FINAL REPORT

Review of the Transition Away From Halons in U.S. Civil Aviation Applications

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September 2004

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Preface and Peer Review Summary

This report was prepared by ICF Consulting (ICF) and ICF's subcontractor, Hughes Associates, Inc. (HAI), under a contract with the U.S. Environmental Protection Agency (EPA). The report examines the status of the transition away from halons in the U.S. civil aviation sector and describes technical, regulatory, and procedural issues impeding the transition to next generation alternatives.

In March 2004, the draft final report was peer reviewed for its technical content to ensure that information was both current and accurate. Reviewers included Mr. Jeff Gibson of American Pacific, Mr. Dave Catchpole of BP Exploration, Mr. Steve McCormick of the U.S. Army, and representatives of both Kidde Aerospace and The Boeing Company. Based on their input, edits and corrections have been incorporated into the report.

In the written comments received from peer reviewers, a number of technical areas were identified as needing further clarification or modification. For example, reviewers commented on the accuracy of various cost data, noting the inability to precisely predict the future cost of Halon 1211, and questioning the cost/weight penalty associated with alternative agents that were originally cited in the report.

Additionally, some reviewers identified the need to acknowledge other technical constraints in the report. In particular, procedural requirements associated with lavatory trash receptacle extinguishing systems ("Lavex systems") involving designing, conforming, qualifying, and certifying new extinguishing systems on commercial aircraft have been added to the report.

In addition, several comments pertaining to regulatory issues were also received. Some noted that the barriers to halon replacement in civil aviation applications may not be overcome by the introduction of regulations alone. One reviewer noted that any mandated phaseout would spur a transition to alternatives in new commercial aircraft several years before halon supplies dwindle—not in the same year of the mandated phaseout—to avoid the re-engineering and re-certification costs associated with system retrofits.

All comments received from reviewers were considered, and the document was modified if appropriate. Certain comments regarding policy, which were considered to be outside the scope of this report, were not incorporated into the final document.

The authors wish to acknowledge every individual that contributed to the development of this report, and in particular to thank reviewers for their extensive time, effort, and expert guidance. The involvement of peer reviewers and other scientific contacts greatly enhanced the technical soundness of this report. ICF Consulting accepts responsibility for all information presented and for any errors contained in this document.

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1. Executive Summary

This report examines current Federal Aviation Administration (FAA) Minimum Performance Standards (MPSs) and fire test scenarios employed to evaluate and approve alternatives to ozone-depleting halons in civil aviation fire extinguishing systems. Halon fire extinguishing products and systems are used in the following aviation applications: (1) lavatory trash receptacle extinguishing systems, (2) handheld extinguishers, (3) engine nacelle/auxiliary power unit (APU) protection systems, and (4) cargo compartment extinguishing systems. To date, all new installations of fire extinguishing systems for lavatory trash receptacles, engines, and cargo compartments use Halon 1301; all new installations of handheld extinguishers use Halon 1211. After assessing the MPSs and fire test scenarios used for the above aviation applications, several major findings can be made:

- The fire test scenarios described in the current FAA MPSs are realistic. Finalized MPSs are available for lavatory systems, handheld extinguishers, and cargo compartment fire protection systems; a finalized MPS is not yet available for engine nacelle/APU protection systems.
- The MPS test protocols for lavatory trash receptacle extinguishing systems, handheld extinguishers, and engine nacelle/auxiliary power unit (APU) protection systems have been designed to provide an equivalent level of safety to that of halons, and the test protocol goals for halon alternatives are not excessively stringent. However, debate surrounds the MPS test protocol for cargo compartment extinguishing systems which incorporates an alternative aerosol can test for systems that do not employ gaseous agents (e.g., water mist/inert gas system). The failure of these systems to pass the original aerosol can test raises a concern by some that the objective of providing a level of safety equivalent to that of halon may not be met.
- Alternatives to halons are available and have passed testing that meets the requirements of the relevant MPS for almost all applications; the exception is for engine nacelle/APU protection systems which currently lack a finalized MPS.
- To date there are no known in-service examples or new aircraft designs that replace halons in aviation fire protection applications.

In addition to assessing MPSs and test scenarios for all civil aviation fire protection applications and reviewing the status of halon replacement in each end use, this report identifies the barriers to adoption. Given that finalized MPSs are not yet available for all aviation fire protection applications, and that new aircraft are still being designed with halons, it is apparent that barriers exist to the transition away from halons in civil aviation a decade after the end of halon production in developed countries.

Table 1 illustrates the procedures that need to be completed in order for halons to be replaced in the specified applications on new airframes, along with the estimated time for their completion; the marked boxes indicate those steps that have been achieved. The implications of this timeline and the current status of halon replacement in these applications are further discussed in Chapter 9 in the context of considering various halon phaseout options for civil aviation.

Table 1. Progress Toward the Introduction of Alternative Extinguishing Systems in New Aircraft Design

Step	Estimated Time Required to Complete (months)	Status by Civil Aviation Application			
		Lavatory Trash Receptacle	Handheld	Engine Nacelle/APU	Cargo Compartment
1) FAA Development of Final MPS	35+	X	X	Ongoing	X
2) FAA Testing to Finalized MPS	6-12	X	X	Ongoing	X
3) Airframe Manufacturer Qualification Testing	12-18	X			
4) Preparation and Submittal of Modified Type Certificate	3-6	Ongoing			
5) FAA Approval of Modified Type Certificate	3-6				
6) Alternative Unit on Drawing, Installation Allowed	3-6				

The main barriers to the transition away from halons in civil aviation have been identified as: (1) the lack of any regulatory mandate to replace halons, (2) regulatory concerns associated with some of the halon alternatives, (3) space, weight, and cost penalties of the halon alternatives, and (4) the lack of effective leadership within the aviation community in setting non-regulatory halon phaseout target dates or goals. While it is not the intent of this report to fully address all of these potential barriers to the halon transition in civil aviation, it is worth noting that other sectors that formerly relied on halons (e.g., military, merchant shipping, oil and gas production, explosion suppression) faced many of these same "barriers" but have successfully made the transition away from halons.

In particular, the lack of a mandate to eliminate halon use has been cited as a significant regulatory constraint to the transition away from halons in civil aviation. With the phaseout of production of halons in 1994, the post-phaseout U.S. halon management strategy combines government regulations with revisions to industry standards and practices, a focused program to develop, evaluate and promote alternatives, public and industry outreach, voluntary codes of practice, and support for halon recycling and banking efforts. Fire protection industry leadership has been instrumental in the significant progress made to date, including the earliest production phaseout of an ozone-depleting substance, a halt to emissive testing and training procedures and service and maintenance practices, and progress in implementing halon recycling and recovery programs. Regulations that allow the continued use of recycled halon have enabled users to avoid the costs of early equipment retirement, prevented unnecessary emissions, allowed for a smooth transition to available alternatives, and enabled market forces to move halon from non-critical to critical uses. As such, current halon needs (including those of civil aviation) are being met with halon from existing stockpiles or from decommissioned systems reaching the end of useful equipment lifetime. Prudent users are aware that this halon source will diminish and eventually disappear as the number of remaining halon installations dwindle. Some users that have critical halon needs, such as the military, have assessed current and future needs and taken the necessary steps to ensure a secure supply. Since the lack of a mandate to halt halon use has not forestalled progress in the transition away from halons in many sectors of use (military, essential electronics, oil and gas production), the need for such a requirement must be carefully considered with regard to the transition away from halons in civil aviation.

Other potential regulatory barriers identified include current or future regulations on some of the available alternatives. In particular, consideration of the available alternatives must include the pending regulatory phaseout of hydrochlorofluorocarbon (HCFC) production and any future regulations that ban or severely restrict the use of hydrofluorocarbons (HFCs) in fire suppression applications.

Economic barriers to the transition away from halons in civil aviation are the current relatively low cost of halons and the comparatively higher cost of the alternatives. Currently, airlines continue to employ Halon 1211 and Halon 1301, since recycled halon is readily available at low prices. Conversely, prices for alternative agents are up to 10 times higher. Therefore, until supplies of recycled halon become prohibitively expensive to procure or simply unavailable, the civil aviation industry lacks an economic incentive to move away from halons to the higher-priced alternatives. Furthermore, with the exception of lavatory bottles, the identified alternatives present weight and volume penalties, which translate into economic disincentives.

However, it should be noted that, despite similar cost penalties in other sectors, halon users in those sectors (e.g., military, oil and gas) have successfully transitioned away from halons by maintaining existing halon systems (and retaining that initial equipment investment), but adopting halon alternatives in all new installations. Indeed, a decade earlier, the technical barriers to the transition away from halons were certainly daunting—not only in civil aviation but in all sectors of use—when halon production ended and the search began for suitable alternatives. These barriers were effectively overcome, allowing alternatives to reach the market that were safe and had improved environmental characteristics compared to halons. Extensive performance testing and approval of the alternatives for specific applications and revision of industry codes and standards have allowed adoption of halon alternatives by many sectors of use.

As previously described, halon alternatives in almost all civil aviation applications have been tested to and passed the relevant MPS. However, given that technical constraints must still be addressed (to finalize the engine nacelle/APU MPS and resolve concerns over the finalized Cargo Compartment MPS), and final approval and certification of the alternative systems are still pending, the timing of the actual inclusion of halon alternatives in new aircraft designs remains uncertain. Stated simply, unless the process to design, conform, qualify, and certify new extinguishing systems on commercial aircraft is made a priority by the approval authorities and expedited accordingly, these processes will represent significant barriers to the halon transition.

In short, the status of the transition away from halon in civil aviation reflects progress that has already been made in other sectors of use: minimizing emissions of halons from testing and training practices, recycling and recovery of halons, testing of the available alternatives. Unlike those other sectors, however, the civil aviation industry continues to be dependent on halons, has not demonstrated further progress through adoption of alternatives in new airframe designs, and lacks a focused plan to implement halon alternatives in the near future. Until supplies of recycled halons either become cost-prohibitive to procure or simply unavailable, or until policy changes push a transition to the alternatives, the situation is unlikely to change in the near- to mid-term.

2. Study Objective

Hughes Associates, Inc. (HAI) was requested by ICF to prepare a report on the technical and regulatory barriers impeding the transition from halons to next generation alternatives in civil aviation applications (e.g., lavatories, aircraft engine nacelles). In an effort to better understand and define these barriers, HAI was requested to review the current fire test scenarios employed by the Federal Aviation Administration (FAA) to evaluate fire extinguishing agents and systems. Specific goals of this report are to:

- Provide an overview of the development of the current FAA Minimum Performance Standards (MPSs) and review the current FAA fire test scenarios employed to evaluate:
  - Lavatory protection systems
  - Handheld extinguishers
  - Engine nacelle/auxiliary power unit (APU) protection systems
  - Cargo compartment protection systems
- Examine the MPS fire test scenarios in detail to address questions including:
  - Are the FAA fire test scenarios realistic?
  - Are the test protocol goals for halon alternatives excessively stringent?
  - Which halon alternatives have been tested, and which have passed the fire tests?
  - Should additional steps/testing be undertaken?
- Assess the fire test scenarios and recommend whether they should be kept or changed.
- Identify technical, regulatory, economic, and other barriers impeding the transition from halons to next generation alternatives; recommend actions to address barriers.
- Assess various phaseout options to expedite the transition away from halons in civil aviation fire protection applications.

3. Introduction

The Montreal Protocol on Substances That Deplete the Ozone Layer (Montreal Protocol) is a landmark international agreement designed to protect the stratospheric ozone layer, which acts as a shield against the harmful effects of ultraviolet radiation from the sun. The treaty was originally signed in 1987 and substantially amended in 1990, 1992, and 1997. The Montreal Protocol stipulates phaseout schedules for the production and consumption of compounds that deplete ozone in the stratosphere.

Halons, historically used in fire extinguishing applications, have extremely high ozone depletion potentials (ODPs) due to the presence of bromine, which reacts more strongly with ozone than chlorine. Specifically, Halon 1211 has an ODP of 3.0 and Halon 1301 has an ODP of 10.0 (relative to CFC-11 which has an ODP of 1.0). Halon has been the fire suppression agent of choice in many applications because it is a clean agent (i.e., does not leave residue on equipment or in the protected enclosure after discharge), is safe for limited, acute human exposure, works well over broad temperature ranges, and requires relatively simple design and installation.

To date, significant progress has been made in reducing emission levels of Halon 1211 and 1301 from nearly all applications.[1] Continued dependence on halon in civil aviation applications, however, remains an issue.

Recognizing the environmental threat posed by halons, the United States Federal Aviation Administration (FAA) initiated a program to determine performance criteria and certification methods with the objective of developing Minimum Performance Standards (MPS) for nonhalon fire extinguishing and suppression systems onboard aircraft. This program is being performed in cooperation with the Joint Aviation Authorities (JAA) in Europe, the Civil Aviation Authority (CAA) in the United Kingdom, and Transport Canada Aviation (TCA).

