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Options to the Use of Halons for Aircraft Fire Suppression Systems—2012 Update

February 2012

Final Report

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16. Abstract

This report reflects the many changes that have occurred in the aircraft fire suppression arena since the last update was published in 2002. Changes have occurred in regulatory restrictions, commercialized halocarbon replacements, halocarbon replacements in development, alternative technologies, and the evaluation of fire fighting effectiveness for the four primary aircraft onboard applications: (1) engine nacelles, (2) hand-held extinguishers, (3) cargo compartments, and (4) lavatory protection. Test-based fire suppression halon equivalency guidance is provided for these applications.

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PREFACE

The International Halon Replacement Working Group (IHRWG) was established by the Federal Aviation Administration (FAA) and cooperating agencies in 1993 to provide input for the FAA halon replacement program. Originally, this group was formed to develop minimum performance standards and test methodologies for nonhalon aircraft fire protection agents or systems in cargo compartments, engine nacelles, hand-held extinguishers, and lavatory trash receptacles. The focus of the IHRWG has since been expanded to include all system fire protection research and development for aircraft. The name of the working group was changed to the International Aircraft System Fire Protection Working Group (IASFPWG). Participants include aviation regulatory authorities, other government agencies involved in research and development, airframe manufacturers, airlines, industry associations, manufacturers and suppliers of fire protection equipment and agents, and researchers.

The first meeting of the IHRWG was held on October 13-14, 1993, at the FAA Technical Center, Atlantic City International Airport, New Jersey, USA. A number of task groups were established at that meeting. Among these were task groups for the four onboard areas of aircraft fire protection: cargo compartment, engine nacelle, passenger cabin (hand-held extinguishers), and lavatory. Task Group 6, later designated as the Halon Options Task Group, was assigned to review chemical options to halons. The goal was to recommend two to three agents for use in developing FAA test protocols for each major area of onboard aircraft use: (1) engine nacelles, (2) hand-held extinguishers, (3) cargo compartments, and (4) lavatory protection. A final report was published in February 1995, “Chemical Options to Halons for Aircraft Use,” DOT/FAA/CT-95/9.

At the April 19-20, 1995, meeting of the IHRWG in Rome, Italy, a decision was made to maintain a review of new halon option technologies as they became available and to continue updating the February 1995 report. All the original Task Group members were contacted to determine who wished to maintain membership, and an announcement was made to find new members. This group prepared a second updated report, “Halon Replacement Options for Use in Aircraft Fire Suppression Systems,” DOT/FAA/AR-96/90, 1996.

At an IHRWG meeting in London on October 9-10, 1996, a decision was made to continue the work of the Halon Options Task Group and to begin preparing the second update of the initial February 1995 report. A slight change in the mandate was issued to assess the applicability of various technologies for each major onboard aircraft application rather than to recommend agents for development of test protocols. The major areas of onboard aircraft use are (1) engine nacelles and auxiliary power unit (APU), (2) hand-held extinguishers, (3) cargo compartments, and (4) lavatory protection. A third updated report was published “Options to the Use of Halons for Aircraft Fire Suppression Systems—2002 Update,” DOT/FAA/AR-99/63, 2002.

The IASFPWG agreed to update the report in 2009. Section leads and assists were selected from the meeting attendees and assistants for each section were solicited at that and subsequent task group meetings. This report reflects significant changes that have occurred in the aircraft fire suppression arena since the last update was published in 2002.

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LIST OF ACRONYMS

AC	Advisory Circular
APU	Auxiliary Power Unit
2-BTP	2-bromo-3,3,3-trifluoropropene
AFB	Air Force Base
APU	Auxiliary power unit
ARFF	Aircraft rescue firefighting
ATK	Alliant TechSystems, Inc.
CAA	Civil Aviation Authority
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CO_2	Carbon dioxide
DoD	Department of Defense
EC	European Commission
EPA	Environmental Protection Agency
ERPG	Emergency Response Planning Guideline
EU	European Union
FAA	Federal Aviation Administration
FIC	Fluoroiodocarbon
FK	Fluoroketone
FMRC	Factory Mutual Research Corporation
FSS	Fire Suppression System
GWP	Global Warming Potential
HAG	Halon Alternatives Group
HCFC	Hydrochlorofluorocarbon
HF	Hydrogen fluoride
HFC	Hydrofluorocarbon
HFE	Hybrid fire extinguisher
IASFPWG	International Aircraft System Fire Protection Working Group
ICAO	International Civil Aviation Organization
IHRWG	International Halon Replacement Working Group
IR	Infrared
ISO	International Standards Organization
LEL	Low effect level
LOAEL	Lowest observed adverse effect level
MAP	Monoammonium phosphate
MDC	Minimum design concentration
MOP	Montreal Protocol
MPS	Minimum Performance Standard
MPSe	Minimum Performance Standard for Engines
NASA	National Aeronautics and Space Administration
NFPA	National Fire Protection Association
NEAG	New Extinguishants Advisory Group
NEL	No effect level
NOAEL	No observed adverse effect level

OBIGGS	Onboard Inert Gas Generation System
ODP	Ozone Depletion Potential
OEM	Original equipment manufacturer
PAA	Physical action agent
PBPK	Physiologically based pharmacokinetic modeling
PFC	Perfluorocarbon
PGA	Pyrotechnically generated aerosol
S.F.E.	Spectrex fire-extinguishing
SNAP	Significant New Alternatives Policy
SPGG	Solid propellant gas generator
TOGW	Takeoff gross weight
UK	United Kingdom
UL	Underwriters Laboratories
U.S.	United States
VSLS	Very Short-Lived Substances

EXECUTIVE SUMMARY

Halon fire extinguishers have been used in commercial aviation for about 50 years, but their production was banned by an international agreement because halon is an ozone-depleting chemical. The aviation industry, Federal Aviation Administration (FAA), chemical companies, fire extinguisher manufacturers, and others have been evaluating replacement agents. To support and report on this work, the FAA convened the International Halon Replacement Working Group (now called the International Systems Fire Protection Working Group). The first order of business was to develop Minimum Performance Standards (MPS) that describe the fire tests required to demonstrate fire extinguishment or suppression effectiveness equivalent to halon for each aircraft application; viz., lavatories, cabin hand-held extinguishers, engines, and cargo compartments. Moreover, in support of the aviation halon replacement activities, in 1992, the working group prepared a report containing a wealth of related information and data, entitled "Chemical Options to Halons for Aircraft Use." This report is the third update of the original report, reflecting the significant changes since the previous updated version in 2002.

The selection of a fire-extinguishing agent is dependent upon many factors, particularly in aviation applications, but highest on the list are extinguishing concentration (effectiveness), toxicity, environmental properties, and physical properties. The report contains extensive data related to these factors for halocarbon replacement agents, that are similar to halon, and alternative agents which are everything else. Many new alternative agents/systems are available or under development since the previous report, including water mist, gas and particulate generators, and inert gases. Regarding the latter, onboard inert gas generation systems (OBIGGS) are now being installed in airplanes to meet a new regulation adopted by the FAA in 2008 to prevent fuel tank explosions. It may become feasible to use the inert gas from OBIGGS to suppress a cargo compartment fire.

In recent years environmental concerns have spurred actions to remove halon extinguishing agents in commercial aviation. The European Commission has adopted a regulation to require application-dependent "cut off dates" for the use of halon in new type certificates (new airplane designs) and "end dates" for the actual removal and replacement of halon in operating aircraft, although these dates are far into the future. Also, the International Civil Aviation Organization (ICAO) adopted a resolution for production airplanes that requires a halon replacement agent for lavatory extinguishers and hand-held extinguishers by 2011 and 2016, respectively. Also, although the manufacture of halon was banned because of ozone depletion, future restrictions related to Global Warming Potential (GWP) is an increasing concern of the aircraft manufacturers. For example, it is highly unlikely that any of the halocarbons that have high GWP values will be considered by the aircraft manufacturers, particularly in cargo compartments or engines, which require relatively high agent quantities in more complex systems than in lavatories (trivial weight) or hand-held extinguishers.

Since the last report in 2002, Airbus and Boeing have installed halon replacement agents in lavatory trash extinguishers on all their production aircraft, and Bombardier and Embraer have started the replacement process in their production aircraft. Although three agents meet the MPS for hand-held extinguishers, none are in use because they are heavier than halon, require a larger bottle, and because of GWP concerns. However, Boeing is committed to supporting the

commercialization of a promising, environmentally acceptable agent. Other agents/extinguishers may also surface as the 2016 ICAO deadline approaches. Three halocarbon agents have been tested in accordance with the MPS for engines, and the minimum extinguishing concentration has been determined. One of these agents, a liquid at room temperature that gasifies quickly, has been developed extensively by one major aircraft manufacturer for use in new aircraft. However, concern with extinguishing effectiveness at low temperature has tempered this activity. Another agent, a solid aerosol, has also undergone extensive engine MPS testing, which was revised to take into account its highly directional discharge characteristics compared to total-flooding gaseous agents such as halon and the replacement halocarbons. Fire-extinguishing tests will be conducted in 2012 in a real engine because the solid aerosol differs considerably in discharge behavior than traditional total flooding agents. Cargo compartment fire suppression has proven to be the most difficult application for halon replacement agents. A number of gaseous agents have been tested in accordance with the MPS but have been discounted because of poor or potentially hazardous behavior. Water mist has shown promise when MPS-tested, perhaps in combination with an inert gas system, but these approaches would require significant systems development. Halon replacement in cargo compartments represents the largest future challenge.

During preparation of this report, draft versions were circulated among task group members and reviewed at the International Aircraft System Fire Protection Working Group meetings. All manufacturers were given the opportunity to review and comment on the discussions of their products.

1. INTRODUCTION.

This report updates three earlier reports [1, 2, and 3] and reflects the many changes that have occurred in the aircraft fire suppression arena since the last update was published in 2002. Changes have occurred in regulatory restrictions, commercialized halocarbon replacements, halocarbon replacements in development, alternative technologies, and the evaluation of firefighting effectiveness for aircraft onboard applications.

The fire suppression technologies are discussed and the applicability of each is assessed for the four primary applications: (1) engine nacelles, (2) hand-held extinguishers, (3) cargo compartments, and (4) lavatory protection. Test-based fire suppression halon equivalency guidance is also provided for these applications.

This report summarizes available fire suppression agents and their properties and provides information on physical properties, design concentrations, and exposure limits for halon replacements. Environmental and toxicological properties of halon replacement agents are discussed and tabulated. Manufacturers, product names, and company contact information are provided in appendix A for commercially available agents and systems.

Overviews of fire protection and environmental and toxicological acceptability, as well as definitions of key terms are provided below.

1.1 OVERVIEW OF FIRE PROTECTION.

The most common fuels in fire and explosion incidents are petroleum products, cellulosic materials (wood and paper), and polymers. Fires of cellulosic materials are termed “Class A,” and liquid fuel fires are termed “Class B.” Polymeric material fires can exhibit characteristics of either Class A or Class B, depending on the extent of melting (if any) during combustion. Class C fires involve energized electrical equipment and Class D fires, flammable metals. Rapid gas phase combustion can result in an explosion or, in the limit as the combustion becomes very rapid, detonation.

There are five general types of fire and explosion protection applications for aircraft: (1) total-flood fire extinguishment, (2) total-flood fire suppression, (3) streaming fire extinguishment, (4) explosion suppression, and (5) inertion against explosions and fires. The Fire Protection Handbook and the SFPE Handbook of Fire Protection Engineering are excellent sources of information on all aspects of fire and explosion protection [4 and 5].

In total-flood applications, an extinguishing agent is discharged into an enclosed space to achieve a concentration sufficient to extinguish or suppress an existing fire. The agent concentration that a system/agent combination is designed to produce is termed the “design concentration.” Total-flood extinguishment usually uses fixed systems (e.g., nonportable systems attached to a protected structure) with either manual or automatic activation. Automatic systems detect a fire and automatically discharge the extinguishing agent. Total-flood applications include protection of enclosed spaces, such as aircraft cargo compartments.

In streaming applications, an agent is applied directly onto a fire or into the region of a fire. This is usually accomplished using manually operated, wheeled, or portable extinguishers. Hand-held portable extinguishers provide fire protection in aircraft passenger compartments.

Halons are bromine-containing gaseous or volatile liquid chemicals used in fire and explosion protection. Most widely used are Halon 1301, bromotrifluoromethane ($CBrF_3$), used primarily as a total-flood agent; and Halon 1211, bromochlorodifluoromethane ($CBrClF_2$), used primarily in streaming applications. These clean (residue-free) chemicals are applicable to Class A, B, and C fires. They cannot be used for Class D fires.

1.2 ENVIRONMENTAL OVERVIEW.

Although airworthiness regulations for most applications do not require using a particular fire suppression agent (hand-held extinguisher regulations are the exception), halons have been the agents of choice of airframe manufacturers. In 2010, worldwide production of halons used for fire protection ended under the provisions of the Montreal Protocol (MOP). The primary environmental characteristics to be considered in assessing a new chemical option to halons are Ozone Depletion Potential (ODP), Global Warming Potential (GWP), and atmospheric lifetime. The agent selected should have environmental characteristics in harmony with international laws and agreements, as well as applicable national, state, and local laws. An agent that does not have a zero or near-zero ODP and the lowest practical GWP and atmospheric lifetime may have problems of international availability and commercial longevity.

1.3 TOXICOLOGY OVERVIEW.

The toxicological acceptability of a chemical option to halons is dependent on its use pattern. As a general rule, the agent must not pose an unacceptable health risk for workers during installation, maintenance, or operation of the extinguishing system. In areas where passengers or workers are present, or where leakage could cause the agent to enter the passenger compartment, at no time should the cumulative toxicological effect of the agent, its pyrolytic breakdown products, and the byproducts of combustion pose an unacceptable health risk during probable normal and failure conditions.

1.4 OPTIONS.

The following defines some of the terms used in this report. The term “options” is used for anything that could be used in place of halons.

- “Replacements” denote halocarbon fire extinguishants, i.e., agents that are chemically similar to the present halons.

- “Alternatives” are everything else.

    - “Chemical alternatives” are materials such as carbon dioxide (CO_2), foam, water, and dry chemicals, whose chemistry differs significantly from halons.

- “Engineering alternatives” (not covered in this report) involve such approaches as rapid response and fire-resistant structures.

Note that many alternative technologies are actually “chemical/system” alternatives since the agent and system cannot be separated (e.g., solid propellant gas generators (SPGG)).

Alternatives and replacements have been discussed in a number of papers (overviews are given in references 6 , 7, and 8).

Any option to using halons in the United States (U.S.) must be determined acceptable by the U.S. Environmental Protection Agency (EPA) Significant New Alternatives Policy (SNAP) program, which implements section 612 of the amended Clean Air Act of 1990. A current list of SNAP acceptability decisions can be found on the U.S. EPA website [9 and 10].

2. HALOCARBON REPLACEMENTS.

At present, halon replacements (e.g., halocarbons) fall into four major categories (see table 1). Note that one category included in the 2002 update report from the Task Group on Chemical Options to Halons [3]—perfluorocarbons (PFC)—are no longer being marketed. A new category of replacements—fluoroketones (FK)—has been marketed since the 2002 update.

Table 1. Halon Replacement Classes

HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
FICs	Fluoroiodocarbons
FKs	Fluoroketones

There are a number of desirable characteristics for halon replacement agents. They must have acceptable global environmental characteristics (low-zero ODPs and GWPs, and short atmospheric lifetime) and, if applicable, an acceptable low risk of adverse health effects from exposure that is comparable to halons, specifically Halon 1301. The debate on acceptable levels for these characteristics continues. The primary reason for using halocarbons, rather than such alternatives as foams and dry chemicals, is that halocarbons are clean, volatile, and electrically nonconductive. 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 are those that operate primarily by chemical means—removal of flame-free radicals. The chemical effect contribution to extinguishment by PAAs is only 10% to 25% of the physical contribution [11]. In general, chemical action agents are much more effective extinguishants than PAAs. Halons 1211 and 1301 and trifluoroiodomethane (CF_3I) are primarily chemical action agents. Other halocarbon agents are primarily PAAs. It has been shown that Halon 1301 extinguishment of n-heptane in air is approximately 20% physical and 80% chemical [12]. The analysis also indicates that about 25% of the extinguishment is due to the CF_3 group and about 55% is due to bromine. Although chemical action agents are more effective, they often have higher ODPs because they usually contain bromine. One exception is CF_3I.

Most halocarbons now commercialized as halon replacements require significantly higher design concentrations than Halons 1301 and 1211 and, in the event of a fire, produce larger amounts of toxic or corrosive byproducts (e.g., hydrogen fluoride and, for chlorine-containing agents, hydrogen chloride) [13]. One halocarbon, CF_3I, produces relatively large amounts of iodine. Byproduct formation is strongly influenced by the mass flux of inhibitor into the flame sheet and the extinguishment time. Slow extinguishment, due to using lower concentrations of agent, produces more byproducts.

2.1 TOXICOLOGY.

2.1.1 Cardiac Sensitization.

Cardiac sensitization is the term used for the phenomenon of the sudden onset of cardiac arrhythmias caused by a sensitization of the heart to epinephrine (adrenaline) in the presence of some concentration of a chemical. Cardiac sensitization (specifically leading to ventricular fibrillation) was first demonstrated in 1912 in cats exposed to chloroform in the presence of epinephrine (chloroform is nonhazardous without epinephrine) [14]. Since then, cardiac sensitization has been demonstrated in humans as well as laboratory animals.

When assessing a new agent for toxicity, a number of studies must be completed to show how toxic the agent is, at what concentrations adverse effects can occur, what the adverse effects are, and if the adverse effects are reversible. When comparing concentrations necessary to elicit acute toxic responses, such as anesthesia, cardiac sensitization, or lethality, cardiac sensitization usually occurs at a lower concentration for halocarbons than other acute toxicity endpoints. Anesthesia and anesthetic effects occur at concentrations higher than the concentration at which cardiac sensitization first occurs. Although anesthesia and anesthetic effects are considered in the assessment of agents, they are not considered a significant concern at the concentration at which cardiac sensitization first occurs. Therefore, regulatory and standard-making authorities have used cardiac sensitization thresholds as the criterion for determining acceptability for use in areas where human occupancy may occur. Cardiac sensitization is particularly important in firefighting. Higher levels of epinephrine secreted by the body, under the physiological stress of a fire event, may increase the possibility of sensitization.

For halocarbon agents, cardiac sensitization is the health effect of greatest concern. The use conditions for halocarbon substitutes under the SNAP program are based on the no observed adverse effect level (NOAEL) and lowest observed adverse effect level (LOAEL) for cardiac sensitization. LOAEL and NOAEL concentrations entail measurement of cardiotoxic effects in animals made sensitive to these effects by the administration of epinephrine. The administered epinephrine doses are just below the concentration at which epinephrine alone would cause cardiotoxicity in the experimental animal and are approximately ten times greater than the concentration a human would be likely to secrete under stress. Thus, LOAEL and NOAEL values are conservative, even in high-stress situations [15 and 16].

2.1.2 Physiologically Based Pharmacokinetic Modeling.

Because the cardiac sensitization potential was measured in dogs, a means of providing human relevance to the concentration at which this cardiosensitization occurs (LOAEL) was established through physiologically based pharmacokinetic (PBPK) modeling.

The PBPK model, as described in the National Fire Protection Association (NFPA) 2001 gaseous agents standard and the International Standards Organization (ISO) 14520 gaseous agents standard [17 and 18], provides safe human exposure times for various concentrations of halocarbons. A PBPK model is a computerized tool that describes time-related aspects of a chemical's distribution in a biological system. The PBPK model mathematically describes the halocarbon uptake into the body and the subsequent distribution of the halocarbon to the areas of the body where adverse effects can occur. For example, the model describes the breathing rate and uptake of the halocarbon from the exposure atmosphere into the lungs. From there, the model uses the blood flow bathing the lungs to describe the movement of the halocarbon from the lung space into the arterial blood that directly feeds the heart and vital organs of the body.

It is the ability of the model to describe the halocarbon concentration in human arterial blood that provides its primary utility in relating the dog cardiac sensitization test results to a human who is unintentionally exposed to the halocarbon. The halocarbon concentration in the dog arterial blood at the time the cardiac sensitization occurs (5-minute exposure) is the critical arterial blood concentration (target concentration), and this blood parameter is the link to the human system. Once the critical arterial blood concentration was measured in dogs, the U.S. EPA-approved PBPK model simulates how long it will take the human arterial blood concentration to reach the critical arterial blood concentration (as determined in the dog test) during human inhalation of any particular concentration of the halocarbon agent.

2.1.3 Exposure Limits.

Exposure criteria have been established for the use of halocarbon agents in total-flood applications as part of the NFPA 2001 and ISO 14520 standards [17 and 18]. Under these international standards, a halocarbon agent may be used at a concentration up to its cardiac sensitization NOAEL value in normally occupied enclosures provided the maximum expected exposure time of personnel is not more than 5 minutes. A halocarbon agent may be used at a concentration up to its cardiac sensitization LOAEL value in normally occupied and normally unoccupied enclosures provided certain criteria are met that depend on agent toxicity, egress time, and in some cases, PBPK model values. In addition, these standards call for avoidance of unnecessary exposure to agents covered in that standard and for suitable safeguards to ensure prompt evacuation. Audible and visual predischarge alarms are required. The U.S. EPA references the exposure criteria in the current version of NFPA 2001 for agents listed as acceptable under the SNAP program.

