

## “Halon Replacement Options for Aircraft”

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### ABSTRACT

In 1987, an international treaty—the Montreal Protocol—was established to control the release of materials that cause stratospheric ozone depletion. Under the Protocol, the production of halon fire and explosion protection agents was phased out in all industrialized countries at the end of 1993. To date, no environmentally acceptable halon replacement equivalent to the existing halons in toxicity, effectiveness, and dimensionality across all applications has been identified. A large number of new agents and technologies that provide adequate protection in most applications (usually, with tradeoffs) have, however, been developed.

This paper presents an overview of halon options that have been commercialized or are near to commercialization. The term “options” is used here for anything that could be used in place of halons. There are two types of options: (1) “replacements” are halocarbon agents chemically similar to the present halons; (2) “alternatives,” are everything else. “Chemical alternatives” are materials such as carbon dioxide, foam, water, and dry chemical, which are chemically distinct from the halons. “Engineering alternatives” (not covered here) refer to approaches such as rapid response and fire resistant structures.

### HALON FIRE EXTINGUISHANTS

Halon fire extinguishing agents are low boiling point halocarbons (chemical compounds that contain carbon and one or more of the halogen elements—fluorine, chlorine, bromine, and iodine) that have been extensively used in the past to suppress fires and to protect against explosions (Table 1). The term “halon” can be applied to any halocarbon fire extinguishing agent. In this paper, however, “halon” is used only to denote Halons 1211, 1301, and 2402.

TABLE 1. HALON FIRE AND EXPLOSION PROTECTION AGENTS.

Halon Number	Halocarbon Number	Chemical Name	Formula	Boiling Point, °C
Halon 1301	BFC-13B1	bromotrifluoromethane	CBrF <sub>3</sub>	-58
Halon 1211	BCFC-12B1	bromochlorodifluoromethane	CBrClF <sub>2</sub>	-3
Halon 2402	BFC-114B2	1,1-dibromotetrafluoroethane	CBrF <sub>2</sub> CBrF <sub>2</sub>	47

There are four general types of fire and explosion protection applications for halons. (1) In total-flooding applications, the agent is discharged into a space to achieve a gas or vapor concentration sufficient to extinguish or suppress an existing fire. This is often done by an automatic system, which detects the fire and then automatically discharges. (2) In streaming applications, the agent is applied directly onto a fire or into the region of a fire. This is usually accomplished using manually operated portable units. (3) In explosion suppression, a halocarbon is discharged to suppress an explosion that has already been initiated. (4) In inertion, a halocarbon is discharged into a space to prevent an explosion or a fire from occurring. The last two applications (explosion suppression and inertion) often use systems similar or identical to those used for total-flooding fire extinguishment and can be considered to be total-flooding applications (as done for convenience in this paper). There are, however, some differences. For example, explosion suppression performance appears to be highly dependent on heat absorption by the discharged agent, whereas fire suppression appears to be highly dependent on interference by an agent in the chemistry of a fire.

Halon 1301 is typically used in total-flooding applications, and Halon 1211 is usually used in streaming (in Europe, Halon 1211 is also often used in total-flooding and similar systems). There are two reasons for this. First, Halon 1301 has a very low boiling point and discharges from a nozzle as a gas, which allows rapid filling of an enclosed area. With its higher boiling point, Halon 1211 discharges as a mixture of gas and liquid, which allows streaming over longer distances from a nozzle. Second, the toxicity of Halon 1301 is lower than that of Halon 1211, which allows use with the higher exposure levels typical of total-flooding systems.

## COMMERCIALIZED REPLACEMENTS

### Chemical Families

At present, halon replacements (e.g., halocarbons) fall into four major classes of compounds (Table 2). Two additional classes of replacement agents that had a short use in the past—CFCs (chlorofluorocarbons) and HBFCs (hydrobromofluorocarbons)—are no longer commercialized as halon replacements.

TABLE 2. CLASSES OF HALON REPLACEMENTS.

HCFCs	Hydrochlorofluorocarbons
FCs (PFCs)	Perfluorocarbons
HFCs	Hydrofluorocarbons
FICs	Fluoroiodocarbons

A number of characteristics are desirable for replacement agents. They must, of course, have acceptable environmental characteristics. Of particular importance is the requirement for a low impact on stratospheric ozone and global warming. The toxicity must also be acceptable, though there may be some debate about what is acceptable. The primary reason for using halocarbons, rather than such alternatives as foams and dry chemicals, is that halocarbons are clean, volatile, and electrically non-conductive. Finally, the agent must be effective. Note, however, that effectiveness does not necessarily mean as effective as the present halons, though this is desirable.

