

**The Case for New Production of HCFC-123 Beyond 2020
for use in Production of Halotron I and in Other
Niche Fire Protection Applications**

Prepared by

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EXECUTIVE SUMMARY

Specific industries and applications rely on a clean firefighting agent (i.e. quickly evaporates, leaving no residue after a fire is put out). Using portable or mobile equipment, personnel employing a clean agent can suppress unwanted fires to prevent damage to critical or valuable property and provide life safety to occupants. Halotron I (also called HCFC-Blend B), primarily composed of HCFC-123 as a raw material, has been the best alternative to halon 1211 as a clean agent, streaming, fire suppression agent since 1994. Halon 1211, a potent ozone depleter, is being phased out because of its impact to the environment. HCFC-123 faces a production ban in 2030 because it is a Class II substance (defined as all HCFCs) in the widely adopted Montreal Protocol of 1987 despite its low environmental impact. This paper describes the status of environmental regulations related to halon 1211, HCFCs and other alternatives, the development and use of Halotron I, and the positive impact of its longer-term (post 2020) production from new HCFC-123.

The Montreal Protocol invoked control of new production and consumption of harmful, ozone depleting substances such as halon 1211. The Protocol also addressed production and consumption of HCFCs many of which are interim substitutes for CFCs and halons. While HCFCs all have non-zero Ozone Depletion Potential (ODP), they cause much less ozone depletion than the CFCs and halons they replaced. The Protocol addresses Global Warming Potential (GWP) concerns indirectly, but these concerns have evolved in time to be a key criterion in the acceptance of halon replacements. The toxicity of candidate replacements is also a key criterion. Used in portable handheld and wheeled extinguishers, and vehicle-mounted cylinders, halon 1211 gained wide acceptance for special hazard protection. It can be used to extinguish fires involving ordinary combustibles (“Class A” materials such as wood, paper, and plastics), liquid fuels (“Class B” materials such as jet fuel), and electrically energized equipment (“Class C” hazards). It leaves no residue, preventing damage to sensitive equipment like computers and jet engines.

The prohibitions on halon from the Montreal Protocol afforded the fire protection industry an opportunity to develop an environmentally friendly, clean, streaming agent. After more than 20 years, however, a “magic bullet,” i.e., a one-to-one, drop-in replacement, has yet to be developed. All alternatives are either less efficient, have undesirable environmental qualities or cause collateral damage. With supplies of halon 1211 dwindling, the need for an acceptable alternative is becoming more acute. The United Nations Environment Programme (UNEP) Panel has stated that, due to the lengthy process of testing, approval, and market acceptance of new fire protection equipment and agents, no additional options are likely to be available in time to have an appreciable impact by the year 2015.

Halotron I was developed to replace halon 1211 and is currently the most widely used clean streaming agent alternative. Since it is a clean agent which extinguishes the three major classes of fire (A, B, C), it is widely used in commercial buildings, computer rooms/electronic spaces, communication facilities, and in museums and historic buildings. It is a critical component in aviation fire protection; over 100 U.S. Airports use Halotron I in their crash trucks. It is used in the marine, manufacturing, utility, and rail industries. Halotron I has undergone extensive testing and evaluation by U.S. and international regulatory authorities including Underwriters Laboratories Inc., Underwriters Laboratories of Canada, the U.S. Coast Guard, the U.S. Federal

Aviation Administration, the U.S. Environmental Protection Agency, and other government and private agencies. It has proven effective, as supported by feedback from users who have extinguished accidental fires.

Halotron I is a blend of dichloro-trifluoroethane (HCFC-123, CF_3CHCl_2), tetra-fluoromethane (CF_4), and argon. Low in toxicity, it is SNAP listed by the U.S. EPA as an alternative for halon 1211 for use in streaming applications. HCFC-123 has a near-zero ozone depleting potential ($\text{ODP} = 0.0098$) and extremely low global warming potential ($\text{GWP} = 77$). Of the available clean agents which have a lower Global Warming Potential (GWP) than halon 1211, only Halotron I offers Underwriters Laboratories listed extinguishers for all three classes of fire, ABC. Despite its near-zero ODP and extremely low GWP, HCFC-123 faces a production ban in 2030.

An analysis was performed on the impact of new, post-2020 production of HCFC-123 for use in Halotron I. Only a small impact on stratospheric ozone depletion would occur due to its precisely measured, near-zero ozone depletion potential of 0.0098, and its low emission rate, estimated at 65 metric tons per year. This continued use would also only have a small impact on global warming due to its low global warming potential (assuming a 2% CF_4 content) and emission rate combined to represent approximately 2% of the total carbon dioxide equivalent emissions associated with fire protection. Replacement of Halotron I with the only other currently commercially available (defined as available in UL-listed hardware actively sold) clean agent alternative to have both Class A and Class B Underwriters Laboratories listings would dramatically increase greenhouse gas emissions associated with fire protection.

Certain niche fire protection applications require the use of a clean streaming agent having Class ABC capability. Halotron I has met this need for fifteen years. Without Halotron I, users will likely be left with less effective, ineffective, and/or extremely high GWP alternatives. The environmental impact of continued use of Halotron I appears to be small. As a reasonable need/impact trade off, regulators and policymakers should consider excluding HCFC-123 from future production bans when it will be used for fire protection.

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THE CASE FOR NEW PRODUCTION OF HCFC-123 BEYOND 2020 FOR USE IN PRODUCTION OF HALOTRON I AND IN OTHER NICHE FIRE PROTECTION APPLICATIONS

1.0 INTRODUCTION

Halotron I, primarily composed of hydrochlorofluorocarbon 123 (HCFC-123) as a raw material, has been the best alternative to halon 1211 for use in portable, clean agent fire extinguishers since 1994. While not composing a large volume of overall halon alternative use, the use of a clean (halocarbon) streaming agent is necessary for certain limited, important applications where combined extinguishment of ordinary combustibles, flammable liquids, and electrical hazards is needed. No environmentally “perfect” clean agent has been developed and the most effective alternative, HCFC Blend B, contains HCFC-123 which faces a new production ban in 2030 despite its low environmental impact. Without Halotron I, users will be left with less effective, ineffective, and/or extremely high Global Warming Potential (GWP) alternatives in certain niche applications. This paper describes the status of environmental regulations related to halon 1211 and alternatives, the development and use of Halotron I, and the impact of longer-term, continued use of this agent in terms of fire protection and the environment.