2.2 ENVIRONMENTAL CONSIDERATIONS.

2.2.1 Ozone Depletion Potential.

ODPs are the calculated ozone depletions per unit mass of material released relative to a standard, normally chlorofluorocarbon (CFC)-11. It should be noted that ODPs are calculated; they cannot be measured. Although calculations of ODPs require time horizons (see section 2.2.3), steady-state calculations have generally been used. Although ODPs vary somewhat, depending on the calculation method, it is believed that relative values for compounds containing the same ozone-depleting element are relatively reliable. Thus, halocarbons that contain only chlorine and fluorine (in addition to carbon and, possibly, hydrogen) can be compared to CFC-11. It is well established that bromine is much more damaging to ozone than chlorine on a per atom basis. Exactly how much more damaging is not precisely known and lends uncertainty to the ODPs of bromocarbons. The model calculations used by the U.S. EPA incorporate an effect ratio of 55 chlorine atoms to 1 bromine atom. A nontechnical historical overview is contained in reference 19.

2.2.2 Atmospheric Lifetime.

Atmospheric lifetimes are generally modeled as e-folding lifetimes. The gas concentration decays exponentially, following the equation

$$C_t = C_0 e^{t/L}$$

where C_0 is the initial concentration, C_t is the concentration at any time t, and L is the atmospheric lifetime. After one lifetime, the gas concentration drops to $1/e$ (approximately 0.369) of its initial value. Note that this equation predicts that the concentration will never reach zero, although it can approach it very closely. For example, after only five lifetimes, the concentration drops to 0.0067 of its initial value.

2.2.3 Global Warming Potential.

The GWP is the change in radiative forcing resulting from the emission of 1 kilogram of a chemical relative to the radiative forcing resulting from the emission of 1 kilogram of a reference gas. In the past, CFC-11 was often used as the reference; however, CO_2 is now typically used. The GWP depends on three variables: (1) the location of the infrared (IR) absorption bands, (2) the strength of the IR absorption bands, and (3) the lifetime of the gas. It is important to note that the GWP can vary significantly, depending on the time period used for the comparison of the radiative forcing of the chemical relative to the reference. The time period used to calculate the GWP is termed the time horizon and is primarily a policy decision. Time horizons of 100 and 500 years are often used in calculated GWP values; however, other time horizons may be more appropriate. GWPs with longer time periods are believed to be more inaccurate than those with shorter time periods [20]. All GWPs in this report are 100-year time horizon values referenced to CO_2 from the Intergovernmental Panel on Climate Change Fourth Assessment Report [20].

2.2.4 Atmospheric Impacts of Blends.

Some replacement agents are blends of more than one component. The atmospheric impacts of blends should be evaluated by looking at the ODP, GWP, and the atmospheric lifetime of each component separately because each component acts independently when released to the atmosphere, even if it has been blended with other components. The atmospheric effects of an individual component in a blend have the same impact as if the individual component were released to the atmosphere as a pure substance.

Some manufacturers calculate and report averages of ODP, GWP, and/or atmospheric lifetime for a blend. Other manufacturers do not identify all components and use the environmental characteristics of a principal component to represent the atmospheric impact of a blend. Neither the parties to the MOP nor government agencies, such as the U.S. EPA, accept such practices as representing an accurate evaluation of the atmospheric impact. Instead, such groups and organizations use the ODP, GWP, and atmospheric lifetime of each component to evaluate the overall atmospheric impact of a blend.

2.3 REGULATORY RESTRICTIONS.

2.3.1 Halons.

Under the MOP, global production of halons for use in fire protection applications ended in 2010. In most countries, recycled halons can be used to service existing equipment and for continuing important uses for which suitable alternatives are not yet available.

The exception is the European Union (EU), which banned all noncritical uses of halons in 2003. Critical uses are listed in the current Annex VI to European Commission (EC) Regulation No. 1005/2009 (table 2). All current onboard uses of halons in aviation are included on the critical use list under the EC regulation. Annex VI was revised in 2010 and now contains “cut-off dates” for using halons in new equipment or facilities and “end dates” when all halon systems or extinguishers in a particular application must be decommissioned.

Table 2. Halon Phase-Out Dates in EC Annex VI

Purpose	Type of Extinguisher	Type of Halon	Cut-Off Date: Application for new Type Certification	End Date: All Halons Decommissioned
Normally unoccupied cargo compartments	Fixed system	1301 1211	2018	2040
Cabin and crew compartments	Portable extinguisher	1211 2402	2014	2025
Engine nacelles and auxiliary power units	Fixed system	1301 1211 2402	2014	2040

Table 2. Halon Phase-Out Dates in EC Annex VI (Continued)

Purpose	Type of Extinguisher	Type of Halon	Cut-Off Date: Application for new Type Certification	End Date: All Halons Decommissioned
Inerting of fuel tanks	Fixed system	1301	2011	2040
Lavatory waste receptacles	Fixed system	1301 1211	2011	2020
Protection of dry bays	Fixed system	1301 1211 2402	2011	2040

In September 2010, a new resolution on halon replacement (A37-9) was adopted at the 37th Session of the ICAO Assembly. It replaces Resolution A36-12 that was adopted in 2007.

The new resolution directs the ICAO Council to establish a mandate for the replacement of halon:

- In lavatory fire-extinguishing systems used in aircraft produced after a specified date in the 2011 timeframe

- In hand-held fire extinguishers used in aircraft produced after a specified date in the 2016 timeframe

- In engine and auxiliary power unit (APU) fire-extinguishing systems used in aircraft for which application for type certification will be submitted after a specified date in the 2014 timeframe.

The ICAO Air Navigation Commission is moving forward with amendments to Annex 6, Operation of Aircraft, and Annex 8, Airworthiness of Aircraft, in order to implement the new resolution.

2.3.2 Hydrochlorofluorocarbons.

Under the MOP, production of HCFCs for fire protection uses will be phased out on January 1, 2020, in developed countries and January 1, 2030, in developing countries. HCFCs are restricted from use in fire protection in the EU under EC No. 1005/2009. This regulation allows EU states to apply for exemptions that would allow HCFCs to be used through 2019.

2.3.3 Hydrofluorocarbons.

Due to global warming concerns, amendments were proposed in 2009 and 2010 under the MOP to slowly phase down the global production of HFCs used as alternatives for ozone-depleting substances. The proposed HFC amendments were considered but not approved at the 2009 and

2010 Meeting of Parties to the MOP. Similar amendments are likely to be proposed for consideration at the 2011 MOP.

Currently, only a few countries, such as Switzerland and Denmark, have restricted HFC use in fire protection. The EU F-gas regulation (EC No. 842/2006) does not restrict HFC use in fire protection, but instead requires containment, leak inspection, labeling, training, reporting, and recovery to reduce emissions. This regulation is scheduled for review in 2011.

None of the current key regulatory initiatives would place restrictions on HFC use in fire protection. HFC emissions for fire protection are estimated at less than 1% of total HFC emissions from all sources.

2.4 COMMERCIALIZED HALOCARBON REPLACEMENTS.

The term “commercialized” refers to materials now being marketed or are planned to be marketed in the near future. Halocarbons are considered “in-kind” replacements to halons. This means that these compounds are volatile (evaporate, leaving no particulates), extinguish fires by reaching a specific vapor concentration in the fire zone, and are electrically nonconductive. Because of their gaseous nature, these agents have a better capability to pass tests that involve hidden fires or fires with heavily obstructed hazards than nonvolatile agent options. Specific halocarbon replacements have been approved for lavatory, hand-held extinguishers, and engine protection. Halocarbon replacements tested against the exploding aerosol can test, required by the minimum performance standard (MPS) for cargo protection, have been shown to act differently than Halon 1301. These specific successes and failures are described in more detail in section 4.

All the commercialized total-flood agents in table 3, except for Halon 1301, are listed in NFPA 2001 and most in ISO 14520 [17 and 18]. Halon 1301 is listed in NFPA 12A [21].

Table 3. Commercialized Total-Flood Agents

Agent	Chemical	Formula	Company/Trade Name
Halon 1301	Bromotrifluoromethane	$CBrF_3$	No longer manufactured
HCFC Blend A HCFC-123 HCFC-22 HCFC-124	Additive plus Dichlorotrifluoroethane Chlorodifluoromethane Chlorotetrafluoroethane	3.75 wt.% $CHCl_2CF_3$ 4.75 wt.% $CHClF_2$ 82 wt.% $CHClFCF_3$ 9.5 wt.%	Safety HiTech/NAF S-III
HCFC-124	Chlorotetrafluoroethane	$CHClFCF_3$	DuPont/FE-241
HFC Blend B	Tetrafluoroethane Pentafluoroethane Carbon dioxide	CH_2FCF_3 86 wt.% CHF_2CF_3 9 wt.% CO_2 5 wt.%	American Pacific/Halotron II

Table 3. Commercialized Total-Flood Agents (Continued)

Agent	Chemical	Formula	Company/Trade Name
HFC-23	Trifluoromethane	CHF_3	DuPont/FE-13
HFC-125	Pentafluoroethane	CHF_2CF_3	DuPont/FE-25
HFC-227ea	Heptafluoropropane	CF_3CHFCF_3	DuPont/FM-200 or FE-227
HFC-236fa	1,1,1,3,3,3-Hexafluoropropane	$CF_3CH_2CF_3$	DuPont/FE-36
FIC-13I1	Trifluoroiodomethane	CF_3I	Ajay/Iodoguard
FK-5-1-12	Dodecafluoro-2-methylpentan-3-one	$CF_3CF_2(O)CF(CF_3)_2$	3M/Novec 1230

2.4.1 Physical Properties, Design Concentrations, and Exposure Limits.

The physical properties of commercialized total-flood agents are shown in table 4. The design concentrations for total-flood fire extinguishment for Class A and Class B fires, the inerting concentrations, and the NOAEL and LOAEL exposure limits for commercialized total-flood agents from ISO 14520 are shown in table 5. These design concentrations are, in general, determined as the extinguishment concentration for the specific fuel increased by a safety factor of 30%; though the results of other tests may be taken into account. ISO 14520 requires a minimum safety factor of 30% for all fuels [18]. Some users are employing some agents at considerably higher concentrations than the minimum recommended values shown in table 5 based on the specific fuel, scenario, and threat.

Table 4. Physical Properties of Commercialized Total Flood Agents

Generic Name	Vapor Pressure at 20ºC, Bar	k1 (m^3/kg)	k2 ($m^3/kg/ºC$)	Vapor Density, at 20ºC and 1 atm (kg/m^3)	Liquid Density at 20ºC (kg/m^3)
Halon 1301[1]	14.3	0.14781	0.000567	6.255	1574
HCFC Blend A	8.25	0.2413	0.00088	3.861	1200
HCFC-124[2]	3.30	0.1585	0.0006	5.858	1373
HFC Blend B[2]	12.57	0.2172	0.0009	4.252	1190
HFC-23	41.80	0.3164	0.0012	2.933	807
HFC-125	12.05	0.1825	0.0007	5.074	1218
HFC-227ea[3]	3.89	0.1269	0.0005	7.282	1408
HFC-236fa	2.30	0.1413	0.0006	6.544	1377

Table 4. Physical Properties of Commercialized Total Flood Agents (Continued)

Generic Name	Vapor Pressure at 20ºC, Bar	k1 (m^3/kg)	k2 ($m^3/kg/ºC$)	Vapor Density, at 20ºC and 1 atm (kg/m^3)	Liquid Density at 20ºC (kg/m^3)
FIC-13I1	4.65	0.1138	0.0005	8.077	2096
FK-5-1-12	0.33	0.0664	0.000274	13.908	1616

Notes: All values are from ISO 14520 [18] unless otherwise indicated.
[1] NFPA 12A (2009 edition [21]) and Thermodynamic Properties of Freon 13B1 (DuPont T-13B1)
[2] NFPA 2001 (2012) [17]
[3] DuPont

Table 5. Minimum Extinguishing Concentrations and Exposure Limits for Commercialized Total-Flood Agents

Generic Name	Minimum Design Concentration, Class A Fire Vol.%[1]	Minimum Design Concentration, Class B Fire Vol.%[1]	Inerting Concentration Methane/Air Vol.%	NOAEL Vol.%[2]	LOAEL Vol.%[2]
Halon 1301	5.0[3]	5.0[3]	4.9	5	7.5
HCFC Blend A ISO 14520-6	(7)	13.0	20.5	10	>10
HCFC-124[5, 6] (not included in ISO)	(7)	8.6[4]	-	1	2.5
HFC Blend B (not included in ISO)	(7)	14.7	-	5	7.5
HFC-23 ISO 14520-10	16.3	16.4	22.2	30	>50
HFC-125 ISO 14520-8	11.2	12.1	-	7.5	10
HFC-227ea ISO 14520-9	7.9	9.0	8.8	9	10.5
HFC-236fa ISO 14520-11	8.8	9.8	-	10	15
FIC-13I1[5] ISO 14520-2	(7)	4.6	-	0.2	0.4
FK-5-1-12 ISO 14520-5	5.3	5.9	-	10	>10

Notes for table 5:

[1] Design concentration = extinguishing concentration x 1.3, the minimum permitted by ISO 14520.

[2] A halocarbon agent may be used at a concentration up to its NOAEL value in normally occupied enclosures provided the maximum expected exposure time of personnel is not more than 5 minutes. A halocarbon agent may be used at a concentration up to the LOAEL value in normally occupied and unoccupied enclosures provided certain criteria are met that depend on agent toxicity and egress time. The reader is referred to NFPA 2001-1.5 [17] and ISO 14520-G.4.3 (2006) [18] for details of the recommended safe exposure guidelines for halocarbon agents.

[3] Exceptions, Halon 1301 design concentration is taken as the historical employed value of 5%.

[4] HCFC-124 data from reference 3.

[5] Not approved for use in occupied spaces.

[6] These agents are not generally supplied in new suppression systems but may be found in legacy systems.

[7] Agent manufacturer did not provide Class A extinguishing concentration data.

2.4.2 Weight and Volume Equivalents to Halon 1301.

Tables 6 and 7 show weight and storage volume equivalents relative to Halon 1301 for design concentrations for Class A and B fuel fires. The weight equivalent is the weight of agent required divided by the weight of Halon 1301 required. The storage volume equivalent is the storage volume of agent required divided by the storage volume of Halon 1301 required. Three things must be noted. (1) The storage volume equivalent is different from the simple ratio of the design concentrations. The storage volume equivalent accounts for the volume occupied by the agent (usually, but not always, a liquid) when contained in a cylinder. (2) This definition results in different values than one would obtain if extinguishing concentrations rather than design concentrations were used, because the design concentration for Halon 1301 is more than 130% of its extinguishing concentration. In general, this makes the storage volume and weight equivalents lower than would be predicted from the cup burner value or some other measure of extinguishing efficiency. (3) These equivalents are based on the minimum design concentrations (MDC) contained in table 5. Larger design concentrations may be used for aviation applications based on results from the various MPSs for each system (e.g., engine, handheld, lavatory, and cargo). Thus, the values for the equivalents in tables 6 and 7 are minimum values.

Table 6. Halocarbon Agent Quantity Requirements for Class A Combustible Hazard Applications[1, 2]

Generic Name	Agent Mass, kg/m^3 of Protected Volume at 20°C	Mass Relative to Halon 1301	Agent Liquid Volume litre/m^3 of Protected Volume	Maximum Cylinder Fill Density[3] (kg/m^3)	Cylinder Storage Volume Relative to Halon 1301[4]	Cylinder Pressure at 20°C Bar
Halon 1301[5]	0.331	1.00	0.210	1121	1.00	25 or 42
HCFC Blend A[6]	0.577	1.74	0.481	900	2.17	25 or 42
HCFC-124[6, 7]	0.549	1.66	0.400	1185	1.57	25
HFC Blend B[6, 7]	0.733	2.21	0.616	929	2.67	25 or 42
HFC-23	0.571	1.73	0.708	860	2.25	43
HFC-125	0.640	1.93	0.525	929	2.33	25 or 42
HFC-227ea	0.625	1.89	0.444	1150	1.84	25 or 42
HFC-236fa	0.631	1.91	0.459	1200	1.78	25 or 42
FIC-13I1[6]	0.389	1.18	0.186	1680	0.79	25
FK-5-1-12	0.778	2.35	0.482	1480	1.78	25 or 42

Notes:

[1] Halon alternative agent quantities based on 1.3 safety factor.

[2] Mass and volume ratios based on MDCs Class A fire from table 5.

[3] Fill density based on 25-bar pressurization, except for HFC-23.

[4] Agent cylinder volume per m^3 protected volume = (agent mass, kg/m^3 protected volume)/(maximum fill density, kg/m^3 cylinder) = ($V_{CYL}/V_{ProtVol}$). For Halon 1301, cylinder volume per m^3 hazard = (0.331-kg/m^3 hazard)/ (1082-kg/m^3 cylinder) = 0.0003059-m^3 cylinder/m^3 protected volume.

[5] NFPA (12A) [21]; ASTM D 5632-08 [22].

[6] The agent manufacturer did not supply complete Class A extinguishing data, hence, no Class A MDC was established; the heptane MDC was used in this table.

[7] NFPA 2001 (2012) [17]

Table 7. Halocarbon Agent Quantity Requirements for Class B Fuel Applications[1, 2]

Generic Name	Agent Mass, kg/m^3 of Protected Volume at 20°C	Mass Relative to Halon 1301	Agent Liquid Volume litre/m^3 of Protected Volume	Maximum Cylinder Fill Density[3] (kg/m^3)	Cylinder Storage Volume Relative to Halon 1301[4]	Cylinder Pressure at 20°C Bar
Halon 1301	0.331	1.00	0.210	1121	1.00	25 or 42
HCFC Blend A	0.577	1.74	0.481	900	2.17	25 or 42
HCFC-124	0.549	1.66	0.400	1185	1.57	25
HFC Blend B	0.733	2.21	0.616	929	2.67	25 or 42
HFC-23	0.575	1.74	0.713	860	2.27	43
HFC-125	0.698	2.11	0.573	929	2.55	25 or 42
HFC-227ea	0.720	2.18	0.512	1150	2.12	25 or 42
HFC-236fa	0.711	2.15	0.516	1200	2.01	25 or 42
FIC-13I1	0.389	1.18	0.186	1680	0.79	25
FK-5-1-12	0.872	2.63	0.540	1480	2.00	25 or 42

Notes:

[1] Nominal maximum discharge time is 10 seconds in all cases.

[2] Mass and volume ratios based on MDCs Class B fire from table 5.

[3] Fill density based on 25-bar pressurization except for HFC-23.

[4] Agent cylinder volume per m^3 of protected volume = (agent mass, kg/m^3 of protected volume)/(maximum fill density, kg/m^3 cylinder) = ($V_{CYL}/V_{ProtVol}$). For Halon 1301, cylinder volume per m^3 of protected volume = (0.331-kg/m^3 hazard)/ (1082-kg/m^3 cylinder) = 0.0003059-m^3 cylinder/m^3 of protected volume.

2.4.3 Environmental Properties.

The environmental properties of commercialized total-flood agents are shown in table 8. ODP, GWP, and atmospheric lifetime values shown in the table come from the 2006 Scientific Assessment of Ozone Depletion [23]. All agents (except Halon 1301) listed in table 8 are acceptable under the U.S. EPA SNAP program; however, there are use limitations for certain agents (see table footnotes).

Table 8. Environmental Properties of Commercialized Total-Flood Agents

Generic Name	Ozone Depletion Potential	Global Warming Potential, 100 yr.[1]	Atmospheric Lifetime, yr.[1]
Halon 1301	12	7,140	65
HCFC Blend A	HCFC-22—0.05 HCFC-124—0.02 HCFC-123—0.0098	HCFC-22—1,810 HCFC-124—609 HCFC-123—77	HCFC-22—12 HCFC-124—5.8 HCFC-123—1.3
HCFC-124	0.02	609	5.8
HFC Blend B	0	HFC-134a—1,430 HFC-125—3,500 CO_2—1	HFC-134a—14 HFC-125—29 CO_2—N/A
HFC-23	0	14,800	270
HFC-125	0	3,500	29
HFC-227ea	0	3,220	34.2
HFC-236fa[2]	0	9,810	240
FIC-13I1	0.0001	1	0.005
FK-5-1-12	0	1	0.01

Notes

[1] Source: 2006 Scientific Assessment of Ozone Depletion [23], except for FK-5-1-12 for which data was supplied by the manufacturer and HCFC-123, which is from the *Journal of Environmental Science and Technology* [24].

[2] Under the U.S. EPA SNAP program, HFC-236fa is restricted for use in total-flooding fire suppression to applications where other alternatives are not technically feasible.

2.4.4 Commercialized Streaming Agents.

Commercialized halocarbon steaming agents are listed in table 9. Note that two categories of streaming agents included in the 2002 update report from the Task Group on Chemical Options to Halons [3]—PFCs and FICs—are no longer being commercialized. In addition, three HCFC-based streaming agents that were included in the 2002 report—HCFC Blend C, HCFC Blend D, and HCFC Blend E—are no longer being commercialized. The environmental and toxicity properties of commercialized streaming agents are shown in table 10. Additional information on the potential use of halocarbon agents in hand-held extinguishers for aviation is contained in section 4.3.