In 1993, the International Halon Replacement Working Group (IHRWG) was established by the FAA and cooperating agencies to provide input for this program.[2] 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.

At the first meeting of the IHRWG on October 13-14, 1993, held at the FAA Technical Center in Atlantic City International Airport, New Jersey, a number of task groups were formed with the goal of developing FAA test protocols for each of the major areas of onboard aircraft use of halon fire protection systems:

- Lavatory trash receptacle protection;
- Handheld extinguishers;
- Engine nacelles/Auxiliary power units (APUs); and
- Cargo compartments.

[1] UNEP 1998 Assessment Report of the Halon Technical Options Committee, March 1999.

[2] Tapscott, et al., Options to the use of Halons for Aircraft Fire Suppression Systems, 2002 Update, DOT/FAA/AR-99/63, Final Report, February 2002.

In 2000, the scope of the original IHRWG was expanded to include all system fire protection R&D for aircraft, and the name of the working group was changed to the International Aircraft Systems Fire Protection Working Group (IASFPWG). In addition to the four halon replacement areas indicated above, the IASFPWG focuses on the following areas of aircraft fire protection:

- Fuel tank inertion;
- Fire protection in hidden areas of the aircraft; and
- Fire detection R&D.

General requirements for candidate halon replacement agents have been published by the FAA and include the following provisions:[3,4]

- The agent must be suitable for the likely Class of fire, and should provide a level of protection equivalent to Halon 1301 (engine nacelle, cargo compartments, and lavatory trash receptacles) or Halon 1211 (handheld extinguishers);
- In the case of handheld extinguishers, the agent and its byproducts of combustion must have an acceptable toxicity for use when people are present and must not cause visual obscuration or passenger discomfort;
- The agent should be recognized by a technical, listing, or approval organization (e.g., NFPA, UL, FMRC) as suitable for the intended purpose;
- The agent should be compatible with construction materials in the areas where fires may occur and with materials used in the extinguishing systems;
- The agent should comply with the provisions of the Montreal Protocol; and
- The agent must have a near-zero ozone depletion potential (ODP), and a low global warming potential (GWP) and atmospheric lifetime (ALT) are desirable.

It should be noted that, although the majority of R&D into halon alternatives in civil aviation applications has been conducted in the United States, primarily by the FAA, the test criteria and procedures developed by the IASFPWG are the result of agreement between both U.S. and international stakeholders (e.g., airframe manufacturers, airlines, industry associations, manufacturers and suppliers of fire protection equipment and agents, and researchers).

The remainder of this report assesses the current status of halon replacement in lavatory trash receptacle protection, handheld extinguishers, engine nacelles/APUs, and cargo compartments. For each of these civil aviation applications, this report explains and evaluates the current MPS, describes the agents tested to the MPS, identifies the status of halon replacement, and assesses the barriers to halon replacement. A summary of barriers to halon replacement and recommended actions are also provided, and various options to expedite the halon phaseout are presented. This report focuses on the replacement of halon in new airframe designs—not existing aircraft, where retrofitting of extinguishing systems may pose a cost penalty in certain applications and is unlikely to occur.

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[3] Tapscott, et al., Options to the use of Halons for Aircraft Fire Suppression Systems, 2002 Update, DOT/FAA/AR-99/63, Final Report, February 2002.

[4] Halon Replacement Performance Testing Notice, Fed. Reg. 58 (115), 33477, 17 June 1993.

While this paper aims to help foster the development of a targeted industry and/or government policy approach to expedite the transition away from halons in new airframe designs, several key considerations are beyond the scope of this report. Other critical analyses needed to expedite halon phaseout include: economic costs and environmental benefits of various phaseout scenarios; economic analyses of various incentives and disincentives; short- and long-term availability of local (U.S.) and global halon supplies; U.S. and global costs of halon supplies over time; current and projected U.S. market demand for halons; current and projected U.S. demand for halons in civil aviation applications (including current fleets and new airframes); and potential cost savings associated with early halon planning and management.

All information contained in this report is based on published documents or as a result of communications with technical experts in the fire protection and aviation sectors.

4. Lavatory Trash Receptacle Protection

The requirement for an automatic fire extinguisher that discharges into a lavatory trash receptacle was proposed in FAA Notice 84-5 as a consequence of two incidents. The first involved an aircraft cabin fire aboard an Air Canada flight in 1983, in which 23 people perished. The second incident occurred in the same year at Tampa International Airport, and resulted in the evacuation of the aircraft without injuries or loss of life. Following these incidents, an FAA inspection survey of the U.S. carrier fleet indicated that the fire containment capabilities of the trash containers could be compromised over a period of time as a result of normal use.

Given the seriousness of in-flight cabin fires, enhanced fire protection was considered necessary, and on April 29, 1987, a rulemaking was implemented that required each lavatory trash container to be equipped with a built-in automatic fire extinguisher. U.S. Department of Transportation, Federal Aviation Regulation (FAR), 14 CFR 121.308(b) specifies that

> [...] no person may operate a passenger carrying transport category airplane unless each lavatory in the airplane is equipped with a built-in fire extinguisher for each disposal receptacle for towels, paper, or waste located within the lavatory. The fire extinguisher must be designed to discharge automatically into each disposal receptacle upon occurrence of a fire in the receptacle.

The disposal receptacles themselves must comply with the requirements of FAR 14 CFR 25.853 (f) which states:

> Each receptacle used for the disposal of flammable waste material must be fully enclosed, constructed of at least fire resistance materials, and must contain fires likely to occur in it under normal use. The ability of the receptacle to contain those fires under all probable conditions of wear, misalignment, and ventilation, expected in service must be demonstrated by test.

FAA Advisory Circular 25-17 entitled, "Transport Airplane Cabin Interiors Crashworthiness Handbook," provides an acceptable method to demonstrate compliance with this rule.[5]

Currently, all lavatory fire extinguisher systems ("Lavex systems") onboard civil aircraft employ Halon 1301 as the fire-extinguishing agent. Two nozzles (for redundancy purposes) extend from the bottle and are inserted into the waste compartment. At the end of each nozzle is a fusible tip, held in place by eutectic solder.[6] When the compartment temperature reaches a sufficiently high temperature such that the temperature at the tip exceeds the melting point of the eutectic, the tip is forced off by the pressure of the Halon 1301 agent, and Halon 1301 is discharged through the nozzles.

In addition to the essential requirements for candidate halon replacements identified earlier in Section 3, an agent for Lavex applications must also meet the following requirements:[7]

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[5] FAA Advisory Circular AC 25-17, Transport Airplane Cabin Interiors Crashworthiness Handbook, July 15, 1991.

[6] An alloy whose melting point is lower than that of any other alloy composed of the same constituents in different proportions.

[7] Marker, T., *Development of a Minimum Performance Standard for Lavatory Trash Receptacle Automatic Fire Extinguishers*, DOT/FAA/AR-96/122, Final Report, February 1997.

- The agent must extinguish a Class A[8] (paper towel) fire as defined in the Minimum Performance Standard; and

- The agent must have toxicity characteristics such that, if the same quantity of agent used for the trash container is released into the entire lavatory, the No Observed Adverse Effect Level (NOAEL) of the agent is not exceeded.

The NOAEL is defined as the highest concentration of agent at which no adverse toxicological or physiological effect has been observed.[9]

4.1 Development of the MPS for Lavatory Trash Receptacle Automatic Fire Extinguishers

To establish that a replacement agent provides an equivalent level of safety to that of the currently employed agent, the FAA requires that the performance of a replacement agent be measured against a standard test method. Thus, at the second meeting of the IHRWG, held in England in March 1994, Task Group 7 was assigned responsibility for developing and recommending a test protocol to establish a minimum performance standard for Lavex systems.

The perceived fire threat in lavatory trash receptacles is a smoldering combustion, for example, from a glowing cigarette buried in the trash contained in the receptacle. In June 1994, the first working group of Task Group 7 was hosted at the Walter Kidde Aerospace (WKA) facility in Wilson, North Carolina. A series of trash container fire tests were conducted during the meeting to facilitate the group's understanding and the formulation of recommendations.

At the suggestion of the Boeing Commercial Aircraft Group, testing was initiated using a test article representing the largest size trash receptacles available for this application. The test article was defined as a rectangular box measuring 18 inches in width, 8 inches in depth, and 16 inches in height (internal volume 1.333 cubic feet). On the top surface, a 6.2-square inch opening was located at the left-hand side. A plate was mounted 0.5 inches above this opening, leaving a ventilation area of 12.4 square inches. Twelve 1-inch-diameter ventilation holes were provided at the bottom of the test article to provide ventilation. The ventilation holes were provided with damper flaps, which were closed upon the initiation of agent discharge to minimize leakage of the agent from the bottom of the test article. It should be noted that, by design, an actual trash container does not provide ventilation at its bottom. A Lexan viewing window was provided on the front of the test article to allow observation of the preburn and suppression events. The Lavex unit was mounted such that the discharge tube and the temperature-sensitive closure entered at a central location in the top of the test article. The discharge tube projected approximately 1 inch into the test article.

The intention of the test was to simulate ignition of the receptacle contents by a glowing cigarette buried in the trash, resulting in smoldering combustion. As a representative fire load, the fire test load proposed in FAA Advisory Circular 25-17 (under Test Methods for Fire Containment of

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[8] Fires are typically classified into 4 categories: Class A fires involve solid materials, including cellulosics (e.g., wood) and plastics; Class B fires involve liquid or gaseous fuels; Class C fires involve electrically energized equipment; and Class D fires involve burning metals.

[9] NFPA 2001 Standard for Clean Agent Fire Extinguishing Systems, 2004 Edition, NFPA, Batterymarch Park, MA.

Containers, Carts and Compartments) was initially employed.[10] Specifically, the following items were placed in the trash (presented as a percent of total number of items):

- 40 percent 2-ply paper towels (10 x 11 inches)
- 25 percent 2-ply towels (16 x 16 inches)
- 20 percent 8-ounce hot drink paper cups
- 10 percent 3-ounce cold drink cups
- 5 percent empty cigarette packs

However, according to the Task Group, the initial tests using both Halon 1301 and HFC-227ea indicated that the test fire was too easily extinguished. Subsequent tests using one pound of shredded newsprint as the fire load demonstrated that the currently employed Halon 1301 Lavex unit could not suppress a fire of this nature (very smoky, deep-seated), presumably due to the high degree of compaction of the fuel.

It was then suggested that replacement of the shredded newsprint with crumpled paper towels would represent a more realistic fire load. Tests were conducted using 8-inch by 13-inch 2-ply paper towels. The volume of the fuel load was set at 50 percent of the receptacle volume to minimize fuel disturbance during agent discharge. Table 2 presents the results of these paper towel tests.

Table 2. Extinguishment of Crumpled Hand Towels with Standard Halon 1301 Lavex Bottle, Fuel Load Volume at 50 Percent

Agent	Paper Towels (grams)	Result
Halon 1301	468	Easily extinguished
Halon 1301	702	Extinguished
Halon 1301	938	Not extinguished
Halon 1301	814	Extinguished
HFC-227ea	814	Extinguished

Task Group members agreed that the fire load of 814 grams of paper towels represented the proper degree of difficulty, as the current Halon 1301 Lavex unit could just extinguish this fire. The resulting procedure was drafted, circulated to the Task Group members for comment, and presented at the IHRWG meeting in July of 1994. Several concerns were raised at the July 1994 meeting, including the conditioning of the paper towels. Ultimately, it was agreed that the conditioning process specified for fire testing of flame resistant textiles and films in NFPA 701 would be suitable. Beginning in May 1995, the FAA Technical Center began testing according to the suggested procedure. Agents tested included Halon 1301, HFC-227ea, HFC-125 and water. In general, the FAA tests required twice as much agent for extinguishment as the original WKA tests. Subsequent testing by both FAA and Walter Kidde Aerospace led to several procedural changes, to make the tests more reproducible. These changes involved:

- *The type and conditioning of the paper towels employed*—a specification was developed based upon the towels employed in the FAA tests, with the aid of the towel manufacturer.
- *The method of installing the crumpled towels into the test article*—the test article was packed full.

[10] FAA Advisory Circular AC 25-17, Transport Airplane Cabin Interiors Crashworthiness Handbook, July 15, 1991.

- *The ignition source employed*—the ignition source was standardized to achieve better consistency in the fire growth.

One issue that developed during the test program concerned the minimum operational temperature of the Lavex units. Some Task Group members believed that the minimum operating temperature should be as low as 0°F, since many aircraft are left unoccupied for extended periods of time in severe climates, resulting in very low cabin temperatures. This was a problem because subsequent FAA Technical Center and Walter Kidde Aerospace tests showed that eutectic failures resulted when the agent was cooled to below approximately 23°F. Failure to extinguish the test fires at these lower bottle temperatures was due to the failure of the bottle eutectic device, rather than a failure of the agent to extinguish the fire. When later testing by the FAA and Walter Kidde Aerospace in late 1996 demonstrated proper eutectic operation at agent temperatures of 30°F or higher, it was agreed that the specification of a minimum operational temperature of 30°F would provide a level of safety equivalent to that of Halon 1301.