Physical action agents (PAA) are those that operate primarily by heat absorption. Chemical action agents (CAA) are those that operate primarily by chemical means. In general, CAAs are much more effective extinguishants than are PAAs. Halons 1211 and 1301 are primarily CAAs. Though CAAs are more effective, they often have an unacceptable environmental impact because they often contain bromine. One exception is trifluoroiodomethane,  $\text{CF}_3\text{I}$ , which is the only CAA being commercialized today.

### Environmental Characteristics

There are three environmental characteristics of particular interest in assessing halon replacements. (1) The Ozone Depletion Potential (ODP) is a measure of the ability of a chemical to deplete stratospheric ozone. ODPs are the calculated ozone depletions per unit mass of material released relative to a standard, usually CFC-11. (2) The Global Warming Potential (GWP) of a chemical is the change in global warming caused by release of a chemical relative to that resulting from release of a reference gas (now, usually carbon dioxide). (3) The atmospheric lifetime gives the persistence of a chemical in the atmosphere. Atmospheric lifetime is of increasing concern, in part due to the potential for global warming. Global warming usually increases as the atmospheric lifetime increases (though there are exceptions). There is, however, also concern about unanticipated effects of a chemical lasting for many years in the atmosphere. ODPs, GWPs, and atmospheric lifetimes are calculated; they cannot be measured.

HCFCs have much lower impact on stratospheric ozone than do the halons. Nevertheless, this impact is not zero, and, for this reason, the production of these chemical agents will eventually be phased out. Some restrictions are already in place in parts of Europe (and to a limited extent in the USA). The European Community (EC) regulation 3093/94, entered into force 1 June 1995, bans the use of HCFCs for fire protection.

PFCs are fully fluorinated compounds, unlike HCFCs or HFCs, and have several attractive features. They are nonflammable, have a low toxicity, and do not contribute to stratospheric ozone depletion. The PFC environmental characteristics of concern, however, are their large impact on global warming and their long atmospheric lifetimes.

HFCs are receiving increased prominence as replacements for ozone depleting substances because they are not ozone depleting, as are the HCFCs, and because they have lower atmospheric lifetimes than PFCs. There is, however, still considerable concern about the contribution of HFCs to global warming.

### Toxicological Characteristics

Cardiac sensitization is usually the first toxicological effect observed during acute exposures by inhalation to halocarbons. Cardiac sensitization refers to a sudden onset of cardiac arrhythmias (irregular heartbeats) caused by a sensitization of the heart to epinephrine (adrenaline). The lowest exposure level that has been observed to cause an adverse effect is termed the "Lowest

Observed Adverse Effect Level” (LOAEL), and the highest exposure level that has been found to cause no adverse effect is termed the “No Observed Adverse Effect Level” (NOAEL).

In the United States, two slightly different sets of toxicological restrictions have been established for total-flooding protection. The 1996 NFPA (National Fire Protection Association) Standard 2001 [1] requires that the design concentration for total flooding of a normally occupied area by halocarbons not exceed the cardiac sensitization NOAEL. As an exception, a halocarbon agent may be used up to the LOAEL value for Class B (liquid fuel fire) hazards in normally occupied areas where a predischage alarm and time delay are provided. The time delay must be set to ensure that occupants have time to evacuate prior to the time of discharge. In addition, halocarbon agent concentrations above 24 vol% are not allowed in normally occupied areas.

The United States Environmental Protection Agency (U.S. EPA) applies the following: (1) Where egress from an area cannot be accomplished within one minute, the agent concentration cannot exceed the NOAEL. Where egress takes longer than 30 seconds but less than one minute, the agent concentration cannot exceed the LOAEL. (3) Agent concentrations greater than the LOAEL are only permitted in areas not normally occupied by employees provided that any employee in the area can escape within 30 seconds. Thus, unlike the NFPA, the U.S. EPA applies specific time limits for evacuation from areas where a total-flooding discharge is used.