Table 9. Commercialized Streaming Agents

Agent	Chemical	Formula	Company/Trade Name
Halon 1211	Bromochlorodifluoromethane	$CBrClF_2$	No longer manufactured
HCFC-123	Dichlorotrifluoroethane	$CHCl_2CF_3$	DuPont/FE-232
HCFC-124	Chlorotetrafluoroethane	$CHClFCF_3$	DuPont/FE-241
HCFC Blend B PFC-14 HCFC-123 Ar	Proprietary blend of Tetrafluoromethane Dichlorotrifluoroethane Argon	CF_4 $CHCl_2CF_3$ Ar	American Pacific/ Halotron I
HFC-227ea	Heptafluoropropane	CF_3CHFCF_3	DuPont/FM-200 or FE-227
HFC-236fa	1,1,1,3,3,3-Hexafluoropropane	$CF_3CH_2CF_3$	DuPont/FE-36
FK-5-1-12	Dodecafluoro-2-methylpentan-3-one	$CF_3CF_2(O)CF(CF_3)_2$	3M/Novec 1230

Table 10. Environmental and Toxicity Properties of Commercialized Streaming Agents

Agent	ODP[1]	GWP[1, 2] (100 years)	Atmospheric Lifetime[1] (years)	NOAEL (%)	LOAEL (%)
Halon 1211	7.1	1890	16	0.5[3]	1.0[3]
HCFC-123	0.0098	77	1.3	1.0[4]	2.0[4]
HCFC-124	0.026	609	5.8	1.0[5]	2.5[5]
HCFC Blend B[6]		Ar – N/A	Ar – N/A		
PFC-14/Ar (<4%)	0.0	PFC-14-7390	PFC-14-50,000		
HCFC-123 (>96%)	0.0098	HCFC-123-77	HCFC-123-1.3	1.0[4]	2.0[4]
HFC-227ea	0.0	3220	34.2	9.0[5]	10.5[5]
HFC-236fa	0.0	9810	240	10.0[5]	15.0[5]
FK-5-1-12	0	1	0.01	10[5]	>10[5]

Notes:

[1] Relative to CFC-11, references 23 and 24

[2] Based on a time horizon, relative to CO_2

[3] Reference 25

[4] Reference 16

[5] Reference 17

[6] The amount and type of PFC must be considered when assessing the environmental impact (see section 2.2.4). This blend contains small proportions of PFC.

2.4.5 Combustion Byproducts.

All halocarbon agents have tradeoffs for total-flood and/or streaming applications. As noted earlier, halon replacements should have four characteristics: a low global environmental impact, acceptable toxicity, cleanliness/volatility, and effectiveness. Although it is very easy to find candidate replacements that meet any three of these criteria, it has been difficult to find agents that meet all four. For most (but not all) applications, significantly more replacement agent is needed to provide the same degree of protection as provided by the present halons.

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 (HF) than Halon 1301 during comparable extinguishment [11 and 26]. Although a large amount of information is available on HF toxicity [27 and 17], it is difficult to determine what risk is acceptable. A good review of the toxicity of HF as it relates to short exposures of high HF concentration can be found in the NFPA 2001 Appendix [17]. Some data exists to determine what HF levels are likely in real fire scenarios. In general, agent decomposition products and combustion products increase with fire size and extinguishment time [28 and 17]. To minimize decomposition and combustion products, early detection and rapid discharge are recommended.

The effects of HF occur at the site of contact and are observed as inflammation (irritation) that can progress to severe, deep-penetrating irritation. At high concentrations of HF (>200 ppm) for an extended duration of time, e.g., 1 hour, fatalities may occur, particularly in the absence of any medical treatment.

At concentrations of <50 ppm for up to 10 minutes, definite irritation of upper respiratory tract, skin, and eyes can be expected to occur. At these low concentrations, escape-impairing effects would not be expected in the healthy individual. As HF concentrations increase to 50 to 100 ppm, an increase in irritation is expected. At 100 ppm for 5 minutes, moderate irritation of all tissue surfaces would be expected, and as the duration of exposure increases to 10 minutes, escape-impairing effects would begin to occur. As the concentration of HF increases, the severity of irritation, including escape-impairing irritation of the eyes and respiratory tract, increases and the potential for delayed systemic effects also increases. At these higher concentrations, humans would be expected to shift to mouth breathing, and deeper lung irritation is expected. At greater concentrations (>200 ppm), respiratory discomfort, pulmonary (deep lung) irritation, and systemic effects are possible. Continued exposure at these concentrations can be lethal in the absence of medical treatment.

The American Industrial Hygiene Association Emergency Response Planning Guideline (ERPG) presents limits established for emergency release of chemicals [29]. These limits are established to also account for sensitive populations, e.g., those with compromised health. The ERPG limits are designed to assist emergency response personnel in planning for catastrophic releases of chemicals. These limits are not to be used as safe limits for routine operations. The ERPG limits consist of three levels for use in emergency planning and are typically 1-hour values; 10-minute values have also been established for HF. For the 1-hour limits, the ERPG 1 (2 ppm) is based on odor perception and is below the concentration at which mild sensory irritation has been reported (3 ppm). ERPG 2 (20 ppm) is the most important guideline value set and is the concentration at which mitigating steps should be taken (such as evacuation, sheltering, donning masks). This level should not impede escape or cause irreversible health effects and is based mainly on the human irritation data in references 30 and 31. ERPG 3 (50 ppm) is based on animal data and is the maximum nonlethal level for nearly all individuals. This level could be lethal to some susceptible people. The 10-minute values established for HF and used in emergency planning in fires when HF vapor is generated are ERPG 3 = 170 ppm, ERPG 2 = 50 ppm, and ERPG 1 = 2 ppm.

The concentration of thermal decomposition products from a halogenated fire suppression agent depends on several factors. The size of the fire at the time of system activation and the discharge time of the suppression agent play major roles in determining the amount of decomposition products formed. The smaller the fire, the less energy (heat) is available to cause thermal decomposition of the suppression agent and, hence, the lower the concentration of thermal decomposition products. The size of the fire at the time of system activation depends on the fire growth rate, the detector sensitivity, and the system discharge delay time. The first factor is primarily a function of the fuel type and geometry, whereas the latter two are adjustable characteristics of the fire protection system. The discharge time affects the production of thermal decomposition products, as it determines the exposure time to the fire of sub-extinguishing concentrations of the fire suppression agent. Suppression systems have traditionally employed a combination of rapid detection and rapid discharge to limit both the production of thermal decomposition products and damage to assets by providing rapid flame extinguishment.

The enclosure volume also affects the concentration of thermal decomposition products, since larger volumes, that is, smaller fire size to room volume ratios, will lead to dilution of decomposition products. Additional factors affecting the concentration of thermal decomposition products include vaporization and mixing of the agent, the preburn time, the presence of hot surfaces or deep-seated fires, and the suppression agent concentration.

This decomposition issue is not unique to the new, clean halogenated agents. The thermal decomposition products resulting from the extinguishment of fires with Halon 1301 have been investigated by numerous authors (Ford, 1972 [32] and Cholin, 1972 [33], for example), and it is well established that the most important Halon 1301 thermal decomposition products from the standpoint of potential toxicity to humans or potential corrosion of electronic equipment are the halogen acids HF and hydrogen bromide.

2.5 HALOCARBON REPLACEMENTS IN DEVELOPMENT.

In 1999, the University of New Mexico Research Institute performed initial toxicology tests on several compounds in the brominated alkene family. From this work, as well as additional work performed by the Advanced Agent Working Group, 2-bromo-3,3,3-trifluoropropene (2-BTP) was identified as a promising halon replacement. This agent was of interest especially for cargo protection and was performed on a one-to-one weight basis with Halon 1301 in small-scale bulk load tests. In Federal Aviation Administration (FAA) cargo tests conducted in 2003, it was determined that this agent added to the intensity of the exploding aerosol can event when used at concentrations lower than required to extinguish the fire. The agent was then evaluated for engine protection and passed the tests. It was noted that, when the reflash of the fuel occurred, there was an additional pressure pulse present that was not observed when the fuel reflashed with

Halon 1301. It was never fully determined whether 2-BTP was acceptable for engine protection, but due to the results of the cargo and initial engine tests, further development of this agent was put on hold. These results are discussed further in section 4.

Some work using 2-BTP in hand-held extinguishers was performed in 2004 and no abnormal results were noted. Based on this data, interest arose again to use this agent in hand-held extinguishers because it could fit into the same cylinder size as the standard equipment on Boeing aircraft. This capability was validated by tests performed at Underwriters Laboratory (UL) in 2009 as part of a joint American Pacific and Boeing program. Based on these results, this agent is being further evaluated for commercialization. While several acute toxicology tests have been completed, there is still an array of additional toxicology tests required before the agent can be approved under the U.S. EPA SNAP program. If testing moves forward and is successful, this agent would be commercially available in 2013. Table 11 provides an overview of the properties of 2-BTP. It was noted that this material may react with air and moisture, and stabilizing additives were developed to maintain stability under storage conditions. Further discussion of using 2-BTP in hand-held extinguishers is presented in section 4.

Table 11. Properties of 2-BTP

Atmospheric Lifetime[1]	30°N to 60°N: 7.0 days
	60°S to 60°N: 4.3 days
GWP (100 year, CO_2 = 1)[1]	30°N to 60°N: 0.0050
	60°S to 60°N: 0.0028
ODP[1]	30°N to 60°N: 0.0028
	60°S to 60°N: 0.0052
NOAEL (%)[2]	0.5
LOAEL (%)[2]	1.0

Notes:

[1] Reference 34. 30°N to 60°N represents the major industrialized areas of the world and cover the U.S., EU, and major portions of Asia.

[2] Reference 35.

3. ALTERNATIVE TECHNOLOGIES.

Nonhalocarbon substitutes are increasingly being considered as options to using halons. Water-based suppression systems are replacing halon systems in many applications. Dry chemical extinguishants and CO_2 are also receiving increased use. Alternatives can be divided into two types: classical alternatives and new alternatives (see table 12). Note that the word “new” does not necessarily imply that a technology was developed recently, but that there is a new or renewed interest in using technology as a replacement for halons. Misting and particulate aerosols require decreased amounts of agent. This may decrease the probability of secondary fire damage. Thus, these technologies may allow protection while minimizing the problems normally associated with water and solids. Because of recent advances, inert gases and inert-gas blends can be used in new applications, particularly in occupied areas.

Table 12. Alternatives

Classical	New
Foams	Water misting
Wetting agents	Inert gases
Water sprinklers	Onboard Inert Gas Generation System
Dry chemicals	Particulate aerosols
Carbon dioxide	Solid propellant gas generators
Loaded stream	Combination

3.1 FOAMS AND WETTING AGENTS.

Foams are an alternative to halon systems for a number of hazards, particularly those involving flammable liquids [36]. Foams extinguish fires by establishing a barrier between the fuel and air. Drainage of water from the foam also provides a cooling effect, which is particularly important for flammable liquids with relatively low flash points and for Class A fuels where glowing embers are a problem. The disadvantages of foams are similar to those of water. They can cause secondary damage and cannot be used on fires involving electrical equipment without careful design considerations.

There are four basic classifications for foam fire protection systems:

- Fixed foam systems are complete installations with foam piped from a central location and discharged through fixed nozzles. The concept is similar to a fixed halon system; although the applicability is very different.

- Semifixed foam systems come in two types. (1) The foam agent is connected to a fixed piping system remote from the fire threat at the time the foam is required. (2) Foam is delivered from a central station to portable foam makers, which may include hose reels.

- Mobile systems are vehicle-mounted or vehicle-towed complete foam units.

- Portable systems are nothing more than hand-carried mobile systems. Portable foam extinguishers are generally intended for use on flammable liquids; although foam extinguishers may also be used for general protection against Class A fires in the same manner as water extinguishers.

3.1.1 Low-Expansion Foam.

Low-expansion foams have the following limitations:

- Low-expansion foams are suitable only for horizontal or two-dimensional fires, not three-dimensional fires.

- The correct foam must be used, depending on the type of liquid fuel. There are two basic types of low-expansion foams: hydrocarbon fuel foams and polar-solvent foams. The polar-solvent foams are primarily for alcohol fires, but may also be used on hydrocarbon fires. These are sometimes called universal foams. Hydrocarbon fuel foams are usually cost less, but the foam blanket degrades in the presence of polar chemicals like alcohols.

- Different kinds and brands of foam concentrates may be incompatible and should not be mixed during storage.

- Since low-expansion foams consist of at least 90% water, their use is limited to applications where unacceptable water damage or electrical conductivity is not a problem.

- Foams are generally used as concentrates, which are proportioned with water during delivery. The effectiveness of a foam on a fire is highly dependent on the system designed to proportion and deliver the foam.

3.1.2 High- and Medium-Expansion Foams.

High-expansion foam systems are uncommon but can be used for total flood of a protected space; particularly when access to a Class A fire is difficult via manual firefighting. Examples of applications include areas between floors, where a small number of high-expansion foam systems have been used in preference to halon, and marine machinery spaces. A preliminary evaluation of high-expansion foams for U.S. Naval shipboard applications has been performed [37]. Disadvantages of high-expansion foam systems include greater weight and space requirements, the need for a suitable water supply, relatively long extinguishing time, and possible cleanup problems. Also, due to poor visibility, using high-expansion foams can be dangerous in large, cluttered, or hazardous enclosures where people may be present. Toxicity and asphyxiation are not considered to be problems with high-expansion foam systems. Federal Express has developed a medium expansion foam fire suppression system (FSS) for cargo containers and are in use on their fleet of aircraft. See section 4.4.4 for further discussion.

High- and medium-expansion foams have the following limitations:

- Since high- and medium-expansion foams have a relatively low water content, they are not as effective as low-expansion foams for most fire scenarios. The hazard must be carefully evaluated and the foam system carefully designed.

- Using high- and medium-expansion foams for fires involving flammable liquids and gases must be carefully evaluated in view of the actual situations. These foams are not as forgiving of poor engineering design and application. In particular, high- and medium-expansion foams are often useless against fires involving liquefied natural gas.

- Although high- and medium-expansion foams contain less water than low-expansion foams, they should not be used with fires of water-reactive materials or on Class C fires without careful evaluation and testing.

3.1.3 Wetting Agents.

UL's Guide Information [38] provides the following description,

> "Wetting agents are liquid concentrates which, when added to water in the concentrations specified in the individual Listings, reduce the surface tension and increase the wetting agent solution's ability to penetrate and spread. Wetting agent solutions extend the efficiency of water in protection against fire exposure and the extinguishment of Class A and Class B fires in ordinary combustibles and flammable or combustible liquids that are not soluble in water and ordinarily stored at atmospheric temperatures and pressures. Wetting agents are not intended to be stored at temperatures below 0°C (32°F) or above 49°C (120°F)."

Wetting agents have some foaming ability, but unlike foams, they provide little capability to protect against burnback. There is some variation to wetting agents and some are more effective on Class B than Class A fires, and vice-versa.

The disadvantages of wetting agents are similar to those of water. They can cause secondary damage and cannot be used on fires involving electrical equipment without careful design considerations.

There are several UL-listed wetting agents available. The listings are limited to fire service and pumper applications applied through handlines with flow rates of 10 gallons per minute or greater. There are no UL-listed hand-held extinguishers that contain wetting agents. Only a few wetting agents have been submitted to the U.S. EPA and been approved under the SNAP program. These are discussed below.

3.1.3.1 FlameOut.

FlameOut is sold by Summit Environmental Corporation, Inc. This extinguishant is a blend of complex alcohols, lipids, and proteins, which is diluted to strengths of 1% to 10% in water for use. The surfactants, like all wetting agents, may enhance the rate of heat absorption by water. The blend acts on oil, gasoline, and petroleum-based liquid fires (Class B) by encapsulating the fuel, thus removing the fuel source from the fire. This feature prevents flame propagation and reduces the possibility of reignition. The agent is UL listed as a wetting agent in addition to water for extinguishing Class A and B fires. FlameOut and ColdFire are both U.S. EPA-approved as a replacement for Halon 1211, under the generic name Surfactant Blend A [10]. Regardless, these two wetting agents are purported to have differing compositions.

3.1.4 ColdFire.

FireFreeze Worldwide, Inc. manufactures ColdFire, a proprietary blend of organic surfactants and water, which is diluted to strengths of 1% to 10% in water. The surfactants in ColdFire, like all wetting agents, may increase heat absorption by water. ColdFire is UL listed as a wetting agent for Class A and B fires. The agent is said to extinguish Class B fires by fuel encapsulation to separate fuel from fire, reducing possible reignition and preventing flame propagation.

3.1.5 FireXPlus.

FireXPlus, a wetting agent produced by Firefox Industries, is SNAP approved as a Halon 1301 replacement under the generic name Foam A (formerly Water Mist/Surfactant Blend A) [10].

3.2 WATER SPRINKLERS.

Water is a very effective extinguishing agent because of its unusually high specific heat and heat of vaporization. Water can be delivered in three ways—from fixed systems, from handlines, and from portable extinguishers. Primarily, it is a Class A fire extinguishant, cooling the fuel to a temperature below the fire point. However, fine water sprays can be very effective against Class B fires and have the additional benefit of cooling, which helps reduce the chance of reignition.

As an extinguishing agent, water has a number of disadvantages compared with halons:

- Secondary damage (water damage to facilities and contents) may result from discharge.
- A cleanup requirement may exist after discharge: runoff water may have to be removed and contents of protected areas may require drying.
- Water is unsuitable for discharge onto live electrical equipment.
- Water does not penetrate enclosures as well as halons and other gaseous agents.
- Discharge normally takes longer than a gaseous agent.
- Most water fire protection applications are unsuitable for Class B fires, although this may be overcome by misting systems.
- Water causes problems with storage, discharge, and cleanup at very low temperatures.
- Of particular importance in aviation is that water may carry a relatively large weight penalty, although this may not be true for zoned systems using water mist (discussed in section 3.6).

There are several types of fixed water systems for fire protection.

- Wet pipe sprinkler systems are widely used. These systems have pipes that are constantly pressurized with water and are connected to heat-activated sprinkler heads. They require no electrically activated fire detectors.
- Dry pipe systems are filled with air or nitrogen under pressure. When the sprinkler heads are opened by fire, the gas is released, allowing water to flow to the sprinkler heads. These systems are a little more costly than wet pipe systems and have a slower response time.
- Pre-action sprinkler systems require a detection system to actuate a valve allowing water to fill the pipes connected to the sprinkler heads. The valve is closed until activated. Primarily, these systems are used when inadvertent discharge must be avoided and a fire detector is required.
- Water deluge systems have sprinkler heads that are normally open unlike the wet pipe, dry pipe, and pre-action systems that require fire activation of the sprinkler heads. A detector activates a valve allowing water to discharge from all the sprinkler heads. This type of system results in widespread water discharge and, therefore, has a higher possibility of water damage. Water deluge systems are unlikely to be used for replacement of Halon 1301 total-flood systems.
- Other (combination and special) systems have been used, including some that shut off the water when a fire has been extinguished.

Automatic sprinkler systems were first developed in the last century and are a well-proven, highly reliable form of fire protection. This is particularly true in general industrial and commercial premises in which none of the disadvantages listed above are of major practical significance. Automatic sprinklers may be used for protection of many facilities (e.g., computer rooms) for which halon is traditionally used. To avoid damage to the equipment, however, the electrical power must be deactivated before water is discharged. Although most of the new-generation computer equipment is not permanently damaged by water, if it is first powered down, it must be dried out before use. This means that either redundant equipment is needed or the facility must be able to withstand any losses due to downtime.

A fixed water sprinkler system may be very cost-effective for protection of an area that already has halon systems if existing piping, valves, and miscellaneous equipment do not require major modifications. However, if protection of a limited area involves installation of a water supply and if a storage tank, pumps, and increased pipe size are required, sprinkler protection could be much more expensive than a halon system. Predesign inspections should be a mandatory consideration for all existing halon-protected areas.

The types of traditional water sprinklers discussed in this section would be expected to result in large weight penalties if used onboard aircraft. When water is misted, it can achieve a Class B extinguishing capability, which cannot be achieved by the water systems discussed in this section. Therefore, if water or water with additives is used in onboard systems, they are envisioned to be part of a water mist system, as described in section 3.6.

3.3 DRY CHEMICALS.

Certain finely ground powders can be used as extinguishing agents. The extinguishing mechanism is complex and not fully understood. However, the mechanism depends mainly on the presence of a chemically active surface within the reaction zone of the fire. Sodium bicarbonate was one of the first dry chemical extinguishants to be used. Potassium bicarbonate and monoammonium phosphate were developed later in the 1960s. These powders typically have particle sizes of less than 10 μm up to 75 μm with average particle sizes of 20 to 25 μm.

Dry chemicals generally provide very rapid knockdown of flames and are more effective than halons in most applications [39]. The main disadvantages of dry chemical fire extinguishants include:

- Poor penetration behind obstacles
- No inhibiting atmosphere after discharge
- No direct cooling of surfaces or fuel[1]
- Secondary damage to electronic, electromechanical, and mechanical equipment
- Cleanup problems
- Temporary loss of visibility if discharged in a confined space
- Corrosion of surfaces not cleaned after discharge

Fixed dry chemical systems are commonly used to protect paint spray booths and used in localized applications, such as with textile machines. These systems are also used for fire suppression in some marine engine spaces and transportation engine compartments, such as on public transit buses. Dry chemicals were previously used for deep fat fryers, but this is no longer allowed under UL 300.

Dry chemical extinguishers are rated for Class B and C fires and, in some cases, Class A fires, depending on the type of powder used. Dry chemical extinguishers are often suitable substitutes for halon in flammable liquid fires. They are also suitable for situations where a range of different fires can be experienced, e.g., electrical fires, flammable liquid fires, and fires in solids. In this respect, dry chemical extinguishers resemble halon extinguishers.

An aircraft original equipment manufacturer (OEM) released a Service Letter [40] in 2005 that states

> "Dry chemical extinguishers use extinguishing agents such as monoamonium-phosphate, sodium bicarbonate, or potassium bicarbonate (commonly called

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[1] Cooling of the flame due to thermal decomposition has been proposed as a mechanism for flame suppression by dry chemical agents (Ewing, C.T., Hughes, J.T., and Carhart, H.W., "The Extinction of Hydrocarbon Flames Based on the Heat-Absorption Processes Which Occur in Them," *Fire and Materials*, Vol. 8, No. 3, pp. 148-156, 1984). However, this is somewhat different from the direct cooling of surfaces, fuel, and flames by an agent such as water when cooling occurs in the absence of flame/agent interaction.