2.0 BACKGROUND

The two halons most widely used in the United States are halon 1211 and halon 1301. While effective fire suppression agents, halons are among the most potent ozone-depleting substances (ODSs). The stratospheric ozone layer protects life on Earth from harmful ultraviolet (UV-B) radiation. Excessive UV-B exposure increases risk of skin cancer, cataracts, and suppressed immune function, as well as damage to plant life and aquatic ecosystems. Emissions of halogenated gases that have lifetimes longer than a few days or weeks and contain chlorine and bromine, including chlorofluorocarbons (CFCs), halons, methyl bromide and to a lesser extent, HCFCs contribute to the destruction of stratospheric ozone. Production and consumption of these chemicals is therefore controlled globally under the Montreal Protocol on Substances That Deplete the Ozone Layer and in the United States under the Clean Air Act (CAA) as amended in 1990, which implemented the Montreal Protocol commitments into U.S. law.

The U.S. Environmental Protection Agency (EPA) developed and administers the Significant New Alternatives Policy (SNAP) Program to evaluate and regulate substitutes for the ozone-depleting chemicals that are being phased out under the stratospheric ozone protection provisions of the CAA. In section 612(c) of the CAA, the EPA is authorized to identify and publish lists of both acceptable and unacceptable substitutes for Class I or II ozone-depleting substances. A Class II Substance is a chemical listed in section 602, comprising hydrochlorofluorocarbons such as HCFC-123 used to manufacture Halotron I. HCFCs have ozone-depletion potentials (ODPs) of less than 0.2 (CFC-11=1.0). A more complete description of ODP for Halotron I and other agents is provided later in this paper.

In the CAA, it is stipulated in section 605 that effective January 1, 2015, it will be unlawful for any person to introduce into interstate commerce or use any Class II substance unless such a substance:

1. Has been used, recovered, and recycled;
2. Is used and entirely consumed (except for trace quantities) in the production of other chemicals; or
3. Is used as a refrigerant in appliances manufactured prior to January 1, 2020.

Effective January 1, 2015, it will be unlawful, as stipulated in the Clean Air Act, Section 605, for any person to produce any Class II substance in an annual quantity greater than the quantity of such substance produced by such person during the baseline year (1989). By January 1, 2030, it will be unlawful for any person to produce any Class II substance.

Adjustments to the Montreal Protocol phase out schedule of HCFCs have resulted in a 75% reduction in consumption and production of agreed upon caps by 2010, a 90% reduction by 2015, and a 99.5% reduction by 2020. By 2020, new production of HCFC 123 must effectively cease.

A new, state-of-the-art analysis of the environmental effects of HCFC Blend B and HCFC-123 was completed earlier this year (Wuebbles, 2009). The analysis shows that HCFC-123 for fire protection applications is even more benign than previously thought. This will be discussed in more detail later in this paper.

On April 17, 2009, the U.S. EPA announced a proposed endangerment finding and declared a group of gases with GWPs to be pollutants that endanger public health and welfare [Broder, 2009]. The group includes CO₂, methane, nitrous oxide, perfluorocarbons, sulfur hexafluoride and hydrofluorocarbons (HFCs). The EPA stated that the science supporting the finding was “compelling and overwhelming.”

Summarizing, Halotron I was developed to replace halon 1211 and is currently the most widely used halon 1211 alternative. The primary raw material in the manufacture of Halotron I is HCFC-123, which faces a new production ban in 2030 as a Class II substance despite its near-zero ODP and extremely low GWP. Without Halotron I, users will likely be left with less effective, ineffective, and/or extremely high GWP alternatives in certain niche applications. The following sections describe in detail the use of clean agents, the accelerated elimination of halon 1211 availability, development and environmental characteristics of halon 1211 alternatives, the widespread use and effectiveness of Halotron I in niche markets, and recent assessments of HCFCs as they affect the environment.

3.0 THE NEED FOR MULTIPURPOSE STREAMING CLEAN AGENTS

3.1 Attributes of Clean Agents

Halon 1211, initially developed in the 1950s, was the premiere streaming agent until its link to stratospheric ozone depletion led to restrictions under the 1987 Montreal Protocol on Substances that Deplete Stratospheric Ozone and a production ban in 1994. Halon 1211 is

popular because of its acceptable toxicity, relatively low price, and high extinguishing efficiency with respect to most classes of fires: Class A solid material fires, Class B flammable liquid fires and Class C fires involving electrically energized materials. Most importantly, it is a clean agent.

Clean agents' great advantage is their ability to extinguish A, B and C fires without leaving a residue. This is particularly significant where prevention of collateral damage is essential (e.g., protection of aircraft engines, important records, and sensitive electronics). "Optimum" clean agents should exhibit the following characteristics [Robin, 2009]:

- Clean (no residues)
- High fire extinguishment efficiency – preferably for all Class A, B and C fires
- Low chemical reactivity
- Long-term storage stability
- Non-corrosive to metals
- High material compatibility (metals, plastics)
- Electrically non-conducting
- Low toxicity
- Zero ozone depletion potential (ODP)
- Zero global warming potential (GWP)
- Reasonable manufacturing costs

To date, no halon replacement agent has been developed which meets all of these requirements. Research spanning decades has failed to identify a one-to-one, drop-in halon 1211 replacement [Gann, 2007]. Other extinguishing agents have been proposed for use where clean agent extinguishers have historically been used, including carbon dioxide, dry chemical, and foam; these agents are less than optimum for many situations. Carbon dioxide (CO₂), dry chemical and foam are not recognized as suitable for many of the hazards associated with clean agents:

Carbon dioxide:

1. Is ineffective on Class A materials;
2. Has a chilling effect in portable fire extinguishers from solid carbon dioxide (snow) which may damage delicate electronic components by thermal shock;
3. Has a total weight (container and agent) greater than similar agent capacities of the halon alternative units; and
4. Has no throw range in the mildest of wind conditions due to its gaseous nature.

Dry chemical:

1. May obscure the operator's vision, particularly in confined spaces such as an aircraft;
2. Has the possibility of forming an insulating chemical layer on delicate electrical contacts, which could affect continued safety (e.g. in flight situation);
3. Can irritate the eyes and mucous membranes even though it is not considered toxic; and
4. Depending on the type, may be highly corrosive if not immediately cleaned up.

Foam:

1. Is electrically conductive; and
2. Requires clean up.

3.2 Hazards Protected and Markets Served by Streaming Clean Agents

The focus of sales activities for Halotron I is the aviation, marine, and special hazards markets where a handheld portable, wheeled, or truck-mounted unit is used to extinguish combined Class A, B and C hazards for which collateral damage is a concern. For example, the U.S. Navy identified the need for such an agent to combat aircraft engine fires on air-capable ships and at land-based facilities. Halotron I was recognized as an agent potentially meeting the Navy's requirements [Carpenter, 1999]. Subsequent testing and approvals, described later in this report, have been conducted to meet the need for a clean agent replacement to halon 1211.