The New Extinguishants Advisory Group NEAG, a subgroup of the Halon Alternatives Group (HAG) in the U.K., has attempted to base allowable design concentrations for automatic total-flooding fire suppression systems in occupied areas on six endpoints: LC<sub>50</sub>, Central Nervous System (CNS) effects, cardiac sensitization, respiratory sensitization, genotoxicity, and developmental toxicity [2]. For the three halocarbon agents that they evaluated, NEAG found that cardiac sensitization or, for very low-toxicity agents, hypoxia (adverse health effects due to low oxygen levels) is the critical endpoint.

## COMMERCIALIZED HALON REPLACEMENTS

Halon replacements being commercialized for total-flooding applications are shown in Table 3, and the design concentrations for fire extinguishment are shown in Table 4. These design concentrations are minimum manufacturer-recommended values for extinguishment of *n*-heptane fuel fires. Design concentrations may differ for other fuels and will be higher for inertion of an area. Some users are employing agents at considerably higher concentrations than the minimum recommended values based on the specific fuel, scenario, and threat. The new draft International Standards Organization (ISO) standard [3] calls for larger design concentrations than shown in Table 4 for some agents. Table 4 also gives the NOAEL and LOAEL toxicity levels for commercialized total-flooding agents. Some of these agents cannot be used for total flooding in occupied areas under NFPA Standard 2001 criteria [1], with the exception of Class B fires with a predischage alarm and a time delay. Table 5 gives the global environmental characteristics of agents commercialized for total-flood applications. The ODPs are relative to CFC-11 and the GWPs (calculated for a 100-year time horizon) are relative to CO<sub>2</sub>.

TABLE 3. COMMERCIALIZED TOTAL-FLOODING HALON REPLACEMENTS.

Agent	Chemical	Formula	Trade Name
HCFC-124	Chlorotetrafluoroethane	CHClFCF <sub>3</sub>	DuPont "FE-241"
HCFC Blend A	Additive plus		North American Fire
HCFC-123	Dichlorotrifluoroethane	CHCl <sub>2</sub> CF <sub>3</sub>	Guardian "NAF S-III"
HCFC-22	Chlorodifluoromethane	CHClF <sub>2</sub>	
HCFC-124	Chlorotetrafluoroethane	CHClFCF <sub>3</sub>	
HFC-23	Trifluoromethane	CHF <sub>3</sub>	DuPont "FE-13"
HFC-125	Pentafluoroethane	CHF <sub>2</sub> CF <sub>3</sub>	DuPont "FE-25"
HFC-227ea	Heptafluoropropane	CF <sub>3</sub> CHFCF <sub>3</sub>	Great Lakes "FM-200"
HFC-236fa	1,1,1,3,3,3-Hexafluoropropane	CF <sub>3</sub> CH <sub>2</sub> CF <sub>3</sub>	DuPont "FE-36"
FC-218	Perfluoropropane	CF <sub>3</sub> CF <sub>2</sub> CF <sub>3</sub>	3M "CEA-308"
FC-3-1-10	Perfluorobutane	CF <sub>3</sub> CF <sub>2</sub> CF <sub>2</sub> CF <sub>3</sub>	3M Company "CEA 410"
FIC-131I	Trifluoroiodomethane	CF <sub>3</sub> I	Pacific Scientific "Triodide"; West Florida Ordnance "Iodoguard"; Ajay North America

TABLE 4. DESIGN CONCENTRATIONS, TOXICITIES OF TOTAL-FLOODING AGENTS.

Agent	Minimum Design Concentration for <i>n</i> -Heptane, vol%	NOAEL, vol%	LOAEL, vol%
Halon 1301	5	5	7.5
HCFC-124	8.5	1.0	2.5
HCFC Blend A	11.9	10.0	>10.0
HFC-23	16	30	>50
HFC-125	10.9	7.5	10.0
HFC-227ea	7	9.0	10.5
HFC-236fa	6.4	10.0	15.0
FC-218	8.8	30	40
FC-3-1-10	6.0	40	>40
FIC-131I	3.6	0.2	0.4

TABLE 5. ENVIRONMENTAL CHARACTERISTICS, TOTAL-FLOODING AGENTS.