> Purple K). All of these dry chemical agents are corrosive and abrasive, and may cause moderate to severe damage to aluminum alloys and electrical/electronic equipment. Monoamonium-phosphate is used in A-B-C rated fire extinguishers (also called multi-purpose extinguishers) and is especially corrosive to aluminum alloy structures. Monoamonium-phosphate melts from the heat of a fire and flows into cracks, crevices and faying surfaces in structures making it difficult to remove before corrosion starts. … [OEM] recommends that operators and airplane maintenance providers take positive actions to prevent the use of dry chemical fire extinguishes in and around airplanes."

3.3.1 Monoammonium Phosphate.

Monoammonium phosphate (MAP) is often referred to as "ABC powder" and is the most common dry chemical extinguishing agent used today. It is an excellent explosion and fire suppressant and is effective on Class A, B, and C fires. It is, however, corrosive on metals. It is noted that the MAP content of ABC powders has generally gone down over the years due to rising MAP costs.

3.3.2 Sodium Bicarbonate.

Sodium bicarbonate is considered an excellent explosion suppressant and is effective on Class B and C fires. Sodium bicarbonate does not seal the surface of the combustible material, such as with MAP and, therefore, lacks Class A capability. Sodium bicarbonate is recommended for residential stovetop fires as it has a mild saponification effect on hot grease, which forms a smothering soapy foam that helps block re-ignition. Commercial kitchens have transitioned away from sodium bicarbonate to loaded stream, Class K-rated, extinguishing agents, as discussed in section 3.5.

3.3.3 Potassium Bicarbonate.

Potassium bicarbonate is a widely used dry chemical fire extinguishant suppressant used by aircraft rescue firefighting (ARFF) vehicles because it (1) is more effective than other dry chemicals on jet fuel and (2) has better capability for three-dimensional fires than the foam-equipped ARFF vehicles. Potassium bicarbonate, often referred to as "Purple K," is effective on Class B and C fires and has been shown to be 2-3 times as effective as sodium bicarbonate on a weight basis when tested under laboratory conditions [41]. It does not seal the surface of the combustible material, such as with MAP and, therefore, lacks Class A capability. There is some indication that the potassium ion has a chemical effect on fires. It is widely recognized that the amount of CO_2 released by this agent, and by sodium bicarbonate, in fires is insufficient to explain the fire suppression ability.

3.3.4 Proprietary.

Here, the term "proprietary" is used to denote a special dry chemical rather than one of those described above that have small amounts of an additive to improve flow and other characteristics. Monnex, a urea and potassium bicarbonate complex (developed by ICI), is an exceedingly effective proprietary dry chemical on Class B fires, but like sodium and potassium bicarbonate, lacks Class A capability. It is more expensive than the generic agents discussed above.

3.4 CARBON DIOXIDE.

CO_2 resembles the other inert gases discussed in section 3.9. However, CO_2 is considered a classical alternative and is commonly used as a fire extinguishant today. The physiological effects of carbon dioxide, however, differ significantly from inert gases. CO_2 inhalations result in respiratory and pulmonary changes, and CO_2 is not considered a simple asphyxiant as other inert gases. Like Halons 1301 and 1211, CO_2 is a gas at normal ambient temperature and pressure. It is also a clean, electrically nonconductive agent with good penetrating capability. CO_2 is discharged as a gas, though some frozen particulate (dry ice) often forms. The presence of frozen particulate increases the heat absorption capacity. Liquid discharge occurs only with refrigerated systems.

At one time, CO_2 systems were used for many of the applications that now use halon. Indeed, fixed CO_2 systems still remain in use for a number of applications, particularly in unmanned areas. CO_2 is also a common agent in portable fire extinguishers and in localized, fixed systems. Research is under way for using CO_2 as a component in twin-fluid water misting systems (section 3.6) and mixed with particulate aerosols (section 3.7). CO_2 is used as a pressurizing agent in some dry chemical extinguishers. It is also used in the Inergen and HFC Blend B halon alternative agents in small proportions.

Design concentrations for CO_2 total-flood systems for protection against Class B fires involving typical liquid hydrocarbons range from 34% to 43% depending on the fuel [42] compared with approximately 5% to 8% for Halon 1301 systems [21]. Carbon dioxide is less efficient than halons and, in general, storage requirements are greater. CO_2 is, however, more efficient than other inert gases due to its greater heat capacity [43]. For most total-flood applications, an agent storage volume of approximately eight times that required for halon is required for most CO_2 systems (however, see the next paragraph for a discussion on liquid CO_2 systems where the ratio can be as low as four times). Weight and space considerations are more relevant in retrofitting than in new installations, but they are unlikely to be major obstacles for retrofit into existing industrial and commercial facilities. On the other hand, weight and space requirements are likely to be a barrier for CO_2 retrofit of onboard aircraft applications.

Pyrozone Sales Pty. Ltd. in Australia manufactures a range of modular low-pressure CO_2 storage units that use liquid CO_2. Liquid CO_2 requires considerably less volume than the gas phase agent found in most CO_2 systems; moreover, it is claimed that Pyrozone Systems have the potential to use existing Halon 1301 pipework and detection equipment. The Pyrozone units use refrigeration to maintain the CO_2 as a liquid and have an integral contents-measuring capability. Pyrozone units are designed to be refilled in situ, negating the need to dismantle any part of the system after a discharge.

There are concerns about the safety hazard to personnel in areas protected with fixed, total-flood CO_2 systems. Unlike the other inert gases, CO_2 is toxic in large amounts (it is a respiratory regulator), and the design concentrations are well above dangerous levels (above 9%, loss of consciousness occurs within a short time, with death occurring around 25% to 30% [44]). With most fixed, localized systems, on the other hand, the hazard is much less and with portable extinguishers, any hazard is minimal. It is possible to manage the safety hazard with fixed, total-flood CO_2 installations by designing the system to ensure that automatic discharge does not occur while people are present in the protected area or by using manual activation. Many well-developed, internationally recognized standards provide guidelines for the safe use of CO_2 total-flood systems. Concerns have been expressed about magnetic tape erasure and damage from thermal shock due to CO_2. Testing has failed to substantiate the first concern, and thermal shock does not normally occur unless the discharge is directed at objects close to the nozzle. Some specialized installations are designed to pass the CO_2 through a vaporizing unit (converting all the CO_2 to a gas) to reduce cooling by vaporization and sublimation. Continued use by telecommunications and modern power supply industries support compatibility of CO_2 with risks of this type.

CO_2 portable fire extinguishers have been available for many years and are commonly used. They have certain disadvantages compared with Halon 1211: larger size, greater weight, lower efficiency, shorter throw range, and no Class A rating. In many applications, however, these disadvantages do not rule out using CO_2 fire extinguishers. Note, however, that complete protection of any facility with CO_2 may leave the facility devoid of sufficient Class A protection, and other types of agents—water, foam, dry chemical—may be needed.

3.5 LOADED STREAM.

The term “loaded stream” is used to indicate any mixture of a salt (usually an acetate, a citrate, and/or a carbonate) with water. This mixture is rated for Class K fires (cooking oil and fats). Most loaded stream agents are used for protection of cooking and restaurant facilities. Kidde manufactures two different types of loaded water extinguishers with sodium acetate, water, and ethylene glycol—one contains a mixture with 50% sodium acetate and the other a mixture with 30% sodium acetate.

One study has shown that sprays of aqueous solutions containing 60% potassium lactate or 60% potassium acetate are far superior to neat water sprays in extinguishing JP-8 fuel fires [45].[2] The improved performance is attributed to the release of solid salts upon evaporation of the water droplets. The study also shows that iodide salt solutions are superior to bromide salt solutions. The disadvantages of the loaded stream agents are potential secondary damage, requirement for cleanup, unsuitability for discharge onto live electrical equipment, and its inability to penetrate enclosures as well as halons and other gaseous agents.

3.6 WATER MISTING SYSTEMS.

Water misting systems use fine water sprays to provide fire protection with reduced water requirements and reduced secondary damage. Calculations indicate that on a weight basis, water can provide fire extinguishment capabilities better than 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

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[2] JP-8 is a hydrocarbon fuel with a flashpoint typically about 50°C. The fuel in the study cited here had a flashpoint of 50°C.

capability. The NFPA 750 standard on water mist systems [46] establishes a 1000-micron water droplet size (micrometers, μm) or less in order for a system to be designated a water mist system; however, many mist systems have droplet sizes well below this value. Water mist systems extinguish fires using three mechanisms: (1) heat absorption through evaporation and, to a lesser extent, vapor-phase heat capacity, (2) oxygen dilution by the water vapor formed on evaporation, and (3) radiative heat obstruction by the mist.

A detailed review of water mist was written by the Navy Technology Center for Safety and Survivability and Hughes Associates [47]. More recent reviews are presented in references 48 and 49. Water misting has been evaluated both as a possible replacement for total-flooding Halon 1301 systems [50] and for use in hand-held extinguishers [51].

At the request of the U.S. EPA, manufacturers of water mist systems and other industry partners convened a medical panel to address questions concerning the potential physiological effects of inhaling very small water droplets in fire and nonfire scenarios. Disciplines represented on the medical panel included inhalation toxicology, pulmonary medicine, physiology, aerosol physics, fire toxicity, smoke dynamics, and chemistry with members coming from the commercial, university, and military sectors. The executive summary of reference 52 states the following:

> "The overall conclusion of the Health Panel's review is that water mist systems using pure water do not present a toxicological or physiological hazard and are safe for use in occupied areas. The Panel does not believe that additional studies are necessary to reach this conclusion. The Health Panel recommends that additives be evaluated on a case-by-case basis depending on the toxic properties of the additive and the concentration at which it is used."

As a result of this study, the U.S. EPA lists water mist systems composed of potable water and natural sea water as acceptable without restriction under SNAP. Water mist systems comprised of mixtures in solution must, however, be submitted to the U.S. EPA for review on a case-by-case basis.

There are two basic types of water mist suppression systems—single fluid and twin fluid. Single-fluid systems use 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 in 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 (12.1 bar) or less). Both single- and twin-fluid systems have been shown to be promising for fire suppression. Single-fluid systems have lower space and weight requirements, reduced piping requirements, and easier system design and installation; whereas 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 [47].

The performance of a water mist system depends on the ability to generate small droplet sizes and the ability to distribute mist throughout a compartment in concentrations that are effective [47]. Suppression effectiveness depends on five factors: (1) droplet size, (2) droplet velocity,

(3) spray pattern, (4) momentum and mixing characteristics of the spray, and (5) geometry and other characteristics of the protected area.

Water mist systems are reasonably weight-efficient. Using small-diameter distribution tubing and possibly using composite, lightweight, high-pressure storage cylinders can increase this efficiency. It may also be possible to integrate a central storage of water for use in several potential fire locations (for example, cargo and passenger cabin locations). However, this integration may not always be beneficial; it could introduce failure modes, decrease availability, and reduce safety.

The major difficulties with water mist systems are those associated with design and engineering. These problems arise from the need to generate, distribute, and maintain an adequate concentration of the proper size drops throughout a compartment while gravity and agent deposition loss on surfaces deplete the concentration. Water mist systems have problems extinguishing fires located high in a space away from the discharge nozzles. Water mists also have difficulty extinguishing deep-seated Class A fires. Other concerns that need to be addressed are (1) collateral damage due to water deposition, (2) electrical conductivity of the mist, (3) inhalation of products of combustion due to lowering and cooling of the smoke layer and adhesion of the smoke particles to the water drops, (4) egress concerns due to loss of visibility during system activation, (5) lack of third-party approvals for most or all applications, and (6) lack of design standards [53]. Concern has also been expressed about the possibility of clogging the small nozzle orifices used in some systems.

For aircraft use, mist systems are most appropriately considered for cargo bays and, possibly, engine nacelles. Some concern has been expressed that water mists may be inappropriate for cargo bays due to the possibility of deep-seated and hidden fires. The FAA William J. Hughes Technical Center data show that deep-seated fires are probable and have caused several fatal cargo compartment fires. Tests by the FAA and others on deep-seated cargo fires indicate that water mist systems can be effective in combating such fires. Water mist may hold several advantages and should be considered for cargo bay application.

Using water mist systems to protect nacelles may be difficult. First, the low temperatures, around -57°C (-70°F) at altitudes of 36,000 feet, hinder storage, discharge, and evaporation. Second, there is concern about the possible collateral damage due to thermal shock when water contacts hot titanium components. Third, water systems are likely to be bulky. Finally, water is not expected to be distributed as uniformly as halocarbon and other gaseous agents.

Table 13 shows a list of water mist system manufacturers. Only the country for the main headquarters is listed; however, most have locations in several countries.

Table 13. Commercial Water Misting Systems

Manufacturer or Distributor	Trade Name	Pressure
Single Fluid		
MicroMist Systems, USA	MicroMist	High
Chemetron Fire Systems, USA	Chemetron	Low
Fike Corporation, USA	Micromist	Medium
FOGTEC Fire Protection, Germany	FOGTEC	High
Ginge-Kerr, Denmark/Kidde-Deugra, Germany	AquaSafe	Low
Tyco Fire Supression & Building Products, USA (formerly Grinnell)	AquaMist	Medium
GW Sprinkler, Denmark		Low/medium
Marioff Oy, Finland	HI-FOG	High
Phirex, Australia	Mistex[1] Fogex	Low/medium High
Semco Maritime A/S, Denmark	Sem-Safe	High
Spraying Systems Company, USA[2]	FogJet	High
Tyco Fire & Integrated Solutions, UK (formerly Total Walther)	MicroDrop	Low
Tyco, UK	ProtectoMist	Low
Ultra Fog AB, Sweden	Ultra Fog	High
Twin Fluid		
International Aero Inc., USA	IAI Water Mist	Low
Securiplex, Canada	Fire Scope 2000	Low
Life Mist Technologies, USA	Life Mist	Low
Victaulic	Vortex	Low

Notes:

[1] Both fixed and self-contained portable systems.
[2] Manufactures nozzles only.

3.7 FINE PARTICULATE AEROSOLS.

Fine particulate aerosols are air-suspended dry chemicals with micron-size particles that provide some total-flood capabilities. Dry chemical agents are at least as effective as halons in suppressing fires and explosions in many applications; however, such agents can damage electronic and mechanical equipment. Moreover, dry chemical agents, as now used, do not provide explosion inertion or fire suppression for time periods similar to those provided by halon systems due to settling of the particles. The discharge of dry chemicals also obscures vision.

Most, but not all, commercialized technologies for producing particulate aerosols use an oxidizing agent and a solid fuel, which when ignited, produces a fine, solid particulate aerosol providing extinguishment similar to dry chemical agents. An alternative process manufactures aerosol-size dry chemical agents by spray drying—spraying aqueous solutions into a heated space [54]. The small particle size appears to increase efficiency, decrease deposits, and increases the space-filling capability (multidimensionality) relative to normal dry chemical agents. Some have termed this type of technology “pyrotechnically generated aerosol (PGA).” Others have suggested that the term “pyrogenic aerosol” is more appropriate. In this report, “pyrotechnically generated aerosol” and “pyrogenic aerosol” are considered synonymous. PGAs are generated from nonpressurized containers. For a review of this area see reference 55.

As particle size decreases, the particulate surface on which heterogeneous recombination of combustion chain propagators can occur increases (e.g., reactions 1 and 2). Moreover, as particulate size decreases, the sublimation rate increases, enhancing homogenous gas-phase inhibition mechanisms, examples of which are shown in reactions 3 through 5 for potassium-containing aerosols (the most common type) [56]. Thus, in addition to improving dispersion, the small particle sizes inherent in particulate aerosols give these materials a greater weight effectiveness than standard dry chemical agents, decreasing problems due to residue. Both heterogeneous (particulate surface) and homogenous (gas-phase) inhibition appear to contribute to flame inhibition by particulate aerosols. Heat absorption by decomposition reactions and phase changes may also contribute.

Reaction 1: $\bullet\bullet\mathrm{O} + \bullet\mathrm{H} \rightarrow \bullet\mathrm{OH}$
Reaction 2: $\bullet\mathrm{H} + \bullet\mathrm{OH} + \mathrm{M} \rightarrow \mathrm{H_2O} + \mathrm{M}$
Reaction 3: $\bullet\mathrm{K} + \bullet\mathrm{OH} + \mathrm{M} \rightarrow \mathrm{KOH} + \mathrm{M}$
Reaction 4: $\mathrm{KOH} + \bullet\mathrm{H} \rightarrow \bullet\mathrm{K} + \mathrm{H_2O}$
Reaction 5: $\mathrm{KOH} + \bullet\mathrm{OH} \rightarrow \mathrm{H_2O} + \mathrm{KO}\bullet$

Here, “•” denotes a free radical.

The following presents information on some commercialized materials. NFPA has developed a design standard for aerosol generators, NFPA 2010 [57]. Aerosols may extinguish surface-burning Class A fires, and Class B and C fires. Per NFPA 2010, aerosols should not be used for deep-seated Class A fires unless it can be proven effective to the authority having jurisdiction for that application. All aerosol generators currently approved by the U.S. EPA are limited to either unoccupied areas or areas not normally occupied.

3.7.1 Spectrex Fire-Extinguishing Agent.

The family of Spectrex fire-extinguishing agents (S.F.E.) (also known as Encapsulated Micron Aerosol Agent) [58] are contained in generators and in applicators. Ansul is licensed by Spectrex Inc. of New Jersey, USA, to produce the S.F.E. agents under the trade name Micro-K and to market them worldwide. The powdered aerosol agents are produced in an oxidation-reduction combustion process that takes place in a combustion chamber specifically designed to contain various amounts of solid-casted material from 100 grams up to several kilograms. The combustion chamber is introduced in modular units (generators) that include a cooling means (chemical and physical) as well as discharge outlets that direct the aerosol flow towards the protected volume. The agents provide an air-suspended dry chemical aerosol with micron-sized particles that give total-flood capabilities [59].

U.S. Navy and U.S. Air Force tests and evaluation programs [55] indicate that on a weight basis, the agents are three times more efficient than regular dry chemical and five times more efficient than halocarbon extinguishing agents. The agents, designated as "Powdered Aerosol A," have been approved under SNAP for total flooding of unoccupied areas [10]. The S.F.E. agents were also evaluated by the FAA in a test program performed at its test facilities at the William J. Hughes Technical Center. S.F.E. formulation D performance is reported in reference 60 and in section 4.4.3 of this report.

Before ignition, S.F.E. has a density of 1300 to 1800 kg/m^3. The combustion temperature is 1500 to 2400 K, and the combustion velocity is 0.3 to 1.5 mm/sec. The material, which may be a solid pellet or a gelled paste, has a shelf life of 15 years. Prior to combustion, the S.F.E. solid material is not affected by prolonged exposures to extreme temperatures (from -55°C to +250°C) and remains functional in its original state (does not change phases to liquid or gas). Emissions from S.F.E. contain 40% particulate aerosols with a median diameter of 1 to 2 micron [61], comprising salts such as K_2O, KCl, and K_2CO_3. The remaining 60% of the emissions are gaseous combustion products such as CO_2, N_2, H_2O, O_2, and traces (ppm) of hydrocarbons. Hazardous gases, such as CO and NO_x, are not observed in improved formulations recently tested.

The toxicity of S.F.E. agents was evaluated by the U.S. Navy Medical Research Institute Toxicology Detachment [62-66]. Two formulations, A1 and A2, were compared. Prolonged exposure of test rats to powdered aerosol S.F.E formulation A1 at concentrations exceeding 80 g/m^3 caused toxic effects that resulted in deaths and led to the development of formulation A2. Multiple exposures to the byproducts of pyrolyzed formulation A2 at concentrations ranging from 50 to 240 g/m^3 caused no deaths to Fischer 344 rats and only minimal toxic effects [64]. All the animals recuperated after the exposure ceased. Formulation A2 is commercialized as S.F.E.

The S.F.E. agents are casted solids contained in modular units (generators) of various sizes, containing from 100 grams to 5 kilograms net weight S.F.E., some of which include cooling. The approximate design factor is 50 g/m^3 for direct material activation in enclosed areas and 100 to 120 g/m^3 when discharged from cooled generators, where a safety factor of 20% is included [67]. Typical system configurations include several modular units connected in a loop to a control box/display panel activated electrically by a signal from a separate detection system or by a self-contained detection element incorporated in the modular unit. The modular units and systems are commercially available. The main applications/installations are electrical compartments, engine compartments, nuclear power stations, and transformer rooms. These are also sold by a company in Israel as a deployable and portable extinguisher.

3.7.2 PyroGen.

A PGA manufactured by Pyrogen Corporation has been approved under SNAP as Powdered Aerosol C for total flood of normally unoccupied areas [9 and 10]. Pyrogen Corporation has offices serving Asia, Africa, The Americas, Australia, New Zealand, and Europe. The agent is marketed by Pyrogen Corporation under the trade name PyroGen[3].

The self-contained, nonpressurized canister contains two solid tablets—an aerosol-producing propellant and a coolant. Upon activation of the canister, either electrical or thermal, the propellant burns to produce a fire-extinguishing aerosol—a mixture of micron-sized chemical powders and inert gases. The aerosol propels itself through the coolant and out the canister into the enclosure.

The aerosol-producing propellant consists mainly of potassium nitrate and plasticized nitrocellulose. Combustion products of the propellant are finely dispersed potassium carbonates, CO_2 gas (1.2%), nitrogen gas, and water vapor; the mixture being the actual extinguishing medium. The design concentration—the mass of nonignited solid aerosol-producing propellant required to produce an adequate amount of aerosol to extinguish a specified type of fire per unit of volume—has been established as 100 g/m^3 for Class B fires and Class A surface fires.

Like other PGAs, using Powdered Aerosol C in the U.S. is limited to normally unoccupied areas, in part because the finely dispersed solid particles of the aerosol decrease visibility in the protected enclosure. Some byproducts of the aerosol-generating reaction of the solid propellant (e.g., CO_2 and nitrogen oxides) could cause moderate local irritation of the upper respiratory tract and eyes. Elevated temperature of the aerosol at the discharge outlet requires that minimum clearances be observed.