The following are representative markets and associated hazards served by Halotron I:

Commercial

Commercial buildings – this application includes workplace environments such as office buildings, wholesale and retail sales facilities, warehouses and computer rooms/electronic data storage areas. The requirements for a clean agent in this application are historically high. A minimum UL 2-A rated extinguisher is typically required in installations to meet National Fire Protection Association (NFPA) 10 guidelines. The 7 kg Halotron I 2A-10BC rated units or equivalent non U.S. units have been sold extensively for these uses.

Computer Rooms/Electronics Spaces (including marine environment) – a clean agent is the agent of choice for these high value, sensitive installations.

Communication facilities – typically include a significant presence of electronics and a clean agent portable is appropriate. Portable Halotron I units have been installed extensively in these types of facilities in the UL listed 5-B (5 lb/2.27 kg) to 2-A:10-BC (15.5 lb/7 kg) or equivalent non U.S. size portables.

Cultural resource fire protection – irreplaceable and priceless artifacts are housed in museums and historic buildings. Agents that may cause collateral damage are inappropriate in these situations. A clean streaming agent is recommended to prevent misuse; many museums provide only multipurpose extinguishers. A clean agent is an obvious choice since there is no residue. An NFPA-sponsored research group is studying this application and the role of clean agents.

Civil Aviation

Aircraft Rescue and Firefighting (ARFF) – commercial and military crash rescue fire services have traditionally relied on a clean agent to prevent collateral damage. Typically this involves extinguishing engine fires. Decades ago, very large capacity CO₂ vehicles were used. The advent of halon 1211 permitted “secondary agent” units on the order of 150 to 500 lbs to be used. The elimination of halon 1211 significantly reduces ARFF capability. Potassium bicarbonate (PKP), an alternative for three dimensional (i.e., spill,

leaking fuel) firefighting, is corrosive and may damage an engine. Later sections of this report describe in detail the testing and approvals of Halotron I for this application.

Aircraft Passenger and Cargo Compartment – in response to potential terrorist threats and actual onboard, underway fires involving concealed spaces, the U.S. Federal Aviation Administration (FAA) requires aircraft to carry portable halon 1211 extinguishers. An FAA Minimum Performance Standard (MPS) specifies two new tests that replacement agents must pass in addition to requiring national certifications such as those provided by Underwriters Laboratories. The first test evaluates the “flooding” characteristics of the agent against a hidden in-flight fire. This test determines the ability of a streaming agent to function as a flooding agent. The second test evaluates the performance of the agent in fighting a terrorist fire scenario and the associated toxicity hazard. This test measures the agent’s ability to extinguish a triple-seat fire in an aircraft cabin under in-flight conditions and the toxicity characteristics of both the neat agent and the products of decomposition [Webster, 2002]. The elimination of halon 1211 requires an alternative to combat these threats. A UL-listed Halotron I portable is FAA approved for onboard use (5.5 lb, 2.5 kg).

Marine

Cargo and Vehicle Decks – large shipboard vehicle or cargo decks may require a fast-response, multipurpose agent capable of extinguishing vehicle/cargo fires, and two-and-three dimensional liquid fuel fires. Clean agents are well suited for this purpose.

Small craft – the U.S. Coast Guard requires ABC rated extinguishers on most small craft. A clean agent is preferred since operators do not desire cleanup or collateral damage from ABC dry chemical extinguishers. Halotron I portables are U.S. Coast Guard Approved in type B, size I (5 lb/2.27 kg) and II (15.5 lb/7 kg) or equivalent non U.S. units.

Industrial

Semiconductor Manufacturing/Clean Rooms – these areas require minimization of nuisance dust and contaminants and are ideal for clean agents.

Records Storage – clean agents are the obvious choice to prevent water or dry chemical residue damage to sensitive paper or electronics records.

Manufacturing Plants (heavy and light) – facilities where process contamination is an issue and/or electronics, computers, PLC hardware, motors, etc. are present are well suited for clean agent, electrically non-conductive, portable fire extinguishers. Typically, a minimum UL 2A rating is required with higher class B ratings also common. Therefore, the 7 kg 2A-10BC to 4A-60BC rated Halotron I portables and wheeled units, or equivalent non U.S. units, are most common in these applications.

Laboratories – labs are typically filled with delicate electronic instruments. A clean agent is ideal for portable fire protection in these areas assuming there is no incompatibility with the materials used in those work areas.

Utilities

Power Plants, Transmission Facilities, Public Works, Control and Transmission and Telecom Facilities – these facilities typically contain electronics and moving equipment that are appropriate for clean agent portable fire protection. For Halotron I, the most common size unit used in these areas is the UL 1-A rated (11 lbs/5 kg) unit. UL 2A rated units (15.5 lb/7 kg) or the equivalent non U.S. units, are also prevalent.

Civilian Ground Transportation

Railroad Equipment, Short and Long Haul trucks, Delivery Vehicles – this environment also typically includes electronics and moving energized parts that are ideal for a clean agent where a lack of residue and/or conductivity is of great value.

Automobiles – peripheral damage from the use of water (municipal fire departments) and ABC dry chemical over use in auto fires frequently causes agent-derived damage. The application of a clean agent directly or indirectly (through hood vents/grilles) with Halotron I is highly effective due to its volatile and gaseous expanding nature.

Government Services/Natural Resources Development

Facilities, Libraries, Museums, Record Storage, FAA Control Towers, Spacecraft Facilities, Natural Resource Processing – these are areas where either electrically-conductive or powder-based agents have disadvantages. Halotron I has been used extensively for this purpose. These areas typically include computer installations and/or energized equipment where a clean agent is ideal for portable fire protection.

3.3 Restricted Availability of Halon 1211

The current supply of halon 1211 (the “halon bank”) is finite and dwindling. The FAA has noted that “shortages of halon 1211 are expected within the next few years” [Speitel, 2006]. The stockpile for the U.S. military is in an obvious, accelerated decline. For example, the U.S. Navy uses halon 1211 150 lb cylinders for aviation fire protection and several other applications. It is estimated that the Navy will run out of 1211 in about two years, unless additional agent is purchased on the open market or the other services provide the Navy with some of their 1211.

Halon 1211 could perhaps be obtained from countries withdrawing it from service; however, imported halon 1211 is subject to an excise tax. The amount of tax is equal to the base tax amount for halon 1211 in the year of sale or use (2009 halon 1211 base = \$11.65), multiplied by the ozone depletion factor (halon 1211 = 3). The 2009 excise tax for halon 1211 is \$34.95 per pound. The excise tax increases annually and no one is exempt – not even the federal government [U.S. Dept of the Treasury, 2009].

