OPTIONS FOR AIRCRAFT ENGINE 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 aircraft fire protection. The team recommends that FAA conduct test using Triodide [CF_3I] and Pentafluoroethane [HFC-125, FE-25, CHF2CF3]. These two agents are teams' 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 six options for engine fire protection selected for review and evaluation. Sub-teams were formed to prepare a report that explains the reasons the 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 decided to include Powdered Aerosol C (Pyrogen) to make information available to the readers. Pyrogen proposal did not go through the review and comment process as the previously selected six options. Also, this agent was not included in the selection process. Pyrogen data was provided by John Brooks (International Aero Inc.) and is included in Appendix A.

1.1 Recommendation

The Team recommends, by consensus, the following two agents for FAA tests.

1. TRIODIDE (CF_3I)
2. PENTAFLUOROETHANE [HFC-125, FE-25]

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. HEXAFLUOROPROPANE [HFC-236fa, FE-36] ENGINE FIRE PROTECTION

   Proposed by Konstantin Kallergis (Lead) & Harry Stewart

2. FM-200 [HFC-227ea, HEPTAFLUOROPROPANE, CF_3CHFCF_3] FOR ENGINE FIRE PROTECTION.

   Proposed by Robert Glaser (Lead), P.E

3. PENTAFLUOROETHANE [HFC-125, FE-25] FOR ENGINE FIRE PROTECTION.
   Proposed by Giuliano Indovino (Lead) & Harry Stewart

4. TRIODIDE (CF_3I) FOR AIRCRAFT ENGINE FIRE PROTECTION
   Proposed by Douglas Ferguson (Lead), Philippe Pene and Simon Chaer

5. INERT GASES (CO2 OR N2) FOR ENGINE FIRE PROTECTION
   Proposed by Sham Hariram (Lead), Eric Lyon and Konstantin Kallergis

6. WATER MIST FOR ENGINE FIRE PROTECTION
   Proposed by – John J. O'Sullivan, MBE (Lead) & Dr. Panos Papavergos

3.0 Hexafluoropropane [HFC-236fa, FE-36, $CH_3CH_2CF_3$]

Hexafluoroprane is a halocarbon and belongs to the Hydrofluorocarbon (HFC) family. It is commonly known as HFC-236fa and FE-36. Its significant properties are as follows:

Formula:	$CH_3CH_2CF_3$
Molecular Weight:	152
Boiling Point:	-1.5°C
ODP:	0
GWP:	6300
Liquid Density (at 25°C):	1370 kg/m^3
Vapor Pressure (at 25°C):	275.1 kPa
Storage Pressure (at 21.1°C):	1.27 bar (without N_2 pressurization)
Heat of Vaporization:	38.67 cal/g
Extinguishing Concentration. (Cup burner, n-heptane):	5.3 % - 7.1%
Approximate Lethal Concentration, ALC;	>189000 PPM
No Observed Adverse Effect level, NOAEL:	10 Vol.%
Low Observed Adverse Effect level, LOAE	15 Vol.%
Lethal Concentration- 50%, LC_{50} (4h, rats):	2841 mg/l
Suppression Principle:	Physical (cooling), little chemical (breaking chain reaction)
Possible decomposition products:	HF, CO

3.1 Features

FE-36 is recognized by the National Fire Protection Association, NFPA, as a clean agent in NFPA, Standard 2001, Reference 1, and is listed on the USEPA Significant New Alternatives Policy (SNAP) list. The agent is non-corrosive and non-conductive. Its has low toxicity, and has zero Ozone Depleting Potential. Cup-burner extinguishing concentration has been determined as 5.3% (Fenwal Safety Systems Company), 5.6 (New Mexico Engineering Research Institute), and 6.5% by National Institute for Standards and Technology). DuPont, the manufacturer, advertises the extinguishing concentration as 7.1%. International Halon Replacement Working Group's 'Task Group on Halon Options" estimated weight and volume equivalents for this agent as 1.95 and 2.23 using the manufacturer advertised 7.1% extinguishing concentration, Reference 2.

Information on FE-36 is posted on DuPont's web site (www.dupont.com/fire). In particular the DuPont lists the cup burner value as 6.3%. At cup burner plus 30% the wight and volume comparison to 5% halon 1301 is 1.8 and 1.6.

3.2 Advances to date

Airbus Industrie is evaluating FE-36 for use in fire extinguisher used in the lavatory trash container. The extinguisher will be offered, as an option, this year. FE-36 is sold in the United States and other countries in Underwriters' Listed portable fire extinguishers.

3.3. Concerns and Benefits

FE-36 has high Global Warming Potential (GWP) like all other hydrofluorocarbons (HFCs). This concerns regulatory agencies. This may, in the future, lead to production phase out or to use restrictions. FE-36 has the best weight and volume equivalents among all hydrofluorocarbons. This may provide weight and volume advantages. .

3.4 Team submitted comments, concerns and other data

(1) Ref: DuPont Fire Protection web site (http://www.dupont.com/fire/techinfo/feprop.html)

The relatively high boiling point of FE-36 (+30F) will need to be evaluated, especially for performance at low temperatures, along with it's very high GWP (6300). These characteristics may override the perceived benefits.
[The withstand and operating temperatures are important in agent selection. It may be possible to modify withstand and operating temperatures by locating agent reservoir in an area that is normally at a higher temperature. Other techniques such as heating tapes and insulation can also be used. See also comment (30 below. .]