In 1996 a survey conducted by the IASFPWG of 24 airlines showed that 66 percent preferred halocarbons or halocarbon blends for use in lavatory trash receptacles due to reduced weight, minimum impact on current installation, and effectiveness.[11] Sixteen percent preferred water.

In February 1997, the finalized MPS for Lavex systems, incorporating the changes discussed above, was published as DOT/FAA/AR-96/122.[12]

4.2 Technical Evaluation of the Lavex MPS

Based on an examination of available published material, the following conclusions may be reached regarding the Lavex MPS:

- *The FAA Lavex fire test scenario is realistic.* The fire test protocol is based on a smoldering fire, which is a realistic fire scenario for Lavex systems.

- *The Lavex test protocol has been designed to ensure an equivalent level of safety compared to Halon 1301.* The test program leading to the development of the protocol carefully examined the important variables involved in the protocol (i.e., volume and configuration of the test article, fuel characteristics and mode of packing within the test article, ignition of the fuel, and minimum operational temperatures).

- *The Lavex test requirements are not excessively stringent for Halon 1301 alternatives.* Baseline testing with Halon 1301 was included in the test program, and demonstrated the limitations of the currently employed Halon 1301 Lavex systems. This allows determination of the quantities of halon replacements required to provide an equivalent level of safety compared to Halon 1301.

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[11] Hill, R., ed., User Preferred Fire Suppression Agent for Lavatory Trash Container Fire Protection, DOT/FAA/AR-96-8, April 1996.

[12] Marker, T., *Development of a Minimum Performance Standard for Lavatory Trash Receptacle Automatic Fire Extinguishers*, DOT/FAA/AR-96/122, Final Report, February 1997.

4.3 Agents Tested to the Lavex MPS

As discussed above, tests undertaken between 1994 and 1997 on Halon 1301, HFC-227ea, HFC-125, and water served as the basis for the development of the Lavex MPS. In 1998, the Task Group on Halon Options concluded that the following alternative agents were most likely to have utility in lavatory trash receptacle applications:[13]

- HFC-125
- HFC-227ea
- HFC-236fa
- Envirogel (a gelled halocarbon and dry chemical suspension using HFC-236fa and ammonium phosphate)

Initial testing of Envirogel (by Pacific Scientific) and HFC-227ea (by Walter Kidde Aerospace) to the MPS was reported in April of 1999.[14]

In October 1999, Boeing reported that they had begun their internal process of approving Halon 1301 alternatives for Lavex applications, scheduling bottle assembly qualification tests, bottle installation certification tests, and the revision of the Boeing specification to indicate non-halon agent/bottle assemblies.[15, 16]

In December 2000, testing of Envirogel, HFC-227ea, and HFC-236fa was conducted at the FAA Technical Center, the results of which were reported at the March 2001 meeting of the IASFPWG and by Mazzone et al. at the 2001 Halon Options Technical Working Conference.[17, 18] HFC-227ea from one supplier and HFC-236fa from two suppliers passed the tests; an Envirogel formulation of ammonium phosphate in HFC-134a failed the tests, in part due to re-ignition of the fire in two of four tests.

Also in March of 2001, Boeing reported that the successful suppliers were preparing to submit Qualification Test Procedures (QTPs) to Boeing for review.[19]

In July 2001, it was reported that Airbus had conducted several tests and received CAA approval for the use of Lavex equipment containing HFC-236fa.[20] In March 2002, it was reported that Airbus was completing the paperwork for use of HFC-236fa and was close to production.[21]

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[13] Tapscott, et al., Options to the Use of Halons for Aircraft Fire Suppression Systems, 2002 Update, DOT/FAA/AR-99/63, Final Report, February 2002.

[14] Minutes of the International Halon Replacement Working Group Meeting, April 21-22, 1999, Seattle, WA.

[15] Minutes of the International Halon Replacement Working Group Meeting, October 13-14, 1999, Ottawa, Canada.

[16] Mazzone, R.J., *Halon 1301 Replacement for Lavatory Trash Receptacle Fire Extinguisher,* International Aircraft Systems Fire Protection Working Group Meeting, October 1999.

[17] Mazzone, R.J., *Halon Replacement Lavex Bottle Tests,* International Aircraft Systems Fire Protection Working Group Meeting, March 27-28, 2001.

[18] Mazzone, R.J., et al., *Halon Replacement in Airplane Lavatory Trash Receptacle Extinguishers,* Proceedings of the 2001 Halon Options Technical Working Conference, April 24-26, 2001, p. 41.

[19] Mazzone, R.J., Halon Replacement Lavex Bottle Tests, International Aircraft Systems Fire Protection Working Group Meeting, March 27-28, 2001.

[20] Minutes of the International Aircraft Systems Fire Protection Working Group Meeting, July 17-18, 2001, Wilson, NC.

4.4 Status of Halon 1301 Replacement in Lavex Systems

To date, there have been no in-service examples of the replacement of Halon 1301 in aircraft lavatory trash receptacles with an alternative agent, despite two alternatives having passed MPS testing requirements as of 2001: HFC-227ea and HFC-236fa.

Boeing reports that HFC-227ea has successfully passed Boeing tests in larger trash receptacle containers of various configurations, representing all of their current model aircraft. Once FAA approval is granted, Boeing will submit for FAA approval a revised Type Certificate to include one or more alternatives to Halon 1301. Once this FAA approval is granted, Boeing can indicate the preferred alternative agent in its engineering documentation so that manufacturers of Lavex systems can install HFC-227ea-based systems.[22, 23] Pending FAA approval of Boeing's alternative Lavex bottle assembly and installation and approval of the Type Certificate soon after, it would seem reasonable that introduction of the alternative units into commercial aircraft could be accomplished within the next few years.

The current status of HFC-236fa within Airbus is unknown to the agent supplier at this time. It is believed, however, that HFC-236fa units have been approved or will be approved shortly.

At this time, it is unknown when alternative Lavex systems will replace halon systems on current model aircraft or in new airframe design specifications.

4.5 Barriers to the Use of Halon Alternatives in Aircraft Lavex Applications

Currently there appear to be no technical, economic or regulatory barriers to the transition from Halon 1301 to alternative agents in lavatory trash receptacle extinguishing systems. At least two alternatives are available that have passed the MPS testing requirements as of 2001. In fact, according to a 2002 report, the alternatives currently undergoing testing (HFC-227ea, HFC-236fa, and Envirogel) are technically superior and economically preferable to Halon 1301 units,[24] and the Halon Technical Options Committee (HTOC) actually recognized that Halon 1301 performed rather poorly in this application.[25] Other than document changes, no engineering is required to introduce these alternatives to the fleet because they carry no substantial weight or space penalties.[26]

Although no barriers have been identified with the transition to halon alternatives for Lavex systems, at this time it is unknown when the alternative systems will begin replacing halon units on new airframe engineering specifications. The ready availability of safe, cost-effective replacements for halons in this application supports a transition to the alternatives as soon as possible.

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[21] Minutes of the International Aircraft Systems Fire Protection Working Group Meeting, March 12-13, 2002, Seattle, WA.

[22] Personal communication from Robert Glaser, Walter Kidde Aerospace, September 2003.

[23] Personal communication from Doug Ingerson, FAA, September 2003.

[24] Wickham, R., Status of Industry Efforts to Replace Halon Fire Extinguishing Agents, March 16, 2002.

[25] UNEP 1998 Assessment Report of the Halon Technical Options Committee, March 1999.

[26] Wickham, R., Status of Industry Efforts to Replace Halon Fire Extinguishing Agents, March 16, 2002.

5. Handheld Extinguishers

FAA regulations mandate that handheld fire extinguishers be conveniently located in passenger compartments. The number of required extinguishers depends on the passenger capacity of the aircraft and is specified in 14 CFR 25.851 and presented in Table 3. Current FAA regulations further stipulate that in the passenger compartment, Halon 1211 must be used in at least one of the extinguishers on an aircraft with a passenger capacity greater than 30 and at least two of the extinguishers on an aircraft with a passenger capacity greater than 60. In addition, at least one handheld fire extinguisher must be located in the cockpit, and at least one extinguisher must be available for use in each Class A or Class B baggage compartment and in each Class E cargo or baggage compartment that is accessible to crew members during flight (see Appendix A for an explanation of the various baggage/cargo compartment classes). The handheld extinguishers required in the pilot or baggage compartments need not be Halon 1211.

Table 3. Handheld Extinguishers Required for Commercial Aircraft

Passenger Capacity	Number of Extinguishers	Number of Halon 1211 Extinguishers in Passenger Compartment
7-30	1	0
31-60	2	1
61-200	3	2
201-300	4	2
301-400	5	2
401-500	6	2
501-600	7	2
601-700	8	2

Halon 1211 was initially selected for use in aircraft cabins in response to the hijacking/arsonist scenario.[27] This scenario consisted of gasoline splashed on a seat cushion and ignited, which is the basis for one of the two performance tests required in the Handheld MPS. It was later found that Halon 1211—while primarily a streaming agent—could also act as a total flooding agent. However, due to toxicity concerns, total flooding applications have been limited to unoccupied areas. The total flooding capabilities of Halon 1211 were demonstrated on several in-flight hidden fire incidents in large transport aircraft, where Halon 1211 prevented the loss of the aircraft. The first performance test required in the handheld MPS addresses such "hidden" fires.

In addition to the general requirements for candidate replacement agents identified in Section 3, a handheld extinguisher must meet the following three requirements:[28]

- The extinguisher must have a minimum UL 5B:C rating;
- The extinguisher must be able to extinguish fires in indirectly accessible areas as effectively as Halon 1211; and

[27] Hill, R.G. and Speitel, L., In-Flight Aircraft Seat Fire Extinguishing Tests (Cabin Hazard Measurements), DOT/FAA/CT-82/111, December 1982.

[28] Webster, H., Development of a Minimum Performance Standard for Hand-held Fire Extinguishers as a Replacement for Halon 1211 on Civilian Transport Category Aircraft, DOT/FAA/AR-01/37, Final Report, August 2002.

- The extinguisher must have an acceptable toxicity for use when people are present and must not cause visual obscuration or passenger discomfort.

Underwriters Laboratories, Inc. (UL) has developed fire test procedures and a rating system for portable extinguishers. A "B" rating indicates that the portable extinguisher is suitable for fighting fires involving flammable liquids and flammable gases; a "B:C" rating indicates the portable extinguisher is suitable for fighting the same type of fires as a "B" rated extinguisher and can also be used on fires that involve energized electrical equipment. Class B fire tests are performed on heptane fires in square metal pans, and the numerical value of the B rating is 40 percent of the area of the test fire pan. This relationship is based upon the observation that a novice could achieve extinguishment proficiency equal to 40 percent of that of a professional fire fighter performing the UL test. Table 4 shows the test conditions for ratings up to 30-B. There is no rating system for the Class C designation, as testing is limited to determining that the extinguishing agent is electrically non-conductive.

Table 4. UL Class B Ratings: Test Conditions

Rating-Class	Indoor or Outdoor Test	Pan Size (ft^2)	Commercial Grade Heptane Used (gallons)	Minimum Effective Discharge Time (seconds)
1-B	Indoor	2.5	3.3	8
2-B	Indoor	5.0	6.3	8
5-B	Indoor	12.5	15.5	8
10-B	Indoor	25.0	31.0	8
20-B	Indoor	50.0	65.0	8
30-B	Outdoor	75.0	95.0	11

Source: UL 711

The FAA requires that replacement extinguishers demonstrate equivalence to the currently employed halon unit. All replacement extinguishers must first meet the certification requirements of a national listing organization, such as UL Standard 711 or British Standard BS EN 3.[29, 30] This ensures a fire fighting capability equal to a UL 5B:C rated 2.5-pound Halon 1211 fire extinguisher. In addition, the extinguisher must be able to extinguish fires in inaccessible areas ("hidden fire test") as effectively as the currently required Halon 1211 2.5-pound 5B:C rated extinguisher, and must pass a seat fire/toxicity test ("hijacking/arsonist test") to further demonstrate equivalence to Halon 1211.

5.1 Development of the "Hidden Fire Test"

Because UL 711 measures the streaming capability of a fire suppression agent but not its total flooding capability, a new test had to be developed. Under contract to the Civilian Aviation Authority, Kidde International Research in Colnbrook, England developed a handheld extinguisher total flood test.[31, 32] Following some range-finding work, a suitable test fixture was

[29] UL Standard 711, *Rating and Fire Testing of Fire Extinguishers,* 6th edition, Underwriters Laboratories, Inc., Northbrook, IL, August 2002.

[30] British Standard Specification for Portable Fire Extinguishers, BS EN 3, 1996.