The elimination of halon 1211 is no longer an academic question. Underwriters Laboratories (UL) will no longer accept the submittal of new or revised products covered under the categories of Liquefied Gas-type Extinguishers and Liquefied Gas-type Marine Extinguishers. All manufacturing of new compliant products covered under these categories will continue to be authorized to bear the Classification Mark of Underwriters Laboratories Inc. until October 1, 2014 [Underwriters Laboratories Inc., 2009]. UL is withdrawing the *Standard for Halogenated*

Agent Fire Extinguishers, UL 1093; there will be no replacement for this standard. UL believes that there will be a diminished need to support UL 1093 and the continued UL Listing of these products and that they can be eliminated. Special consideration has been provided for the U.S. commercial airline industry. To allow an easier transition to other forms of extinguishers and systems, UL will continue to offer UL certifications for extinguishers using halogenated agent for commercial airline cabin protection due to the ability of current UL subscribers to obtain compliant agent in the marketplace. At such point that the availability of the agent prevents continued production based on the request from the current applicants, UL will withdraw the Listings for these specific products. Otherwise, they anticipate that the availability of the agent in the marketplace will be at such a level as to prevent continued extinguisher production, and UL will withdraw all remaining certifications on new hardware by October 1, 2014. Hardware manufactured prior to this date should be able to remain in service as long as the extinguisher can be maintained in accordance with the manufacturer's manual and NFPA 10.

3.4 New Environmental Regulations

States are beginning to adopt and enforce their own environmental restrictions related to greenhouse gases and climate change. For example, Minnesota has passed a law which requires both producers and purchasers of HFCs, PFCs, and SF₆ to report activity to the state Pollution Control Agency [Rasky, 2008]. Producers must report the total amount of each applicable gas sold to purchasers; the manufacturers of CF₄, a very small component in Halotron I, may have an obligation to report produced quantities of agent. Fire equipment distributors who purchase 500 metric tons or more of carbon dioxide equivalent gas including HFCs, PFCs or SF₆ must report the amount and purpose for which the gas will be used ("Carbon dioxide equivalent" means the quantity of carbon dioxide that would have the same global warming impact as that of another greenhouse gas). For Halotron I, which contains a small percentage of PFC, approximately 9,000 lbs would have the equivalent of 500 metric tons of carbon dioxide equivalent. For HFC-236fa (FE-36), the amount is 112 lbs. The law was effective October 1, 2008. This demonstrates the need for regulatory clarification and action at the federal level.

The European Union is embarking on a plan to ban the use of halon 1211 entirely. For example, halon 1211 use is proposed to be prohibited for new equipment and new facilities at airports and most commercial/industrial facilities by 2009, and on aircraft (except for unoccupied cargo bays) by 2011 [Commission of European Communities, 2009]. End dates, the time when halon 1211 may not be used in existing equipment, are proposed in the range of 2011 to 2030, depending on the application. The rationale is that technically and economically feasible, environmentally acceptable alternatives are available.

Additionally, the International Civil Aviation Authority (ICAO) has recently released a proposed mandate to replace aircraft onboard halon 1211 handheld extinguishers by 2014 for new production aircraft [ICAO, 2007]. This does not affect halon 1211 handheld extinguishers on existing aircraft.

Korea has begun invoking environmental criteria for approval of gaseous ABC extinguishers [Korea Eco-Label, 2003]. The fire extinguishing material must have an ODP less than 0.055 and GWP less than 3000. Halotron I was evaluated under this program and received an ECO-label.

Summarizing, clean streaming agents are needed for specific fire protection applications, particularly in the commercial aviation and manufacturing industries. Other niche applications, while not large in amount of total agent used, need a clean agent as the optimum choice for protection. The dwindling supplies of banked halon 1211 are an important factor.

4.0 DEVELOPMENT OF HALOTRON I

4.1 Chemical and Physical Properties of Alternatives

Halotron I is a blend of dichloro-trifluoroethane (HCFC 123, CF_3CHCl_2 , a liquid), tetrafluoromethane (CF_4 , a gas) and argon (gas), developed and marketed by American Pacific Corporation. Argon (Ar), not nitrogen, is used as the propellant in this blend. It was developed as an alternative to halon 1211 (CF_2ClBr) for use in portable extinguishers as a streaming fire protection agent. Halotron I was SNAP (Significant New Alternatives Policy) listed by the U.S. EPA as an alternative agent for halon 1211 for use in streaming applications, referred to as "HCFC Blend B" [U.S. EPA, 1994]. The EPA considers it as an acceptable halon 1211 substitute for commercial, industrial, and military applications as described in the final SNAP Rule published in March, 1994.

After the production ban was announced as part of the Montreal Protocol, many alternatives to halon 1211 were developed. Most of these alternatives consist of hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). Other halon alternative agents developed and proposed for extinguisher/streaming applications include: HFC-227ea (1,1,1,2,3,3,3-heptafluoropropane, C_3HF_7 , FM-200, FE227), HFC-236fa (1,1,1,3,3,3-hexafluoropropane, $\text{C}_3\text{H}_2\text{F}_6$, FE-36), FC-5-1-14 (perfluorohexane, C_6F_{14} , CEA-614), FIC-131I (trifluoroiodomethane, CF_3I , Triiodide), HCFC-123 (2,2-dichloro-1,1,1-trifluoroethane, $\text{C}_2\text{HCl}_2\text{F}_3$, FE-232), HCFC-124 (2-chloro-1,1,1,2-tetrafluoroethane, C_2HClF_4 , FE-241), and HCFC Blends C, D and E (NAF P-III, Blitz III and NAF P-IV).

In general, the alternative compounds offer either little or no ozone depletion potentials (ODPs) (per unit mass emitted relative to CFC-11 (CFCl_3)), while requiring more agent mass to obtain similar UL-711 ratings. Several of the alternatives, for various reasons, have not been fully developed, or their market is extremely small. A comparison of the physical properties of the more common alternative agents and halon 1211 are given in Table 1 and comparison of the agent masses required to obtain similar UL-711 ratings to halon 1211 are given in Table 2 and illustrated in Figures 1 and 2. In Table 2, if a comparably rated unit is unavailable, the highest-rated extinguisher using that agent is included in the table.

All of these alternative agents are considered to be low in toxicity, with the exception of carbon dioxide which is life threatening at a concentration of 10 percent by volume [Air Products, Inc, 2004] and requires a higher concentration than this to extinguish a fire. The no observable adverse effect level concentration (NOAEL) and the lowest observable adverse effect level concentration (LOAEL) given in Table 1 are based on cardiac sensitization. Cardiac sensitization is defined as an increased occurrence of heart arrhythmias in the presence of the agent and adrenaline. All of these agents, with the exception of CO_2 , represent a decrease in toxicity relative to halon 1211. Detailed toxicity data for Halotron I is provided by the manufacturer [American Pacific Corporation, 1998].