(2) High boiling temperature and low vapor pressure for applications where the agent environment temperature is low. (Note: some bottles are installed in the –65^{o}F, -70^{o}F temperature environment.) The low temperature in the delivery and engine environment could also pose problems. Additionally bottle pressures are normally in the 600 to 800 psig range. The application of an agent with low vapor pressure needs to be assessed even though the bottles are super pressurized with N_2.
[See comment 1, above. Bottles can be supercharged to higher pressure, if required. Halon bottles for engine fire suppression systems and cargo compartment fire suppression systems are super charged to different pressure levels – 800 psig and 360 psig respectively.]

(3) Compliance with certification requirements of minimum specified concentration of agent in all fire zones for a minimum of 0.5 second simultaneously (if similar to Halon 1301) could pose a problem at low temperatures and with low vapor pressures.
[The requirement – concentration and duration – for this agent is presently not known. This needs to be determined by test. Low temperature tests should be performed to determine agent compatibility with the withstand and operating temperature requirements.]

(4) This agent may be eventually banned due to its high GWP.
[This is a concern with all HFCs. However, presently there is no rule or rule in the making that will phase out HFC production or use.

(5) SNAP approved, ranked fourth most environmental friendly vaporizing liquid agent (high GWP); poor fire suppressant when compared to Halon 1301, NFPA/EPA approved for occupied applications, no toxicity concerns, low vapor pressure agent

but vapor pressure, extinguishing concentration at -65°F, agents of similar vapor pressures have been used successfully before; good storage efficiency due to acceptable density and low vapor pressure at high temperature; commerciall available but not fielded in military or commercial fire suppression systems.
[All HFCs have poor fire suppression capability (n-heptane cup burner test) compared to halon 1301. Besides, HFC-125 no other HFC is fielded in military or commercial aviation fire suppression systems. HFC-125 use is limited to a small number of military applications.
It is better than HFC-125 or HFC-227ea and is used in UL portable fire extinguishers.]

(6) The Scientific Assessment of Ozone Depletion ’98 (last issue) reports the updated environmental factors for CFCs, HCFCs and HFCs (Chapter 10, Climate Effects of Ozone and Halocarbon Changes, page 26). Accordingly, the new data on GWP (100 year time horizon) for HFC 236fa is 9400 against 6300 previously reported. This represents a substantial increase and the figure should be amended. Moreover, the same document reports for both HFC 125 and HFC 227ea a new GWP of 3800 and it is not fair to put these two products, which show a low or moderate GWP, at the same level as HFC 236fa, which shows one of the highest GWP values.
[We used the data from reference 2 that was peer reviewed. See also comment 4.]

(7) Atmospheric Lifetime (ALT) is a parameter that should also be taken into account, since products with a reduced ALT allow Environmental Authorities to adopt corrective policies in case of new negative indications relevant to the use of these substances. The Scientific Assessment of Ozone Depletion ’98 reports for HFC 236fa an Atmospheric Lifetime of 226 years, compared to 32.6 years for HFC 125 and 36.5 years for HFC 227ea.
[Good information / comment.]

(8) Although HFC 236fa is suitable for use as a total flooding agent for the protection of enclosures at normal ambient temperatures (20°C) and features the best weight and volume performances among halocarbon agents, tests conditioning the system components at very low temperatures should be carried out in order to confirm that this product is suitable for engine fire protection systems.
[We concur, the tests must be performed.]

3.5 Reference

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

2. DOT/FAA/AR-98/XX Halon Options for Aircraft Fire Suppression Systems- 1999 Update

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

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 agents for use in the engine nacelle applications including vaporizing liquid agents, dry chemical based agents, aqueous agents and gas generators. The studies performed by Walter Kidde Aerospace 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 HFC-125, HFC-227ea and FIC-13I1 as the agents for testing on the engine nacelle at the FAA technical center. Table 4.1-1 lists the properties of these vaporizing liquid 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 data will be used to show HFC-227ea is an appropriate agent for aircraft engine fire protection.

Considering environmental properties first, the Table 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. [Based on NOAEL and LOAEL values HFC-236fa is less toxic than HFC-227ea, Reference NFPA 2001 Standard for Clean agent Fire Extinguishing Systems.] However, this data is of secondary importance for the engine nacelle application as this is an unoccupied area.

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 the extinguisher reservoir for HFC-227ea will be smaller 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. HFC-236fa is more weight efficient than HFC-227ea (Reference NFPA 2001)

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. I should be noted that super pressurization with nitrogen may override any advantage in cylinder construction attributable to the lower vapor pressure of 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
HGWP (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 various engine nacelle 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. 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 engine nacelle 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. As with other HFCs HFC-227ea will continue to be scrutinized for its Global Warming Potential (GWP) under the Kyoto Protocol. This may limit its and other HFC's useful life.

4.4 Team submitted comments, concerns and other data

(1) Ref: DuPont Fire Protection web Site (http://www.dupont.com/fire/techinfo/feprop.html)

The relative high boiling point of FM-200 (+3 F) will need to be evaluated, especially for performance at low temperatures.
[The withstand and operating temperatures are important in agent selection. It may be possible to modify withstand and operating temperatures by locating agent reservoir in an area that is normally at a higher temperature. Other techniques such as heating tapes and insulation may also be used.]