Agent	ODP	GWP	Lifetime, yrs
Halon 1301	12	5,400	65
HCFC-124	0.03	470	6.1
HCFC Blend A	0.044	1,450	12
HCFC-123	0.014	90	1.4
HCFC-22	0.04	1,500	12.1
HCFC-124	0.03	470	6.1
HFC-23	0.0	11,700	264
HFC-125	0.0	2,800	32.6
HFC-227ea	0.0	2,900	36.5
HFC-236fa	0.0	6,300	209
FC-218	0.0	7,000	2,600
FC-3-1-10	0.0	7,000	2,600
FIC-131I	0.0001	<1	<0.005

Table 6 lists those agents being commercialized for streaming, and Table 7 gives toxicological data. With the possible exception of FIC-131I, none of the streaming agent candidates appears likely to exceed the cardiac NOAEL in normal streaming applications. Table 8 gives the global environmental characteristics.

TABLE 6. COMMERCIALIZED HALON REPLACEMENT STREAMING.

Agent	Chemical	Formula	Trade Name
HCFC-123	Dichlorotrifluoroethane	$\text{CHCl}_2\text{CF}_3$	DuPont "FE-232"
HCFC-124	Chlorotetrafluoroethane	$\text{CHClFCF}_3$	DuPont "FE-241"
HCFC Blend B	Primarily		American Pacific
HCFC-123	Dichlorotrifluoroethane	$\text{CHCl}_2\text{CF}_3$	"Halotron I"
HCFC Blend C	Proprietary additive plus		North American Fire
HCFC-123	Dichlorotrifluoroethane	$\text{CHCl}_2\text{CF}_3$	Guardian "NAF P-III"
HCFC-124	Chlorotetrafluoroethane	$\text{CHClFCF}_3$	
HFC-134a	1,1,1,2-Tetrafluoroethane	$\text{CH}_2\text{FCF}_3$	
HCFC Blend D	Proprietary additive plus		North American Fire
HCFC-123	Dichlorotrifluoroethane	$\text{CHCl}_2\text{CF}_3$	Guardian "BLITZ"
HFC-227ea	Heptafluoropropane	$\text{CF}_3\text{CHF}_2\text{CF}_3$	Great Lakes "FM-200"
HFC-236fa	1,1,1,3,3,3-Hexafluoropropane	$\text{CF}_3\text{CH}_2\text{CF}_3$	DuPont "FE-36"
FC-5-1-14	Perfluorohexane	$\text{CF}_3(\text{CF}_2)_4\text{CF}_3$	3M Company "CEA 614"
FIC-131I	Trifluoroiodomethane	$\text{CF}_3\text{I}$	Pacific Scientific "Triodide"; West Florida Ordnance "Iodoguard"

One potential problem that occurs with many (but not all) of the new halocarbon agents is that they generate four to ten times more hydrogen fluoride than Halon 1301 does during comparable extinguishment. Although a large amount of information is available on hydrogen fluoride toxicity, it is difficult to determine what risk is acceptable. Moreover, insufficient data exist to determine what hydrogen fluoride levels are likely in real fire scenarios. In general, agent decomposition and combustion products increase with fire size and extinguishment time. To minimize decomposition and combustion products, rapid detection and rapid discharges are recommended.

TABLE 7. TOXICITY PROPERTIES OF COMMERCIALIZED STREAMING AGENTS.

Agent	NOAEL, vol%	LOAEL, vol%
Halon 1211	0.5	1.0
HCFC-123	1.0	2.0
HCFC-124	1.0	2.5
HCFC Blend B		
HCFC-123	1.0	2.0
HCFC Blend C		
HCFC-123	1.0	2.0
HCFC-124	1.0	2.5
HFC-134a	4.0	8.0
HCFC Blend D		
HCFC-123	1.0	2.0
HFC-227ea	9.0	10.5
HFC-236fa	10.0	15.0
FC-5-1-14	40	>40
FIC-131I	0.2	0.4

## COMMERCIALIZED ALTERNATIVES

Non-halocarbon substitutes are increasingly being considered for replacement of halons. Already, water sprinklers are replacing halon systems in many applications. Dry chemical extinguishants and carbon dioxide are also receiving increased use. Alternatives can be divided into two types: “Classical” Alternatives and “New” Alternatives (Table 9). Note that the word “New” does not necessarily imply that the technology was developed recently, but that there is a new or renewed interest in the use of the technology as a replacement for halons. The following presents some discussions of only “New” Alternatives.

TABLE 8. ENVIRONMENTAL CHARACTERISTICS, STREAMING AGENTS.

