# Description and Status of Civil Aviation's Halon Replacement Program

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## 1. SUMMARY

Civil aviation has a major program to replace halons with environmentally acceptable agents/systems in transport aircraft fire extinguishing systems. The program is international in participation and is harmonized amongst the regulatory authorities in the U.S., Europe and Canada. An International Halon Replacement Working Group provides for frequent review and critique of progress, task group studies of issues that arise and planning of technical test activities. The program emphasizes full-scale fire tests to evaluate the effectiveness of replacement/alternative agents and to develop certification criteria for those agents that are equivalent to halon in firefighting effectiveness and are compatible with operational requirements. This will ensure that the current level of fire safety will continue to be maintained in future aircraft fire extinguishing systems.

## 2. INTRODUCTION

On January 1, 1994, the production of Halon 1211 and Halon 1301 ceased in the developed countries as required by an international agreement known as the Montreal Protocol. The production of those Halons was banned because they are chemicals that have been shown to deplete the stratospheric ozone layer. Recent amendments to the Protocol suggest that those agents may soon be banned from use with a mandate for their destruction. This poses a rather large problem in the aviaiton industry. The primary fire suppressing agent used on-board commercial aircraft in total flood systems is Halon 1301. Halon 1211 is required in portable extinguishers for use against passenger cabin fires.

## 3. HALON USE IN AIRCRAFT

Fire extinguishing systems and fire extinguishers are employed in civil transport aircraft to safeguard against an uncontrollable in-flight fire. Although the incidence of fatal in-flight fires is rare, the consequences can be great in terms of lives lost. For example, in 1980, a fire originating in the aft cargo compartment of a Saudia L-1011 spread into the passenger cabin, causing 301 fatalities in commercial aviation's worst in-flight fire accident. There was no fire extinguishing system in the cargo compartment. More recently, the ValuJet DC-9 fatal in-flight on May 11, 1996 illustrated the vulnerability of a commercial transport to unusually severe fire conditions, in this case created by the shipment of hazardous materials.

Most cabin in-flight fire and smoke incidents are controlled by the aircraft crew usually without passengers being aware of any problem. In the United States, the frequency of these reported minor fire/smoke incidents is approximately two events per week. Crewmembers are able to quickly identify the fire/smoke source (e.g., overheated lighting ballast, galley fire, etc.) and eliminate the problem. Of greater concern, however, are those fire sources which originate in hidden or inaccessible cabin areas, or vulnerable areas such as cargo compartments and engines. To protect these areas, an active fire detection and/or extinguishing system is required. The extinguishing system is designed to either extinguish the fire or suppress the fire until the aircraft can be safely landed. In the latter case, protection of aircraft crewmembers and passengers as well as critical flight systems must be assured.

Contemporary transport aircraft employ fire extinguishing agents in four applications: cargo compartments, engines and auxiliary power units, lavatory trash receptacles and hand-held extinguishers. The operational and ambient conditions and fire threats are very different in each application. In an engine nacelle, high velocity air at relatively low temperature tends to render most agents ineffective because of their low volatility and poor dispersal characteristics. On the other hand, cargo compartment agent selection is based on initial flame extinguishment and sustained inerting of the entire compartment volume for lengthy periods of time, as long as 3 hours on a transoceanic flight.

The agent of choice in total flooding applications - cargo compartment, engine nacelle and lavatory trash receptacles - is Halon 1301 ($CBrF_3$). This remarkable agent is effective over a wide range of operational and ambient conditions, and against various probable fire threats, which exist in these applications areas. Other important selection considerations include effectiveness per unit weight, low toxicity, low corrosivity and virtually no clean-up. The aviation authorities also require a minimum of two hand-held extinguishers employing the streaming agent Halon 1211 ($CBrClF_2$). Although the requirement was initially based on fuel-drenched seat fire extinguishing effectiveness, other important considerations for hand-held extinguishers include low bottle weight, hidden fire extinguishing effectiveness and relatively low toxicity. An illustration of the relative quantities (pounds) of halon required in the four application areas is provided below for the B-777:

| | |
|---|---|
| Cargo compartments | 270 |
| Engines and APU | 70 |
| Lavatories | 3.5 |
| Hand-held extinguishers | 15 |

## 4. HALON REPLACEMENT PROGRAM

The halon replacement program for transport aircraft is based on the research program outlined by the Federal Aviation Administration (FAA) in 1993 (ref. 1). Although initially proposed by FAA, this is an international program with active participation by the aviation industry and the regulatory authorities in Europe and Canada, provided in large part through the International Halon Replacement Working Group, as discussed later.