(2) High Boiling point and low vapor pressure for applications where the agent environment temperature is low. (Note: some bottles are installed in the –65^{o}F, -70^{o}F temperature environment.) Additionally the low temperature in the delivery and engine environment could also pose problems.
[See comment 1, above]

(3) The required bottle pressures are normally in the 600 to 800 psig range. The application of an agent with low vapor pressure needs to be assessed even though the bottles are super pressurized with N_2.
[Bottles can be supercharged to higher pressure, if required. Halon bottles for engine fire suppression systems and cargo compartment fire suppression systems are super charged to different pressure levels – 800 psig and 360 psig respectively.]

(4) Compliance with certification requirements of minimum specified concentration of agent in all fire zones for a minimum 0.5 second simultaneously (if similar to Halon 1301) could pose a problem at low temperatures and with low vapor pressures. This agent may be eventually banned due to its high GWP.
[The requirement – concentration and duration – for this agent is presently not known. This needs to be determined by test. Low temperature tests should be performed to ensure compliance with the withstand and operating temperature requirements. All Hydrofluorocarbons have high Global Warming Potential. This is a concern with all HFCs. However, presently there is no rule or rule in the making that will phase out HFC production or use.]

(5) SNAP approved ranked third most environmentally friendly vaporizing liquid agent; poor fire suppressant when compared to Halon 1301, NFPA/EPA approved for use in occupied applications, no toxicity concerns, low vapor pressure agent but vapor pressure > fire extinguishing concentration at -65°F<u>; good storage efficiency</u> due to acceptable density and low vapor pressure at high temperature; commerciall available and fielded in many of Halon replacement systems in industrial applications, however, no formal design equations or certification criteria. Essentially this agent is as good or better than HFC-125 in all its characteristics but HFC-125 has more test data and is fielded on military applications.
[All HFCs have poor fire suppression capability (n-heptane cup burner test) compared to halon 1301. Besides, HFC-125 no other HFC is fielded in military or commercial aviation fire suppression systems. HFC-125 use is limited to a small number of military applications. In our opinion, HFC-227ea is a better choice than HFC-125.]

(6) Fire Protection Systems using HFC 227ea have been tested and approved for ambient temperatures ranging from 0°C to 52°C. Like for HFC 236fa, it should be confirmed by testing that at very low temperatures this product would distribute homogeneously in the protected enclosure and perform fast extinguishemt. The vapor pressure of HFC 227ea at –20°C is already less than 1 bar compared to about 3 bar of HFC 125 at the same temperature.
[We concur. Tests will allow determination of agent performance characteristics.]

(7) Since in the previous Edition ('96) of the NFPA 2001, heptane cup burner data for the various halocarbon agents varied substantially from laboratory to laboratory, and after the extinguishing problems encountered during some fire testing where the concentrations used were based on the lowest available cup burner data, in the Edition 2000 of the NFPA 2001 Standard it has been decided to include new cup burner data which represent the average results from the different laboratories. For HFC 227ea the new accepted cup burner data for heptane is 6.5%. The resulting extinguishing concentration by weight (@ 20°C) based on cup burner would be therefore 506 grams per m^3. Based on the same principle the new HFC 125 heptane cup burner is 8.7% and its extinguishing concentration by weight is 483 grams per m^3. Shortly, if we take into consideration the maximum fill densities of system cylinders reported in the NFPA 2001 for the different agents, we find out that

although cylinders for HFC 227ea systems allow 30% more agent than HFC 125, the latter requires about 30% less agent to protect the same risks. Therefore, the two products as far as size of containers is concerned are equivalent.
[Your conclusions may be correct based on n-heptane cup burner test data in the quoted reference. We used Table 4.1-1 data which is was peer reviewed.] .

(8) The requirements to build system cylinders depend on the superpressurization level of the same. If a cylinder has to be pressurized for example at 1000 psig with nitrogen (as in the case of some Halon 1301 systems for engine protection), the same will be built accordingly.
[We concur. Cylinder design depends on the normal operating pressure, single failure pressure, burst disk (or pressure relief valve) pressure, proof pressure and burst pressure.]

(9) For HFC 125 the design concentration of 10.5 (8.7% cup burner, plus 30% of safety factor) is based on the new cup burner data reported in the NFPA 2001 Edition 2000, which, represents the average data among different results obtained by some independent laboratories. Accordingly, the design concentration reported in the table of HFC 227ea should be based on 6.5% cup burner data, which would lead to a design concentration of 8.5%.
[Table 4.1-1 data is from FAA report DOT/FAA/AR-98/XX Halon Options for Aircraft Fire Suppression Systems. Cup burner data for all agents has variations because of differences in the cup burner design and test procedures.]

(10) With the recent introduction of the physiologically based pharmacokinetic (PBPK) modeling, there is no reason why HFC 227ea should be considered safer to humans than HFC 125 at the normal concentrations of use. According to this new time-related equation, that measures the time that different concentrations of agent take to reach dangerous concentrations in the blood (NOAEL), at concentrations equivalent to the cup burner data plus 20% or 30% (design concentrations) both halocarbons are granted of a safe exposure time of 5 minutes. In any case, in this particular application, toxicity would not be a concern.
[We concur toxicity is not important for this application.]

(11) There are no significant advantages of weight and space that HFC 227ea can offer compared to HFC 125. The physical properties that HFC 125 features, though, appear more appropriate for the specific application compared to those of HFC 227ea. No HFC 227ea system has been installed onboard aircraft to protect engines and only testing simulating this fire application will eventually confirm its suitability.
[We concur tests will provide the necessary information.]