[31] Chattaway, A. *The Development of a Hidden Fire Test for Aircraft Hand Extinguisher Applications,* CAA Paper 95013, 1995.

devised, comprised of arrays of four fires in two of five locations (for a total of eight fires) within a 6-foot by 6-foot by 1.5-foot wide enclosure, to establish in which regions of the test enclosure an extinguishing concentration had been attained. Testing was carried out with Halon 1211, HFC-227ea, HFC-125, FC-4-1-10, FC-6-1-14, and FIC-13I1. The relative performance of the agents in this hidden fire test was found to correlate to the n-heptane cup burner extinguishing concentration of the agents, indicating that the test procedure is indeed providing a measure of the total flooding ability of the agent.

Subsequent testing by the FAA refined the hidden fire test procedure developed by Kidde International Research. The FAA procedure differs from the Kidde International procedure in that all 20 cup fires are ignited, rather than only eight. The preburn period (time lapse between lighting the cups and discharging the extinguisher) was found to be critical to the results, and was limited to 30 seconds. Effects of enclosure temperature were examined and found to be negligible for enclosure temperatures between 52°F and 175°F. Effects of nozzle orientation on extinguisher performance were also examined, and these tests showed that the performance of an extinguisher charged with Halon 1211 was greatly affected by the angle of discharge. As a result, it was recommended to orient the nozzle level and parallel with the long sides of the test fixture.

The results of the preburn time tests, fixture temperature tests, and nozzle orientation tests were ultimately incorporated into the MPS. For a preburn time of 30 seconds, with the fixture temperature at normal room temperature and the nozzle correctly oriented, a 2.5-pound Halon 1211 extinguisher was found to consistently extinguish nine cup fires out of twenty.

The effects of ventilation openings in the test fixture were also examined. The test fixture includes ports to simulate the air exchange normally encountered in the cheek area of an aircraft fuselage. Blocking the ventilation ports resulted in improved extinguisher performance, due to the attainment of higher agent concentrations within the test fixture. The MPS retains open ventilation ports, as this is a more realistic condition.

5.1.1 Hidden Fire Tests Conducted by the FAA

In 2000, the FAA tested HFC-236fa, HFC-236fa/HFC-23, HCFC Blend B, and two versions of Envirogel in the Hidden Fire Test Apparatus. Note that at the time of this testing UL 5B:C rated units were not available for HFC-236fa or for the HFC-236fa/HFC-23 blend. HFC-236fa, HFC-236fa/HFC-23 and HCFC Blend B passed the Hidden Fire Test (9 of 20 fires extinguished) after minor adjustments to the submitted units. The Envirogel units extinguished between 12 and 18 of 20 fires, a performance superior to that observed with the standard UL 5B:C 2.5-pound Halon 1211 unit, which extinguished 9 of 20 fires. However, the test fixture required extensive cleaning after discharge of the Envirogel agent.

5.1.2 Hidden Fire Tests Conducted by Underwriters Laboratories

Late in 2000, an agreement was reached between the FAA and UL that the hidden fire tests would be conducted and witnessed by UL, and the hidden fire test apparatus was subsequently relocated to UL's test facilities in Northbrook, IL. UL 5B:C rated units of HCFC Blend B and

[32] Chattaway, A. *The Development of a Hidden Fire Challenge,* Fire and Materials, Vol. 21, 219-228 (1997).

HFC-236fa successfully completed testing according to the MPS in December 2001 and February 2002, respectively. A UL 5B:C rated HFC-227ea unit successfully completed testing according to the MPS in May 2003, extinguishing 13 to 14 of the 20 test fires.[33] These UL test results, and those of FAA (described above), are summarized in Table 5.

Table 5. Summary of Hidden Fire Test Results: FAA and UL Testing

Agent[a]	Supplier	Number of cup fires extinguished out of 20		Comments
		FAA Testing[b]	UL Testing	
Halon 1211	-	9	Data not available	-
HFC-227ea	Great Lakes Chemical	Tests not run	13-14[c]	UL 5B:C unit
HFC-236fa	Du Pont	9	≥ 9[d]	FAA Testing: Not 5B:C unit UL Testing: 5B:C unit
HFC-236fa/HFC-23	Du Pont	9	Tests not run	FAA Testing: Not 5B:C unit
HCFC Blend B	American Pacific	9	9-10[e]	UL 5B:C rated unit
Envirogel (HFC-236fa with phosphate)	Powsus, Inc.	12-18	Tests not run	UL 5B:C rated unit; extensive cleaning of test fixture required after discharge
Envirogel (HFC-236fa with bicarbonate)	Powsus, Inc.	12-18	Tests not run	UL 5B:C rated unit; extensive cleaning of test fixture required after discharge

[a] See Table 7 for the quantity of agent used in the FAA tests.
[b] Webster, H., Development of a Minimum Performance Standard for Hand-held Fire Extinguishers as a Replacement for Halon 1211 on Civilian Transport Category Aircraft, DOT/FAA/AR-01/37, Final Report, August 2002.
[c] Underwriters Laboratories, Report on Clean Agent Fire Extinguishers, SeaFire Products Division of MetalCraft Inc., Baltimore, MD, File Ex5131, Project 01NK45106, May 20, 2003..
[d] Proprietary information; at least 9 cup fires must be extinguished.
[e] Colton, B.A. and Gibson, J.M. Development of a Halotron I Handheld Fire Extinguisher for Use Onboard Commercial Aircraft, Proc. 2003 Halon Options Technical Working Conference, Albuquerque, NM.

5.2 Development of the "Seat Fire/Toxicity Test"

The second fire test required in the Handheld MPS is the Seat Fire/Toxicity test. The basis for this test is the triple-seat fire test developed by Hill et al. (1982), which was developed in response to the hijacking/arsonist scenario that was prevalent in the late 1970s.[34] This scenario consists of an arsonist smuggling gasoline in a glass bottle onto an aircraft, dumping the gasoline on a seat cushion, and igniting it. Tests performed by the FAA demonstrated that Halon 1211 performance greatly exceeded that of the commonly used carbon dioxide (CO_2) and dry chemical extinguishers. The results of this work were eventually incorporated into FAR 25.851, which requires Halon 1211 to be carried on all commercial passenger jets with more than 30 passengers.

[33] Underwriters Laboratories, Report on Clean Agent Fire Extinguishers, SeaFire Products Division of MetalCraft Inc., Baltimore, MD, File Ex5131, Project 01NK45106, May 20, 2003.

[34] Hill, R.G. and Speitel, L., In-Flight Aircraft Seat Fire Extinguishing Tests (Cabin Hazard Measurements), DOT/FAA/CT-82/111, December 1982.

Today, the performance/toxicity test retains the triple passenger seat arrangement, even though the seats on modern aircraft are now highly fire-blocked, which inhibits an external fire from igniting the foam seat cushions and causing a much larger fire. As a result, the handheld MPS employs the triple passenger seat test developed in 1982 but with a fire provided by the ignition of only a quart of gasoline (instead of one gallon) as the basis for testing the capabilities of a Halon 1211 UL 5B:C extinguisher.

The seat fire toxicity tests were performed in September through December 1999, and employed the forward cabin of the FAA William J. Hughes Technical Center's TC-10 aircraft fuselage, a fire-hardened fuselage designed to match the dimensions of a DC-10 aircraft. The cabin was fitted with three stations where concentration levels of oxygen, carbon dioxide, carbon monoxide, and neat agent concentrations were continuously monitored using infrared analyzers. In addition, sample tubes were employed to collect acid gases (primarily hydrogen fluoride [HF]) formed during suppression, and acid concentrations were determined using ion chromatography. Thermocouple trees measured cabin air temperatures, and fire severity was measured with a calorimeter. Details of the analytical method and fire load can be found in the Handheld MPS.[35] The initial test design specified the use of a remote firefighting device (robot) for the discharge of suppression agent. This proved to be too slow to effectively fight the fire and was later replaced with a live firefighter in full protective gear and breathing equipment. The firefighter was positioned 6 feet in front of the fire, and discharged the agent after a 30-second preburn period.

The pass/fail criteria developed for the seat fire/toxicity tests are:

- Extinguishment of the test fire;
- HF concentration cannot exceed 200 parts per million (ppm) averaged over the highest one-minute interval; and
- HF concentration levels cannot exceed 100 ppm averaged over the highest 4.5- minute interval.[36]

Baseline testing was conducted with Halon 1211, and tests were then conducted with HFC-236fa, a mixture of HFC-236fa/HFC-23, HFC-227ea, HCFC Blend B, HCFC Blend E, Envirogel with bicarbonate powder, and Envirogel with phosphate powder. The test results are summarized in Table 6. All candidate agents passed the HF toxicity requirement and extinguished the test fire. All extinguishers were characterized by a total charge weight (i.e., weight of agent plus extinguisher) exceeding that of the standard Halon 1211 extinguisher.

Table 6. Seat Fire/Toxicity Test Results

Test	Agent Used (pounds)	Peak Cabin Temperature (°F)	HF, 1 minute Average (ppm)	HF, 4.5 Minute Average (ppm)
Uncontrolled burn	-	111	2	1
Uncontrolled burn	-	114	1	1
Uncontrolled burn	-	100	1	1

[35] Webster, H., Development of a Minimum Performance Standard for Hand-held Fire Extinguishers as a Replacement for Halon 1211 on Civilian Transport Category Aircraft, DOT/FAA/AR-01/37, Final Report, August 2002.

[36] The criteria for HF were developed in conjunction with input from industry and the U.S. Environmental Protection Agency (EPA).

Test	Agent Used (pounds)	Peak Cabin Temperature (°F)	HF,1 minute Average (ppm)	HF, 4.5 Minute Average (ppm)
Halon 1211	1.2	85	9	6
Halon 1211	0.8	82	21	14
Halon 1211	0.96	80	20	13
HFC-236fa	2.0	97	65	46
HFC-236fa	1.9	105	103	67
HFC-236fa	1.5	75	64	45
HFC-236fa/HFC-23	3.7	90	111	83
HFC-236fa/HFC-23	1.5	90	50	38
HFC-236fa/HFC-23	1.3	89	98	64
Envirogel (phosphate)	1.6	85	14	10
Envirogel (phosphate)	0.8	86	20	12
Envirogel (phosphate)	1.8	88	12	11
Envirogel (bicarb)	0.94	77	20	14
Envirogel (bicarb)	1.85	76	42	28
Envirogel (bicarb)	0.88	65	21	14
HCFC Blend B	2.1	95	24	17
HCFC Blend B	2.0	82	26	20
HCFC Blend B	2.3	89	23	14
HFC-227ea	2.55	101	64	45
HFC-227ea	1.91	85	104	74
HFC-227ea	4.14	92	66	46
HCFC Blend E	4.44	96	25	18
HCFC Blend E	5.01	77	38	21
HCFC Blend E	4.17	71	42	32

The finalized handheld MPS was published by Webster in August 2002.[37]

5.3 Technical Evaluation of the Handheld MPS

Based on an examination of available published materials, the following conclusions may be drawn regarding the Handheld MPS:

- *The FAA fire test scenario is realistic.* The hijacking/arsonist scenario is appropriate as the basis for the seat fire/toxicity test.

- *The test protocol ensures an equivalent level of safety compared to Halon 1211.* The hidden fire test procedure is necessary to measure the flooding characteristics of the extinguishing agents in aircraft cheek areas, and the test program which led to the development of the protocol fully examined the major variables involved in each test.

- *The test requirements are not excessively stringent for Halon 1211 alternatives.* Baseline testing with Halon 1211 was included in the test program and demonstrated the limitations of the currently employed Halon 1211 handheld extinguishers. This allows determination of the quantities of halon replacements required to provide an equivalent level of safety compared to Halon 1211.

[37] Webster, H., Development of a Minimum Performance Standard for Hand-held Fire Extinguishers as a Replacement for Halon 1211 on Civilian Transport Category Aircraft, DOT/FAA/AR-01/37, Final Report, August 2002.

5.4 Agents Tested to the Handheld MPS

As indicated above, during the development of the handheld MPS, the FAA performed the hidden fire tests on HFC-236fa, HFC-236fa/HFC-23, HCFC Blend B and two versions of Envirogel. Note that, at the time of this testing, UL 5B:C rated units were not available for HFC-236fa or for the HFC-236fa/HFC-23 blend. HFC-236fa, HFC-236fa/HFC-23 and HCFC Blend B passed the Hidden Fire Test (extinguishing 9 of 20 fires) after minor adjustments to the submitted units. The Envirogel units also passed the test, demonstrating performance superior to that of Halon 1211, although they are not clean agents (see Section 5.1.1).

As discussed, the FAA carried out the seat fire/toxicity tests on HFC-236fa, HFC-236fa/HFC-23, HFC-227ea, HCFC Blend B, HCFC Blend E, and two versions of Envirogel. All agents tested extinguished the fires and passed the toxicity test.