The objective of the technical program is to develop certification criteria for approval of non-halon extinguishing agents and systems by the regulatory authorities in the aforementioned application areas. New agents/system must exhibit equivalent fire extinguishing/suppression performance to the currently used halons in order to maintain the excellent record of in-flight fire safety.

The major tasks of the program are as follows:

- Develop Full-Scale Fire Test Articles
- Conduct Full-Scale Evaluation Tests
- Develop Minimum Acceptable Levels of Performance
- Develop Standard Performance Tests
- Develop and Issue Certification Acceptance Criteria

In summary, full-scale test articles are developed in each application area to realistically simulate the operational and ambient environment, and fire scenarios, against which to evaluate agent performance. Selection of fire scenarios is critical in the determination of agent effectiveness, and is based on past and future likely fire loads (involved materials), including those posing a serious threat to flight systems and aircraft occupants. Full-scale tests will identify quantities of agent required to extinguish/suppress each fire condition, at the experimental discharge conditions, as well as those agents which are proven ineffective. Moreover, full-scale test data will guide the development of standard performance tests, if applicable, and will provide the primary basis for the development of certification acceptance criteria.

The technical program is guided by the International Halon Replacement Working Group (IHRWG), which since its inception in October 1993, meets three times per year in North America or Europe. The IHRWG provides for input and participation by the aviation industry and coordination and harmonization of the technical program amongst the regulatory authorities. Membership includes aircraft manufacturers, airlines, regulatory authorities, agent suppliers, extinguishing system manufacturers, the military and research organizations (government and private sector). A typical meeting will be attended by 50-75 people; however, the mailing list for distribution of meeting minutes and other information has over 400 names.

An important function of the IHRWG is the creation of task group to address issues or concerns raised during the conduct of the program. Task group memberships includes individuals with the expertise or capabilities to perform the assigned task. To date, 19 task groups have been created in less than three years to work on topics such as agent toxicity, user preferred extinguishing agents, detector service performance, etc. Perhaps, the most important task groups are those developing minimum acceptable levels of performance for each of the four application areas, an ongoing process As discussed later, task group findings, in some cases, have been published as technical reports in order to document and disseminate results. Thus, the IHRWG is in a true sense a working group, generating needed information and guiding the direction of the technical program. One of the initial task groups formed was given the assignment of conducting a review of agents options to halon. The task group prepared an extensive report which contains a summary of available fire suppression agents, their properties and applicability in the various aircraft applications (ref.2). The relatively new halocarbon replacement agents as well as classical alternatives, including recent developments such as water mist and gas generators, are discussed in the report. Classes of agents, with presently available agents listed, were recommended for use in the development of test protocols.

## 5. LAVATORY TRASH RECEPTACLES

Lavatories have been the source of several fatal in-flight fires (Varig, 1973; Air Canada, 1983) accounting for 146 fire fatalities. Serious uncontrolled lavatory fires continue to occur. In 1993 an in-flight fire in the lavatory of a Dominicana 727 spread out of control and destroyed the aircraft. Also, in 1995 an International Airlines DC9 was gutted by a lavatory fire while parked at a ramp. Past fatal lavatory fires and recent serious incidents highlight the need for maintaining, if not improving, lavatory fire protection.

Lavatories present a fire safety design challenge because of four factors: (1) the existence of a variety of hidden potential ignition sources, (2) reported incidents of improper passenger activity (smoking, detector tampering, etc), (3) high ventilation rates that may mask early detection and kindle a fire, and (4) long periods when the lavatory may remain unoccupied. In the past, a source of lavatory fires has been the trash receptacle, which was the probable cause of the Varig accident that caused 123 fire fatalities. To counteract this fire threat, a built-in fire extinguisher is required to discharge automatically into the receptacle upon the occurrence of a fire. These extinguishers employ Halon 1301 and are often called "potty bottles".

Two task groups were formed to assist in the development of a halon replacement performance standard for lavatory trash receptacles. The task group entitled User Preferred Fire Suppression Agent for Lavatory Trash Container Fire Protection conducted a survey to determine airline preference for lavatory extinguisher replacement agents. A second task group was assigned responsibility for developing and recommending a standard test protocol for automatic lavatory trash receptacle extinguishers.

The survey study indicated that 83% of the airline respondents stated a preference when given the choice between halocarbon and blends (gaseous agents) and water and water based agents. That preference was gaseous halocarbon over water by a factor of 4:1. Factors such as effectiveness, "drop-in" compatibility and zero cleanup/damage were stated considerations. Nevertheless, the task group recommended that the minimum quantity of water to achieve extinguishment should be determined to better define a water based system. A report documenting the user survey was issued (ref. 3).