(12) It was mention that trade studies show volume and weight reductions. Should not the source of these studies be reference.
The statement is based on data contained in FAA report- *DOT/FAA/AR-98/XX Halon Options for Aircraft Fire Suppression Systems]*

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

Pentafluoroethane, a halocarbon belonging to the hydrofluorocarbon family and commonly referred to by its trade name HFC-125 and FE-25, is proposed for test for engine fire protection. Like other members of the HFC family it has zero Ozone Depletion Potential (ODP). We prefer it over Heptafluoropropane [HFC-227ea, CF_3CHFCF_3] and Hexafluoropropane [HFC-236fa,
FE-36, $CF_3CH_2CF_3$]; other potential agents of the hydrofluorocarbon family due to its physical properties (e.g., low boiling point, -48.5^{0}C vs –57.75^{0}C of halon 1301), environmental properties (GWP, atmospheric life, and fire extinguishing concentration (gr/m^3)). United States Department of Defense selection of HFC-125 for engine fire protection also supports our selection. We did not evaluate Triodide [FIC-I311, CF3I]. It is a non-zero ODP agent and is toxic at low concentrations.

Property	**HFC 125**	**HFC 227ea**	**HFC 236fa**
Molecular weight	120.02	170.03	152
Boiling point @ 760 mm Hg (°C)	- 48.5	- 16.4	-1.4
Freezing point (°C)	- 102.8	- 131.0	-103
Critical temperature (°C)	66.0	101.7	124.9
Critical pressure (kPa)	3,595	2,912	3,200
Critical volume (cc/mole)	210	274	274
Critical density (kg/m^3)	571	621	555.3
Specific heat, liquid @ 25°C (kJ//kg°C)	1.260	1.184	0.844
Heat of vapor at boiling point @ 25°C (kJ/kg)	164.7	132.6	160.1
Viscosity of liquid @ 25°C (centipoise)	0.145	0.184	0.360
Solubility of water in agent	0.07% by weight @ 25 °C	0.06% by weight @ 21 °C	740 @ 20°C
Vapor pressure @ 25°C (kPa)	1,371	457.7	272.4
Global Warming Potential, GWP	2800	2900	6300
Atmospheric Life, Years	32.6	36.5	209
Cup-burner extinguishing concentration (%) by volume Required agent by weight gr/m^3 at 20^{0}C	8.7 483	6.5 506	6.3 440

5.1 Features

Penatfluoroethane is a clean agent; it does not leave any residue. National Fire Protection Association, NFPA, recognizes it in NFPA Std 2001, Reference 1. It is listed on the US EPA Significant New Alternatives Policy (SNAP) list. The agent is non-corrosive and non-conductive. It has low toxicity, zero ODP, and a low atmospheric life (lowest of all HFCs), Reference 2.

5.2 Advances to date

USAF Wright Patterson Air Force Base tests have confirmed its performance over a wide range of operating conditions. Production versions of F/A-18 E/F, V-22, and F-22 will use HFC-125 for engine fire suppression.

5.3 Concerns and Benefits

The Global Warming Potential of Penatfluoroethane is the lowest of potential fire suppression agents of the halocarbon family. Yet, it is of concern to the regulatory agencies. This may, in the future, lead production phase out or to use restrictions of halcarbons. The agent has a low boiling point, and physical properties (vapor pressure, liquid density and heat of vaporization) that favor low pressure drop in a duct system. This will allow faster dischargethrough a given distribution system. The agent has a low concentration requirement (mg/ m^3) for flame extinguishment; this promises low agent weight. HFC –125 has been extensively tested t for engine fire protection; the tests confirm it performs the intended function remarkably well. HFC 125 offers the best compromise among all other candidate halocarbons due to its low atmospheric life in the Global Warming effects.

5.4 Team submitted comments, concerns and other data

(1) Ref: DuPont Fire Protection web Site (http://www.dupont.com/fire/techinfo/feprop.html)

a) Currently the production versions of the F/A-18 E/F, V-22, and F-22 are all scheduled to use HFC-125 to protect the engine nacelle.
[We concur.]

b) The low boiling temperature of FE-25 (- 55 F) is more like HALON 1301 than any of the other alternatives.
[The -55F boiling point of HFC 125 is comparable to –72F boiling point of halon 1301.]

(2) A good overall alternative agent but may require redesign of the engine fire extinguishing system because of the higher volume of agent required. Also may be eventually banned due to its high GWP.
[Redesign will be required with essentially all agents. There is no true drop-in agent; CF3I is nearly a drop in agent. All Hydrofluorocarbons have high Global Warming Potential. This is of concern. However, presently there is no rule or rule in the making that will phase out HFC production or use.