3.7.3 Soyus.

Dynamit Nobel GmbH Explosivestoff und Systemtechnik, Troisdorf, Germany, produces a number of different-sized PGA fire-extinguishing generators. The aerosol-generating units, which are marketed under the trade name Soyus, contain an ignition device, the fire-extinguishing composition, a reaction compartment, and a cooling unit in a cylindrical metal housing. The generators produce potassium carbonate, K_2CO_3, of which 99% has a particle size of 0.5 to 4 microns. The SO 200 E-E01 unit (height = 118 mm, diameter = 82 mm, weight = 0.88 kg) protects a volume of approximately 2.0 m^3. The SO 300 E-E01 unit (height = 208 mm, diameter = 82 mm, weight = 1.49 kg) protects a volume of approximately 3.0 m^3. Aerosol generation is reported to last 8 seconds for the first unit and 10 seconds for the second unit with a particulate residence time of approximately 1 hour. Ignition can either be electrical or manual.

3.7.4 Stat-X.

Fireaway Inc. purchased the rights to the aerosol products previously sold under the Aero-K trademark, and has further enhanced and harmonized the products under the Stat-X trademark. The Stat-X family of products includes eight UL-listed models of aerosol generator. These units are designed to generate 0.07 to 5.5 lb (0.03 to 2.5 kg) of condensed aerosol agent, protecting volumes from 16 to 1380 ft^3 (0.5 to 37.3 m^3), respectively. Stat-X units are listed for Class A (surface), B, and C category hazards. These units have also been tested and listed by UL for a shelf life of at least 10 years. Internally, in each Stat-X unit, is a pressed reagent-grade solid

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[3] This agent was originally marketed as FEAS by Bytenet Holdings, Australia.

chemical compound, from which condensed aerosol agent consisting of ultra-fine particles and inert gases are generated. The agent is 70% by weight solid particles (mostly potassium carbonate of median diameter of 1-2 microns) and 30% by weight gases (composed of 73% N_2, 22% H_2O vapor, and 4.5% $C0_2$. This agent is approved under the U.S. EPA SNAP as "powdered aerosol D" for total flood protection. Stat-X units were tested and are qualified to the military standards MIL-STD-810G, MIL-STD-461F, MIL-DTL-62546C, and MIL-STD-62547C. These units are currently protecting the engine compartment of over 8000 U.S. Army mine-resistant, ambush-protected vehicles. The Stat-X products were also successfully tested and evaluated in two Naval Research Laboratory advanced research performance fire test programs—halon alternatives for gas turbine enclosures of the U.S. Navy Landing Craft Air Cushion and Ship-to-Shore Connector, and fire protection options for diesel engine rooms and flammable liquid storerooms onboard the U.S. Navy Landing Craft Utility. In addition, NASA has selected Stat-X as the fire suppression system for its giant twin crawler transporters. The toxicity of the Stat-X aerosol agent was evaluated by the German Hygiene-Institut des Ruhrgebeits under their industry fire-hygienic assessment and evaluation standards, including 30-minute exposure of Wistar rats to the agent. The animals survived without any short- or long-term recognizable symptoms. The toxicity was further evaluated in whole body rat exposure tests conducted by Charles River Labs with a 15-minute exposure period with no ventilation. Tests for evidence of eye and skin irritation were performed. The test conclusions were that no eye and skin irritation was found, no long-term effects were observed, and no testing on larger rat populations was warranted. Testing was performed with a condensed aerosol density level slightly in excess of that listed by UL for Class A category hazards, and approximately 1.5 times of that for Class B category hazards. Initiation of Stat-X generators can be electrical, thermal automatic, or manual, using listed or special battery-powered release control units.

3.7.5 Kidde-Deugra Aerosol, KD-A-96.

Kidde-Deugra produces a very fine aerosol powder (KD-A 96) using a dry-spray technique [54]. The aerosol powder is stored in cylinders together with inert gases as the propellant. This procedure avoids hot gas emission problems found in PGAs. This agent is used in limousines and certain high-hazard industrial applications.

3.7.6 Kidde Aerospace & Defense, KSA.

Kidde Aerospace & Defense manufactures a KSA fire-suppressing agent/system designed to provide fire protection for aircraft engine nacelles and APUs.

3.8 SOLID PROPELLANT GAS GENERATORS.

SPGGs are similar to fine-particulate aerosol generators that are based on a solid propellant. The exception is that SPGGs can produce limited particulates and those generated particulates may be filtered before the discharge, leaving a clean discharge stream of inert gas. Depending on the generator, the discharge gas may be nitrogen, or a mixture of nitrogen, CO_2, and water vapor. Some SPGGs use chemical additives to create a limited amount of fine aerosol particulates. These particulates are often potassium salts, which will enhance Class B performance, but do not provide additional Class A performance. The U.S. Navy has conducted numerous feasibility and design verification tests on several aircraft platforms to assess and refine SPGG designs. Naval

Air Systems Command has qualified, installed, and accumulated over 15 years of flight experience with SPGG technology aboard their F/A-18E/F and V-22 aircraft. Notably, they have successfully extinguished an in-service three-dimensional, pressurized, fuel-fed fire in a V-22 mid-wing area. The U.S. Air Force has been evaluating the technology for aircraft dry-bay applications and will be testing SPGGs for protection of F-22 aircraft. The U.S. Army Tank Automotive Command (TACOM) has been performing tests in engine compartments of tracked vehicles and may also evaluate SPGG technology in crew compartments. Several overviews of SPGG technology and the progress of the tests conducted to date have been presented [68, 69, and 70].

3.8.1 Aerojet (Formerly General Dynamics and Primex Aerospace Company).

Aerojet SPGGs are used on the V-22 Osprey and the F/A-18E/F Super Hornet for dry-bay fire protection. They use an electrically activated squib to ignite a solid propellant that generates an inert gas mixture of nitrogen, CO_2, and water vapor. The Aerojet SPGGs are designed to discharge rapidly (on the order of ~100 milliseconds) to address explosive fire threats. They have been qualified through a series of U.S. Department of Defense (DoD)-sponsored test programs [71, 72, and 73].

Aerojet has been involved with DoD and commercial vehicle testing and has developed and manufactured generators for this use. These devices were originally considered for fire protection of aircraft dry bays [72]. Chemically active propellants and hybrid fire extinguisher (HFE) technology has been developed where the generator is used in combination with other extinguishing agents. The original Aerojet device used an electrically activated squib to ignite a solid propellant that generates an inert gas mixture consisting of nitrogen, carbon dioxide, and water vapor. More recently, these devices have incorporated a propellant composition that has been modified to generate a fine aerosol particulate composed of potassium carbonate together with the inert gas blend; this aerosol significantly enhances effectiveness in fire suppression, presumably via the chemical means common to other potassium-based suppression (agents). These chemically active generators are cleaner than aerosol gas generators and the small amount of particulates result in a large gain in weight efficiency for Class B fires. Tests have demonstrated a 50% to 70% propellant weight reduction when compared with inert gas generator technology for Class B fires [74 and 75]. Aerojet has a range of chemically active generator sizes, but the most common size has a gross weight of ~2.5 lb (1 kg) and occupies the space of a 2-in.-diameter cylinder with a length of 8 in. The protected volume for Class B hazards is approximately 35 ft^3 (1 m^3), depending upon airflow conditions. These devices are used by at least one tactical vehicle manufacturer for fire protection in engine compartments.

Aerojet SPGGs installed on the V-22 and F/A-18E/F aircraft use the FS 0140 agent, which has been listed as acceptable under the U.S. EPA SNAP program as “inert gas/powdered aerosol blend” for use as a total-flood agent in unoccupied areas [10]. This limitation is due to levels of CO_2 generated at effective loading concentrations. Aerojet’s chemically active compositions are effective at CO_2 levels within occupied space limitations.

3.8.2 Alliant Techsystems, Inc., ATK.

The ATK OS-10 quad-generator system is U.S. EPA-approved for occupied spaces. The discharge stream is comprised of 34% nitrogen and 66% water vapor, with trace amounts of other combustion byproducts within acceptable exposure limits. This exothermic process of gas generators results in large quantities of excess heat. This heat is typically absorbed with external coolant beds (such as residing within the overall system) or radiated outwardly from the exterior of the container. Since water vapor is a significant component of the extinguishing agent generated with the system, some of this water vapor condenses onto the surfaces of the internal cooling bed, leaving within the gaseous effluent a mass proportion of water vapor equal to the saturation humidity ratio at the local temperature (the higher the temperature, the higher the mass proportion).

The ATK quad-generator system can protect 1360 ft^3 (38.5 m^3) of Class A hazard or 904 ft^3 (25.6 m^3) of Class B hazard [76]. This system has a gross weight of 261 lb (118.4 kg) and occupies a space of 16.4 by 16.4 by 30.3 in. (41.7 by 41.7 by 77.0 cm).

3.8.3 N2 Towers.

N2 Towers has developed a gas generator that has a discharge stream comprised of almost pure nitrogen, with only trace amounts of other combustion byproducts within acceptable exposure limits. N2 Towers has two generator concepts: (1) a fast-acting generator intended for crew compartments and other hazards that need response times under a second, and (2) a slower-burning generator that discharges on the order of seconds, which would be daisy-chained together for industrial and commercial applications, such as computer rooms.

The fast-acting generator was tested in military crew compartment simulations and performed well [77]. This test used two 6-in.-long, 6-in.-diameter generators mounted in the opposite left and right corners of a 130-ft^3 (3.68-m^3) Lexan test booth. The left generator was activated 40 milliseconds after the explosive fire was detected and the second generator was activated 100 milliseconds later. The fire consisted of gasoline fuel directed across an electrical arc igniter with the fuel supply valve left open for 2 seconds and the igniter left on for 3 seconds. The fire was detected in approximately 2 milliseconds; a delay of 40 milliseconds was programmed into the release control box and the fires were extinguished in approximately 55 to 173 milliseconds. The generator extinguished the fire and brought the protected space down to approximately 15.7% oxygen per volume at a 2-psi pressure increase, and the ambient noise level increased to approximately 138.8 decibels for 150 milliseconds inside the test compartment.

The slower-burning generator design uses a 6-in.-diameter, 24-in.-long (15.2-cm-diameter, 61-cm-long) generator assembly. Each generator can protect 400 ft^3 (11.3 m^3). A U.S. EPA SNAP application has been submitted for the N2 Tower generators and the U.S. EPA has provided a preliminary decision that these generators will be acceptable for occupied areas.

3.9 INERT GASES AND ONBOARD INERT GAS GENERATION SYSTEM.

Combustion cannot occur when the oxygen content of air at normal pressures is sufficiently reduced (below approximately 15% oxygen, many fires cannot be initiated, and at lower concentrations, fires are extinguished). However, 12% or below is required to inert aircraft fuel tanks. Thus, inert gases, such as nitrogen and argon, can extinguish fires by diluting the air and decreasing oxygen content. Extinguishment is also facilitated by heat absorption.

Health problems can occur at low concentrations of oxygen. Although asphyxiation is not probable at concentrations required to extinguish a fire, sufficient impairment could occur that would prevent safe evacuation or emergency response. The Occupational Safety and Health Administration requires that no one enter a space with less than 19.5% oxygen without a self-contained breathing apparatus. The National Institute for Occupational Safety and Health gives the following effects at varying oxygen concentrations [78]. Note, however, that health problems that can occur would not happen immediately and would be a problem only for extended stays in an environment with a low oxygen level. Thus, there is some feeling that these predictions are meaningless without specifying a time period [79].

- 16%—impaired judgment and breathing
- 14%—faulty judgment and rapid fatigue
- 6%—difficult breathing, death in minutes

The minimum oxygen concentration in which astronauts can still perform the minimum physical and mental activities required to safely pilot a spacecraft (although with great difficulty) has been established by the National Aeronautics and Space Administration (NASA) as 12.3% [80]. Between 16% and 12.3% oxygen, performance is increasingly impaired. An expert panel has reported, however, that a 3-minute exposure to an atmosphere containing 10 percent oxygen provides an adequate margin of safety considering the variability of a working population, but that lethality occurs quickly at oxygen concentrations below 8% [81].

One method that can be used is to increase the atmospheric pressure so that the partial pressure of oxygen does not decrease below that required for human respiration while reducing the percent oxygen to the point that extinguishment occurs [82]. The higher-heat capacity due to increased atmospheric pressure also helps suppress fires. For example, submarines could use nitrogen flooding to dilute the oxygen while keeping its partial pressure constant to maintain life support [83]. This method can only be applied to completely enclosed areas with high structural strengths and is, therefore, limited to very few applications.

Pure and blended inert gases marketed as alternatives to halons are shown in table 14. All the agents shown in table 14 are U.S. EPA-approved under SNAP. The agent concentrations needed for extinguishment are approximately 34% to 52%, depending on the fuel and the fire scenario. The extinguishing properties of argon are similar to 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). Effective extinguishment of a series of *n*-heptane, wood crib, and polyvinyl chloride cable crib fires has been reported by the United Kingdom Loss Prevention Council for IG-541, IG-55, and IG-01 using the recommended design concentration and systems provided by commercial equipment manufacturers [84]. In general, extinguishment times were longer with the inert gases than for halocarbon extinguishing agents.

NOAEL and LOAEL values, which are normally based on cardiac sensitization for halocarbons, are inappropriate for inert gases. The U.S. EPA allows design concentrations to an oxygen level of 10% (52% agent) if egress can occur within 1 minute, but to an oxygen level of no lower than 12% (43% agent) if egress requires more than 1 minute [9 and 10]. Designs to oxygen levels of less than 10% 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 NOAEL and LOAEL values, NFPA 2001 [17] uses a no effect level (NEL) and a low effect level (LEL) for inert gases. 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 NFPA 2001 have sea level-equivalent[4] NEL and LEL values of 43% (12% oxygen) and 52% (10% oxygen), respectively. Similar to halocarbon agents, NFPA 2001 allows an inert gas agent to be used up to the LEL value for Class B hazards in normally occupied areas where a predischarge alarm and time delay are provided. In the absence of a time delay, only design concentrations up to the NEL are allowed. One major difference between the NFPA and EPA approaches is that the allowable design concentrations are not based on specific egress times in NFPA 2001.

Table 14. Inert Gases

Designation	Composition	Extinguishment Concentration* (vol.%)	Manufacturer
IG-541 (INERGEN)	Nitrogen 52% ±4% Argon 40% ±4% CO_2 8 ±1%	31	Ansul Incorporated, USA, and Fire Eater A/S, Denmark
IG-55 (ARGONITE)	Nitrogen 50% ±5% Argon 50% ±5%	35	Ginge-Kerr Denmark A/S
IG-01 (Argotec)	100% Argon	42	Minimax GmbH
IG-100 (NN100)	100% Nitrogen	31	Koatsu, Japan

*Cup-burner extinguishment concentration with *n*-heptane fuel, NFPA 2001 [17].

New Extinguishants Advisory Group/Halon Alternatives Group (NEAG/HAG) [85] recommends that oxygen concentrations in occupied areas protected by inert gas systems not be less than 12% 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%. NEAG/HAG also recommends that exposures to oxygen levels less than 10% not be allowed for any period of time.

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[4] The term “sea level equivalent” means concentrations that have the same oxygen partial pressures as those given by the NEL and LEL values at sea level (respectively, 91.2- and 76-Torr partial pressures at an ambient total pressure of 760 Torr). For example, at an ambient total pressure of 600 Torr, the oxygen concentrations would have to be 15.2% and 12.7% to achieve the same oxygen partial pressures. This would correspond to allowable agent concentrations of 27.6% and 39.5%.

3.10 ONBOARD INERT GAS GENERATION SYSTEM.

The Onboard Inert Gas Generation System (OBIGGS) is a gas separation technology that separates oxygen and nitrogen gas from air. These systems are quite similar to inert gas systems that use nitrogen as the extinguishing agent. The main difference is that OBIGGS generates nitrogen-enriched air on an as-needed basis. Therefore, over the length of a flight, the OBIGGS has the capability to generate more nitrogen than would be possible using high-pressure nitrogen cylinders. However, the OBIGGS flow rate limits the speed at which the nitrogen-enriched air may be supplied to a chamber. A NASA study [86] provides the following description concerning how various OBIGGS operate:

> "This [gas separation] can be accomplished by application of different technologies such as by the use of a permeable membrane or pressure swing adsorption or by air distillation columns. Gas separation devices can separate an incoming stream of air into two exit streams with the composition of one being nitrogen-enriched air (approximately 95% nitrogen and 5% oxygen) and the other being oxygen-enriched air. These devices are currently in use in commercial trucks and ships to transport fresh fruit and vegetables in a nitrogen gas atmosphere to preserve freshness and for a longer storage life.
>
> There are some military aircraft that employ gas membranes for the generation of nitrogen for fuel tank inerting and dry bays for fire and explosion protection and oxygen for crew breathing.
>
> There are newer technologies in development that utilize distillation columns and cryogenic coolers to generate and store both liquid nitrogen and oxygen to meet the requirements for inerting and passenger and crew breathing. One such system now in development is called TALON, an acronym for total atmospheric liquefaction of oxygen and nitrogen. This type of system is capable of providing 99% pure oxygen and >96% pure nitrogen."

All the systems described use a bleed air stream as input. Phyre Technologies, Inc. proposed a system that would pull air and fuel vapor directly from the ullage of the fuel tank. This system used a catalytic gas separation system to lower the oxygen and fuel content of the air returned to the ullage.

OBIGGS is becoming common on aircraft due to the 2008 FAA ruling requiring a decrease in the flammability of center wing fuel tanks. The ruling affects all future fixed-wing aircraft designs (passenger capacity greater than 30) and requires OBIGGS to be retrofit on more than 3200 Airbus and Boeing aircraft with center wing fuel tanks. Both the new Airbus 380 and Boeing 787 are equipped with OBIGGS. Because of this, there has been interest in whether the nitrogen-enriched air available from these systems could be diverted for use in other areas, especially for cargo protection. The drawback is that the flow rate of nitrogen-enriched air is limited, which requires a long time period to inert the cargo compartment.

The systems currently being installed on aircraft are based on membrane technology that separates the nitrogen and oxygen from a bleed air stream. These membrane separation units are installed in the pack bay within the wings of the aircraft.

There has been significant interest in developing a more advanced OBIGGS that would have higher flow rates. Additionally, there has been interest in creating combination systems where a secondary agent could be used to inert the space during the time it takes the OBIGGS to deliver enough nitrogen into the protected space.

3.11 COMBINATION AND NEW FOAM AGENTS.

Mixtures with water or with halocarbon bases have been marketed for many years. One example is the loaded stream type of agents discussed in section 3.5. 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 an increased interest in and development of such mixtures.

3.11.1 Envirogel.

The SNAP list gives a variety of formulations under the category “gelled halocarbon/dry chemical suspension” (designated as Powdered Aerosol B in the first SNAP listing [9]) developed for particular markets. The materials, which are marketed under the trade name Envirogel by Powsus Inc., have been tested in a number of applications, including tracked vehicles [87 and 88]. Testing to date indicates that at least some formulations have an effectiveness similar to Halon 1301 on either a weight basis or a storage volume basis [89]. Each blend contains one or more halocarbons, a dry chemical, and a gel that keeps the powder and gas uniform.

The gelled agents are acceptable under SNAP for use in a streaming application provided that any halocarbon contained has a cardiac sensitization LOAEL of at least 2.0% and that the dry chemical is one that is now widely used (i.e., MAP, potassium bicarbonate, and sodium bicarbonate) or is ammonium polyphosphate [10]. Among the halocarbons included in the SNAP submission were HFC-227ea, HFC-125, HFC-134a, and HFC-125 blended with HFC-134a. Also judged acceptable under SNAP for use as total-flood agents in normally unoccupied areas are formulations containing ammonium polyphosphate and MAP blended with either HFC-125 or HFC-134a [9 and 10].

3.11.2 Cease Fire.

Cease Fire manufactures CF-33, a patented blend of MAP and a polymer that absorbs an extinguishing gas. The automatic overhead Cease Fire units are UL-listed for Class A, B, and C fires and are available in four sizes with coverage from 800 to 2700 cubic feet.

3.11.3 Aerojet.

Aerojet HFE technology uses a solid propellant gas generator to pressurize and dispense a tank of fire suppression fluid [90 and 91]. Aerojet developed and manufactured a hybrid unit that is used for fire suppression on the Ford Crown Victoria Police Interceptor [92]. This system uses a gas generator to pressurize and distribute a firefighting foam solution. Aerojet has also developed and tested HFEs for ground vehicle crew compartments [93 and 94]. The protected crew volumes are dependent upon the chosen fire suppression agent (both aqueous and halocarbon agents are used) and a range of extinguisher sizes are available. Nominally, this extinguisher is 5 in. in diameter and 12 in. long for a protected volume ranging from 90 to 150 ft^3 (2.5 to 4.2 m^3).

3.11.4 ECOLOG Extinguishing System.

Airbus teamed with two partners to develop a replacement engine and APU fire-extinguishing system: Siemens' subsidiary SAS, which specializes in onboard fire safety, and SNPE-PyroAlliance, which is a division of France's SNPE. The ECOLOG extinguishing system consists of a gas generator sized to provide the pressurization source for a spherical cylinder containing the FK-5-1-12 extinguishing agent. The FK-5-1-12 agent has a high boiling point, 118.4°F (48°C), and therefore, the heat from the gas generator also helps to vaporize the agent. Full-scale tests were conducted in July 2007 at the Airbus test facility in Toulouse, France. The test consisted of an engine assembly using a Rolls Royce Trent 500 jet engine, which is typically used on the Airbus A340 aircraft. These test results met the FAA MPS requirements for both the engine and APU compartments [94].