In August 2000 it was announced that UL would be performing the hidden fire tests for interested parties. In December 2001, HCFC Blend B passed the hidden fire tests in an Amerex UL 5B:C rated extinguishing unit. In March 2002, DuPont reported that Ansul had completed all handheld MPS tests with a UL 5B:C rated HFC-236fa extinguishing unit. In May 2003, Great Lakes Chemical Corporation reported that Sea-Fire, Division of MetalCraft, Inc., had completed all handheld MPS requirements with a UL 5B:C rated HFC-227ea extinguishing unit. Hence, by mid 2003, three agents (HFC-227ea, HFC-236fa, and HCFC Blend B) had been tested to and met the requirements of the Handheld MPS.

5.5 Status of Halon 1211 Replacement in Handheld Extinguishers

To date, no alternative agents have replaced Halon 1211 in handheld fire extinguishers in passenger compartments on current aircraft models or new airframe designs. As discussed above, by mid-2003, three halon alternatives (HFC-227ea, HFC-236fa and HCFC Blend B) had successfully completed all of the required handheld UL and MPS tests, and the next step towards introduction of these alternative units into commercial aircraft is internal qualification by an airframe manufacturer, which has apparently not begun. This involves the airframe manufacturer qualifying a new bracket for the extinguisher, finding a location that supports the larger extinguisher, and conducting structural analyses to ensure that the larger, heavier extinguisher and bracket can meet mandated load requirements.

5.6 Barriers to the Use of Halon Alternatives in Aircraft Handheld Applications

Constraints to the transition away from halons in handheld civil aviation applications have been identified as economic or regulatory in nature. These are discussed in detail below.

5.6.1 Economic Barriers

One identified barrier to the use of halon alternatives in aircraft handheld applications is the lack of any economic incentive. Although the alternative systems can offer equivalent levels of safety to Halon 1211, they:

- are less effective on a weight basis than the Halon 1211 units;
- may cost more than the Halon 1211 units;
- take up more space than the Halon 1211 units; and
- will require new engineering (approved by FAA) prior to being introduced to the fleet.

Table 7 compares the properties of a typical Halon 1211 UL 5B:C-rated extinguisher with those of the HFC-227ea, HFC-236fa, and HCFC Blend B extinguishers which have passed the tests required in the Handheld MPS.[38, 39, 40, 41] The weight and volume penalties associated with the alternative extinguishers relative to a Halon 1211 unit are shown in Table 7.

Table 7. Properties of Handheld Extinguishers

	Halon 1211	HFC-227ea	HFC-236fa	HCFC Blend B
Extinguisher Model	Amerex A352TS	SeaFire C-50	Ansul FE05	Amerex B394TS
UL Rating	5B:C	5B:C	5B:C	5B:C
Pounds of agent	2.5	5.75	4.75	5.5
Charged weight, pounds (with bracket)	5.5	9.8	10	10
Charged weight relative to Halon 1211 unit	1.0	1.8	1.8	1.8
Dimensions, inches				
Height	14.5	16.5	17	15.25
Width	3.0	7.5	8.5	5
Depth	3.0	4.3	4.4	4.25
Dimensions, cubic feet	0.0755	0.3079	0.3679	0.1875

While the HFC-227ea, HFC-236fa, and HCFC Blend B units are characterized by a gross weight almost twice that of the Halon 1211 unit, the actual cost penalties associated with this additional space and weight requirement are not believed to be significant in terms of overall aircraft (i.e., jet fuel) costs. For example, the weight increase associated with the replacement of the four 2.5-lb Halon 1211 units required by NFPA 408[42] to protect an aircraft with an occupancy of between 121 and 200 and equipped with two galleys with any of the three alternatives is equivalent to or slightly less than the weight of a single passenger carry-on bag. To estimate actual costs associated with the alternative agents, some rough calculations can be made:

- FAA estimates of incremental fuel consumption range from approximately 0.003 to 0.010 gallons per flight hour per pound of weight added, depending on the particular aircraft type.[43] FAA data also indicate that all aircraft types exhibit a minimum of 50 percent frequency of use, or approximately 4,400 hours per year.[44] Hence, the additional fuel required per year per pound of added weight ranges from approximately 13.2 gallons (4,400 hrs × 1 lb × 0.003 gallons/hr lb =

[38] Sea-Fire Data Sheet, Part No. 130-136.

[39] Personal communication from Jeff Gibson (American Pacific), August 2003.

[40] Hand Portable Extinguishers Data Sheet, Cleanguard Clean Agent Extinguishers, Ansul.

[41] Personal communication from Jeff Gibson (American Pacific), August 2003.

[42] *NFPA 408 Standard for Aircraft Hand Portable Fire Extinguishers*, 1999 edition.

[43] "Impact of Weight Changes on Aircraft Fuel Consumption," Draft Report, July 20, 1998, Hickling Lewis Bod Inc. Available at <http://apo.faa.gov/arcc/Research%20Reports/HLB%20Weight%20Changes%20and%20Fuel.pdf; also see http://api.hq.faa.gov/economic/742SECT7.pdf>.

[44] "Impact of Weight Changes on Aircraft Fuel Consumption," Draft Report, July 20, 1998, Hickling Lewis Bod Inc. Available at <http://apo.faa.gov/arcc/Research%20Reports/HLB%20Weight%20Changes%20and%20Fuel.pdf; also see http://api.hq.faa.gov/economic/742SECT7.pdf>.

6. Engine Nacelle/Auxiliary Power Unit (APU) Fire Protection

According to Title 14 of the Code of Federal Regulation (CFR) Part 25.1195, the requirements for fire suppression systems in aircraft power plants include the following:

- A fire suppression system is required if other means are not provided to control typical fires, as identified in the CFR;
- The suppression system must be shown to be effective in quantity of agent, rate of discharge, and distribution by live test during actual or simulated flight conditions; and
- The suppression system must provide adequate, simultaneous protection throughout the compartment.

To be deemed acceptable, a Halon 1301 suppression system must effectively distribute agent within an engine nacelle. The current level of safety has been historically defined as a quantity of Halon 1301 providing a volumetric concentration of 6 percent for a duration of 0.5 seconds throughout the protected zone within the nacelle. This quantity is based on experience from experiments performed in the 1950s and 1960s by the Civil Aviation Administration, U.S. Air Force, U.S. Navy, and other investigators that examined the effects of varying nacelle conditions and configurations on the extinguishing performance of Halon 1301.[55, 56, 57, 58, 59, 60] The test requires an engine to be operating at critical conditions when the agent release occurs. Typically, 12 sampling probes from a gas analyzer are located within the compartment during this test to allow for determination of the gas concentration vs. time relationship. FAA Advisory Circular 20-100 summarizes of the various aspects of the discharge test.[61]

The fire threat in engine nacelle and APU compartments is a Class B fire (aviation fuel, hydraulic fluid, lubricant). The compartments are normally ventilated, have complex airflow pathways, possess excessively heated materials, and are approximately at ambient pressure. The presence of heated surfaces, the potential for residual fuel after agent discharge, and the continuous airflow through these compartments can adversely impact system design.

Fires in these compartments result when an engine failure produces conditions that permit combustion. Typically, mechanical failures cause the release of flammable fluid that comes into contact with an ignition source (e.g., hot surfaces, hot gases, sparks). Detection of a fire activates warnings on the flight deck. The accepted practice to combat an engine compartment fire is to

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[55] Aircraft Fire Extinguishment, Part I- A Study of Factors Influencing Extinguishing System Design, Technical Development Report No. 184, October, 1952.

[56] Aircraft Fire Extinguishment, Part II - The Effect of Air Flow on Extinguishing Requirements of a Jet Power-Plant Fire Zone, Technical Development Report No. 205, June, 1953.

[57] Aircraft Fire Extinguishment, Part III - An Instrument for Evaluating Extinguishing Systems, Technical Development Report No. 206, June 1953.

[58] Aircraft Fire Extinguishment, Part IV, Evaluation of a Bromochloromethane Fire Extinguishing system for the XB-45 Airplane, Technical Development Report No. 240, June 1954.

[59] Aircraft Fire Extinguishment, Part V, Preliminary Report on High-Rate Discharge Fire Extinguishing Systems for Aircraft Power Plants, Technical Development Report NO. 260, February 1956.

[60] An Investigation of In-flight Fire Protection with a Turbofan Powerplant Installation, Report No. NA-69-26, April 1969.

[61] Advisory Circular 20-100, General Guidelines for Measuring Fire-Extinguishing Agent Concentrations in Powerplant Compartments, September 21, 1977.

eliminate ignition and fuel sources and then discharge the fire suppression system. This process is achieved by shutting the engine down, closing local flammable liquid valves, turning off local electrical power, and then discharging the suppression system.

The Engine Nacelle Task Group initially focused on a large-scale, multiphase program run by the U.S. Air Force (USAF). Phase One of the USAF program involved the identification of the factors that would most significantly impact the quantity of an agent required to suppress a nacelle fire, and the selection of three potential alternative agents: FIC-13I1, HFC-125, and HFC-227ea. In Phase Two of the USAF program, one of the three potential replacement agents—HFC-125—was selected as the recommended replacement for Halon 1301 in aircraft engine nacelles. Finally, in the third phase of the program, further work was conducted on HFC-125, which eventually led to the development of equations intended for use in designing protection systems for aircraft engine nacelles.[62]

6.1 Development of the Engine Nacelle MPS

The replacement process for Halon 1301 in engine nacelles and APUs is described in the draft Engine Nacelle/Auxiliary Power Unit MPS, titled, *The Minimum Performance Standard for Engines and Auxiliary Power Unit Compartments (MPSE)*.[63] The MPS describes the geometry of a nacelle simulator and a process for demonstrating the equivalence of a replacement agent to that of Halon 1301. The MPS retains the current level of safety (i.e., Halon 1301 at 6 percent volumetric concentration simultaneously throughout the protected zone for a duration of 0.5 seconds).

The engine nacelle/APU MPS is currently undergoing revision, and a finalized MPS is likely to be published in 2005. Unfortunately, it is not available for public review at this time. FAA efforts toward the development of an acceptable engine nacelle MPS have been reported at the meetings of the IASFPWG, and are outlined below.

In November 1997, a proposed engine nacelle simulator was described and the commencement of construction of the simulator was reported in June 1998.[64, 65] In October 1999, results were presented on the impact of airflow temperature on agent distribution in tests employing HFC-125.[66] Mechanical assembly of the simulator was completed in early April 2000, and characterization tests commenced (e.g., on subsystem performance, air flow capacity, fire scenario sensitivities).[67] Spray and pool fires were proposed at that time.

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[62] Bennett, M.V. and Bennett, J.M., Aircraft Engine/APU Fire Extinguishing System Design Model (HFC-125), AFRL-VA-WP-TR-1999-3068, May 1997.

[63] Website http://www.fire.tc.faa.gov/systems/engine/engine.stm ; note that this document is not available to the public.

[64] Minutes of the International Halon Replacement Working Group Meeting, November 19-20, 1997, Atlantic City, NJ.

[65] Minutes of the International Halon Replacement Working Group Meeting, June 24-25, 1998, Zurich, Switzerland.

[66] Minutes of the International Halon Replacement Working Group Meeting, October 13-14, 1999, Ottawa, Canada.

[67] Ingerson, D., *Engine Nacelle Halon Replacement, FAA WJ Hughes Technical Center*, International Halon Replacement Working Group, Bremen, Germany, May 3-4, 2000.

Baseline testing of HFC-125 in the nacelle simulator was performed in May 2000 and the results were reported in August 2000.[68]

In September 2000, the IASFPWG recommended FIC-13I1 and HFC-125 for engine nacelle protection.[69] HFC-236fa, HFC-227ea, water mist, and inert gases (carbon dioxide, nitrogen) were rejected.

Agent concentration analysis problems plagued the engine nacelle work at the FAA from December 2000 through 2002.[70, 71, 72, 73, 74] In July 2001 it was reported that the problem was solved, the analytical unit would be operational within several weeks, and distribution experiments with HFC-125 would soon commence. However, the analytical problems were not fully resolved until March 2002.[75]

Difficulties with the hot surface ignition portion of the test protocol were reported in June 2002.[76, 77] A recommendation was made to employ continuously-operating electrodes to relieve difficulties associated with hot surface ignition phenomena. Investigations of the hot surface ignition portion of the test protocol continued through the end of 2002.

At the March 2003 meeting of the IASFPWG, it was announced that the engine nacelle simulator was ready for agent testing.[78] At the same meeting, Boeing suggested that the tests include a range of conditions (airflow, temperature) and include testing at a bottle temperature of -65°F in addition to testing at a bottle temperature of 100°F.[79]

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[68] Ingerson, D., *Recent Simulator Activity,* International Aircraft Systems Fire Protection Working Group Meeting, August 29-30, 2000, Pleasantville, NJ.