(3) SNAP approved ranked second most environmentally friendly vaporizing liquid agent; poor fire suppressant when compared to Halon 1301, NFPA/EPA approved for use in unoccupied applications, no toxicity concerns; high vapor pressure agent ensures good distribution at low temperatures and vapor pressure at -65°F , fire extinguishing concentration; poor storage efficiency due to low density and high vapor pressure at high temperature; commercially available and is fielded in several US military applications, US DOD has design equations and certification criteria. [*[All HFCs have poor fire suppression capability (n-heptane cup burner test) compared to halon 1301. US DOD uses HFC-125 for engine fire protection. The DOD design equations and certification criteria were not accepted by the civil aviation industry. For these reasons test of the agent is recommended.]*

5.5 References

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

2 DOT/FAA/AR-98/XX Halon Options for Aircraft Fire Suppression Systems-1999
Update

6.0 Triodide [CF_3I]

Triodide (CF_3I, FIC-13I1, Trifluoroiodomethane) is SNAP listed for use in normally unoccupied areas. It has a near zero Ozone Depleting Potential and Global Warming Potential. Triodide has been shown during Wright Patterson testing to be a fire extinguishant, comparable to Halon 1301 in nacelles. There have been numerous side-by-side flight and ground tests on nacelles which demonstrate the ability of Triodide to distribute comparably with Halon 1301 (See Comment 1 and Reference 1). This has been done with room temperature bottles as well as cold soaked bottles (Reference 2).

6.1 Features

Based on several series of tests, the recommended fire suppression design concentration is 5.0 percent, the same as Halon 1301. Tests have shown equivalence of Triodide to Halon 1301 for fire extinguishment to be 1.36 and its volume equivalence to be 1.0. Because of the increased density of Triodide, the weight of agent is 35% greater than Halon 1301. This means that the average bottle is 15 to 20 % heavier.

Triodide has a very low Ozone Depletion Potential (0.0001 compared to CFC-11) a Global Warming Potential of less than 5 compared to CO_2, and an atmospheric lifetime of less than 1 day. Based on these low levels of potential environmental damage it is not likely to be included in any future listings of ozone depleting or global warming chemicals.

6.2 Advances to date

Triodide is presently installed as an engine nacelle fire suppression agent on at least two aircraft platforms: the SH2 Helicopter by Kaman Aerospace and the CASA (Spain) C295. Triodide has been installed in the engine test facilities for QANTAS, Ansett and the Australian Air Force. It has been used as a simulation agent to test the Halon 1301 systems on the Collins class Submarines.

6.3 Concerns and Benefits

The cost of Triodide remains higher (approx $50/lb) than other popular compressed gas agents. However the demand and manufacturing volume remain low, so there has been no driver to lower the price. Triodide appears to be the only drop in replacement. It will be the most cost-effective agent if retrofit of existing systems is ever required. It is expected that retrofit of most installations may require simply recharging the bottles with the equivalent volume of Triodide.

Triodide is more toxic and poses greater cardiac sensitization risks than other popular new compressed gas agents. However it compares closely to Halon 1211 and Halon 2402 which have been used world wide, even in residential extinguishers, without significant problems. There is probably no reason to restrict its use on aircraft areas for toxicity reasons.

When heated above 700 degrees F, Triodide breaks down, creating the vivid purple gas cloud. This is not unlike Halon 1301 and the other gases, but the purple color is eye catching. This might be an advantage since it provides a definite view of areas to avoid during fire fighting.

The US EPA presently is concerned that at high altitudes the ODP of this substance may increase notably.

Cold discharge will not be a problem in most engines. Halon 1301 boils at about –58 C. Vaporization in cold environments is complete in tests down to –54 C. Triodide boils at –22 C. Discharge tests at –40 C (–40 C Triodide into a –40 C chamber) showed vaporization of 85 % of the agent in a time comparable with Halon 1301 under the same conditions. 15% of the agent remained in liquid drop form for the initial seconds of the test.   Testing conducted by Pacific Scientific demonstrated that Triodide distributes adequately during cold engine conditions. For those applications which have a true cold fire zone environment, below –40 degrees F, specialized adjustment of nozzles or increased Triodide quantity may be required to mitigate the effects of condensation in Triodide rich areas. This should not impose a penalty on the use of Triodide for extinguishing engine nacelle fires because the temperature during the fire will be greatly in excess of –40 degrees F. For environments which could result in the bottle temperature dropping below –40C, special consideration should be given to move the bottle or provide a means of maintaining the bottle temperature at an acceptable level.

Note: The in-flight side-by-side data has been used as a basis for certification of a commercial fire suppression system and is presently only published in proprietary reports. This data was generated by Pacific Scientific and is available from Bill Meserve (Telephone 626 434 1139) or Simon Chaer (Telephone 33 1 39 20 99 30).

6.4 Team submitted comments, concerns, and other data

(1) CF3I has the least environmental impact of any of the liquid/gas agents being considered with a near zero ODP (.0001), low GWP <1), and short atmospheric lifetime (< 2 days).

[It is the most environmentally friendly agent.]

(2) The relatively high boiling point (- 9 F) makes additional work necessary to insure there is adequate performance at low temperatures.

[The operating temperature is important in agent selection. It may be possible to modify operating temperature requirement by locating agent reservoir in an area that is normally at a higher temperature. Other techniques such as heating tapes and insulation may also be used.]

(3) This agent is probably the best drop in replacement for Halon 1301 in the Engine application. Work needs to be accomplished to overcome and or verify the effects of high boiling point and low vapor pressure on engine fire extinguishing. Toxicity may not be a real concern for engine fire extinguishing since fires occurs when the engine is running. Toxicity should not affect inflight fires. For “on ground” cases locks and logic controls may be required for inadvertent discharges (e.g., require the cowl door to be closed and the engine spooling “for the ground case” before the agent can be discharged. Additional training for mechanics to be wary of the situation during manual opening of the starter air valve during engine start will be required. Training for handling the extinguishing agent bottles will also be required.