4. APPLICABILITY OF TECHNOLOGIES TO AIRCRAFT APPLICATIONS.

As noted in section 1, a major goal for the Halon Options Task Group was the assessment of the applicability of halon substitute technologies to each major area of onboard aircraft use: (1) engine nacelles and APU compartment, (2) hand-held extinguishers, (3) cargo compartments, and (4) lavatory protection.

When evaluating agents, the essential properties/characteristics, the likely fire threat, the present fire detection and suppression practices, applicable regulations, and the current state of the technology should be considered.

4.1 REQUIREMENTS.

The candidate agents must meet the following requirements. The requirements imposed by the specific threat or application are additional to these requirements. A discussion of requirements or possible requirements by application has been published by the FAA [95].

- The agent must be suitable for the likely Class of fire. It should be recognized by a technical, listing, or approval organization—NFPA, UL, Factory Mutual Research Corporation (FMRC), etc.—as a suitable agent for the intended purpose or such recognition should be anticipated in the near future.

- 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.

- It should comply with the provisions of the MOP. It must have a near-zero, ozone-depleting potential. Low GWP and atmospheric lifetime are desirable, but presently, there are no generally accepted requirements.

4.2 ENGINE AND APU COMPARTMENT.

Title 14 Code of Federal Regulations (CFR) Parts 25.1195, 25.1197, 25.1199, 25.1201, and 25.1207 [96] identify the requirements for fire-extinguishing systems in aircraft power plants.

The following are related to the objectives and performances of the system:

- A fire-extinguishing system is required as identified in the CFR.
- The extinguishing 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.
- The extinguishing system must provide adequate, simultaneous protection throughout the compartment or compartments (also termed fire zones).

The following are related to the extinguishing agent:

- The agent must be capable of extinguishing flames emanating from any burning fluids or other combustible materials in the area protected by the fire-extinguishing system.
- The agent must be stable, taking into account storage conditions.
- The toxicity of the agent must be taken into account to not endanger personnel.

The following are related to the agent container, assuming a typical pressurized container architecture where the agent is fired into the nacelle or compartment using a pyrotechnic cartridge (see figure 1).

- The container must be protected against bursting due to excessive pressure.
- The pressure relief system must not damage the airplane.
- There must be a means to identify when the container has been discharged or when the internal pressure is too low to operate.
- The temperature of the container must be maintained to prevent pressure from becoming too low to operate, and from becoming too high, causing premature discharge, or to cause deterioration of the pyrotechnic device, if used.

The following are related to the material of the extinguishing system:

- The extinguishing system material must not react chemically with the agent itself.

- The components of the system in the fire zones (the zones to be protected) must be fireproof.

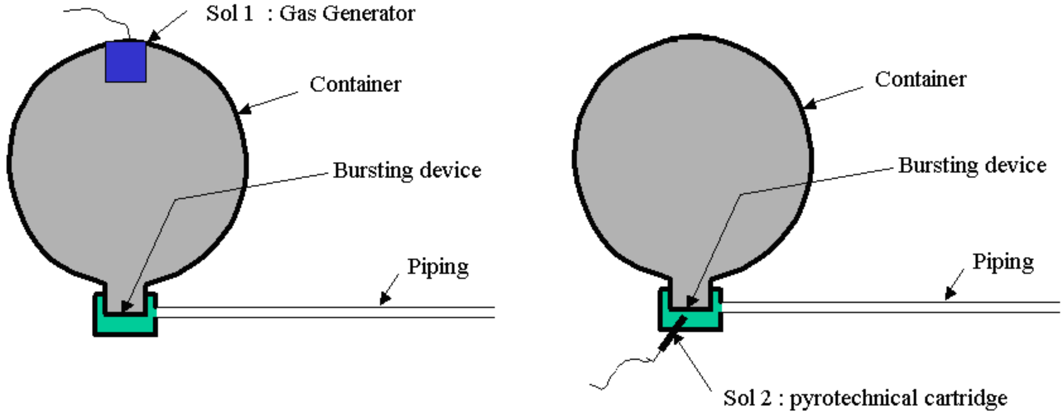

Figure 1. Typical Fire Extinguisher Architecture (Solution 1 illustrates how a gas generator pressurizes the vessel at the time of discharge. Solution 2 illustrates a normally pressurized vessel that is discharged by initiation of a pyrotechnic cartridge.)

Compliance to these requirements can be shown by tests and analyses, including full-scale fire tests, tests of similar powerplant configurations, tests of components, and/or service experience of similar powerplant configuration or analysis.

These requirements apply to all designated fire zones, except for the combustor, turbine, and tail sections of the turbine engine installations that contain lines or components carrying flammable fluids or gases. These areas are exempted because a fire originating in these sections can be controlled.

The fire threat addressed for these compartments is a Class B fire (aviation fuel, hydraulic fluid, and oil lubricant). The compartments are normally ventilated, have complicated air flow pathways, possess excessively heated materials, and are approximately at ambient pressure. Considerations that may adversely impact the system design are the continual presence of ventilation air flow during and after an agent discharge, potential residual fuel after a shutdown, and the presence of heated surfaces. Extinguishing agent storage and delivery were also added as considerations.

Fires result when a failure allows flammable fluid to contact an ignition source under conditions permitting combustion. A flammable fluid release results from a mechanical failure; a hose, tube, or fitting failure; or even a maintenance error. 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 that is detected by thermal sensors activates 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 activate the fire-extinguishing system. The process is achieved by shutting the engine down; closing local flammable liquid valves, including the fuel and hydraulic system; turning off local electrical power; and then activating the fire-extinguishing system.

A gaseous fire-extinguishing system is evaluated by an agent discharge test, which confirms the capability of the distribution system to provide the design agent concentration for the necessary time duration. (Other systems for solid, liquid, aerosol, hybrid agents, and possibly other methods shall have their individual test methods and procedures approved by their individual certification authorities.) The test requires an engine to be operating at critical conditions when the agent release occurs. For gaseous agents, a minimum of 12 sampling probes from a gas analyzer, customarily a Statham or Halonizer type unit, are located in critical areas of the compartment during this test. The device records the discharge event in the form of a gas concentration versus time relationship. The record is reviewed for compliance with FAA-accepted criteria for certification. Advisory Circular (AC) 20-100 [97] provides a good summation for the aspects of a discharge test.

The basis of AC 20-100's means of compliance to 14 CFR 25.1195 requirements consists of showing the agent concentration exceeds the AC 20-100 threshold for known gas agents. AC 20-100 also provides guidance for gas concentration measurement apparatus. To demonstrate compliance to 14 CFR Part 25 requirements, the threshold to be met by a replacement candidate must be established. In engine nacelle/APU compartments, it was established that Halon 1301 performance is the reference for minimum extinguishing performance expected from any replacement candidate. Therefore, the Minimum Performance Standard for Engines (MPSe) was put in place based on fire tests to enable this comparison.

A detailed history of the MPSe can be found on the FAA William J. Hughes Technical Center Fire Safety website [98]. The MPSe is currently at issue 4, published March 2010. Under MPSe revision 3, three agents were successfully tested and minimum concentrations were established. The minimum concentration thresholds established under MPSe revision 3 are [99]:

•	FK-5-1-12	6.1%v/v
•	CF_3I	7.1%v/v
•	HFC-125	17.6%v/v

The agent 2-BTP was evaluated under MPSe revision 3; however, the test sponsor stopped the test due to pressure effects witnessed upon re-ignition of the spray fires [99]. Additional evaluations are needed to determine if 2-BTP would be acceptable for engine and APU protection.

Successfully testing a replacement candidate through the MPSe process at the FAA William J. Hughes Technical Center is not sufficient to ensure the certification of a fire-extinguishing system based on a new extinguishing agent. All the requirements discussed above must be met, and detailed discussions between FAA Transport Airplane Directorate and/or European Aviation Safety Agency (EASA) with the airframe manufacturer must be conducted to determine the demonstration process for showing compliance. Consideration should be given to specific aircraft installation requirements, distribution requirements, and operational environment for agent storage and agent performance. These include, but are not limited to, agent long-term storage environment, including corrosion, settling, caking, agent decomposition, changes in physical and chemical properties, compatibility with engine materials, including performance in fuel, oil and hydraulic fluid environment, and agent delivery impediments such as funneling, gelling, effects of swirling, loss of driver agent, variations in temperatures during storage and in the fire zones (see reference 100 for discussion on cold operation), vibration, aircraft speed, ventilation, altitude effects, and the effects of humidity and precipitation on agent performance.

4.2.1 The HCFCs, HFCs, PFCs, and Blends.

These agents are similar in their performance and in their system characteristics. For this reason, they can be treated together when establishing a test protocol. These materials are typical PAAs.

Heptafluoropropane (HFC-227ea) and pentafluoroethane (HFC-125) were on the final list of agents tested at Wright-Patterson Air Force Base (AFB) and both are recognized acceptable agents for Class B fires by technical and listing organizations, such as UL or equivalent. Both HFC-227ea and HFC-125 are acceptable under SNAP as Halon 1301 substitutes [10]; however, under NFPA 2001 [17], HFC-125 will be restricted to normally unoccupied areas for most fuels (not a problem in this application). It is also recommended that at least one blend be included in establishing test protocols since there may be differences between blends and pure materials in handling and/or performance.

HFC-125 was the final candidate from the DoD program. The program concluded with a design model for HFC-125 [101] that affords the designer the ability to calculate agent mass requirements for a particular nacelle or APU compartment based on the parameters of ventilation air temperature and mass flow rate, anticipated fuel type, and compartment volume. This model is based on many points of fire extinguishment data produced in a test fixture. Guidance for the designer and limitations of the model are incorporated in the report [101].

The U.S. Navy provided a second source for HFC-125 design information. The Navy's F/A-18E/F underwent an evaluation with respect to potential fire-extinguishing technologies for its aircraft engine nacelle. Ultimately, a quantity of HFC-125, which was considerably less than that predicted as necessary by the design equation derived from the earlier DoD program, successfully met the design challenge [102]. This effort was based on fire test results, as produced in a complex test fixture representing the aircraft engine nacelle. The result represents a single point, but does offer another perspective on the performance for HFC-125 in the engine nacelle.

HFC-125 successfully passed the testing protocol of MPSe revision 3 and subsequently must meet or exceed a concentration of 17.6%v/v to demonstrate performance equivalent to Halon 1301.

4.2.2 Trifluoromethyl Iodide (FIC-13I1) and FIC-13I1 Blends.

Testing at Wright-Patterson AFB has demonstrated that the chemically active agent trifluoromethyl iodide (FIC-13I1) is more effective in engine nacelle fire extinguishment than any other replacement halocarbon tested to date. A number of blends of CF_3I with other halocarbons have been reported as candidate extinguishing agents [103-105]. The material is acceptable under SNAP [9 and 10] in both streaming and total-flood applications with some use restrictions. The environmental characteristics are good, and the volume requirements and effectiveness are essentially identical to Halon 1301. A paper from the National Oceanic and Atmospheric Administration (NOAA) states that

> "...the extremely short lifetime of CF_3I greatly limits its transport to the stratosphere when released at the surface, especially at mid altitudes, and the total anthropogenic surface release of CF_3I is likely to be far less than that of natural iodocarbons such as CH_3I on a global basis. It is highly probable that the steady-state ozone depletion potential (ODP) of CF_3I for surface releases is less than 0.008 and more likely below 0.0001. Measured infrared absorption data are also combined with the lifetime to show that the 20-year global warming potential (GWP) of this gas is likely to be very small, less than 5. Therefore this study suggests that neither the ODP nor the GWP of this gas represent significant obstacles to its use as a replacement for halons." [106]

It should be noted that the likely ODP is actually less than that determined for some of the HFCs, which are given a nominal ODP of zero [107]. The cardiotoxicity of CF_3I is greater than other halocarbon candidates. However, the relatively low cardiac sensitization NOAEL and LOAEL values may be of little concern for engine nacelle and APU applications where potential for contact with personnel is very limited.

CF_3I has successfully passed the MPSe revision 3 test protocol and subsequently must meet or exceed a concentration of 7.1%v/v to demonstrate performance equivalent to Halon 1301.

4.2.3 Novec 1230 (FK-5-1-12).

Novec 1230, $C_6F_{12}O$ fluid is an acceptable halon replacement and is manufactured by 3M (ODP = 0, GWP = 1, and AL = 0.014).

Novec 1230 fluid is a high molecular weight material compared with the first-generation halocarbon clean agents. The product has a 88.1-kJ/kg heat of vaporization and low vapor pressure. Although it is a liquid at room temperature, it gasifies immediately after being discharged in a total-flooding system.

The product is appropriate for use in total-flooding applications, localized-flooding systems, and directional spray-type applications. In addition to the conventional methods of super-pressurization using nitrogen, Novec 1230 fluid can also be used in pump applications because it is a liquid.

Novec 1230 fluid is based on a proprietary chemistry from 3M called C6-fluoroketone, which is also known as dodecafluoro-2-methylpentane-3-one, its ASHRAE nomenclature is FK-5-1-12—the same designation as NFPA 2001 and ISO 14520.

Novec 1230 has successfully passed the MPSe revision 3 test protocol and, subsequently, must meet or exceed a concentration of 6.1%v/v to demonstrate performance equivalent to Halon 1301. Cold-temperature performance is a concern for higher boiling point agents, such as Novec 1230. Since cold-temperature performance was not evaluated in the MPSe, additional tests need to be conducted for this agent.

4.2.4 PhostrEx.

PhostrEx, an alternative to halon for engine fire extinguishing, was certified by the FAA on the Eclipse EA500 very light jet in 2006 and subsequently approved by EASA in November 2008. The EA500 uses PhostrEx, which uses phosphorous tribromide (PBr3) as the fire-extinguishing agent. The certification of the Eclipse engine fire-extinguishing system was based on intensive fire-extinguishing tests for this particular application in lieu of establishing a minimum concentration requirement through MPSe testing. The viability of using PhostrEx for other aircraft must be studied in more detail, including consideration of material compatibility, toxicity, MPSe test protocol, and means for measuring agent concentration.

4.2.5 Gas Generators.

Both inert and next-generation, chemically active SPGGs have been tested as options for engine bay fire protection. Test results indicate that an SPGG (either inert or chemically active) used in engine bay fire protection will impose a significantly lower takeoff gross weight (TOGW) penalty than expected for a typical halocarbon-extinguishing system (HFC-125) [108 and 109]. Early tests used distribution lines, thus negating many of the weight advantages based upon predicted changes in insulation and distribution lines required to protect against the hot gases from an SPGG. Recent studies have demonstrated the effectiveness of radial discharge chemically active SPGGs in an AH-64 Apache helicopter nacelle simulator. The SPGGs extinguished all fire scenarios and were deemed to be a suitable method for protecting the AH-64 engine nacelle environment [110]. In the U.S. Navy F-18 engine bay [111], the results of a different SPGG variant, however, were not promising. No SPGG tested provided adequate fire extinguishment [112]. The F-18 tests were conducted in the mid-1990s, and the AH-64 simulator tests were conducted in the mid- to late 2000s. Studies indicated that factors other than oxygen starvation or cooling contributed to flame suppression by SPGGs in military aircraft engine bays [113], and that chemically active SPGGs are more effective at preventing re-light than halocarbons and inert SPGGs [114]. One in-service success story was the extinguishment of a real, hydraulic fluid-fed, mid-wing fire involving the rotor positioning unit (RPU) in a Navy V-22 aircraft [115].

Although work to date with aircraft engine bay fire protection using an SPGG technology has been mixed, it should not be ruled out as a direct fire suppression system for use in engine nacelles. The advantages of this technology are most pronounced in situations when using distribution lines can be limited or even eliminated altogether.

Rather than using a gas generator as the direct source of fire suppression, gas generators can be used as a pressure generator for the extinguisher container to provide the motive force for a stored agent. An airbus research project [116] demonstrated this technology, which increases the viability of a heavy replacement candidate by eliminating the need to store the agent under constant pressure.

4.2.6 Future Candidates.

MPSe revision 4 includes provisions for testing agents different from the traditional gases studied in the past. Solid aerosols, liquids, nongases, or mixtures may be accommodated under this test revision protocol.

KSA completed the MPS revision 4 Part (A) test on the generic FAA William J. Hughes Technical Center fixture in 2011. The KSA design concentration derived from this effort is equivalent to the current level of safety provided by Halon 1301. Part (B) of the MPS revision 4 test is scheduled to be completed in early 2012, which will demonstrate that the design concentration established, when replicated in a high-fidelity[5] test environment, will simultaneously suppress a spray and pool fire. At the conclusion of Part (B), the FAA will publish the KSA concentration.

4.3 HAND-HELD FIRE EXTINGUISHERS.

Federal aviation regulations mandate hand-held fire extinguishers be conveniently located in passenger compartments. The number of required extinguishers depends on the passenger capacity of the airplane [117]. The total number of extinguishers required is shown in table 15.

Table 15. Hand-Held Extinguishers Required for Commercial Aircraft

Passenger Capacity	Number of Extinguishers
7 through 30	1
31 through 60	2
61 through 200	3
201 through 300	4
301 through 400	5
401 through 500	6
501 through 600	7
601 through 700	8

It is required that at least one fire extinguisher on an airplane with a passenger capacity greater than 31 and two extinguishers on an airplane with a passenger capacity greater than 61 contain Halon 1211 (bromochlorodifluoromethane), or equivalent, as the extinguishing agent. The MPS defines the equivalency.

In addition, at least one hand-held fire extinguisher must be located in the pilot compartment, and at least one extinguisher must be available for use in each Class A[6] or Class B cargo or

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[5] An FAA-owned Boeing 747SP-JT9D engine will be used for the Part (B) test.

[6] To avoid confusing fire classifications (Class A, Class B, etc.) with cargo compartments classifications, the cargo compartments are underlined (Class A, Class B, etc.).

baggage compartment and in each Class E cargo or baggage compartment that is accessible to crew members during flight.

AC 20-42D [118] provides guidance for the fire-fighting effectiveness, selection, and safe-use of hand-held fire extinguishers in airplanes and rotorcraft. It establishes acceptable replacement agents for required halon extinguishers. It provides an acceptable method of compliance for hand-held fire extinguishers in transport category aircraft. The technical basis for the safe use guidance in this AC can be found in references [119 and 120]. This AC establishes an FAA-approved MPS for halon replacement agents, which includes a hidden fire test and a seat fire/toxicity test [121].

Hand-held fire extinguishers for aviation use must meet the following requirements, as specified in detail in the hand-held extinguisher MPS [121].

- Any hand-held fire extinguisher adopted for final use shall be listed by a listing organization such as UL or equivalent, be of a specific rating, and be of a size and weight that a typical flight attendant can use. The smallest recommended hand-held extinguisher has a UL 5-B:C rating in accordance with the UL 711 standard [122]. This corresponds to a 2.5-pound net charge weight for a Halon 1211 extinguisher.

- The extinguisher must be able to extinguish fires in inaccessible spaces (hidden fires) as effectively as a Halon 1211 extinguisher with a 2.5-lb net charge weight. It is desirable that the agent be sufficiently volatile to allow expansion and penetration into such spaces. Hand-held extinguishing agents are, by nature, streaming agents; however, Halon 1211 and most potential replacements have the ability to also function as a flooding agent. To ensure no loss of safety, replacement agents must maintain the same level of flooding ability as Halon 1211. A hidden fire test was developed to assess the firefighting performance of the hand-held extinguisher/agent combination in a flooding scenario. This test [123] was developed by Kidde International-UK, under contract from the UK's Civil Aviation Authority (CAA). The operating procedure and test fixture have since been refined and standardized at the FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ, USA [121]. The hidden fire test was administered by UL. The following agents have passed the hidden fire test to date: Dupont FE-36 (HFC-236fa), DuPont FM-200 (HFC-227ea), POWSUS Envirogel, Safety Hi-Tech NAF P-IV (HCFC Blend E), American Pacific Halotron I (HCFC Blend B), and American Pacific's 2-BTP.

- 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 be acceptable for use in an aircraft fire under in-flight conditions.

    - The FAA aircraft seat fire/toxicity test assesses the held toxicity of the agent decomposition products. This test is described in the hand-held extinguisher MPS [121]. The FAA has determined that the following agents are acceptable from a decomposition product toxicity viewpoint for use in occupied aircraft cabins: DuPont FE-36 (HFC-236fa), DuPont FM-200 (HFC-227ea), POWSUS Envirogel, Safety Hi-Tech NAF P-IV (HCFC Blend E), American Pacific Halotron I (HCFC Blend B), and American Pacific's 2-BTP.

- Guidance for the safe-use perfect mixing concentrations of an extinguisher in an aircraft compartment (e.g., cabin, flight deck, and crew quarters) can be found in AC 20-42D [118]. Safe-use is based on the charge weight of the largest extinguisher in a compartment as well as the volume and air change time of that compartment. Guidance on using higher than tabulated concentrations considering agent stratification and localization will be provided in a future FAA report.

The required FAA hidden fire test is described as follows: A candidate fire extinguisher is fully discharged into the left side of a rectangular box. Inside the box are 20 small cup fires arranged in five arrays of four. The arrays are separated by solid and perforated baffles. The baffles require the agent to extinguish the fire by indirect means. After discharge, the total fires extinguished are counted. Baseline testing with 2.5-lb net charge weight of Halon 1211 extinguished an average of nine cup fires (45% of the cups). This 45% extinguishment of the cups is the requirement for any agent that will replace Halon 1211.

In the first report [1], the Task Group recommended establishing tests for the groups of agents identified in sections 4.3.1 through 4.3.3. These groups of agents operate by different mechanisms and/or have large differences in physical properties. They cover a range of test procedures and apparatuses. Dry chemical extinguishing agents are not listed due to (1) the potential for damage to electronic equipment, (2) the possibility of visual obscuration if the agent were to be discharged in the cockpit area, and (3) the clean-up problem that results from their use. Restricting the use of dry chemicals to cabin areas does not prevent an extinguisher from inadvertently being carried to the cockpit and discharged in an emergency.