[69] Gupta, A., *Options for Aircraft Engine Fire Protection*, Int. Aircraft System Fire Protection Working Group, September 2000.

[70] Ingerson, D., *Engine Nacelle Halon Replacement, FAA WJ Hughes Technical Center,* International Aircraft Systems Fire Protection Working Group Meeting, December 11-12, Gatwick, UK.

[71] Minutes of the International Aircraft Systems Fire Protection Working Group Meeting, December 11-12, 2000, Gatwick, UK.

[72] Ingerson, D., *Engine Nacelle Halon Replacement, FAA WJ Hughes Technical Center,* International Aircraft Systems Fire Protection Working Group Meeting, July 17-18, 2001, Wilson, NC.

[73] Minutes of the International Aircraft Systems Fire Protection Working Group Meeting, March 27-28, 2001, Long Beach, CA.

[74] Minutes of the International Aircraft Systems Fire Protection Working Group Meeting, July 17-18, 2001, Wilson, NC.

[75] Minutes of the International Aircraft Systems Fire Protection Working Group Meeting, March 12-13, 2002, Seattle, WA.

[76] Minutes of the International Aircraft Systems Fire Protection Working Group Meeting, June 13-14, 2002, London, England.

[77] Ingerson, D., *Engine Nacelle Halon Replacement, FAA WJ Hughes Technical Center,* International Aircraft Systems Fire Protection Working Group Meeting, June 13-14, 2002, London, England.

[78] Minutes of the International Aircraft Systems Fire Protection Working Group Meeting, March 26-27, 2003, Phoenix, AZ.

[79] Roseburg, C., *Proposal to Engine Nacelle Halon Alternatives Task Group,* International Aircraft Systems Fire Protection Working Group, Phoenix, AZ, March 25-27, 2003.

At the July 2003 meeting of the IASFPWG, the FAA reported that certification work for high and low ventilation conditions had been completed.[80] The impact of agent storage pressure on test results had been examined and found to be negligible. In addition, equivalence testing of HFC-125 at high ventilation was completed. Debate still continues, however, on how to conduct the cold bottle tests. As of June 2004, testing of HFC-125 and FIC-13I1 (CF_3I) was still ongoing.[81]

6.2 Technical Evaluation of the Engine Nacelle MPS

As the engine nacelle MPS is still in draft format and not available for public review, it is not possible to provide a proper technical assessment. In general, it appears that an appropriate approach for demonstrating equivalency to Halon 1301 is being employed. At present, only HFC-125 and FIC-13I1 are being tested, and a finalized version of the MPS will reportedly be available in 2005.

6.3 Status of the Replacement of Halon 1301 in Engine Nacelles/APUs

To date, there have been no examples of the replacement of Halon 1301 in engine nacelle or APUs of commercial aircraft. A finalized MPS for engine nacelle/APU protection is not currently available, and is not expected to be finalized until 2005.

In stark contrast to the situation in the commercial aviation industry, the U.S. military has made significant progress in replacing halons in engine nacelle applications. Despite the weight, space, and associated cost penalties, HFC-125 has been adopted in a number of military engine/APU applications. HFC-125 was the final candidate for the Department of Defense (DOD) program that identified a design model for HFC-125 that affords the designer the ability to calculate agent mass requirements for a particular engine nacelle or APU compartment. In the case of the U.S. Navy's F/A-18E/F, the quantity of HFC-125 shown to meet the design challenge was considerably less than that originally predicted by the DOD model. Table 8 lists some of the military engine nacelle/APU applications currently employing HFC-125.

Table 8. Engine Nacelle/APU Applications of HFC-125

U.S. Military Branch	Aircraft
U.S. Air Force	– F-22 fighter ("Raptor")
U.S. Marine Corps	– UH1 "Huey" helicopter – AH1"Cobra" helicopter – MV-22 "Osprey" assault transport
U.S. Navy	– F-18 E/F "Super Hornet" fighter – CH-60 helicopter

[80] Minutes of the International Aircraft Systems Fire Protection Working Group Meeting, July 8-9, 2003, Ottawa, Canada.

[81] Ingerson, D. "Engine Nacelles Halon Replacement." International Aircraft Systems Fire Protection Working Group, Grenoble, France, June 20-21, 2004.

6.4 Barriers to the Use of Halon Alternatives in Commercial Aviation Engine Nacelles/APUs

Technical, economic, and regulatory barriers have been cited as impeding the transition away from halons in commercial aviation engine nacelle/APU applications. These barriers are discussed in detail below.

6.4.1 Technical Barriers

The main technical barrier to the use of halon alternatives in commercial aviation engine nacelle and APU applications is the current lack of a Minimum Performance Standard. At the June 2004 meeting of the IASFPWG, it was indicated that the future engine nacelle MPS will be done in two steps; the first step has been fully agreed upon, but the second step is still to be discussed.[82] Hence, it is unlikely that the engine nacelle/APU MPS will be finalized before 2005. Until this MPS is finalized, qualification and certification procedures cannot begin.

6.4.2 Economic Barriers

As discussed above, all of the agents currently being evaluated for engine nacelle applications are characterized by weight and, hence, cost penalties, compared to Halon 1301. However, the incremental costs associated with the installation of the alternatives systems, as well as the annual jet fuel needed to support them, are insignificant in terms of both total aircraft manufacturing costs and total annual jet fuel costs, respectively.

Additionally, despite the weight/cost penalty associated with HFC-125, numerous military aircraft are now employing HFC-125 for engine protection. No comparisons can be made between FIC-1311 and Halon 1301 until testing is complete, which will probably be in 2005.

6.4.3 Regulatory Barriers

The major regulatory barrier cited in the transition away from Halon 1301 in the engine nacelle/APU application is the current lack of any mandate to replace it. However, with the exception of civil aviation, the lack of a mandate to halt halon use has not forestalled the adoption of halon alternatives in other sectors of use (i.e., military, essential electronics, oil and gas production). Until supplies of recycled halons either become cost-prohibitive to procure or simply unavailable, or until policy changes are implemented that push the transition to the alternatives, the civil aviation industry lacks an immediate incentive to replace halons and begin designing and installing alternatives on aircraft engine nacelles. In the absence of a policy or other mandate to replace Halon 1301 in these applications, economic factors will drive airlines to continue to employ Halon 1301 in engine nacelles. Additional considerations for the alternatives are any future regulations that may ban or severely restrict the use of HFCs.

[82] Minutes of the International Aircraft Systems Fire Protection Working Group Meeting, June 21-22, 2004, Grenoble, France.

7. Cargo Compartment Fire Protection

Federal Air Regulations classify cargo compartments according to their accessibility and the type of detection and suppression systems provided in the compartment (see Appendix A).[83] The recent FAA ruling eliminating Class D (i.e., inaccessible compartments that do not have fire/ smoke detection systems or fire suppression systems) as an option for certification for cargo compartments in transport category aircraft will increase the number of compartments requiring fire suppression systems.[84] Such compartments must now meet the standards of Class C and/or Class E compartments.

Most Class C cargo compartments are larger than 1,000 cubic feet and are usually pressurized with a normal pressure corresponding to an altitude of 8,000 feet. During flight, cargo compartment temperatures are maintained above freezing by various means, including ventilation. Smoke detectors or thermal sensors detect fires in cargo compartments. Federal Air Regulation 14 CFR 25.858 requires that the fire detection system be capable of providing a warning within one minute from the start of smoke generation. The extinguishing system for a cargo compartment must also meet the requirements of FAR 25.851b and FAR 25.855h, which specify that:

- Each built-in fire extinguishing system must be installed so that no extinguishing agent likely to enter personnel compartments will be hazardous to the occupants and no discharge of the extinguisher can cause structural damage (FAR 25.851b).
- The capacity of each required built-in extinguishing system must be adequate for any fire likely to occur in the compartment (FAR 25.851b).
- Flight tests must be conducted to show compliance with the provisions of FAR 25.857 concerning compartment accessibility, entry of hazardous quantities of smoke or extinguishing agent into occupied compartments, and the dispersion of the extinguishing agent in Class C compartments (FAR 25.855h).

In addition to the above regulations, FAA Airworthiness Directive 93-07-15 requires that after November 2, 1996, the Class B cargo compartments on Boeing Models 707, 727, 737, 747, and 757 and McDonnell Douglas Models DC-8, DC-9, and DC-10 airplanes have improved fire protection features.

7.1 Development of the Cargo Compartment MPS

Task Group 4 of the IHRWG reported that cargo compartment fires could be categorized as fires resulting from aircraft-supplied ignition sources, and from human and cargo-supplied ignition sources.[85] The likely fire from an aircraft-initiated ignition source is a surface fire, and this will most likely be fueled by Class A materials (i.e., solid materials, including wood and plastics). In some instances, the Class A material may be contaminated by small quantities of Class B

[83] Federal Aviation Regulation (FAR), 14 CFR 25.857

[84] Revised Standards for Cargo or Baggage Compartments in Transport Category Airplanes, Final Rule, Federal Register, Vol. 63, No. 31, pp. 8031-8049, February 17, 1998.

[85] *Likely Fire Threat in Class C Cargo Compartments*, International Halon Working Group, Task Group 4, Seattle, WA, July 26-27, 1994.

material (i.e., flammable liquids, oils, greases, tars, oil-base paints, lacquers, and flammable gases). Human- and cargo-supplied ignition sources can cause a variety of fires (deep seated, flaming, explosive, metallic, fires with their own oxidizer, chemical, etc.), which are not easily characterized.

In July 1998, the FAA reported the results of baseline testing with Halon 1301, and preliminary suppression testing with HFC-125 and a zoned water mist system.[86] At the same time, the FAA began developing an exploding aerosol can test and examining HFC-125 as a simulant for Halon 1301.

In the 1999 draft of the Cargo Compartment MPS, the Task Group defined four different fire test scenarios to address the wide variety of fires possible in cargo compartments. These fire test scenarios included:

1. Bulk load fire
2. Containerized fire
3. Surface burning fire
4. Aerosol can explosion

All four tests are conducted in a 2,000-cubic foot test enclosure, characterized by a 50 cubic feet per minute (cfm) leakage rate. The bulk load and containerized fires are deep-seated. The bulk load fire scenario consists of 178 cardboard boxes containing 2.5 pounds of shredded paper, ignited via a heated Nichrome wire wrapped around folded paper towels. The containerized load fire scenario consists of 33 cardboard boxes inside an LD3 container,[87] with three LD3 containers located in the cargo compartment simulator, and ignition is accomplished in the same fashion as in the bulk load tests. The surface burning fire scenario involves ignition via spark of 0.5 gallons of Jet A fuel with 13 ounces of gasoline. Finally, the aerosol can explosion scenario involves a fire load of 0.2 pounds of propane, 0.6 pounds of denatured alcohol, and 0.2 pounds of water contained in an aerosol can simulator in an empty cargo compartment simulator, ignited by a spark.

In May of 2000, the FAA reported testing of a water mist system to the draft MPS in a modified DC-10 aircraft, and announced plans to test HFC-125 at a later time.[88]

In September 2000, the IASFPWG recommended water mist/inert gas systems and HFC-125 for cargo compartment applications. Envirogel, HFC-227ea, inert gases (carbon dioxide, nitrogen), and water mist or fog were not recommended.[89] FIC-13I1 had previously been eliminated from consideration, due to the large amount of toxic gases formed upon suppression.

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[86] Blake, D., et al., Cargo Compartment Fire Protection in Large Commercial Transport Aircraft, DOT/FAA/AR-TN98/32, July 1998.

[87] An LD3 container is a standardized container used for loading freight into aircraft, approximately 159 ft^3 in volume.

[88] Reinhardt, J., Cargo *Compartment Minimum Performance Standards for Gaseous Total Flood Agents,* International Aircraft Systems Fire Protection Working Group Meeting, May 3-4, 2000, Bremen, Germany.

[89] Gupta, A., *Options for Aircraft Cargo Compartment Fire Protection*, Aircraft System Fire Protection Working Group, September 2000.

An initial version of the Cargo Compartment MPS was published in September 2000, and contains details regarding the development of this version of the MPS.[90] Specifically, baseline tests were performed with no suppression agent, and the performance of Halon 1301 under well-defined cargo fire scenarios was determined in order to define the acceptance criteria that would be employed to certify alternative agents. This version of the Cargo Compartment MPS pertains only to gaseous suppression agents; in September 2000, the IASFPWG recommended water mist/inert gas systems and HFC-125 for FAA tests.