[See comment 2. System can be designed to comply with the requirements. Tests will define the requirements.]

(4) SNAP approved, most environmentally friendly vaporizing liquid agent; <u>excellent fire</u> suppressant, NFPA/EPA approved for use in unoccupied applications, long term exposure concerns but agents with similar toxicological characteristics have been used; low vapor pressure agent but vapor pressure, fire extinguishing concentration at -65° F and agents with similar vapor pressures have been used successfully; excellent storage efficiency due to high density and low vapor pressure at high temperature; commercially available and is fielded in some non U.S. military applications, however, no formal design equations or certification criteria.

[CF3I fire suppression capability (n-heptane cup burner test) is comparable to that of halon 1301 It is not used by US DOD..]

(5) The fact that - according to the US EPA - at high altitudes the ODP of this substance may increase notably should be added in paragraph D. Until this issue is confuted by the US EPA, it represents an important concern and should be included in this paper.

[Good information.]

(6) What is the certification basis for SH2 Helicopter by Kaman Aerospace and the CASA (Spain) C295. Are the certification rules similar to the FARs and JARs.

[The cert basis for the SH2 was MIL E-22285, Extinguishing System, Fire Aircraft, High Rate Discharge Type, Installation And Test Of. This specification has a lot of detail about the system but specifies Halon 1301 so the test plan specified CF3I at 6.2%. 6.2% came from an analysis by Dierdorf and Meserve which looked at Wright Patterson data and cup burner data, selecting 6.2% as a conservative level. The basis for CASA is not known but probably the same. The FARs do not specify a concentration level, but the requirements for the extinguisher are consistent with the MIL spec.

(7) Triodide is not an option for the cargo compartment or hand held fire extinguisher. Also, it is not being considered for non-aviation fire suppression use. These factors limit its market to 10,000 to 15,000 pounds per annum worldwide for engine fire protection. Does CF3I have other commercial uses? If yes, what is it used for and how much is it used? If not, I am concerned that it will be extremely expensive and difficult to obtain worldwide? Please comment

[Although Triodide has been used for some non-aviation purposes –CF3I systems have been installed in railway diesel generating cars, standby diesel generating plants and in telecommunications switch rooms, it is likely to have a higher cost relative to other agents in wider use. The retrofit cost for a system using CF3I is likely to be lower than other agents, however, due to generally being able to use the same Halon 1301 distribution network.]

6.5 References

Reference 1:   "Report of Triodide testing on the Gulfstream V, Rolls Royce BR710 Engine", William J. Meserve and Douglas S. Dierdorf, Pacific Scientific Company, HTL/Kin-Tech Division, Duarte, California and Alburquerque, NM.

Reference 2: Pacific Scientific Document 51750579, "Results of Cold Discharge Tests on Triodide," October 1996.

7.0 Inert gases - Carbon dioxide and Nitrogen

7.1 Carbon dioxide

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.% cause unconsciousness within 5 minutes
Exposure Limit (TLV-TWA):	5000 ppm

(+) CO_2 is heavier than air
(+) CO_2 is available almost everywhere
(-) extinguishing capability is rather poor (numbers found between 30 and 70 Vol.%)
(-) mass: heavy installation (bottles) required
(-) CO_2 is a global warmer
(-) high rate of accidents due to electrostatic charge (being investigated)
(-) System needs to be designed properly. (is odorless, has leaked into the flight compartment and caused asphyxiation of flight crew).

7.2 Nitrogen

Formula	N_2
Molecular Weight	28
Boiling Point:	-195.8°C
Gas Density (at 20°C):	1.251kg/m^3
Health Hazard:	non-toxic down to for breathing necessary oxygen concentration

(+) N_2 is available almost everywhere
(+) very good toxicity values
(+) can be produced out of the ambient air by membranes
(+) lowers burning temperature
(-) extinguishing capability is rather poor (numbers found between 30 and 80 Vol.%)
(-) mass: heavy installation (bottles) required

N_2 is lighter than air. (Molecular weight 28 vs 29)
N_2 is generated by On Board Inert Gas Generating Systems (OBIGGS) on some military aircraft for the purpose of fuel tank ullage inertin

7.3 Team submitted comments, concerns and other data

(1) The gas systems generally have heavier volume penalties and are not as effective as the "chemical" agents or gas generators. The CO_2 systems are reported to cause death each year and the N_2 systems may also cause death if deployed. These issues will need to be addressed.

(2) The agent is not as efficient as halocarbons. It does have a low boiling point and will require a redesign of the engine extinguishing system.

(3) Carbon dioxide. No use restrictions, environmentally acceptable; poor fire suppressant compared to Halon 1301;NFPA approved for use in unoccupied areas; high vapor pressure ensures good distribution at low temperatures; poor storage efficiency due to low density and high vapor pressure at high temperature; commercially available and fielded in numerous commercial and industrial applications. Certification criteria exists for this agent (AC20/100). Old technology, heavy systems

(4) Nitrogen / Inert gases. No use restrictions, environmental friendly; poor fire suppressant compared to Halon 1301; NFPA approved for use in unoccupied areas; high pressure ensures good distribution at low temperatures; poor storage efficiency due to low density and high pressure; commercially available and fielded in numerous commercial and industrial applications and is used in OBIGGS Systems / inert gas generator systems on a/c.