Agent	ODP Relative to CFC-11	GWP Relative to CO <sub>2</sub>	Atmospheric Lifetime, yrs
Halon 1211	5.1		20
HCFC-123	0.014	90	1.4
HCFC-124	0.03	470	6.1
HCFC Blend B HCFC-123	0.014	90	1.4
HCFC Blend C HCFC-123	0.014	90	1.4
HCFC-124	0.03	470	6.1
HFC-134a	0.0	1300	14.6
HCFC Blend D HCFC-123	0.014	90	1.4
HFC-227ea	0.0	2900	36.5
HFC-236fa	0.0	6300	209
FC-5-1-14	0.0	7400	3200
FIC-13I1	0.0001	<1	<0.005

TABLE 9. ALTERNATIVES.

Classical	New
Foams	Water Misting
Water Sprinklers	Particulate Aerosols
Dry Chemicals	Inert Gases
Carbon Dioxide	Gas Generators
Loaded Stream	Combination

### Water Misting

Water misting systems allow the use of fine water sprays to provide fire protection with reduced water requirements and reduced secondary damage. Calculations indicate that on a weight basis, water could provide fire extinguishment capabilities better than those of halons provided that complete or near-complete evaporation of water is achieved. Since small droplets evaporate significantly faster than large droplets, the small droplets achievable through misting systems could approach this capability. The NFPA 750 Standard on water misting systems [4] establishes 1000 microns (micrometers,  $\mu\text{m}$ ) or less as being the water droplet size for a system to be



designated as a water misting system; however, many misting systems have droplet sizes well below this value. The NFPA 750 Standard defines three classes of water mists from finer to coarser based on the size distribution of the water droplets produced. As an approximate definition, the droplet sizes are less than 200 microns for a Class 1 Mist (the finest), 200 to 400 microns for a Class 2 Mist, and 400 to 1000 microns for a Class 3 Mist (the coarsest). The actual definitions are more complex and are based on the size distribution curve.

There are two basic types of water mist suppression systems—single-fluid and twin-fluid. Single-fluid systems utilize water stored or pumped under pressure; twin-fluid systems use air, nitrogen, or another gas to atomize water at a nozzle. The systems can also be classified according to the pressure on the distribution system piping as high-pressure [above 500 psia (34.5 bar)], intermediate-pressure [175 to 500 psia (12.1 to 34.5 bar)], and low-pressure (175 psia (12 bar) or less]. Both single-fluid and twin-fluid systems have been shown to be promising fire suppression systems. Single-fluid systems have lower space and weight requirements, reduced piping requirements, and easier system design and installation; twin-fluid systems require lower water supply pressure, larger nozzle orifices (greater tolerance to dirt and contaminants and may allow the use of higher viscosity antifreeze mixtures), and increased control of drop size.

Table 10 gives a list of manufacturers for water misting systems. Since the manufacturers of water misting systems are constantly changing and the number is continuously increasing, this list will necessarily be incomplete.

TABLE 10. COMMERCIAL AND NEAR-COMMERCIAL MISTING SYSTEMS.

<b>Twin-Fluid</b>	<b>Single-Fluid</b>
ADA Technologies, USA	Baumac International MicroMist
GEC-Marconi Avionics, UK	FOGTEC, Germany
Ginge-Kerr, U.K., Denmark, Norway	Grinnell AquaMist, USA
Kidde International, UK, USA	GW Sprinkler, Denmark
Secuirplex Firescope 2000, Canada	KAMAT, Germany
	Kidde International, UK, USA
<b>Technology Unknown</b>	Marioff Oy Hi-fog, Finland
DAR CHEM, UK	Phirex, U.K./Sprinklerhuest, Sweden
HTC, Sweden	Semco Marine, USA/Denmark
	Spraying Systems, USA
	Total Walther/Wormald MicroDrop
	Unifog Water Mist, Germany
	Unitor, Germany

### Particulate Aerosols

A number of fire extinguishing products have been announced as producing very finely divided dry chemical suspensions (particulate aerosols). In many, if not all cases, the aerosol is a potassium salt suspension produced by combustion and is termed a “pyrotechnically generated aerosol” (PGA). Among the companies now marketing particulate aerosol technologies are

Spectronics in Israel and Spectrex in the United States (“S.F.E.” agents), International Aero Inc. in the United States (“Firepak”), Dynamit Nobel in Germany (“Soyus” extinguishers), and FireCombat in the United States (“Aero-K”).