The test protocol task group has developed a standard test device and is in the final stages of defining the test procedure. As with any fire test standard, it is mandatory that test data generated by different laboratories be in agreement (test reproducibility). Much of the development focused on correcting the variability of the fire load, such as simplifying the type of combustibles used (paper towels only), towel conditioning and how to consistently load the containers with crumpled towels. The remaining items being finalized are the agent temperature, a parameter that dictates agent/system feasibility, and ignitor temperature measurement. It is expected that the minimum performance standard for lavatory extinguishers, which is mainly comprised of the test protocol, will be completed by the end of 1996.

## 6. HAND-HELD EXTINGUISHERS

In order to prevent small cabin fires from becoming a problem, the regulatory authorities require that hand-held extinguishers be conveniently located throughout the cabin. The number of required extinguishers is dictated by the passenger capacity of the airplane. Moreover, at least two of the extinguishers on an airplane with a seating capacity greater than 61 must contain Halon 1211. This requirement is based on the demonstrated superior effectiveness of Halon 1211 in extinguishing a gasoline-soaked seat fire (so called "hijacker scenario"), as compared to "classical" extinguishing agents such as water, dry chemical and carbon dioxide.

Hand-held extinguishers are employed relatively frequently to combat passenger cabin fires. In the Unites States, each year more than 100 halon hand-held extinguishers are discharged against in-flight fires; i.e., a halon extinguisher is used on the average every 3-4 days. However, the mot telling example of the value of halon extinguishers was an in-flight fire which occurred on a trans-Atlantic Delta L-1011 flight on March 17, 1991. In this incident, Halon extinguishers were blindly discharged into air return grilles, successfully extinguishing a severe electrical fire that had spread into the cabin, and likely saving the airplane and its 231 occupants.

Replacement agents for halons must be effective against typical cabin fires, including electrical and flammable liquid cabin fires, as well as the more severe fires discussed above that present a greater threat to the airplane. In addition, the following requirements must be met:

- Acceptable toxicity to occupants when discharged in cabin
- No visual obscuration particularly when used in cockpit
- Listed and rated by a recognized approval laboratory such as Underwriter Laboratories
- Size and weight that allows effective usage by a typical flight attendant

There are three outstanding tasks that need to be completed in order to evaluate halon replacement/alternative agents and develop minimum performance standards for hand-held extinguishers:

- Gasoline-soaked seat fire test standard
- Hidden fire test standard
- Agent toxicity

A standard seat fire test is required to demonstrate equivalent extinguishment capability to Halon 1211 for the hijacker scenario. This relatively simple test method will be comprised of a prescribed seat(s) with given geometry and representative, available cushion materials, and a fixed quantity of spilled gasoline. The quantity of gasoline and/or preburn time will be determined so as to barely allow the fire to be extinguished with the smallest recommended Halon 1211 extinguisher (2.5 pounds). The test will be standardized to assure that test results are repeatable within a laboratory and reproducible between laboratories. Candidate agents will be tested to determine whether or under what conditions (agent quantity, discharge characteristics, etc.) they are equivalent to Halon 2111. This task has recently been undertaken by FAA.

A test method has recently been developed for evaluating the performance of hand-held extinguishers against hidden fires, such as the aforementioned L-1011 fire that was extinguished with Halon 1211 (ref. 4). The research and development effort was commissioned by the Civil Aviation Authority in the United Kingdom and conducted by Kidde International Research. The test method simulates hidden fires such as those that can occur below the floor in the cheek area and in the cabin behind sidewall panels. This is accomplished in a box-like device, incorporating perforated panels and stop plates to simulate airframe ribs and clutter, and using 20 pan fire locations in order to extinguish a fire. Some additional work remains to be done, most notably deriving pass/fail criteria and standardizing the test procedure.

The toxicity issue is being addressed in concert with the standard seat fire test development since this severe fire scenario represents an upper bound of agent discharge quantities and cabin exposure levels. Of concern is that crew members operating the extinguishers or passengers near the discharge location are not subjected to harmful levels of the virgin agent or its decomposition products. Tests will be conducted inside a full-scale passenger cabin to determine agent toxicity during extinguishment of the standard seat fire. Toxicity will be determined from analysis of virgin agent and agent decomposition concentration-time profiles, and animal assay, if deemed appropriate. Those agents which are capable of extinguishing a standard seat fire but create harmful concentrations of agent or agent decomposition products will be rejected.