(5) Both these two inert gas systems require larger amounts of agent compared to halocarbon systems, larger size of high pressure containers, thus resulting in larger and heavier systems and these are key factors when selecting suitable options to Halons onboard of airplanes.

(6) Which inert gas is recommended for test and why?

8.0 Water mist

Water mist is by far the most benign medium for fire protection. 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 previously demonstrated equivalent fire protection to chemical agents including Halon, in a variety of land applications, using little water. Water mist technology is being used for engine rooms in marine applications.

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. Hence, the Chemical Options review group has considered it appropriate to investigate the use of water mist for the fire protection of cargo bays and engine nacelles.

8.1 Features

Water mist is weight efficient compared to available options to halon due to the large number of small drops occupying large spaces. Its suppression offers: effective smoke stripping and acid gas absorption capability and temperature knock-down of environs to levels that may prevent reignition of residual combustibles. Also, it does not produce toxic and corrosive by-products.

8.2 Advances to date

Water mist is an old technology, reference 1. Halon production phase out renewed interest in the technology for Class B (Flammable Fluid) fires, reference 2. Design criteria have been established in a range of land applications, including means to avoid thermal shock on thermally sensitive equipment. It is increasingly being used in marine industry to suppress/extinguish engine room fires.

8.3 Concerns and benefits

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

8.4.1 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.
[There is no test data on water mist system that simulates full up aircraft installation. Some development tests were conducted by FIREDASS, a European consortium. The tests confirmed it is a viable method. For these reasons test of the agent is proposed. Water mist has been extensively tested for Class B (flammable fluid) fires and is being used in marine / industrial applications. Several additives to enhance fire suppression effectiveness are commercially available and are widely used. They have Independent testing laboratories, like Underwriters Laboratories, have tested these additives and listed them. Hydraulic system design methodology is available in handbooks. NFPA has published a Standard on the design of water mist system. Methods to prevent corrosion, bacterial growth, and freezing are known.]

(2) The reported results of the FIREDASS testing indicate that this technology (in several configurations) failed to extinguish engine nacelle fires in all tests unless the fuel was shutoff. This data and the performance achieved need to be evaluated before the technology is selected.
[Fuel shut off is required crew action when an engine fire is annunciated. The non-halon system is required to provide performance equivalent to that provided by the current halon system so aviation safety is not compromised. The proposed agent test will help determine the water mist system requirements (flow rate, operating pressure, droplet size, flow duration, distribution, etc) for a system that is equivalent in performance to the current halon system.]

(3) This is a good candidate for a screening test in a simulator to check if it can put out the fires specified in the MPS. Freezing and delivery problems may be addressed by adding anti-freezing agents aided by heaters and by the use of high-pressure pumps. The other concern is: Will the water mist freeze when it is injected into a low temperature atmosphere created in some parts of the nacelle during flight? If water mist works, this will be the best alternative agent available.
[We doubt it. Water is used in sub-zero climates for fire suppression. To freeze and form ice crystals the water droplets will have to fall to freezing temperature and lose heat of fusion. The ice crystals will absorb heat from the fire (reduce its temperature in a manner similar to the water droplets. It is probable that some water may freeze on extremely cold surfaces. This will protect the surfaces from fire/ heat damage. Tests at low temperatures should be conducted to resolve the concern.]

(4) No use restrictions, environmentally friendly; good fire suppressant if spray can be applied directly on fire, this is impractical in this application; need additives to prevent freezing at low temperatures (corrosive?). Commercially available systems and fielded in numerous commercial and industrial applications.

[Tests have confirmed that water mist suppresses Class B fires by absorbing heat (preventing fuel pyrolysis), reducing oxygen partial pressure, and making fuel less accessible (blanketing) to the fire. It is being used in industrial applications. Additives to prevent corrosion may not be needed if materials compatible with water are selected. Similarly, additives to prevent freezing may not be needed if design features are incorporated to make the system withstand the anticipated low temperatures – water pipes in Nome (Alaska), Thule (Greenland), or Reykjavik (Iceland) do not freeze during the cold months.]

(5) Tests should be carried out in order to determine if the high air flow in airplane engine could affect the size (momentum) of water droplets, thus limiting their extinguishing performance.

[We recommend the water mist system be challenged by the tests defined in the Minimum Performance Standard (MPS) for Engine and APU fire suppression system, developed by the International Halon Replacement Working Group. The pass/fail criteria defined in the MPS should be used to ensure performance equivalent to present halon 1301 system. The MPS represents the collective judgement of world's best brains from user, manufacturer, and regulatory agencies.]

8..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. Extinguishment of Enclosed Gas Fires with Water Spray – Ragnar Wighus, SINTEF – NBL Norwegian fire Research laboratory, N-7034, Norway. [Fire Safety Science-Proceedings of the Third International Symposium, pp 997 –1006]

Appendix A - Powdered Aerosol C [Pyrogen]

Pyrogen Aerosol is a SNAP listed halon 1301 replacement agent. Pyrogen is a proven technology, using a solid aerosol forming compound and chemical coolant, to produce micron size solid particles (mainly, potassium carbonates) and natural gases (mainly, nitrogen, carbon dioxide and water vapor) that form a uniform medium - aerosol. This aerosol is the actual extinguishing medium. Its prime extinguishing action is chemical - removal of free radicals from the flame reaction. Pyrogen will pass the fire tests required in NFPA 2001 and UL1058 but does not qualify as a clean agent as it is not a gas, but a mixture of fine solids and gases. As density of Pyrogen aerosol is close to air, it is neutrally buoyant. This allows the aerosol to disburse like a gas, but absorb heat like a solid.

