. This reduces fuel pyrolysis and thus the combustion rate. Also, it reduces the environment temperature, makes the fuel damp, and the air in the vicinity of the fire humid. This reduces fire spread. Water mist has effective smoke stripping and acid gas absorption capability that may be desirable when animal cargo is on-board. Nitrogen enriched atmosphere suppresses fire. National fire Protection Association (NFPA) Std 2001, reference 1, permits 12% (sea-level equivalent, Oxygen partial pressure equal to 91 mm of mercury) in normally occupied areas.

8.2 Advances to date

Water mist and water-spray are old technologies. Water-spray is used globally to suppress fires in both occupied and non-occupied area. Several design standards have been published by NFPA. It is a mature technology. A European consortium, FIREDASS, evaluated it for use in cargo compartment and determined it as competitive with other non-halon agents/ systems. FAA has performed successfully suppressed cargo compartment fires in the test facility at Atlantic City, NJ (USA). The proposed water-mist / inert gas system will be studied by FIREDETEX, a European consortium. NASA is actively studying On-board Nitrogen Generation for commercial transports.

8.3 Concerns and benefits

Overall system reliability is of major concern. However, this can be solved. Water freezing in airplanes that are left unattended for long duration in cold (sub-freezing) weather is also of concern. Maintenance/ Engineering solution to solve this problem are available. On-board nitrogen generating system will require high-pressure air and the availability of the air from high bypass ratio engines is of concern. However, dedicated compressor can solve this problem. The effect of water on electrical equipment inside the cargo compartment is also of concern. Engineering solution for this is also available. In short, there are concerns but no show stoppers. Technology to develop this type of system currently exists. The proposed system offers a permanent solution, not offered by halocarbon. Also, it is a friendly (to the environment, cargo, airplane, and personnel) solution to fire suppression in the cargo compartment.

8.4 Team submitted comments, concerns, and other data

1. There is little if any test data on "Water Mist" systems that simulate "Full-Up" aircraft installation addressing all the issues associated with the technology. These include including additives (to address flow effectiveness, corrosion, storage stability, bacterial growth, contamination, freezing, etc.), filters to protect the nozzle openings from particulate contamination, ice, etc., any relevant equipment, etc. to allow discharge at low temperatures after cold soaking to -40 F to -65 F. This data needs to be developed.

[Information on a "Full-Up" aircraft installation is available for only one type of system – halon system. The proposed system test will provide information necessary for detailed system design. It must be noted that water fire and inert gas fire suppression systems are used all over the world and in all climates. Technology exists.]

2. "Flash Over" at marginal concentrations may also need to be addressed.
[The condition should be tested.]

8.5 References

NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems. National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02669-9101.