Table 1 – Comparison of Physical and Chemical Properties of Halon 1211 Alternative Agents¹

Property	Units	HFC-12B1	Gaseous Alternatives						
			HCFC Blend B			HFC-236fa	HFC-227ea	IG-001	FK-5-1-12
Trade Names		Halon 1211	Halotron I			FE-36	FM-200 FE-227	CO ₂	Novac 1230 Sapphire
Formula		CF ₂ ClBr	Blend			C ₃ H ₂ F ₆	C ₃ HF ₇	CO ₂	C ₆ OF ₁₂
			C ₂ HF ₃ Cl ₂	Ar	CF ₄				
Molecular Weight		165.36	152.93	39.95	88.01	152.00	170.03	44.01	316.05
Critical Temperature	[°C]	153.9	183.8	-122.4	-45.6	124.9	101.6	31.0	168.6
	[°F]	309.0	362.9	-188.3	-50.0	256.8	214.9	87.9	335.6
Critical Pressure	[kPa]	4,104	3,675	4,874	3,739	3,199	2,927	7,376	1,865
	[psia]	595	533	707	542	464	425	1,070	270
Normal Boiling Point	[°C]	-4.2	27.8	-185.9	-128.0	-1.5	-16.5	-78.6	49.0
	[°F]	24.5	82.1	-302.6	-198.3	29.3	2.3	-109.4	120.2
Liquid Density @ Ambient Temp	[kg/m ³]	2,307	1,478	N/A	N/A	1,373	1,403	763	1,605
	[lb/ft ³]	144.0	92.3	N/A	N/A	85.7	87.6	47.6	100.2
Vapor Density @ Ambient Temp and Press	[kg/m ³]	6.952	6.336	1.655	3.646	6.518	7.256	1.823	13.851
	[lb/ft ³]	0.434	0.396	0.103	0.228	0.407	0.453	0.114	0.865
Storage Conditions	State	Liquid	Liquid			Liquid	Liquid	Liquid	Liquid
	Cyl. Type	Low Press	Low Press			Low Press	Low Press	High Press	Low Press
Ozone Depletion Potential (ODP)	CFC-11=1.0	7.1	0.0098	0	0	0	0	0	0
Atmospheric Life Span	[years]	16	1.34		50,000	240	34.2		0.014
Global Warming Potential (GWP)	CO ₂ =1.0	1890	77	0	7390	9810	3220	1	1
NOAEL	[%]	0.5	1.0			10.0	9.0		10.0
LOAEL	[%]	1.0	2.0			15.0	>10.5		>10
n-Heptane Min Extinguishing Concentration	[%]	4.3	≈6.5			6.3	6.7	28.0	4.5

6

¹ Agent Properties: [NFPA,1990], [American Pacific Corporation Halotron Division, 2006c], [NFPA 2008], [Reid, Prausnitz and Poling, 1987], [Air Products and Chemicals, 2004], [Skaggs, 1992], [3M Corporation, 2009]
 Environmental Properties (ODP, Life Span, GWP): [WMO 2006] [3M Corporation, 2009]

Table 2 – Comparison of Agent Requirements to Achieve Similar UL-711 Ratings to Halon 1211 Extinguishers¹

Property		Units	HFC-12B1	Gaseous Alternatives				
				HCFC Blend B	HFC-236fa	HFC-227ea	IG-001	FK-5-1-12
Trade Names			Halon 1211	Halotron I	FE-36	FM-200 FE-227	CO ₂	Novec 1230 Sapphire
68 kg (150 lb) Halon 1211 Replacement {30A:240B:C}	Rating		30A:240BC	10A:80BC*	NA	NA	NA	NA
	Agent Mass	[kg]	68	68				
		[lb]	150	150				
	Total Extinguisher Mass	[kg]	125	232				
[lb]		275	512					
9 kg (20 lb) Halon 1211 Replacement {4A:80B:C}	Rating		4A:80BC	4A:60BC*	NA	NA	NA	NA
	Agent Mass	[kg]	9	29				
		[lb]	20	65				
	Total Extinguisher Mass	[kg]	18	130				
[lb]		40	286					
5.9 kg (13 lb) Halon 1211 Replacement {2A:10B:C}	Rating		2A:40BC	2A:10BC	2A:10BC	NA	20BC*	NA
	Agent Mass	[kg]	5.9	7.0	6.0		23	
		[lb]	13.0	15.5	13.3		50	
	Total Extinguisher Mass	[kg]	10.0	9.9	11.6		117	
[lb]		22.0	21.8	25.6		257		
4.1 kg (9 lb) Halon 1211 Replacement {1A:10B:C}	Rating		1A:10BC	1A:10BC	1A:10BC	NA	10BC	NA
	Agent Mass	[kg]	4.1	5.0	4.3		9.1	
		[lb]	9.0	11.0	9.5		20.0	
	Total Extinguisher Mass	[kg]	7.6	10.2	11.6		23.0	
[lb]		16.8	22.5	25.6		50.8		
1.4 kg (3 lb) Halon 1211 Replacement {5B:C}	Rating		5BC	5BC	5BC	5BC	5BC	NA
	Agent Mass	[kg]	1.4	2.3	2.2	2.6	2.3	
		[lb]	3.0	5.0	4.8	5.8	5.0	
	Total Extinguisher Mass	[kg]	2.7	4.3	4.3	4.4	6.4	
[lb]		6.0	9.5	9.5	9.8	14.0		

*Wheeled extinguisher rather than stationary tank or portable extinguisher

¹ Extinguisher Sizes and Ratings: [Amerex, 2008], [Ansul, 2006], [Sea-Fire Marine, 2008]