In December 2000, the results of Cargo Compartment MPS testing were presented using Halon 1301, HFC-125, and a water mist/nitrogen system. HFC-125 was tested in the exploding aerosol can and bulk load fire scenarios; it was found to be effective in the exploding aerosol can test, but not in the bulk load fire scenario when employed at its minimum design concentration. The water mist/nitrogen system tested was found to be effective in controlling three out of four MPS fire test scenarios—control of the exploding aerosol can scenario was not accomplished.[91]

In July 2001, further FAA testing of a water mist/nitrogen system was reported.[92] These tests employed a new test scenario combining the aerosol can simulator with 58 cardboard boxes. The water mist/nitrogen system had previously been shown to be ineffective in the original exploding aerosol can scenario. Further testing of the water mist/nitrogen system was reported in June 2002.[93, 94]

As previously stated, the water mist/nitrogen system has been found to be equal in effectiveness to Halon 1301 on a weight basis in the *modified* exploding aerosol can tests. In addition to effectiveness, another consideration is the weight of the system. Furthermore, the feasibility of the water mist/nitrogen system will likely depend to some degree on the ability to use an Onboard Inert Gas Generating System (OBIGGS) for the nitrogen supply.

In July 2002, a draft modification of the original MPS was published,[95] and in April 2003, the current Cargo Compartment MPS was published.[96] The current MPS replaces DOT/FAA/AR-00/28, and includes consideration of nongaseous fire suppression systems. In this most recent MPS, the aerosol explosion protocol has been modified to allow the inclusion of a non-gaseous system such as water spray. There now exists a "long" and a "short" version of the aerosol can

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[90] Reinhardt, J., et al., Development of a Minimum Performance Standard for Aircraft Cargo Compartment Gaseous Fire Suppression Systems, DOT/FAA/AR-00/28, Final Report, September 2000.

[91] Reinhardt, J., *Test Results, MPS for Aircraft Cargo Compartment,* International Aircraft Systems Fire Protection Working Group Meeting, December 11-12, 2000, London, England.

[92] Minutes of the International Aircraft Systems Fire Protection Working Group Meeting, July 17-18, 2001, Wilson, NC.

[93] Minutes of the International Aircraft Systems Fire Protection Working Group Meeting, June 13-14, 2002, London, England.

[94] Kallergis, K., *Status on Firedetex*, the International Aircraft Systems Fire Protection Working Group Meeting, June 13-14, 2002, London, England.

[95] Reinhardt, J., Minimum Performance Standard for Aircraft Cargo Compartment Built-in Fire Suppression Systems, Draft, DOT/FAA/AR-TN02/XX, July 2002.

[96] Reinhardt, J., Minimum Performance Standard for Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems, DOT/FAA/AR-TN03/6, April 2003.

explosion test. Table 9 presents the characterization of both of these tests, as detailed by Reinhardt in his presentation at the October 2002 meeting of the IASFPWG.[97]

Table 9. Characterization of "Long" and "Short" Tests of the Aerosol Can Explosion Test

Parameter	"Long" Version	"Short" (Original) Version
Fire Load	0.2 lb propane, 0.6 lb denatured alcohol, 0.2 lb water in simulator, 59 cardboard boxes in cargo bay	0.2 lb propane, 0.6 lb denatured alcohol, 0.2 lb water; Empty standard compartment
Ignition Source	Nichrome wire/paper towel and electrodes	Electrode arc by electrodes 2 ft from floor, 3 ft from simulator
Activation of Suppression System	1 minute after ceiling T reaches 200°F	Discharge agent and allow 2 minutes for dispersion
Aerosol Can Simulator	Activated 5 minutes after T attached to pipes reaches 400°F	Activated when agent, at 2 ft from floor, is at minimum protection concentration
Test Duration	At least 180 minutes or until simulator is activated	At least 180 minutes or until simulator activated

Source: Reinhardt, J., Minimum Performance Standard for Aircraft Cargo Compartment Built-in Fire Suppression Systems, Draft, DOT/FAA/AR-TN02/XX, July 2002.

The shorter version of the aerosol can test is the original procedure developed for gaseous extinguishing agents. As discussed in detail in the current Cargo Compartment MPS, the Cargo Compartment Task Group has not been able to reach a consensus regarding the introduction of the "long" version of the aerosol can test, which was specifically developed to provide a test for non-gaseous systems. Boeing has objected to the long version on the basis that it does not demonstrate an equivalent level of safety as that afforded by Halon 1301. Others have argued that, since current Halon 1301 systems would pass both the "long" and "short" versions, allowing the passing of only the long version does not demonstrate equivalence to Halon 1301.

7.2 Technical Evaluation of Cargo Compartment MPS

Based on an examination of available published materials, the following conclusions may be reached regarding the Cargo Compartment MPS:

- *The FAA fire test scenarios are realistic.* The fire test protocols, described in the MPS, are representative of possible real world fire scenarios in cargo compartments, and do not appear to be excessively stringent for gaseous suppression systems.

- *The original MPS test protocol, which employs the "short" version of the aerosol can test, ensures an equivalent level of safety compared to Halon 1301.* The inclusion of four tests addresses the possible fire types that may occur (deep seated, flammable liquid,

[97] Reinhardt, J., *Minimum Performance Standard for Aircraft Cargo Compartment Built-in Fire Suppression Systems,* International Aircraft Systems Fire Protection Working Group Meeting, October 30-31, 2002.

aerosol can explosion). Sufficient examination of test variables appears to have been accomplished.

- *As previously indicated, the use of the "long" version of the exploding aerosol can procedure described in the current MPS may not provide a level of safety equivalent to that afforded by Halon 1301.* The introduction of the "long" version of the aerosol can test into the recent MPS has been met with debate, with some industry opposition to the procedure on the basis that it does not provide an equivalent level of safety compared to Halon 1301.

7.3 Agents Tested to the Cargo Compartment MPS

Currently, only water mist/nitrogen systems have been fully tested and passed the final Cargo Compartment MPS. However, as previously described, water mist/nitrogen systems were only capable of passing a modified version of the original exploding aerosol can test, which was developed to evaluate systems that do not employ gaseous agents.

FAA has recently begun testing of HFC-125 and bromotrifluoropropene ($CF_3CBr{=}CH_2$, or "BTP") in the exploding aerosol can scenario.[98]

7.4 Status of the Replacement of Halon 1301 in Cargo Compartments

To date, there have been no cases of Halon 1301 replacement with an alternative agent in cargo compartments of commercial aircraft, although a water mist/nitrogen system has been tested to and met the requirements of the current MPS.

7.5 Barriers to the Use of Halon Alternatives in Cargo Compartments

Technical, economic, and regulatory barriers have been cited as impediments to the transition away from halons in cargo compartment applications. These barriers are discussed in detail below.

7.5.1 Technical Barriers

Although the Cargo Compartment MPS has been finalized, the adoption of the "long" version of the aerosol can test is viewed by some as a radical departure from the original objective of providing equivalent levels of safety to halons. This issue could delay the replacement of the Halon 1301 in this application, if airframe manufacturers do not accept the final MPS and, therefore, continue to seek a replacement agent that meets the original ("short") version of the exploding aerosol can test.

[98] Reinhardt, J.W. "Behavior of Bromotrifluoropropene and Pentafluoroethane When Subjected to a Simulated Aerosol Can Explosion." DOT/FAA/AR-TN04/4, May 2004.

While the debate over the final MPS has caused some to question whether or not water mist/nitrogen systems require sacrificing extinguishing effectiveness relative to Halon 1301, another technical barrier to the introduction of these systems may be their dependence on Onboard Inert Gas Generating Systems (OBIGGS) to produce the required nitrogen. Although OBIGGS technology has been used for decades on military cargo planes, this technology has not been proven for use in cargo compartments in commercial aircraft. One notable benefit of these systems, however, is that they offer the potential of weight effectiveness equivalent to that of Halon 1301.[99]

Additional testing is needed on HFC-125 and bromotrifluoropropene to determine what, if any, technical barriers are associated with these alternative agents.

7.5.2 Economic Barriers

Although not yet fully tested to the MPS, HFC-125 systems have been found to be effective at a concentration of nearly 15 percent, which suggests that their adoption would result in a significant weight penalty compared to Halon 1301–which in turns translates into cost penalties. However, any incremental jet fuel costs associated with this weight penalty would be insignificant in terms of airlines' total annual costs for jet fuel.

7.5.3 Regulatory Barriers

The lack of any regulatory or policy mandate has been cited as a barrier in the transition away from Halon 1301 in the cargo compartment of commercial aircraft. However, with the exception of civil aviation, the lack of a mandate to halt halon use has not forestalled the adoption of halon alternatives in other sectors of use (i.e., military, essential electronics, oil and gas production). Until supplies of recycled halons either become cost-prohibitive to procure or simply unavailable, or until policy changes are implemented that push the transition to the alternatives, the civil aviation industry lacks an immediate incentive to replace halons and begin designing and installing alternatives on aircraft cargo compartment fire protection. In the absence of a policy or other mandate to replace Halon 1301 in these applications, economic factors will drive airlines to continue to employ Halon 1301 in aircraft cargo compartments. Additional considerations for the alternatives are any future regulations that may ban or severely restrict the use of HFCs.

[99] Reinhardt, J., Water Mist Systems: MPS for Aircraft Cargo Compartment Test Results, International Aircraft Systems Fire Protection Working Group Meeting, Wilson, NC, July 17-18, 2001.

8. Summary of Barriers and Recommended Actions

After comprehensively assessing the MPS and test scenarios for lavatory trash receptacle extinguishing systems, handheld extinguishers, engine nacelle/APU protection systems, and cargo compartment extinguishing systems, barriers to halon replacement have been identified in all but one application. This section summarizes the barriers particular to each application, and provides recommendations for addressing them.

8.1 Lavatory Receptacle Extinguishing Systems

Other than the need for FAA to certify the alternative systems, no technical or economic barriers currently exist to prevent the transition from Halon 1301 in lavatory receptacle extinguishing systems. Indeed, three systems (HFC-227ea, HFC-236fa, and Envirogel—a gelled halocarbon and dry chemical suspension using HFC-236fa)—are currently available that are more effective and may cost less than Halon 1301 units. In addition, these three systems are the same size and mount on the same place in the aircraft as Halon 1301, therefore, only document changes (and not engineering modifications) would be required prior to installation of these alternative agents.

Recommended Action: Technically feasible alternatives for halons have been identified and tested to the MPS. Boeing should continue moving forward with the approval process for agents that have met the requirements of the Lavex MPS (HFC-227ea, HFC-236fa, and Envirogel), and other airframe manufacturers should be encouraged to initiate their internal approval processes with these agents for new airframe designs. FAA should expedite the approval process for this and the other applications that currently use halons. Consideration should be given to the timing for beginning the installation of the alternative systems and discontinuing new installations of halon Lavex systems. Additional considerations for the alternatives are any future regulatory actions that ban or severely restrict the use of HFCs.

8.2 Handheld Extinguishing Systems

Currently, no technical barriers exist in this application, as HFC-227ea, HFC-236fa, and HCFC Blend B systems have passed all of the tests required by the Handheld MPS: equivalency to Halon 1211, hidden fire test, seat/toxicity test. For all of these alternative systems, weight and volume (and hence, slight cost) penalties exist compared to Halon 1211 extinguishing units. However, the cost penalties associated with additional jet fuel are insignificant relative to overall fuel costs.

Recommended Action: Technically feasible alternatives for halons have been identified and tested to the MPS. Aircraft manufacturers should initiate or complete their internal approval process for agents that have met the requirements of the Handheld MPS. FAA should expedite the approval process for this and other applications that currently use halons. Consideration should be given to the timing for beginning the installations of the alternative systems and discontinuing new installations of halon handheld extinguishers. Additional considerations for the alternatives are the pending regulatory phaseout of HCFC production and any future regulations that may ban or severely restrict the use of HFCs.

8.3 Engine Nacelle/APU Fire Extinguishing Systems

An Engine Nacelle/APU MPS has not been finalized, as the current draft is undergoing revision and is not available for public review. As a result, it is impossible to evaluate the test protocol, although reports available in the public sector indicate that the tests are being designed to provide an equivalent level of safety compared to Halon 1301.

The engine nacelle simulator at FAA has only been ready for agent testing since March 2003. Current investigations are focused on HFC-125 and FIC-13I1.

Recommended Action: The FAA should expedite the finalization of the Engine Nacelle/APU MPS so that airframe manufacturers can initiate testing, qualification, and approval processes for the alternatives on new airframe designs.

8.4 Cargo Compartment Fire Extinguishing Systems

A final version of the Cargo Compartment MPS was published in April 2003. There continues to be debate on whether this new version of the MPS ensures an equivalent level of safety compared to Halon 1301. Certain agents are not capable of controlling the fire scenario of the original exploding aerosol can test, but can control the scenario of the new alternative procedure.

Recent FAA testing has focused almost exclusively on water mist/nitrogen systems that have passed the MPS "long" version of the aerosol can test, although these systems proved ineffective in controlling the fire scenario of the original aerosol can fire test. In addition, the viability of these systems is tied to the implementation of onboard inert gas generating systems (OBIGGS), which, although widely used in military cargo aircraft, are cited as an unproven technology for use in cargo compartments in commercial aircraft.