4.3.1 Halocarbons and Halocarbon Blends.

The halocarbons and halocarbon blends hold the most promise in being able to successfully replace Halon 1211. Halocarbons are considered "in-kind" replacements to Halon 1211. This means that these compounds are volatile (evaporate, leaving no particulates), extinguish fires by reaching a specific vapor concentration in the fire zone, and are electrically nonconductive. Because of their gaseous nature, these agents have a better chance to pass the hidden fire test than other types of agents. There are three commercially available, UL-listed, and FAA-approved agent/hardware combinations that could be installed today.

The three available combinations each use a different extinguishing agent: HFC-227ea, HFC-236fa, or HCFC Blend B. HFC-125 is not a candidate hand-held extinguisher replacement agent because it is not an effective streaming agent. HFCs have a zero ODP value and, therefore, were not part of the MOP, which phased out the new production of halons and controls the ongoing phaseout of new HCFC production. However, based on global warming concerns, the EU has begun to require HFC reporting and the U.S. has been involved in proposals to add HFCs to the MOP. Potential regulation of HFCs has been discussed in terms of a phasedown versus a complete phaseout of new production (see section 2.3.3).

FIC-13I1 (like some of the other halocarbons) faces some restrictions based on toxicity. Under SNAP, this agent is not permitted as a total-flood agent in a normally occupied area.

HCFCs have a nonzero ODP and currently face an eventual, regulated production phaseout. The phaseout dates in the U.S. depend on the material (see section 2.3.2); however, all HCFCs now considered for streaming have the same phaseout schedule. When used in nonresidential applications, portable fire extinguishers containing HCFCs are exempted by the U.S. EPA from bans on HCFC-pressurized dispensers [124]. In the EU, HCFCs are not allowed to be used without securing an exemption. No EU states have applied for exemptions, which would allow its use until the end of 2019. HCFC Blend B is a blend, based primarily on HCFC-123. Recent three-dimensional environmental models have reduced the ODP of this compound to less than half of the original value listed in the MOP [24]. The analysis evaluated both global warming and ozone depletion and determined that HCFC Blend B resulted in a lower environmental impact than HFCs. Based on this, potential regulatory lifetime extensions are being proposed.

Besides regulatory issues, there is a concern from airframe manufacturers about the larger size and weight of the HFC and HCFC extinguishers. The increased size and weight will generally require changes to the mounting brackets, location of the extinguisher, and in some cases, the structure supporting the extinguisher and bracket. There are up-front engineering, parts, and labor costs associated with the initial design and installation of the hand-held extinguisher replacements.

PFCs are accepted by the U.S. EPA [10] (FC-5-1-14 for streaming and FC-218 and FC-4-1-10 for total flooding) for nonresidential use when other alternatives are not technically feasible due to performance or safety requirements, such as physical or chemical properties of the agent or when human exposure to the extinguishing agent may result in failure to meet applicable use conditions. The principal environmental characteristics of concern for these materials are their extremely high GWPs and long atmospheric lifetimes. Since HFCs and HCFCs meet all requirements, there would be no technical justification to use PFC compounds.

Concerning FICs, the only compound that has been accepted for use by the U.S. EPA is CF_3I. Previously, there was some concern expressed about preliminary mutagenicity assays, which indicated CF_3I could be a carcinogen. However, additional tests were completed and have shown that CF_3I is not considered a carcinogen. In addition, there is some concern that iodine emissions from CF_3I could cause a problem. Although no data has yet been collected showing that iodine emissions are any worse with CF_3I than bromine emissions are with Halon 1211, emissions at altitude only happen during fire events and the quantities released by hand-held extinguishers would be extremely small. CF_3I has a nonzero ODP and falls into a newer category of compounds referred to as Very Short-Lived Substances (VSLS). Since the atmospheric lifetime for VSLS are on the order of days, the ODP and GWP values for these compounds depend on where these compounds are emitted. CF_3I has an ODP similar to HCFC-123. Currently, there are no proposed or existing U.S. regulations limiting the production of CF_3I. In the EU, recent regulatory changes now require reporting CF_3I quantities. Extinguishers containing CF_3I may be a potential solution. There are two primary reasons why CF_3I has not become a commercial product. The first is cost; CF_3I is a difficult compound to manufacture and the cost is several times higher than existing halon replacements. This significantly limits the commercial and industrial markets outside aviation. The second reason is the LOAEL value (0.4 vol.%) compared to Halon 1211 (1.0 vol.%). Another consideration for using of CF_3I in streaming applications is that it is fairly gaseous (boiling point: -22°C), which may make it difficult for CF_3I to be used in all streaming applications where Halon 1211 was used.

One fluoroketone, FK-5-1-12 (sold as Novec 1230), was U.S. EPA accepted for both flooding and streaming use in 2003. This agent requires more weight than the HFCs or HCFCs, but it has made some market penetration in the total-flooding market due to its low environmental values (zero ODP and GWP of 1). While this agent has undergone multiple tests for streaming applications over the years, it is not commercially available in UL-listed hand-held extinguishers. Although this compound should have the potential to pass the required tests for aviation hand-held extinguishers, the size and gross weight of the unit is anticipated to be less than satisfactory (~3 times the gross weight of a Halon 1211 extinguisher and similar in size to the HFC-227ea extinguisher), unless some innovation is developed. FAA seat fire/toxicity tests are planned for this agent.

Based on regulatory and extinguisher relocation concerns, the aviation industry has been evaluating an experimental compound, 2-BTP. This agent is also considered a VSLS with a nonzero ODP. However, in a two-dimensional analysis, the ODP was calculated to be <0.0005 based on discharges in latitudes covering the U.S. and EU [34]. Preliminary, three-dimensional modeling results indicate a slightly higher ODP value. The GWP is extremely low. A hand-held extinguisher containing 2-BTP was tested at UL in a joint effort between Boeing and American Pacific. The results were an agent/hardware combination that passed the 5B pan test and hidden fire test in a cylinder similar to what is currently being used onboard Boeing aircraft. The extinguisher had a net charge weight of 3.75 lb. Evaluations are ongoing for this compound and necessary toxicology tests are currently proceeding, which are required for U.S. and EU approvals. FAA seat fire/toxicity tests have been completed. This agent has not yet been submitted to the U.S. EPA for SNAP review. Table 16 shows the size and weights of the prototype 2-BTP extinguisher as well as the commercially available HFC and HCFC extinguisher options.

Table 16. Size and Weight Matrix for Candidate Hand-Held Extinguishers[1]

Agent	Agent Weight (lb)	Total Weight (lb)	Dimensions (in.) (H x W x D)
Halon 1211	2.5	3.93	17 x 4.8 x 3.25
2-BTP (2-bromo-3,3,3-trifluoropropene)	3.75	5.6	15.75 x 5 x 3.5
FE-36 (HFC-236fa)	4.75	9.5	15.9 x 8 x 4.5
Kidde (HFC-236fa)	5.0	8.0	15.9 x 8 x 4.5
Halotron I (HCFC Blend B)	5.5	9.3[2]	15 x 5 x 4.25
FM-200 (HFC-227ea)	5.75	9.75	16.6 x 6.75 x 4.4
Novec 1230 (FK-5-1-12)	TBD[3]	TBD[3]	TBD[3]

Notes:

TBD = To be determined

[1] The agent/hardware weights and sizes are based on commercially available hardware or hardware that has passed the UL 5B pan and hidden fire tests. The combinations are sorted from lowest to highest gross weight. The values presented for the Halon 1211 extinguisher are based on the Kidde Technologies model 898052, which is standard equipment for Boeing aircraft.

[2] This weight is based on the current carbon steel cylinder. Alteration to an aluminum cylinder has been proposed and would reduce this gross weight to approximately 7.8 lb. The size of the unit would remain the same.

[3] Tests to establish a minimum required weight for a 5B-rated fire extinguisher are currently being conducted by 3M. Successful testing will also result in identifying a total weight and volume.

In summary, three options (two HFC and one HCFC) have been commercially available for several years, but the airframe manufacturers have been reluctant to install these options due to weight and size penalties. Several of the potential agent options currently being evaluated are characterized by nonzero ODPs, and there is a risk that future environmental regulatory actions may place limitations on their use. There are three additional potential agent options, CF_3I, FK-5-1-12, and 2-BTP. CF_3I has been available in small commercial quantities for some time, but only limited interest has been shown in this compound due to cost and comparatively low LOAEL values. The fluoroketone option has not undergone many of the required tests, but based on known data points, the unit would be expected to be heavier, and potentially larger in size, than the options shown in table 16. The 2-BTP agent, which is still in development, will require more agent, but has been shown through testing to fit into a volume similar to what is currently used on Boeing and other commercial aircraft. Additional testing and regulatory approval are required before 2-BTP can be accepted for use. It is estimated that the battery of required tests will be complete by the end of 2012. The results of this testing and regulatory review of the data will determine whether this compound will become commercially available. No additional halocarbon compounds are known to be in development that would be available to be considered in the near term.

4.3.2 Carbon Dioxide.

Hand-held CO_2 fire extinguishers have a long history of use, are known to be safe in a streaming application where people are present, and should be able to reach into inaccessible areas. A major problem exists in the lack of a Class A rating for hand-held extinguishers ranging from 5 pounds (5-B:C rating) to 100 pounds (20-B:C). If the tests show that CO_2 extinguishers cannot extinguish Class A fires of the type likely to be found in cabin fire scenarios, this agent would have to be eliminated from consideration. From past tests [125], more than 10 lb of CO_2 is required to match the seat fire-extinguishing characteristics of 2.5 lb of Halon 1211. Additional concerns regarding CO_2 are related to its limited throw range and potential thermal shock to sensitive electronics. Due to these issues, as well as gross weight requirement, there has been little interest in the development of CO_2 extinguishers for onboard application.

4.3.3 Combination Agents and Foams.

These agents include Surfactant Blend A, Loaded Stream, and Gelled Halocarbon/Dry Chemical Suspension. Although these are listed together, their properties are sufficiently different, therefore, major test procedure differences will probably be required. In the absence of test results, it is impossible to rank the fire extinguishment effectiveness in hand-held extinguishers for aircraft use. They should all prove very effective for Class A fires; however, these agents may lack the ability to penetrate inaccessible areas. A study of hand-held fire extinguishers by FMRC states that “around object capability” for Halon 1301 is good, dry chemical is poor, and water is poor [126]. Most, and possibly all, combination agents may also have problems with penetration and obstacles. Tests with water-based extinguishers have confirmed their inability to pass the hidden fire test. Since the water-based agents are not gaseous, they have limited ability to penetrate significantly through the baffles of the hidden fire test. A test was conducted at the FAA William J. Hughes Technical Center using a sodium bicarbonate extinguisher having a 2.5-lb net charge weight. The dry chemical primarily fell to the floor upon impact with the first baffle. Additionally, there could be some compatibility problems with electrical equipment and, possibly, structural materials with some of the combination agents. Both the Surfactant Blend A and the Gelled Halocarbon/Dry Chemical Suspension series of agents are acceptable under U.S. EPA SNAP.

4.4 CARGO COMPARTMENT.

In 1998, new FAA rules eliminated Class D (prescribed low volume and ventilation rate) as an option for fire safety certification of cargo compartments in certain transport category aircraft. The ruling increased the number of compartments requiring fire suppression systems [127]. Such compartments must now meet the standards of a Class C compartment. Class C compartments require a fire suppression system and are larger than 1000 ft^3; many are larger than 2000 ft^3.

According to an International Halon Replacement Working Group (IHRWG) Cargo Task Group report [128], an aircraft-supplied ignition source is more likely to cause a surface fire than other types of fires. This surface fire would 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, but the Cargo Task Group set, as specified in the Cargo Compartment MPS, four different fire test scenarios (requirements) to address the variety of fires. The cargo compartment fire suppression system must meet the following fire test requirements.

- The system must suppress a Class A deep-seated fire (bulk-loaded cargo) for at least 30 minutes.

- The system must suppress a Class A fire inside a cargo container for at least 30 minutes.

- The system must extinguish a Class B fire (Jet-A fuel) within 5 minutes.

- The system must prevent the explosion of an explosive hydrocarbon mixture by either fire control or inerting the cargo compartment.

The cargo compartments are normally pressurized with a minimum normal pressure corresponding to an altitude of 8000 feet. In flight, the temperatures are maintained above freezing by several means, including ventilation. Cargo compartment fires are detected by smoke and ionization aerosol detectors or thermal sensors. The fire detection system is required to detect and provide a visual indication of the fire to the flight crew within 1 minute after the start of a fire. Also, the system must be capable of detecting a fire at a temperature significantly below the temperature at which the structural integrity of the airplane would be substantially decreased [129]. Fire detection systems are certified using an FAA-approved fire/smoke simulator.

Fire detection systems must provide a warning within 1 minute from the start of a fire to be considered in compliance with 14 CFR 25.858 [130]. The present practice is to control ventilation and drafts within the compartment prior to the activation of the suppression system. However, there is generally a small infiltration of smoke into the passenger compartment through the compartment walls (typically fiberglass liner) and through the door seals. The general practice is to divert the aircraft to the nearest airport on detection of a fire. On long-range (across the ocean) aircraft, suppression is required for up to the maximum diversion time, which could be in excess of 200 minutes [131].

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

The agent or system for cargo compartments must also meet the requirements of 14 CFR 25.795 (b) (3) [132], 14 CFR 25.851, Part B [133], 14 CFR 25.857 [134], and 14 CFR 25.1309 [135].

- The agent or system must be suitable for the types of fires likely to occur. These include Class A and B fires and hazardous materials.

- The discharge of the agent or system must not cause structural damage.

- The agent or system must be able to prevent hazardous quantities of extinguishing agent from entering occupied compartments.

- The agent or system must be able to provide fire suppression over a period of up to the maximum diversion time, which could be in excess of 200 minutes, depending on the aircraft type and route structure.

The agent should have the following attributes.

- Low toxicity, and that it not be an asphyxiant at the concentrations required for extinguishment, is desired to ensure the personnel safety in the event of an accidental discharge while the compartment is occupied. This would also be beneficial in the event of a false alarm while animals are carried in the cargo bay. Furthermore, 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," per 14 CFR 25.857 [134]. 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, per 14 CFR Part 26, appendix F (part 1 for Bunsen burner, part 3 for oil burner) [136]. Therefore, it is unlikely that smoke or extinguishing agent in hazardous quantities would escape from cargo compartments of properly maintained aircraft.

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

- The agent should not require extensive clean-up postdischarge. Cargo bays have many difficult to reach areas due to structure, cargo-handling equipment, and other features. Equipment centers, such as electronics bays, are often located nearby and could also become contaminated if agents requiring clean-up entered them. This concern is exacerbated if the agent is corrosive or conductive.

- The agent or system should not be subject to any additional transport restrictions (relative to current Halon 1301-based systems) that would hinder shipping spare components in aircraft on-ground situations.

The FAA distributed a survey package to airlines and airframe manufacturers in 1996 to determine opinions on agents and technologies proposed for cargo compartments. The response to the survey was poor, but the majority (60%) of the respondents preferred halocarbons, with a small, but significant, number believing that water and particulate aerosols were best [137]. The respondents unanimously agreed that the high-expansion foams are not appropriate for use in cargo compartments. Federal Express has since developed a medium-expansion foam FSS that is widely used in its aircraft fleet. (See section 4.4.4 for further information.)

An MPS for aircraft cargo compartment gaseous fire suppression systems report was published September 2000 [138]. The MPS document provides the extinguishing or suppressing performance of Halon 1301 when subjected to the four fire scenarios mentioned in section 4.4 (the standard test protocols). The MPS has been updated twice since 2000. The current MPS [139] updated the aerosol can explosion test protocol to allow either a "long" or "short" test protocol. The "long" test protocol combines the aerosol can test with the bulk fire test, whereas the "short" protocol is the aerosol can test alone. If temperatures can be maintained below 212°F or the fire is extinguished, the aerosol can simulator is not required to be discharged or activated to pass the test.

To date, several promising agents have failed the aerosol can test. HFC-125, 2-BTP, and FK-5-1-12 failed the aerosol can test by enhancing the overpressure (relative to an unsuppressed event) when agent concentrations fell below the design concentrations [140 and 141]. This is in stark contrast to Halon 1301, which still reduces the pressure pulse (relative to the unsuppressed event) when below inerting concentrations. In addition, FK-5-1-12 also failed to fully control the bulk load fire test (as configured).

FAA test data are now available on Halon 1301, HFC-125, HFC-227ea, PGA, 2-BTP, FK-5-1-12, and water mist. The MPS requirements are shown in table 17 for a 2000-ft^3 cargo compartment.

Table 17. Acceptance Criteria for a 2000-ft^3 Cargo Compartment From Reference 139

Fire Scenario	Maximum Temperature °F (°C)	Maximum Pressure psi (kPa)	Maximum Temperature-Time Area °F-minutes (°C-minutes)	Comments
Bulk Load	720 (382)	[1]	9,940 (5,024)	Temperature limit starts 2 minutes after suppression system activation. Temperature-Time area from 2 to 30 minutes after suppression system activation.
Containerized Load	650 (343)	[1]	14,040 (7,302)	Temperature limit starts 2 minutes after suppression system activation. Temperature-Time area from 2 to 30 minutes after suppression system activation.
Surface Fire	570 (299)	[1]	1,230 (594)	Temperature limit starts 2 minutes after suppression system activation. Temperature-Time area from 2 to 7 minutes after suppression system activation.
Aerosol Can	212 (100)[2]	0	[1]	There shall be no explosion.

Notes:

[1] Not applicable.
[2] Only applicable to "long" aerosol can test.

4.4.1 Water and Water-Based Agents.

Water meets almost all the requirements provided in section 4.4, including the long aerosol can test. Water is the most common fire-extinguishing agent for ordinary combustibles. The efficiency of the agent depends on the application method (sprinkler, mist, total flood, zoned application, etc.). Several investigators have determined it to be as effective as Halon 1301 for identical fire threats. Water can be used in misting or sprinkler applications. It is recommended that mist system tests be performed; however, sprinkler systems could be considered. Both sprinklers and mist systems could use a zoned application. It is possible to use surfactant/water or dry chemical/water blends; however, in the absence of test results to the contrary, it is difficult to determine if there would be a benefit from using these mixtures. Moreover, these mixtures could cause an increase in cleanup efforts.

The FAA William J. Hughes Technical Center has performed a mist system test program for the FAA TC-10 cargo test compartment. The objective was to design and install a water mist system that would prevent a fire in a luggage container from spreading to an adjacent luggage container and maintain temperatures within the space below 350°C for 90 minutes. The program showed that one mist system passed both the loaded luggage container and bulk-loading fire tests for the TC-10 cargo test compartment using 30 gallons of water [142]. These results are encouraging and suggest that an area-coverage water mist system may impose a lower TOGW penalty for large cargo compartments. Another advantage may be lower sensitivity (compared to gaseous agents) to compartment leakage.

It has been suggested that water-based fire suppression systems may be recharged from the portable water system if the initial capacity fails to adequately suppress a fire. It has also been proposed that it may be possible to recycle runoff water from the discharge to reduce the amount of water needed to provide protection. These proposals would require significant engineering to be incorporated into the system and may not be practical. Water-based systems may provide an acceptable environment for animals in the event of a false discharge. In addition, water-based systems may not depend on the integrity of the compartment liner for effective performance. Some concerns have been expressed about the possibility of stored water freezing; however, there are design solutions available to prevent such occurrences.

4.4.2 Halocarbons and Halocarbon Blends.

Table 18 rates halocarbons for various criteria important for its use in cargo compartments. Here, “1” denotes the highest rating, indicating that it is the most attractive for the stated criteria. Ratings were arbitrarily assigned.

Design concentrations were given the following ratings:

- 5% and below: 1
- 5% to 8%: 2
- 8% to 11%: 3
- above 11%: 4

Storage volume and weight equivalents were given the following ratings:

- 1.0 or less: 1
- 1.0 to 1.5: 2
- 1.5 to 2.0: 3
- above 2.0: 4

Table 18. Rating Matrix for Candidate Halocarbons for Cargo Compartments

Agent	Class B Fire Design Concentration (%)	Class B Fire Weight Equivalent	Class B Fire Storage Volume Equivalent	Known or Potential Regulatory Restrictions [1]	Cardiac Sensitization NOAEL
HCFC-124	3	3	3	3	4
HCFC Blend A	3	2	2	3	2
HFC-23	4	3	4	2	1
HFC-125	3	3	4	2	3
HFC-227ea	2	3	3	2	2
HFC-236fa	2	2	2	2	2
FC-218	3[2]	4[2]	4	3	1
FC-3-1-10	2	3	3	3	1
FIC-13I1	1	1	1	1	5

Notes:

[1] Only includes regulatory restrictions based on environmental impact. Does not include restrictions due to toxicity.

[2] The storage volume and weight equivalents used in determining ratings for this agent, which does not appear in NFPA 2001, were calculated from the design concentration, molecular weight, and liquid density. Ratings for the other agents were determined from equivalents calculated using weight requirements and fill densities as reported in NFPA 2001 [17]. See tables 8 and 9.

Note that these effectiveness ratings were derived from data for a Class B fire with *n*-heptane fuel. They may not indicate performance for a deep-seated Class A fire, which is the probable fire in cargo compartments. Agents with NOAEL values of 30% or above are rated a 1 for toxicity. Agents with NOAEL values less than 30%, but are acceptable (or likely to be acceptable) for total flood in normally occupied areas under NFPA 2001 [17], are given a rating of 2. HFC-125, whose NOAEL value is only slightly less than that which would allow total flood use in normally occupied areas, is given a rating of 3. HCFC-124 with a NOAEL of 1.0 and FIC-13I1 with a NOAEL of 0.2 are rated 4 and 5, respectively. Note, that cargo compartments are not considered to be normally occupied areas. Due to its high-vapor pressure, the delivery characteristics and system requirements for HFC-23 may differ significantly from most other halocarbons.