### Inert Gases

Combustion cannot occur when the oxygen content of air at normal pressures is sufficiently reduced (below approximately 15 vol%, fires cannot be initiated; at lower concentrations, fires are extinguished). Thus, inert gases such as nitrogen, argon, etc., can extinguish fires by diluting the air and decreasing oxygen content. Extinguishment is also facilitated by heat absorption.

A number of pure and blended inert gases are being marketed as alternatives to halons (Table 11). The concentrations needed for extinguishment are approximately 34 vol% to 52 vol%, depending on the fuel and the fire scenario. The extinguishing properties of argon are similar to those of nitrogen for Class A, B, and C fires; however, unlike nitrogen, argon is suitable for Class D fires involving metals that react with nitrogen (e.g., magnesium and lithium).

TABLE 11. INERT GASES.

Designation	Composition	Manufacturer
IG-541	Nitrogen 52 ± 4 vol% Argon 40 ± 4 vol% CO <sub>2</sub> 8 ± 1 vol%	Tyco International, Ltd., USA, and Fire Eater A/S, Denmark (“INERGEN”)
IG-55	Nitrogen 50 ± 5 vol% Argon 50 ± 5 vol%	Ginge-Kerr Denmark A/S (“ARGONITE”)
IG-01	100% Argon	Minimax GmbH (“Argotec”)
IG-1	100% Nitrogen	Cerberus AG, Germany; Koatsu (“NN100”), Japan

The U.S. EPA allows inert gas design concentrations to an oxygen level of 10 vol% (52 vol% agent) if egress can occur within one minute, but to an oxygen level of no lower than 12 vol% (43 vol% agent) if egress requires more than one minute. Designs to oxygen levels of less than 10 vol% are allowed only in normally unoccupied areas and only if personnel who could possibly be exposed can egress in less than 30 seconds.

In place of cardiac sensitization NOAEL and LOAEL values, which are inappropriate for inert gases, the 1996 NFPA 2001 Standard [1] uses a No Effect Level (NEL) and a Low Effect Level (LEL). These values are based on physiological effects in humans in hypoxic atmospheres and are the functional equivalents of the NOAEL and LOAEL values given for halocarbons. All inert gas agents listed in the 1996 Standard (IG-01, IG-541, and IG-55) have sea-level-equivalent NEL and LEL values of 43 vol% (12 vol% oxygen) and 52 vol% (10 vol% oxygen), respectively. Similar to that done for halocarbon agents, the Standard allows the use of an inert gas agent up to the LEL value for Class B hazards in normally occupied areas where a predischage alarm and time delay are provided. In the absence of a time delay, only design concentrations up to the NEL are allowed. A major difference between NFPA and U.S. EPA approaches is that the U.S. EPA bases allowable design concentrations on specific egress times.

NEAG/HAG recommends that oxygen concentrations in occupied areas protected by inert gas systems not be less than 12 vol% unless a room can be evacuated in 1 minute (2 minutes in the case of "INERGEN"). This oxygen level corresponds to an inert gas concentration of 43 vol%. NEAG/HAG also recommends that exposures to oxygen levels less than 10 vol% not be allowed for any period of time.

### Gas Generators

Gas generator technology utilizes ignition of solid propellants to generate large quantities of gases. This gaseous effluent can be either used as is to create an inert environment or enhanced with various active agents to more aggressively attack the fire. This technology is new, and much of it is still in the research and development stage. Olin Aerospace Company, which has been supporting U. S. Department of Defense (DoD) testing, has announced that initial engineering, manufacturing, and development contracts have been received from two airframe manufacturers to protect aircraft dry bay. Primex Aerospace markets FS 0140 for use as a total-flooding agent in unoccupied areas. Walter Kidde Aerospace has teamed with Atlantic Research Corporation to develop gas generator technology for aviation and defense applications.

### Combination

Mixtures with water or with halocarbon bases have been marketed for many years. One example is the "loaded stream" type of agents that have been used in the past. In addition, blends of dry chemicals with halons or other halocarbons, sometimes with a gelling agent, have been marketed. With the phaseout of halons, there is increased interest in and development of such mixtures. Among the commercial products are (1) "Envirogel," a series of blends containing one or more halocarbons, a dry chemical, and a gelling agent, produced by POWSUS, Inc., in the U.S., (2) ColdFire 302, a mixture of organic surfactants and water, manufactured by North American Environmental Oil & Chemical Cleaning Supply Co., and (3) Fire-X-Plus, a foam produced by Firefox Industries in the U.S. There are, undoubtedly, many other combination agent products being commercialized or being developed for commercialization.