Recommended Action: The FAA should expedite resolution of the remaining issues of the Cargo Compartment MPS. In addition, R&D and testing efforts on alternatives (e.g., HFC-125, BTP, pyrotechnically generated aerosols) should be continued, as only the water mist/nitrogen system has been tested to and met the requirements of the MPS to date. Airframe manufacturers should continue internal testing, qualification, and approval processes for alternatives as these meet the requirements of the MPS.

9. Phaseout Options

This section considers three phaseout options for prompting an expedited, but realistic halon phaseout in the civil aviation industry. Specifically, the following scenarios are explored:

1. Business-As-Usual (no restrictions on halon use in aircraft applications);
2. Target Halon Phaseout in New Aircraft Applications in 2005; and
3. Target Halon Phaseout in New Aircraft Applications in 2010.

Each of these scenarios assume that no new agents will be developed and, hence, the results correspond to the earliest times at which replacement of halon in aircraft applications could be realized (since the development time associated with new agents would cause delay). In addition, each scenario assumes that halon systems cannot be replaced on board aircraft until the following procedures are completed:

- Finalization of Minimum Performance Standard (MPS);
- FAA testing to MPS;
- Airframe manufacturer qualification testing;
- Modification of airframe manufacturer's Type Certificate to include alternative unit;
- Submittal of modified Type Certificate to FAA;
- FAA approval of modified Type Certificate; and
- Inclusion of alternative unit in airframe manufacturers' engineering documentation.

Table 10 presents estimates of the time needed to complete some of the steps listed above, and indicates the status of each of the civil aviation applications.

Table 10. Estimated Time to Complete Selected Steps Prior to the Introduction of Alternative Extinguishing Units in Commercial Aircraft Applications

Step	Estimated Time Required to Complete	Status by Civil Aviation Application			
		Lavatory Trash Receptacle	Handheld	Engine Nacelle/APU	Cargo Compartment
1) FAA Testing to Finalized MPS	6-12 months	X	X	Ongoing	X
2) Airframe Manufacturer Qualification Testing	12 -18 months	X			
3) Preparation and Submittal of Modified Type Certificate	3-6 months	Ongoing			
4) FAA Approval of Modified Type Certificate	3-6 months				
5) Alternative Unit on Drawing, Installation Allowed	3-6 months				

9.1 Scenario 1: Business-As-Usual

The business-as-usual scenario assumes that current worldwide production bans on halons remain intact and no industry initiatives are made to reduce or limit the use of halons in commercial aircraft applications.

Under this scenario, replacement of Halon 1301 in lavatory trash receptacle extinguishers could begin by late 2004 or early 2005, following completion of testing by airframe manufacturers (currently underway).

However, for all other civil aviation applications, the introduction of alternative agents is not likely to begin much before halon bank supplies dwindle—which is conservatively estimated to be around 2020.[100] This estimate is based on two sources:

1. One industry estimate projects Halon supplies will be adequate to satisfy aircraft industry needs for at least the next 10, and possibly the next 20 years;[101] and

2. The latest report by the Halon Technical Options Committee (HTOC) states that halon stocks are "adequate to meet the future service and replenishment needs of all existing critical or essential halon fire equipment until the end of their useful lifetime," which it estimates is 30 years or more for aircraft.[102]

Table 11 presents the projected phaseout dates based on the above considerations regarding halon stocks and the availability of substitutes.

Table 11. Projected Transition Under Business-As-Usual Scenario

Application	Estimated Year of Introduction of Alternative Agents Into Commercial Aircraft
Lavatory Trash Receptacle	2004/2005
Handheld Extinguishers	2020
Engine Nacelle/APU	2020
Cargo Compartment	2020

9.2 Scenario 2: Target Halon Phaseout in New Aircraft Applications in 2005

This scenario assumes a targeted halon phaseout in new aircraft applications beginning in 2005. Specifically, industry would voluntarily prohibit new installations of halon systems, and only allow the use of recycled halon to service and maintain existing systems.

As discussed above, cost competitive alternatives for lavatory trash receptacle extinguishers already exist, and installation on commercial aircraft should be feasible by late 2004 or 2005.

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[100] Most likely, the transition to alternatives would begin with new commercial aircraft several years before halon supplies dwindle, to avoid the re-engineering and re-certification costs associated with system retrofits.

[101] Personal communication from Tom Cortina (HARC), September 2003.

[102] HTOC (Halons Technical Options Committee) 2002. *2002 Assessment Report of the Halons Technical Options Committee*, UNEP Nairobi, March 2002. Available at http://www.teap.org/REPORTS/downloads/HTOC2002.pdf

For handheld extinguishers, HFC-227ea, HFC-236fa, and HCFC Blend B have passed all tests required by the Handheld MPS. Additional considerations for the alternatives are the pending regulatory phaseout of HCFC production and any future regulatory requirements that may ban or severely restrict the use of HFCs. Assuming the commencement of airframe manufacturer qualification testing of HFC-227ea and HFC-236fa units in late 2004/early 2005, and final approval for installation design and certification, units could be approved for installation as early as 2006 to 2007.

For engine nacelle/APU systems, the MPS may be finalized no earlier than 2005. Assuming the commencement of airframe manufacturer qualification testing in 2005, completion of all requirements to allow installation on commercial aircraft may be possible as early as 2007 to 2009, under a best-case scenario.

For cargo compartments, research efforts to scale the water mist/nitrogen systems which have passed the MPS to real world cargo compartment sizes have begun.[103] Assuming the "long" version of the exploding aerosol can test is accepted by all parties involved, installation of alternative systems could be possible some time between 2006 and 2008.

Table 12 summarizes the projected halon phaseout dates under this scenario. As shown, a 2005 targeted phaseout date would likely not be feasible for most applications. This scenario could provide the civil aviation industry with an incentive to phaseout halons in all applications at the earliest date possible.

Table 12. Projected Transition Under 2005 Targeted Halon Phaseout Scenario

Application	Estimated Year of Introduction of Alternative Agents Into Commercial Aircraft
Lavatory Trash Receptacle	2004/2005
Handheld Extinguishers	2006-2007
Engine Nacelle/APU	2007-2009
Cargo Compartment	2006-2008

9.3 Scenario 3: Target Halon Phaseout in New Aircraft Applications in 2010

This scenario assumes a targeted halon phaseout in new aircraft applications in 2010.

As described under the 2005 halon phaseout scenario, halon alternatives could be approved for installation in Lavex applications in commercial aircraft by late 2004/2005, while the possible phaseout dates for all other applications could likely occur some time between 2006 and 2009. However, unless cost competitive alternatives are developed prior to 2010, airlines would most likely wait until shortly before the targeted phaseout date of 2010 to replace halons.[104] Table 13 summarizes the projected halon phaseout dates under this scenario.

[103] Reinhardt, J.W. "System Scaling: Fire Suppression System Scaling." International Aircraft Systems Fire Protection Working Group Meeting, Atlantic City, NJ, November 3-5, 2003.

[104] The transition would likely begin with new halon-free commercial aircraft designs several years before the 2010 phaseout date, to avoid the re-engineering and re-certification costs associated with system retrofits.

Table 13. Projected Transition Under 2010 Targeted Halon Phaseout Scenario

Application	Estimated Year of Introduction of Alternative Agents Into Commercial Aircraft
Lavatory Trash Receptacle	2004/2005
Handheld Extinguishers	2010
Engine Nacelle/APU	2010
Cargo Compartment	2010

9.4 Summary of Options

Table 14 summarizes the three targeted halon phaseout scenarios. As shown, the fastest halon phaseout is projected to be achieved under the scenario of a targeted halon phaseout in 2005. However, under this scenario, actual achievement of the phaseout would not be possible in three of the four end use applications. Conversely, a targeted phaseout in 2010 would foster a smooth transition in all applications in a more timely fashion than would be achieved in the absence of such an industry target. Under a business-as-usual scenario, halon phaseout is not likely to occur until about 2020 for the majority of end use applications.

Table 14. Transition Scenarios for the Replacement of Halons in Civil Aviation Applications

Application	Estimated Year of Introduction of Alternative Agents Into Commercial Aircraft		
	Business-As-Usual	Halon Phaseout in 2005	Halon Phaseout in 2010
Lavatory Trash Receptacle	2004/2005	2004/2005	2004/2005
Handheld Extinguishers	2020	2006-2007	2010
Engine Nacelle/APU	2020	2007-2009	2010
Cargo Compartment	2020	2006-2008	2010

10. Additional Considerations

While this report characterizes the current status of halon replacement efforts in civil aviation applications in the United States, and assesses various options to expedite the transition away from halons, there are several other considerations that must be borne in mind in order to identify the best path forward. In particular, some considerations that are beyond the scope of this paper but critical to assess include:

- Economic costs and environmental benefits of phaseout scenarios;
- Economic analyses of various incentives and disincentives;
- Availability of local (U.S.) and global halon supplies both short-term and long-term;
- Costs of local (U.S.) and global halon supplies over time;
- Current and projected U.S. market demand for halons;
- Current and projected U.S. demand for halons in civil aviation applications (including current fleets and new airframes); and
- Potential cost savings associated with early halon planning and management.

Future work on halon alternatives in civil aviation applications should focus on these issues to foster the development of a proper industry and/or government policy approach that maximizes potential environmental benefits and supports a safe, smooth transition for these applications.

Appendix A: Cargo Compartment Classification System

Federal Air Regulations classify cargo compartments according to their accessibility and the type of detection and suppression systems provided in the compartment. Classes A through E are defined, as presented below: [105]

- A **Class A** cargo or baggage compartment is one in which: (1) the presence of a fire would be easily discovered by a crewmember while at his station; and (2) each part of the compartment is easily accessible in flight.

- A **Class B** cargo or baggage compartment is one in which: (1) there is sufficient access in flight to enable a crewmember to effectively reach any part of the compartment with the contents of a hand fire extinguisher; (2) when the access provisions are being used, no hazardous quantity of smoke, flames, or extinguishing agent, will enter any compartment occupied by the crew or passengers; and (3) there is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station.

- A **Class C** cargo or baggage compartment is one not meeting the requirements for either a Class A or B compartment but in which: (1) there is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station; (2) there is an approved built-in fire extinguishing or suppression system controllable from the cockpit; (3) there are means to exclude hazardous quantities of smoke, flames, or extinguishing agent, from any compartment occupied by the crew or passengers; and (4) there are means to control ventilation and drafts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment.

- A **Class D** cargo compartment is an inaccessible compartment that does not have a fire or smoke detection system and a fire suppression system.

- A **Class E** cargo compartment is one on airplanes used only for the carriage of cargo and in which (1) there is a separate approved smoke or fire detector system to give warning at the pilot or flight engineer station; (2), there are means to shut off the ventilating airflow to, or within, the compartment, and the controls for these means are accessible to the flight crew in the crew compartment; (3) there are means to exclude hazardous quantities of smoke, flames, or noxious gases, from the flight crew compartment; and (5) the required crew emergency exits are accessible under any cargo loading condition.

[105] Federal Aviation Regulation (FAR), 14 CFR 25.857

Appendix B: Acronyms

ALT	Atmospheric Lifetime
APU	Auxiliary Power Unit
CAA	Civil Aviation Authority
CFR	Code of Federal Regulations
DOD	Department of Defense
DOT	Department of Transportation
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FMRC	Factory Mutual Research Corporation
GWP	Global Warming Potential
HAI	Hughes Associates, Inc.
HARC	Halon Alternatives Research Corporation
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HTOC	Halon Technical Options Committee
IASFPWG	International Aircraft Systems Fire Protection Working Group
IHRWG	International Halon Replacement Working Group
JAA	Joint Aviation Authority
MPS	Minimum Performance Standard
NFPA	National Fire Protection Association
NOAEL	No Observed Adverse Effect Level
OBIGGS	Onboard Inert Gas Generating System
ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substance
QTP	Qualification Test Procedures
R&D	Research and Development
TCA	Transport Canada Aviation
UL	Underwriters Laboratories, Inc.
USAF	United States Air Force
WKA	Walter Kidde Aerospace

Appendix C: Fire Suppression Agent Trade and Chemical Names

Agent	Agent Trade Name	Chemical Formula
Halon 1211	-	CF_2BrCl
Halon 1301	-	CF_3Br
HFC-23	FE-13	CF_3H
HFC-125	FE-25	CF_3CF_2H
HFC-236fa	FE-36	$CF_3CH_2CF_3$
HFC-227ea	FM-200, FE-227	CF_3CHFCF_3
FIC-13I1	Triodide	CF_3I
FC-4-1-10	CEA-410	$CF_3CF_2CF_2CF_3$
FC-6-1-14	CEA-614	$CF_3CF_2CF_2CF_2CF_2CF_3$
HCFC Blend B	Halotron I	CF_3CHCl_2 CF_4 Ar
HCFC Blend E	NAF P-IV	Formulation of HCFC, HFC and additive
Gelled Halocarbon/Dry Chemical Suspension	Envirogel	HFC-236fa ammonium polyphosphate or bicarbonate additive