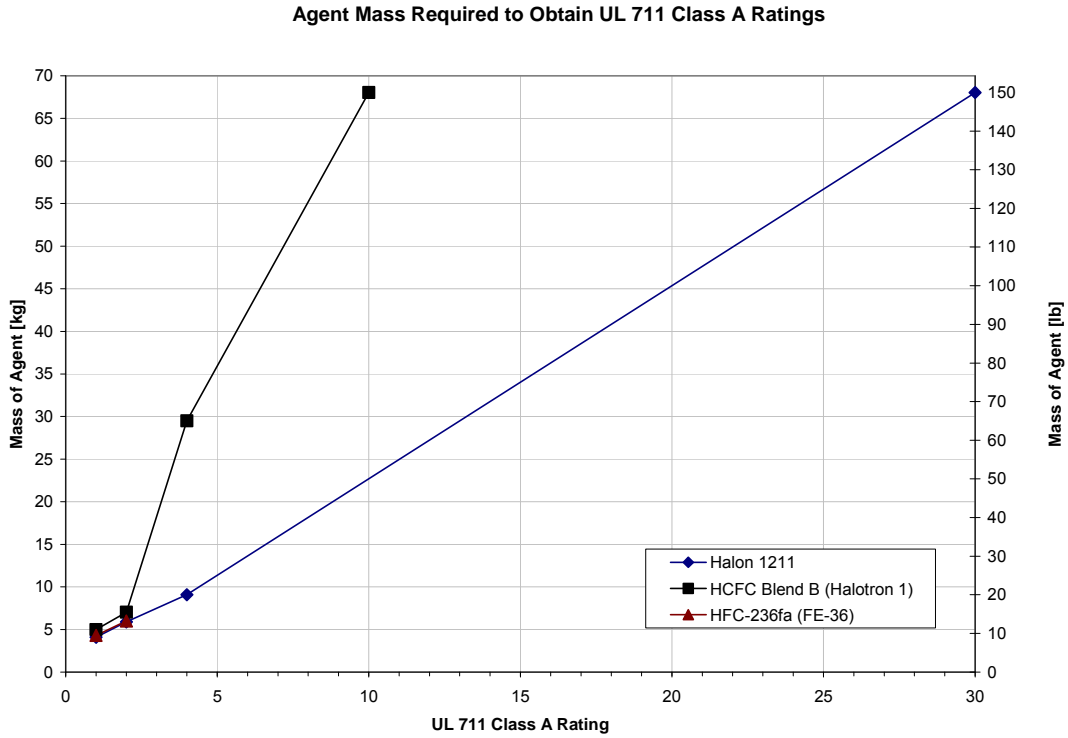


Figure 1 – Agent Mass Requirements to Obtain UL-711 Class A Extinguisher Ratings

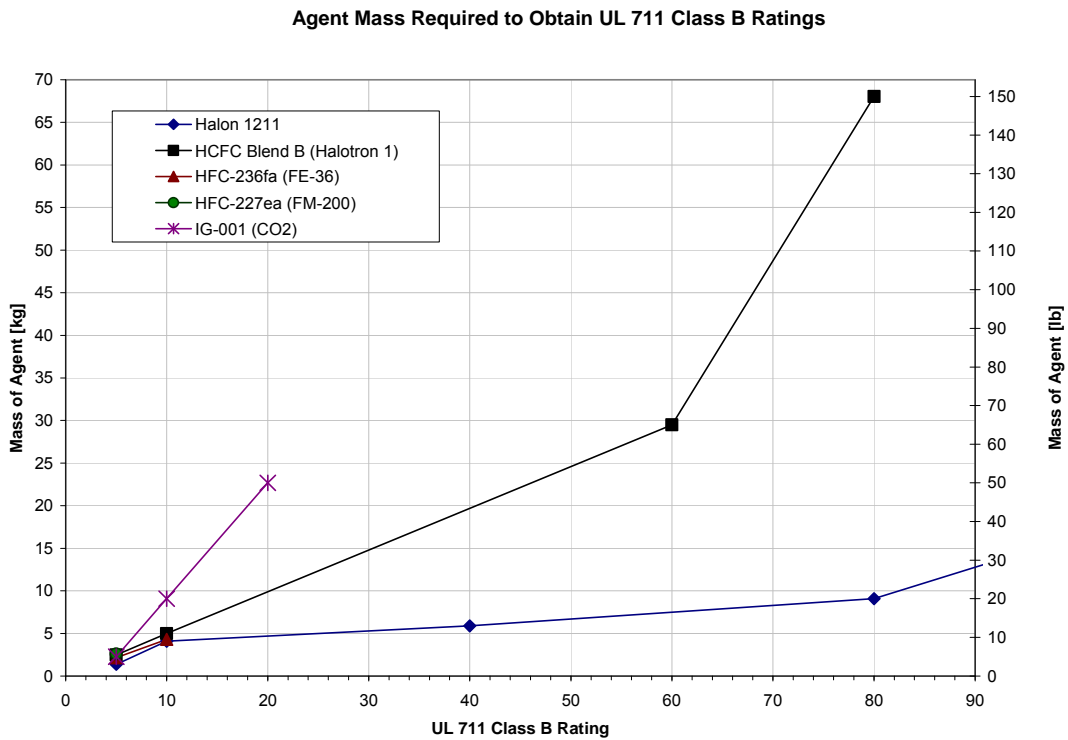


Figure 2 – Agent Mass Requirements to Obtain UL-711 Class B Extinguisher Ratings

As can be seen from Table 1, only Halotron I, CO₂ and Novec 1230 offer reductions in global warming potential (GWP) (per unit mass emitted relative to carbon dioxide (CO₂)) relative to halon 1211. Figure 3 illustrates the magnitude of the reduction in GWP for these three agents compared to halon 1211 and the magnitude of the increase in GWP for the other two alternatives. The data from IPCC/TEAP 2005, Table 11.6 [Metz et al., 2005] infers a CF₄ component of the Halotron I blend of 2.3 percent. For purposes of analysis, 2 percent CF₄ component is assumed (exact amounts are proprietary).