## APPLICABILITY TO AIRCRAFT FIRE PROTECTION

The four major areas of aircraft fire protection are (1) engine nacelles and APU (auxiliary power unit) compartment, (2) handheld extinguishers, (3) cargo compartments, and (4) lavatory protection. There are three major requirements for a halon replacement:

- a. The agent must be suitable for the likely Class of fire, and should be recognized by a technical, listing, or approval organization as a suitable agent for the intended purpose. Alternatively, such recognition should be anticipated in the near future.
- b. It should be compatible with construction materials in the areas where fires may occur and with materials used in the extinguishing systems. There should be, at most, minimal corrosion problems due to extinguishment, either from the neat agent or from likely decomposition products. This is particularly important for aircraft engines and for areas where contact with electronic components could occur.
- c. It should comply with the provisions of the Montreal Protocol. It must have a near-zero ozone depleting potential. Low Global Warming Potential (GWP) and atmospheric lifetime are desirable but presently there are no generally accepted requirements.

## Engine and APU Compartment

FAR 25.1195 [5] identifies the requirements for fire suppression systems in an aircraft power plant: (1) A fire suppression system is required if other means are not provided to control typical fires, as identified in the FAR. (2) The suppression system must be shown to be effective in quantity of agent, rate of discharge, and distribution by live test during actual or simulated flight conditions. (3) The suppression system must provide adequate, simultaneous protection throughout the compartment.

The fire threat addressed by this approach for these compartments is a Class B fire (aviation fuel, hydraulic fluid, lubricant). The compartments are normally ventilated, have complicated airflow pathways, possess regions of high temperature air, and are approximately at ambient pressure. Additional considerations that may impact the system design are the continual presence of ventilation airflow during and after an agent discharge and potential fuel drainage after an engine shutdown.

Fires result when an engine failure provides simultaneous conditions permitting combustion. Typically, a flammable fluid release results from a mechanical failure. This fluid then comes in contact with an ignition source—possibly hot surfaces or gases associated with operating conditions at the time of failure, abnormal conditions posed by friction (heat or sparks), or electrical energy. Any fire is detected by thermal sensors that activate aural and visual fire warnings on the flight deck. The accepted practice to combat an engine compartment fire is to eliminate ignition and fuel sources and then discharge the fire suppression system. The process is achieved by shutting the engine down, closing local flammable liquid valves, turning off local electrical power, and then discharging the suppression system.

A fire suppression system is evaluated by live discharge test. The test requires an engine to be operating at critical conditions when the agent release occurs. Typically, twelve sampling probes from a gas analyzer—customarily a Statham or Halonyzer type unit—are located in the compartment during this test. The device records the discharge event in the form of a concentration vs. time relationship. This record is then reviewed for compliance against historically developed criteria for the agent in question. Advisory Circular 20-100 [6] provides a good summation for the aspects of a discharge test.

## Handheld Extinguishers

Federal Aviation Regulations mandate handheld fire extinguishers be conveniently located in passenger compartments. The number and type of required extinguishers depends on the category and passenger capacity of the airplane. FAR 25.851 [7] states that for aircraft with a capacity greater than 31 passengers, one or more of the required extinguishers must contain Halon 1211. Replacement agents for Halon 1211 must meet the following requirements:

- a. Any handheld fire extinguisher adopted for final use should be listed by a listing organization, be of a specific rating, and be of a size and weight that a typical flight attendant can use. The smallest recommended Halon 1211 extinguisher is 2.5 pounds, and this achieves a UL 5-B:C rating in accordance with the UL 711 Standard [8] or a BS 3A:34B rating in accordance with British standards [9]. It is expected that this UL 5-B:C or BS 3A:34B fire extinguishing ability along with a demonstrated ability to extinguish a hidden fire will be required for agents used in this application.
- b. The extinguisher must be able to extinguish fires in indirectly accessible spaces (“hidden” fires) as effectively as Halon 1211. It is desirable that the agent be gaseous in order to allow expansion and penetration into such spaces. Handheld extinguishers are by nature

streaming agents; however, Halon 1211 has the ability to also function as a flooding agent. To insure no loss of safety, replacement agents must maintain this ability. A hidden fire test has been developed to assess the firefighting performance of the handheld extinguisher/agent combination in a flooding scenario.