## 7. CARGO COMPARTMENTS

Cargo compartments in passenger aircraft present a severe potential fire threat because of the large variety and quantity of combustibles found in luggage, cargo and mail, including hazardous materials. The worst single aircraft fire accident in aviation history (Saudia L-1011, 1980, 301 fatalities) was caused by a cargo fire. The recent ValuJet accident gives evidence of the dangers associated with hazardous materials transport in cargo compartments. Fire protection in large cargo compartments is provided by a built-in fire suppression system mandated by the regulatory authorities.

Currently, all aircraft cargo compartment fire suppression systems employ Halon 1301. This total flooding agent has the capability of rapidly dispersing throughout a cargo compartment and achieving an extinguishing concentration. Moreover, systems employing Halon 1301 are designed to suppress a lingering deep-seated fire for long periods of time, 180 minutes in transoceanic flights. Related fire protection requirements imposed by the regulatory authorities include rapid fire detection (one minute), prevention of hazardous quantities of combustion products or extinguishing agent from accumulating in occupied compartments, and usage of burnthrough resistant cargo liners.

Cargo compartment fire suppression agents must also be compatible with airline operational considerations, as follows:

- Noncorrosive to cargo compartment construction materials
- Minimal residue and cleanup needs
- Non-toxic to animals that may be carried

Low weight

Selection of replacement and alternative agent for evaluation under full-scale fire test conditions is dictated by the IHRWG and a survey of user preferred agents. The latter was a questionnaire sent to airlines throughout the world. The results indicated that a majority of airlines favor halocarbons as replacements for halon, but a significant number selected water and particulate aerosols (ref. 5).

Development of a minimum performance standard for cargo compartments by the IHRWG has focused primarily on the full-scale fire test methodology. Four critical fire threats have been identified for evaluation of replacement/alternative agents:

- Cargo container fire
- Bulk loaded luggage fire
- Surface burning fire
- Aerosol can/luggage fire

Additional test parameters, such as compartment volume and fire load (percentage of compartment volume occupied by cargo) add to the extensiveness of the required testing. Halocarbons, water and particulate aerosols have been tested under selected fire threats and test parameters, as discussed below, to determine their effectiveness against cargo compartment fires.

FAA employs two wide-body cargo compartment test articles for agent evaluation. The cargo compartment and cabin section of the test article are extensively instrumented to measure temperature, smoke levels, and gas concentrations, including agent, agent acid gas decomposition products, oxygen, carbon dioxide and carbon monoxide. Two halocarbon agents, HFC-125 and HFC-227ea, have been evaluated against surface burning and bulk-loaded luggage fires. Both agents required considerably higher quantities than Halon 1301 to achieve fire suppression. Moreover, for the deep-seated fire created by bulk-loaded luggage, the agent quantities for fire suppression were 30-40% higher than laboratory (cup burner) measurements, thus reinforcing the importance of full-scale fire tests for evaluation of agents. Another finding which is of concern is the unusually high measured concentrations of acid gases in the cargo compartment caused by halocarbon agent decomposition. The acid gas concentrations are significantly higher than measured with Halon 1301. The next step is to examine the remaining fire threats and add triodide ($CF_3I$) to the halocarbons evaluation. In order to test triodide; gas analysis techniques are being developed to measure iodine containing decomposition products.

FAA also conducted a preliminary evaluation of pyrotechnically generated aerosols. It was necessary to devise a system that discharged every seven minutes in order to adequately counter agent concentration decay. Based on the preliminary tests, it was concluded that the generators require cooling, and a better system was needed for discharging to the initial extinguishing concentration and sustaining an inerting concentration. These findings, as well as possible corrosion and toxicity issues, and the need for cleanup in the event of an inadvertent discharge, has discouraged further testing of pyrotechnically generated aerosols.

Dual fluid and high pressure (fog) zoned water spray systems have been tested by FAA. Water spray is slowly receiving more consideration as a potentially viable halon alternative. There are not environmental, toxicity or supply concerns, and a cargo compartment system may make a cabin system cost effective (cabin water spray is highly effective improving postcrash fire survivability). On the negative side are concerns associated with an inadvertent discharge, preventing freezing and weight penalty.

At this time, the high pressure system requires the least amount of water. Deep-sealed fires inside a cargo container, believed to be the worst case fire threat for a water-based system, were effectively suppressed for 90 minutes by utilizing 30-35 gallons of water. This "optimal" quantity was determined by trial and error, varying certain spray parameters. A deep-seated, bulk-loaded luggage fire was suppressed with only 25 gallons of water. In both cases, although the system contained eight zones, only a single zone, encompassing the fire location, activated over the test duration. Further optimization of the system to reduce the required water quantity to about 15 gallons would make water spray competitive with Halon 1301 on an equivalent weight basis.