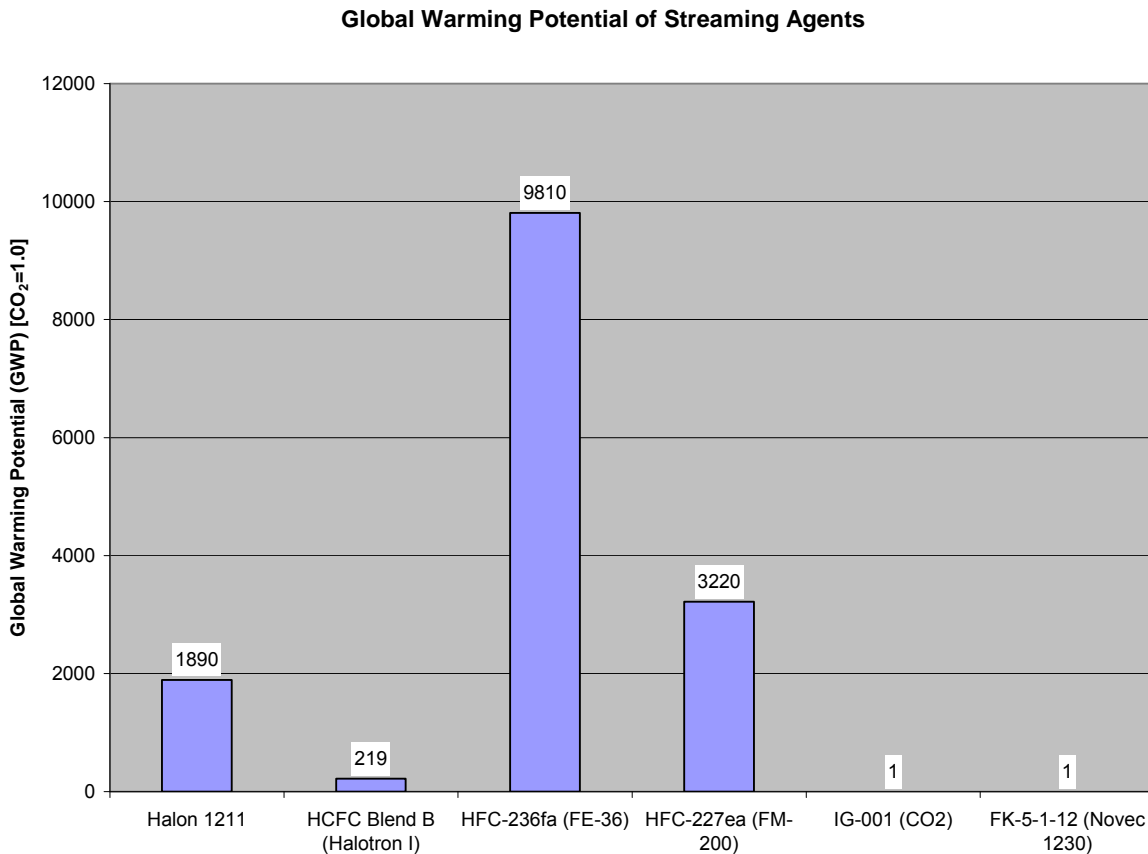


Figure 3 – Global Warming Potential of Streaming Agents

As can be seen from Table 2, only Halotron I has obtained UL-711 portable extinguisher ratings greater than 2A or 20B. Novec 1230 has no UL portable extinguisher listings. Carbon dioxide (CO₂) does not have any Class A ratings and no ratings higher than 20B. For very small Class A fires (1A rating), the mass of the Halotron I agent is close to that of the halon 1211 unit.

The FAA also evaluated Halotron I for use in portable extinguishers to be carried onboard aircraft starting in 1991. Extinguishers utilizing Halotron I were successful in passing both the hidden fire test at UL and the seat fire toxicity tests at the FAA Tech Center in New Jersey, USA [Webster, 2002]. The extinguishers used in these tests were UL 5B:C rated units with 2.5 kg (5.5 lb) of Halotron I. A summary of the results for these tests and extinguishers used are given Table 3. The three agents which have passed the tests have similar agent masses and total extinguisher weights nominally 80 percent more than that required for halon 1211. However,

Table 3 – FAA Minimum Performance Standard (MPS) Tests for Handheld Extinguishers [Webster, 2002]

Property		Units	HFC-12B1	Gaseous Alternatives		
				HCFC Blend B	HFC-236fa	HFC-227ea
Trade Names			Halon 1211	Halotron I	FE-36	FM-200 FE-227
Formula			CF ₂ ClBr	Blend	C ₃ H ₂ F ₆	C ₃ HF ₇
Rating			5BC	5BC	5BC	5BC
Agent Mass		[kg]	1.1	2.5	2.2	2.6
		[lb]	2.5	5.5	4.8	5.8
Total Extinguisher Mass		[kg]	2.5	4.5	4.3	4.4
		[lb]	5.5	10.0	9.5	9.8
		Rel. Halon 1211	1.0	1.8	1.7	1.8
Total Extinguisher Volume		[L]	2.14	5.31	10.42	8.72
		[in ³]	130	324	636	532
		Rel. Halon 1211	1.0	2.5	4.9	4.1
Hidden Fire Test	Minimum of 9 of 20 Extinguished	Cups Ext.	9	9	9	9
		Test Result	Pass	Pass	Pass	Pass
Seat Fire/Toxicity Test	Fire Extinguished	[yes/no]	Yes	Yes	Yes	Yes
	HF Maximum of 200 ppm (1 min Ave)	[ppm]*	17	24	77	78
		Rel. Halon 1211	1.0	1.5	4.6	4.7
	HF Maximum of 100 ppm (4.5 min Ave)	[ppm]*	11	17	53	55
		Rel. Halon 1211	1.0	1.5	4.8	5.0
Test Result			Pass	Pass	Pass	Pass

* Average of three tests conducted

Halotron I utilized an extinguisher that was smaller in volume (2.5 times that of halon 1211) than either HFC-236fa (4.9 times that of halon 1211) or HFC-227ea (4.1 times that of halon 1211). The amount of HF produced in extinguishing the seat fire with Halotron I was significantly lower than that produced by HFC-236fa or HFC-227ea, although slightly greater than that produced by halon 1211.

4.2 Underwriters Laboratories Listing of Halotron I

In evaluations commencing in 1994, Halotron I was tested according to UL Standard 711, "Fire Extinguishers, Rating and Fire Testing of," and UL Standard 1093, "Halogenated Agent Fire Extinguishers." Historically, halon 1211 and halon 1301 portable fire extinguishers listed by UL have been tested according to these standards. Fire testing for Halotron I at UL was conducted for Class A, B, and C ratings. In 1999, UL 2129 ("Halocarbon Clean-Fire Extinguishing Agents") was adopted. Fire testing for Class A ratings was conducted for fires involving ordinary combustible materials such as wood, cloth, paper, rubber and many plastics. The UL fire ratings required extinguishment of indoor wood-crib, wood-panel, and excelsior fires. The Class B testing involved fires with flammable liquids and covers, oils, greases, tars, oil-base paints lacquers and flammable gases. Testing was also conducted for a Class C rating, where agent is discharged on energized electrical equipment to measure conductivity. The electrical non-conductivity of the extinguishing media is important.

In January, 1996, a UL listing was issued for a complete line of Halotron I portable extinguishers. In February, 1996, an Underwriters Laboratories of Canada (ULC) Listing for portable extinguishers containing Halotron I was issued. Based on the developmental efforts, Halotron I has been utilized in portable extinguishers to obtain UL-711 ratings ranging from 5B:C rating for a 2.5 kg (5.5 lb) portable extinguisher to 10A:80B:C rating for a 68 kg (150 lb) wheeled extinguisher system [Underwriters Laboratories, 1990]. Four of the five major fire extinguisher manufacturers currently utilize Halotron I in their extinguishers: Amerex Corporation, Buckeye Fire Equipment, Badger Fire Protection and Kidde. Halotron I was first listed as a recognized component agent for portable extinguishers in 1997 [Underwriters Laboratories, 1998], and continues to be a listed component to this day.

Summarizing, many streaming agent alternatives to halon 1211 have been developed. Halotron I was developed more than 15 years ago. Only HCFC Blend B (Halotron I), CO₂, and FK-5-1-12 offer reductions in GWP compared to other streaming agents. Of these, only Halotron I is currently available as a UL-Listed agent offering a rating for ordinary combustibles, liquid fuels, and electrically energized hazards. It is nontoxic, and produces less acid gas compared to third-party-approved alternative streaming agents. It is supplied to most U.S. fire extinguisher vendors.