Research has indicated that misting (and, perhaps, standard discharge) of higher-molecular weight (lower-vapor pressure) halocarbons can provide total-flood-like protection of enclosed areas [143]. At present, no manufacturer offers such a system, and the technology must still be considered unproven. However, the possibility that one or more new, lower-vapor pressure compounds will be proposed for total-flood protection must be considered.

Since Class A fires develop slowly, it is feasible to detect a fire in a cargo compartment within a zone and suppress it by a zoned fire suppression system. In the past, total-flood systems have been used, but the federal regulations do not mandate a total-flood system. There are two categories of halocarbon agent: liquid agents, which could be applied in a zoned application, and gaseous agents for total-flood applications. It is recommended that test protocols for both types of agents be developed.

4.4.3 Particulate Aerosols.

The FAA has performed preliminary tests on type S.F.E. formulation D particulate aerosols using modular units of 4 kilograms each. The test evaluated the S.F.E. aerosol performance on deep-seated Class A fires, specifically shredded paper. The FAA requirements were to extinguish the fire and inert the protected volume for 30 minutes. The S.F.E. particulate aerosol formulation D was tested at an application concentration of 60-100 gr/m^3. The agent partially suppressed a Class A fire in a 2357-ft^3 compartment and inerted the volume for approximately 17 minutes [60].

These preliminary results and the possible weight/volume cost benefits of the particulate aerosols technology suggest that it is a potentially viable agent for aircraft fire protection, and the technology should be further evaluated.

4.4.4 Foams.

Federal Express has developed a medium-expansion FSS for cargo containers. The system automatically determines the position of the fire on the main deck in the freighter/cargo compartment, penetrates the appropriate container, and injects a proprietary foam aerated with argon gas [144]. Federal Express's entire MD-11 fleet has been modified with the FSS, and a prototype system has been installed on a Boeing 777.

4.5 LAVATORY TRASH RECEPTACLE.

4.5.1 Background.

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 receptacle, such as a lit cigarette. The trash receptacles are designed to contain the fire. No fire detection system is provided in the receptacle. Rulemaking was implemented on April 29, 1987, that required each lavatory trash receptacle to be equipped with a built-in automatic fire extinguisher that discharges automatically into the receptacle in the event of a fire. To accomplish this, the extinguisher bottle incorporates a eutectic device at the end of a tube directed into the receptacle. In the event of a fire, the heat generated melts the eutectic tip, releasing the agent directly into the receptacle. Historically, a small amount of agent (100 grams of Halon 1301) has effectively extinguished this type of fire. Halon 1211 (0.3 kg (0.66 lb), 0.5 kg (1.1 lb), and 0.12 kg (0.26 lb)) has also been used.

The agent used for trash receptacles must meet the following requirements in addition to the essential requirements identified in section 4.1.

- The agent must extinguish a Class A (paper towel) fire, as defined in the MPS [145].
- The agent's toxicity, if the same quantity of agent used for the trash receptacle is released into the entire lavatory, must not exceed the NOAEL.

A survey of 24 airlines showed that 66% preferred using halocarbons or halocarbon blends in aircraft lavatory trash receptacles [146]. The reasons given for this preference were reduced weight, minimum impact on current installation, and effectiveness. Sixteen percent preferred water, and the reasons given were low environmental impact and reduced maintenance. Weight and effectiveness concerns were mentioned as potential drawbacks for water. The IHRWG and the FAA have established an MPS for lavatory trash receptacle fire extinguishers [145]. The following agent types are most likely to have utility in lavatory trash receptacle applications: HFC-125, HFC-227ea, HFC-236fa, and Envirogel.

4.5.2 Water-Based and Combination Agents.

Water, water/surfactant (e.g., Surfactant Blend A), dry chemical/water mixtures, and combination agents meet the requirements in section 4.5.1 for extinguishing laboratory trash receptacle fires. Water is the most common fire-extinguishing agent (sprinkler or mist). Freeze protection would have to be considered for use on airplanes. Loaded stream or surfactant blends could improve surface wetting of Class A materials. Water-based and combination agents are likely to be more effective on Class A materials than halocarbons. Envirogel, combined with other agents such as FE-36, has been considered by fire extinguisher manufacturers.

4.5.3 Halocarbons and Halocarbon Blends.

Most halocarbons provide acceptable extinguishing ability for extinguishing lavoratory trash receptacle fires. Moreover, recent work with HFC-227ea suggests that some halocarbons may allow retrofit into existing systems [147]. However, to achieve the required low-temperature performance (5°F), some halocarbons will need to be pressurized with nitrogen. HFC-227ea (FM-200) was extensively tested and proven to be effective. This agent requires superpressurization with nitrogen to achieve a low-temperature performance. HFC-236fa (FE-36) was also tested and proven to be effective.

4.5.4 Status of Lavatory Trash Receptacle Implementation by Carriers.

4.5.4.1 Airbus Status.

In 2005, Airbus replaced all Halon 1301 automatic fire extinguishers used in production lavatory trash receptacles with HFC-236fa (FE-36). The FE-36 automatic fire extinguishers were also made available as a drop-in replacement for in-service airplanes.

4.5.4.2 Boeing Commercial Airplane Status.

In 2006, Boeing replaced all Halon 1301 automatic fire extinguishers used in production lavatory trash receptacles with HFC-227ea (FM-200). Boeing is currently working with the FAA to gain approval to allow FM-200 automatic fire extinguishers to be used in all models of in-service airplanes.

4.5.4.3 Bombardier Aerospace Status.

Bombardier is in the initial stages of replacing the halon automatic fire extinguishers in the lavatory trash receptacles for production aircraft. The CSeries (not yet in production) will not have Halon automatic fire extinguishers in its lavatory trash receptacles.

4.5.4.4 Embraer Status.

Embraer has selected HFC-236fa (FE-36) as a primary candidate to replace Halon 1301 automatic fire extinguishers used in lavatory trash receptacles. The replacement process in production aircraft has started for some customers. New aircraft in development will not have halon automatic fire extinguishers in its lavatory trash receptacles.

4.6 SUMMARY.

The current report is the third update of the original report, presenting a wealth of information and data on options for the use of halons onboard aircraft. This update reflects the significant changes since the previous updated version in 2002.

In recent years, environmental concerns have spurred actions to remove halon extinguishing agents in commercial aviation. The EC has adopted a regulation to require application-dependent “cut off dates” for the use of halon in new type certificates (new airplane designs) and “end dates” for the actual removal and replacement of halon in operating aircraft. Also, the ICAO adopted a resolution for production airplanes that requires a halon replacement agent for lavatory and hand-held extinguishers by 2011 and 2016, respectively. Also, although the manufacture of halon was banned because of ozone depletion, future restrictions related to Global Warming Potential (GWP) is an increasing concern of the aircraft manufacturers.

MPSs were developed to describe the fire tests required to demonstrate fire extinguishment or suppression effectiveness equivalent to halon for each aircraft application. Agents and systems were tested using the test protocols of the MPSs for hand-held extinguishers, lavatory extinguishers, engine, and cargo compartments. A number of agents passed the MPS tests for hand-held and lavatory extinguishers. Three halocarbon agents have been tested in accordance with the MPS for engines, and the minimum extinguishing concentration has been determined. One of these agents, a liquid at room temperature, which gasifies quickly, has been developed extensively by one major aircraft manufacturer for use in a new aircraft. However, concern with extinguishing effectiveness at low temperature has tempered this activity. Another agent, a solid aerosol, has also undergone extensive tests in the engine MPS, which was revised to take into account its highly directional discharge characteristics compared to total-flooding gaseous agents such as halon and the replacement halocarbons. Fire-extinguishing tests will be conducted in

2012 in a real engine because the solid aerosol differs considerably in discharge behavior than traditional total-flooding agents. Cargo compartment fire suppression has proven to be the most difficult application for halon replacement agents. A number of gaseous agents have been tested in accordance with the MPS, but have been discounted because of poor or potentially hazardous behavior. Water mist has shown promise when MPS tested, perhaps in combination with an inert gas system, but these approaches would require significant systems development. Halon replacement in cargo compartments represents the largest future challenge.

Since the last report in 2002, Airbus and Boeing have installed halon replacement agents in lavatory trash extinguishers on all their production aircraft, and Bombardier and Embraer have started the replacement process in their production aircraft. Although three agents meet the MPS for hand-held extinguishers, none are in use because they are heavier than halon and require a larger bottle, and because of GWP concerns. However, Boeing is committed to supporting the commercialization of a promising, environmentally acceptable agent.

This report summarizes available fire suppression halocarbon replacement agents and alternative agents. It provides information on extinguishing effectiveness, physical properties, environmental, and toxicological properties of these agents. Manufacturers, product names, and company contact information are provided for commercially available agents and systems.

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APPENDIX A—COMPANIES AND MANUFACTURERS

Category	Company Information	Agent/System/Product
Halocarbon Agent Producers	Ajay North America, LLC 1400 Industry Road Powder Springs, GA 30127 USA Phone: 770-943-6202 Fax: 770-439-0369 Email: sales@ajay-sqm.com URL: http://www.iodeal.com or http://www.ajay-sqm.com	CF_3I (Triodide)
	American Pacific Corporation Halotron Division 3883 Howard Hughes Parkway Suite 700 Las Vegas, NV 89169 USA Phone: 702-735-2200 Fax: 702-735-4876 Email: Halotron@apfc.com URL: http://www.halotron.com	HCFC Blend B (Halotron I) HFC Blend B (Halotron II) (2-BTP)
	3M Company Electronics Markets Materials Division Building 0224-03S-11 St. Paul, MN 55144-1000 USA Phone: 1-800-810-8513 or Outside US: 1-651-575-6888 Fax: 651-732-7735 Email: emmdcustomerservice@mmm.com URL: http://www.3m.com/novec1230fluid	3M™Novec™1230 Fire Protection Fluid
	DuPont Company Chemicals and Fluoroproducts Chestnut Run Plaza, Bldg 711 4417 Lancaster Pike Wilmington, DE 19880 USA Phone: 1-800-473-7790 Fax: 302-999-4727 Email: info@dupont.com URL: http://www.cleanagents/dupont.com	HFC-227ea (FM-200) HFC-23 (FE-13) HFC-125 (FE-25) HFC-236fa (FE-36) HCFC-123 (FE-232) HCFC-124 (FE-241)
	Safety Hi-Tech S.r.l. Via Cavour 96 67051 Avezzano (AQ) Italy Phone: 39 863 1940720 Fax: 39 863 1940724 Email: mail@safetyhitech.com URL: http://www.safetyhitech.com	HCFC Blend A (NAF S-III) HCFC Blend D (Blitz) HCFC Blend E (NAF P-IV) HFC-125 plus additive (NAF S 125) HFC-227ea plus additive (NAF S 227) HFC/FIC Blend plus additive (NAF P 5)

Category	Company Information	Agent/System/Product
Water Misting Systems	Amerex Corporation Amerex Defense 7595 Gadsden Highway Trussville, AL 35173-0081 USA Phone: 205-655-3271 Fax: 205-655-0976 Email: jmccullough@amarex-fire.com URL: http://www.amarex-fire.com	Potassium Acetate Wet Chemical (K-Ace) Fire Suppression System
	Chemetron Fire Systems 4801 Southwick Drive, 3rd Floor Matteson, IL 60443-2254 USA Phone: 1-800-878-5631 Fax: 708-748-2847 Email: info@chemetron.com URL: http://www.chemetron.com	Chemetron: Low Pressure
	Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA Phone: 816-229-3405 Email: fpssales@fike.com URL: www.fike.com	Micromist: Medium Pressure
	FOGTEC Brandschutz GmbH & Co. KG Schanzenstr. 19a D-51063 Cologne Germany Phone: 49 221 96223-0 Fax: 49 221 96223-30 Email: contact@fogtec.com URL: http://www.fogtec.com	FOGTEC High- and Low-Pressure Water Mist Systems Hybrid Water Mist Systems Water Mist Foam Systems
	Ginge-Kerr Denmark A/S Industriholmen 17-19 DK-2650 Hvidovre Denmark Phone: 45 36 7711 31 Email: ginge@ginge-kerr.dk URL: http://www.ginge-kerr.com	AquaSafe: Low Pressure
	GW Sprinkler A/S Kastanievej 15 DK-5620 Glamsbjerg Denmark Phone: 45 64 72 20 55 Fax: 45 64 72 22 55 Email: ginge@ginge-kerr.dk URL: http://www.ginge-kerr.com	Low/Medium Pressure

Category	Company Information	Agent/System/Product
Water Misting Systems	Kidde-Deugra (Germany) Brandschutzsysteme GmbH D-40880 Ratingen Germany Phone: 49 2102 405 149 Fax: 49 2102 405 151	AquaSafe: Low Pressure
	Life Mist Technologies P.P.Box 239 Paoli, PA 19301 USA Phone: 610-644-0419 Fax: 908-363-8215 Email: info@lifemist-tech.com URL: www.lifemist-tech.com	Life Mist: Low Pressure
	Marioff North America 400 Main Street Asland, MA 01721 USA Phone: 1-800-654-7763 Ext. 2751 Email: John.Harding@marioff.net URL: http://www.marioff.com	HI-FOG: High-Pressure Water Mist
	Marioff Oy Virnatie 3, Fl-01301 Vantaa, Finland, Phone: +358(0)6880-000 url: www.marioff.com	HI-FOG: High-Pressure Water Mist
	MicroMist Systems (formerly Baumac International) A Division of Sorenson Engineering, Inc. 32032 Dunlop Blvd. Yucaipa, CA 92399 USA Phone: 909-795-7600 Fax: 909-446-0954 Email: info@micromist.com URL: www.micromist.com	MicroMist: High Pressure
	Phirex, Australia Phirex Technology Centre 4 Dellemaarte Rd. Wangera Industrial Estate Wangera, Australia Phone: +61 8-94080908 Fax: +61-8-94080954 Email: sales@phirexfareast.com URL: www.phirex.com.au	Mistex: Low/Medium Pressure Fogex: High Pressure
	SECURIPLEX LLC 3710 Lakeside Court Mobile, AL 36693 USA Phone: 251-602-6111 Fax: 251-661-5340 Email: info@sucuriplexllc.com URL: http://www.securiplexllc.com	Water Mist Fire Suppression Systems

Category	Company Information	Agent/System/Product
Water Misting Systems	Semco Maritime A/S, Denmark Stenhuggervej 12-14 DK-6710 Esbjerg V Denmark Phone: +45 7916 6666 Fax: +45 7515 6580 Email: semco@semcomaritime.com URL: www.semcomaritime.com	Sem-Safe: High Pressure
	Spraying Systems Co. North Avenue at Schmale Road Carol Stream, IL 60188 USA Phone: 630-665-5000 Fax: 630-260-0842 Email: info@spray.com URL: www.spray.com	FogJet: High Pressure
	Tyco Fire Supression & Building Products (formerly Grinnell) 1400 Penbrook Parkway Lansdale, PA 19446 USA Phone: 800-558-5236 Fax: 800-877-1295 URL: www.tyco-fire.com	AquaMist: Medium Pressure
	Tyco Fire & Integrated Solutions (UK) Ltd. (formerly Total Walther) Tyco Park, Grimshaw Lane Newton Heath, Manchester M40 2WL Phone: +44 ()) 161 455 4400 Fax: +44 (0) 161 455 4541 URL: www.tycofis.co.uk	Micro Drop: Low Pressure ProtectoMist: Low Pressure AquaMist: Medium Pressure
	Ultra Fog AB Backa Strandgata 18 SE-422 44 Hisings Backa Sweden Phone: 46 31 979870 Fax: 46 31 982368 Email: info@ultrafog.se URL: http://www.ultrafog.se	High Pressure
	Vitaulic 4901 Kesslerville Road Easton, PA 18040-6714 USA Phone: 610-559-3300 Email: vortex@victaulic.com URL: http://www.vitaulic.com	Vortex: Low Pressure
Particulate Aerosols	Amerex Corporation Amerex Defense 7595 Gadsden Highway Trussville, AL 35173-0081 USA Phone: 205-655-3271 Fax: 205-655-0976 Email: jmccullough@amarex-fire.com URL: http://www.amarex-fire.com	Aerosol Generator (Stat-X®) Systems

Category	Company Information	Agent/System/Product
Particulate Aerosols	Dynamit Nobel Defence GmbH Dynameco Dr. –Hermann-Fleck-Allee 8 57299 Burbach-Wurgendorf Germany Phone: 49 2736 46 2104 Fax: 49 2736 46 2107 Email: info@dynameco.com URL: http://www.dynameco.com	Soyus
	Fireaway LLC 5852 Baker Road Minnetonka, MN 55345 USA Phone: 952-935-9745 Fax: 952-935-9757 Email: mgross@statx.com URL: http://www.statx.com	Stat-X
	Kidde Aerospace & Defense 4200 Airport Drive NW Wilson, NC 27896 USA Phone: 252-246-7004 Fax: 252-246-7181 Email: info@Kiddeaerospace.com URL: www.kiddeaerospace.com	KSA
	Kidde-Deugra Brandschutzsysteme GmbH Halskestrasse 30 D-40880 Ratingen Germany Phone: 49 2102 405 149 Fax: 49 2102 405 151	KD-A 96
	Pyrogen Corporation 18 Barry Avenue Mortdale, NSW2223 Australia Phone: +61-2-9586 3200 Email: enquires@pyrogen.com URL: www.pyrogen.com	Powdered Aerosol C (Pyrogen)
	Spectrex Inc. Peckman Industrial Park 218 Little Falls Road Cedar Grove, NJ 07009 USA Phone: 973-239-8398 Fax: 973-239-7614 Email: Spectrex@spectrex-inc.com URL: http://www.spectrex-inc.com	Powdered Aerosol A (SFE), Green EX, Micro-K
Inert Gases	Ansul One Stanton Street Marinette, WI 54143 USA Phone: 715-735-7411 Fax: 715-732-3479 Email: tcarman@tycoint.com URL: http://www.ansul.com	IG-541 (Inergen)

Category	Company Information	Agent/System/Product
Inert Gases	Fire Eater Volundsvej 17 DK-3400 Hillerod Denmark Phone: +45 7022 2769 Email: info@fire-eater.com URL: www.fire-eater.com	IG-541
	Ginge-Kerr Denmark A/S Industriholmen 17-19 DK-2650 Hvidovre Denmark Phone: 45 36 7711 31 Email: ginge@ginge-kerr.dk URL: http://www.ginge-kerr.com	IG-55 (Argonite)
	Koatsu 1-310 Kitahonmachi, Itami, Hyogo Fref. 664-0836, Japan Phone: 81-72-782-8561 Fax: 81-72-782-8511 URL: www.koatsu.co.jp	IG-100
	Minimax GmbH Industriestrasse 10/12 23840 Bad Oldesloe Phone: (0 45 31) 8 03-0 Fax: (0 45 31) 8 03-248 Email: info@minimax.de URL: www.minimax.de	IG-01 (Argotec)
	Tyco Fire Suppression & Building Products (formerly Grinnell) 1400 Pennbrook Parkway Lansdale, PA 19446 USA Phone: 800-558-5236 Fax: 800-877-1295 URL: www.tyco-fire.com	
Gas Generators	Aerojet – General Corporation Force Projection and Protection Safety Products 11650 137th Place NE Redmond, WA 98052 USA Phone: 425-885-5000 Fax: 425-882-5748 Email: Jennifer.mccormick@aerojet.com URL: http://www.aerojet.com/capabilities/fire.php	Solid Propellant Fire Extinguisher (SPFE) Hybrid Fire Extinguisher (HFE)

Category	Company Information	Agent/System/Product
Hand-Held Fire Extinguishers	Amerex Corporation Amerex Defense 7595 Gadsden Highway Trussville, AL 35173-0081 USA Phone: 205-655-3271 Fax: 205-655-0976 Email: jmccullough@amerex-fire.com URL: http://www.amerex-fire.com	HFC Blend B (Halotron I) Agent Hand Portable & Wheeled FK-5-1-12 (Novec 1230) Agent Hand Portable & Wheeled Water Mist Hand Portable Potassium Acetate (K-Ace) Hand Portable, Wheeled, & Hand-Line Foam AFFF Hand Portable & Wheeled Alcohol Resistant Foam FFFP Hand Portable & Wheeled
	Fire Fighting Enterprises Ltd. 9 Hunting Gate Hitchin, Hertfordshire, SG4 OTJ, United Kingdom Phone: 44 1462 444740 Email: sales@ffeuk.com URL: http://www.ffeuk.com	
Halocarbon Fire Suppression System Hardware	Amerex Corporation Amerex Defense 7595 Gadsden Highway Trussville, AL 35173-0081 USA Phone: 205-655-3271 Fax: 205-655-0976 Email: jmccullough@amerex-fire.com URL: http://www.amerex-fire.com	HFC-227ea (FM200®) Fire Suppression Systems FK-5-1-12 (Novec 1230) Fire Suppression Systems
	Fire Combat; A Division of Sensor Electronics Corporation 2650 Industrial Parkway Marinette, WI 54143 USA Phone: 715-735-9058 Fax: 715-735-7223 Email: shornick@firecombat.com URL: http://www.firecombat.com	Mobile Fire Suppression and Fire Suppression Components
Combination and New Foam Agents	FOGTEC Brandschutz GmbH & Co. KG Schanzenstr. 19a D-51063 Cologne Germany Phone: 49 221 96223-0 Fax: 49 221 96223-30 Email: contact@fogtec.com URL: http://www.fogtec.com	High- and Low-Pressure Water Mist Systems Hybrid Water Mist Systems Water Mist Foam Systems