In Europe, a major water spray R&D program was recently initiated by a consortium of organizations which includes the CAA. Cargo compartment water spray fire suppression tests will be conducted utilizing the fire test methodology and fire threats outlined in the draft minimum performance standard. The primary emphasis is on the development and validation of a water spray/fire suppression computer model.

## 8. ENGINE NACELLES and AUXILIARY POWER UNITS

The regulatory authorities require engine and auxiliary power unit (APU) compartment fire extinguishing systems. The current fire extinguishing systems use Halon 1301 as the fire extinguishing agent. Usually, compliance with the regulations is based on a performance test, demonstrating the ability of the system to deliver and maintain gas concentrations at specified levels. In the case of Halon 1301, the requirement is 6% concentration throughout the protected fire zone for a duration of 0.5 second. With halocarbon replacement agents other criteria will apply. However, with non-gaseous alternative agents, a totally different means of compliance may be required.

One of the primary factors leading to the selection of Halon 1301 in aircraft fire extinguishing systems is its effectiveness over a wide range of operational conditions. This is especially true for the engine/APU application, since a fire may occur during any phase of the flight regime. The agent is discharged rapidly and expands throughout the engine nacelle in order to be able to extinguish any likely fire. All of this must occur in a matter of seconds, before the high speed air flow flushes the agent away. Cold ambient temperatures leads to the selection of volatile, low boiling point agents. Engine fires which can become very intense at flight speeds are a great concern because of the large quantities of fuel supplied to the engine and the proximity of the engine to the fuel tanks or fuselage. Therefore, it is imperative that engine fires are rapidly extinguished and controlled.

Construction of an engine nacelle test article by FAA, which will be capable of evaluating the fire extinguishing effectiveness of replacement agents for equivalency to Halon 1301, is near completion. Testing is expected to commence before the end of 1996. The IHRWG has defined the design of the test article, specified critical test parameters and conditions, and prioritized the evaluation of replacement agents.

Prioritization of agent evaluation was accomplished by a written survey of airlines and engine, APU, and aircraft manufacturers around the world (ref. 6). Based on the survey, the initial replacement agents tested will be FIC-1311 ($CF_3I$) and HFC-227ea ($C_3HF_7$). This will be followed by HFC-125 ($C_2HF_5$), an agent extensively tested and selected for future aircraft by the U.S. Air Force. Upon completion of evaluation of the above three halocarbon gases, gas generator technology will be examined. The end users selection of agents for evaluation reflect two unique engine fire extinguishing system considerations. First, the ability of gaseous agents to operative effectively in a low temperature, high air speed environment. Second, concerns with new agent systems that would require larger storage/plumbing space in an already space-limited environment, emphasizing the preference for a "drop-in" replacement.

A draft minimum performance standard for engine/APU fire extinguishing systems specifies the requirements for replacement agents/systems and the test apparatus and methods for evaluating agents/systems. The latter is detailed in the draft standard, reflecting the many parameters that must be examined and the harsh engine environment, as illustrated below. At least two internal airflow rates are required, with the high rate equivalent to about one air change per second. Temperature extremes must be examined; i.e., air temperatures of 100°F and 400°F, engine casing temperatures of 900-1200 °F and agent storage temperatures of -65°F and 200°F. Simulated blockage or clutter must reduce the local cross section by 50%.

The draft standard describes the types of fires that must be developed for agent evaluation. The fires must be "robust", i.e., capable of being extinguished by a Halon 1301 system compliant with current certification criteria, but not always (a robust fire will be extinguished in 70-90% of repeated fire tests.) Two general types of fires must be employed: a flaring fire (leaking fuel stream on fire, also called a spray fire) and a residual fire (baffle stabilized pan fire due to ignition of accumulated fuel in some part of the fire zone). Three different combustible fluids for the fire must also be considered: aviation engine fuel, hydraulic fluid and engine oil.

The IHRWG has defined an extensive fire test program to evaluate engine/APU halon replacement fire extinguishing agents/systems. The development of engine fire test articles simulating modern engine/APU compartment operating conditions and probable fires in designated fire zones is necessary because the genesis of current halon extinguishing agent certification criteria is testing conducted in the 1950's and 1960's. The key is to determine halon replacement agent quantities and concentrations that will extinguish engine/APU robust fires over the wide range of current powerplant operating conditions.

## 9. REFERENCES


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