Chemical Formula: A mixture of K_2CO_3(s),KH CO_3(s), N_2(g), CO_2(g),H_2O(g)

Molecular Weight: N/A

Fire Extinguishing Design Concentration (mass %) - 100g/m3;

ODP = 0;
HGWP=0;
Atmospheric lifetime (yr.) =0;
Cardio-sensitization LOAEL (vol. %) - N/A
Cardio-sensitization NOAEL (vol. %) - N/A

Toxicity assessment:

Potentially hazardous Aerosol ingredients	Concentration level at 100g/m3	LL (lowest lethal level)
CO	4,240 ppm	12,000ppm/5min 2,500ppm/30min

A.1 Features

Pyrogen is recognized by the Australia New Zealand Standards, and is listed on the USEPA Significant New Alternatives Policy (SNAP). The agent is non-corrosive and non-conductive, it has low toxicity, and has zero Ozone Depleting Potential and zero Global Warming Potential. At the standard design concentration used in AS/NZS 4487.1997 100g/M3 when compared to Halon 1301 330g/M3, is three times more effective. It has an operating range of -50C to +65C.

The solid aerosol forming compound [--] when combusted forms the fire fighting aerosol agent consisting of fine solids and gases {--}

$$[KNO_3(S) + C_NH_MN_PO_q(s) + C(s)] = \{KHCO_3(s) + K_2CO_3(s) + CO_2(g) + N_2(g) + H_2O(g)]$$

The actual ratio of the aerosol ingredients at 100g/m^3 design concentration is as follows:
solid fraction (potassium carbonates) - 7 g/m^3;
nitrogen gas - 70 vol. %;
carbon dioxide gas - 1.2 vol. %;

There are also traces of by-products of the aerosol-forming reaction,
such as:
carbon monoxide - 0.42 vol. %;
nitrogen oxides - 40-100 ppm

A.2 Advances to date

Pyrogen generators were tested in Nov. 1997 by ARL in F-22 engine nacelle applications (report Pending) They were also successfully tested in 737 EE bay. The generators are widely used in the electrical power distribution and generation and the oil/gas industries worldwide. Pyrogen Generators were tested in full scale, EE bay test in a Boeing 737 with the Naval Research Laboratory and Naval Air Systems Command in May 2000 (report pending). In this test four 200mm class B fuel cups were placed throughout EE Bay enclosure forward of the number 1 cargo pit. Suspended vertically above one 400mm cup was aircraft wire bundle containing 132 insulated wires removed from the aircraft. The 200mm cups were ignited and the wire bundle was splashed with fuel and the 400mm cup ignited, When the interior of the bundle reached 200C the Pyrogen was discharged and the all cup fires extinguished, without reignition for 1000 seconds. This was designed as a total flooding test, all the cups were in hidden locations through out the EE bay, and the test was then repeated with identical results. Suppression of wet arc's in artificially aged Polyimide wire was also suppressed with Pyrogen flooding in this series.

The Pyrogen generators are widely used in the electrical power distribution and generation and the oil/gas industries worldwide, listed by SSL (Ref 8). Tests report on portable pyrogen grenades is included in the 1999 HOTWC proceedings. (Ref 7)

A.3 Concerns and Benefits

Global Warming Potential (GWP) unlike hydrofluorocarbons (HFCs) is zero. The aerosol generator is unpressurized, requires no plumbing, and can be electrical or thermally activated. While used as a flooding agent Pyrogen does not displace the oxygen in the atmosphere. In recent test, atmospheric oxygen levels remained above 18%. Optical density of the aerosol is te only concern, but should not be a problem for engine nacelle applications.

A.4 References

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

2. DOT/FAA/AR-98/XX Halon Options for Aircraft Fire Suppression Systems- 1999 Update

3. Pyrogen Fire Extinguishing Aerosol Systems
AS/NZS 4487: 1997 Standards Australia/ Standards New Zealand

4. Maintenance of Fire Protection Equipment, part16: Pyrogen Fire Extinguishing Systems
AS/NZS 1851.16:1997 Standards Australia/ Standards New Zealand

5. UL 1058, Halogenated Agents Extinguishing Systems

6. UL 2166, Halocarbon Clean Agent Extinguishing Systems Unit

7. Halon Options Technical Working Conference (HOTWC) Proceedings 1999 Albuquerque, New Mexico

SSL (Scientific Services Laboratories Australia) Register of Fire Protection Equipment – Pyrogen^{TM}, MAG Series, Pyrotechnically-generated, Fine Aerosol-powder Type Fire-Extinguishing System, afp-1317

Note 1.

The basic requirement for determining the design concentration of clean agents in NFPA 2001 is two fold. First, the minimum extinguishing concentration was determined by the cup burner based on Halon 1301. After this minimum was established by Pyrogen, full-scale third-party approval testing were conducted using the Pyrogen generators on n-heptane, wood crib, and other selected flammable liquids. These tests are performed at the computed cup burner minimum extinguishing concentration, not the design concentration. Further they were conducted with flooding factors lower than utilized in design. The minimum set by pyrogen was tested in full scale as part of the approval/listing process for the pyrogen system.