- c. The extinguisher must have an acceptable toxicity for use where people are present, and must not cause unacceptable visual obscuration or passenger discomfort. In particular, the combined toxicity of the agent and fire products must not be unacceptable when extinguishing large seat cushion fires.

### Cargo Compartment

According to the report of Task Group 4 [10], the likely fire by an aircraft supplied ignition source is a surface fire and will most likely be fueled by Class A material. In some instances the Class A material may be contaminated by small quantities of Class B material. Human and cargo supplied ignition sources can cause a variety of fires (deep seated, flaming, explosive, metallic, fires with their own oxidizer, chemical, etc.). These fires are not easily characterized. The cargo compartments are normally pressurized with a minimum normal pressure corresponding to an altitude of 8,000 feet. In flight, the temperatures are maintained above freezing by several means including ventilation. Fire in the cargo compartments is detected by smoke and ionization aerosol detectors or thermal sensors. The fire detection systems are required to detect fire in its early stage and provide a warning before the fire (1) develops into an uncontrollable or uncontainable condition, or (2) damages liners, wiring, equipment, structure, or essential or critical equipment.

Systems that provide a warning within one minute from the start of smoke generation are considered to be in compliance with Federal Aviation Regulation, FAR 25.858 [11]. The present practice is to control ventilation and drafts within the compartment prior to the activation of the suppression system. However, there is small infiltration into the compartment through the compartment walls (typically fiberglass liner) and leakage out of the compartment through door seals. The general practice is to divert to the nearest field on detection of a fire. On long range (across ocean) aircraft, suppression is required for up to 180 minutes. Cargo compartments often contain animal cargo.

The agent for cargo compartments must meet the following requirements in addition to the essential requirements identified earlier.

The agent for cargo compartments must also meet the requirements of FAR 25.851, part b [7] and FAR 25.1309 [12].

- a. The agent must be suitable for fires likely to occur. These include class A and B fires and hazardous materials.
- b. The agent/system must be able to provide fire suppression over a period of up to 180 minutes, depending on the aircraft type and route structure.

It is desirable for the agent to have the following attributes.

- a. Because cargo compartments can be used for transportation of animals, it is desirable that the agent has a low toxicity and that it not be an asphyxiant at the concentrations required for extinguishment. In addition, no agent can be allowed that could leak into occupied compartments in toxic concentrations. Federal regulations require that “There are means to exclude hazardous quantities of smoke, flames, or extinguishing agent from any compartment occupied by crew or passenger.” Airframe manufacturers meet this by

design. Typical cargo compartments contain a fiberglass liner, which is tested with a smoke generator for leakage and with burners for flame penetration. Escape of smoke or extinguishing agent in hazardous quantities from cargo compartments of properly maintained aircraft is unlikely.

- b. The agent should not impose additional (additional to system recharge and checkout) departure delay following a false discharge.

### Lavatory Trash Receptacle

Lavatories are located in the pressurized aircraft cabin, with environmental conditions similar to the conditions in other occupied areas. The likely fire threat in the lavatory trash receptacle would involve Class A materials (paper and paper products), with the typical ignition source being burning material discarded into the container, such as a lit cigarette. The trash containers are designed to contain the likely fire. No fire detection system is provided in the container. Rulemaking was implemented on April 29, 1987 that required each lavatory trash container be equipped with a built-in automatic fire extinguisher that discharges automatically into the container upon the occurrence of a fire. In order to accomplish this, the extinguisher bottle incorporates a eutectic device at the end of a tube directed into the container. In the event of a fire, the heat generated will melt the eutectic tip, releasing the agent directly into the receptacle. Currently, all aircraft lavatory disposal receptacle fire extinguishers use Halon 1301 as the fire-extinguishing agent. A relatively small amount of agent (100 grams of 1301) is effective in extinguishing this type of fire. For this reason, suitable gaseous replacement agents such as HFC-227ea and HFC-125 can be used in this application, as the additional amount of agent required to extinguish the fire is negligible. Replacement agents are required to meet the minimum performance standard for lavatory trash receptacles [13].

### SUMMARY

Many commercialized options to the use of halons are now available, but tradeoffs are needed in most applications. Due to the multiple choices available and required tradeoffs, careful fire protection engineering is required to select and employ the best option for each application.

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