5.0 FIRE TEST DATA IN SUPPORT OF HALOTRON I

The initial development of Halotron I occurred in Sweden prior to 1992. The exclusive rights were obtained by American Pacific Corporation (AMPAC) in 1992 and thereafter the necessary steps to commercialization and related approvals began. The first fire testing of Halotron I in the U.S. occurred in 1992 at the New Mexico Engineering Research Institute. The

fire test program consisted of class B only fires with round pans. Jet fuel was used for these fires [Marine Corps Air Station Beaufort, 1992].

The initial evaluations of Halotron I indicated that it was a serious potential replacement for halon 1211. This led to a series of large-scale fire testing. Under a U.S. Navy-sponsored program, full-scale fire testing with Halotron I occurred at the Marine Corps Air Station, Beaufort, South Carolina, in October 1992 [Marine Corps Air Station Beaufort, 1992]. The program consisted of “a series of events intended to simulate aircraft-related fires commonly encountered by flightline and fire fighting personnel on which halon 1211 is routinely employed.” These scenarios were typically handled by halon 1211 150-lb “flightline” wheeled extinguishers and 20-lb handheld portables. The effectiveness of Halotron I was compared to halon 1211. The fires included 72 ft² JP-5 pan fires, with and without engine mock ups and running fuel. These fires were extinguished using the nominal 20-lb handheld portables. Larger, 810- ft² JP-5 pool fires were extinguished using the wheeled units.

In each test, there were two tests with halon 1211 in standard Amerex M371 or M600 (wheeled) extinguishers followed by four tests with Halotron I in modified Amerex extinguishers. The modifications included a change in nozzle, o-rings and pressure. Halotron I was successful in extinguishing all but one fire during the USMC evaluation. It was found that, for comparable flow rates using the portable extinguishers, Halotron I required about 35% more time for extinguishment. With higher Halotron discharge rates compared to halon 1211, the extinguishment times were comparable. The differences were not as great for the large fire scenario where the wheeled units were used. The November 1992 final report concluded that Halotron I was “34.4% less effective than halon 1211 during this evaluation” and that “Based on the data obtained from this evaluation, Halotron I is suitable for combating aircraft fires.” These tests demonstrated that Halotron I was a viable agent alternative when tested at a large scale with commercially-available equipment. For equivalent performance to halon 1211, more agent was needed (as suggested in earlier smaller-scale tests). Alternately, the hazard which could be handled by a “drop-in” to existing equipment, i.e., using the existing 150-lb 1211 equipment, could be assessed for a specific scenario. This was the approach used by the FAA in assessing the performance of Halotron I for commercial aviation purposes. Airports are required to have a secondary agent to supplement the primary agent, foam, which is used to combat large spill fires. The secondary agent is required to combat potential three-dimensional fires such as leaking fuel from an engine. Halon 1211 and potassium bicarbonate (PKP) had been approved for this use and were recognized by both the FAA and the National Fire Protection Association (NFPA) in the NFPA 403 Standard.

5.1 Fire Testing for the FAA, 1993–1994

In the spring of 1993, full scale fire testing of Halotron I commenced at the United States Air Force fire test facility at Tyndall AFB, Florida [Rochefort et al., 1993; Wright, 1995]. The tests were sponsored by the FAA. The objective was to compare the fire fighting effectiveness of Halotron I in comparison to halon 1211 in unique flightline type fires. At the same time, perfluorohexane (C₆F₁₄) was tested. All of the fire tests involved either 150 lb wheeled extinguishers or 500 lb truck mounted systems. The testing also included some optimization work with the Halotron I agent using a variety of hardware configurations. All scenarios used low flash point JP-4, except the wheel fire which used the most hazardous hydraulic fluid. The

USAF subsequently changed most of their fueling inventory to JP-8, a higher flash point fuel. Commercial aircraft use Jet A, a high flash point kerosene. The types of fires conducted included:

1. Three Dimensional Inclined Plane (Ramp) Fire Tests. The apparatus was a 20 ft long, 5 ft wide concrete on steel ramp inclined to a 4 ft by 8 ft steel catch basin to be consistent with tests conducted in prior years with 1211. JP-4 was the fuel. Preburn time was 30 seconds.
2. Simulated Engine Nacelle Running Fuel Fire Tests. The apparatus simulated an F-100 engine nacelle. A concrete curbed area below the nacelle was used to catch running fuel and to simulate an associated ground fire. The preburn time was 15 seconds.
3. Dry Pool Fire Tests. This test involved JP-4 fuel directly on concrete over net areas of 250 to 800 ft². The preburn time was approximately 20 seconds.
4. Simulated Wheel Brake Fire Involving Hydraulic Fluid. This test was designed to simulate a hot wheel brake fire commonly encountered on flight lines. An F-4 aircraft tire and magnesium rim was mounted on a stand above a 4 ft by 4 ft pan. The most flammable available hydraulic fluid was thereafter poured on the tire and in the pan and lit. A 90-second preburn was used.

For the pool fire, the Beaufort data suggested that roughly 40% more Halotron I discharge time was required, and about 50% more agent, for comparable extinguishment characteristics to halon 1211. After modifications, the Halotron unit extinguished all four pool fires on which it was tested. Halon 1211 extinguished three out of four fires. For the largest fire (800 ft²), Halotron used 87.5 lbs of agent to extinguish the fire, compared to halon 1211 which required 48 lbs and 13 seconds for extinguishment. The fundamental trends from Beaufort were verified. The perfluorohexane took about the same time and used about the same amount of agent as Halotron.

For the inclined plane tests, Halotron performed slightly better than halon 1211. The average extinguishment time was 15.8 seconds, with 63.5 lbs used compared to halon 1211 where 22.4 seconds was needed, using 75.5 lbs.

Firefighting tactics and techniques along with ambient wind conditions were found to affect the engine nacelle tests. Multiple tests using 150 lbs units were conducted. Halon 1211 extinguished three of four test fires, while Halotron I was successful in nine of fifteen tests; it did not successfully extinguish the full USAF engine nacelle protocol test. In the failures, Halotron I was found to be able to extinguish the ground or nacelle fire, but not both. It was estimated that just a small amount of extra agent would be required to successfully extinguish this fire. This was confirmed with tests of a larger, 500 lbs unit, which was being assessed for ARFF rapid intervention vehicle replacement. A clean agent was considered important for engine nacelle fires, and Halotron I was considered acceptable by the FAA for minor nacelle fires.

In the wheel fire tests, Halotron I easily extinguished all fires.

Halotron I was found to be twice as effective on the inclined plane test and 33% more effective on the wheel test than perfluorohexane.

Ultimately, the FAA concluded that “These results were well within acceptable limits of agents for airport use. Halotron I was approved for use at FAA certificated airports as a complimentary extinguishing agent.”

The FAA found that on average Halotron I takes 50% more mass of agent than halon 1211. Halotron I has a lower liquid density than halon 1211. They performed a cost/benefit analysis for modifications to existing airport vehicles, where halon 1211 would potentially be replaced (this is included in the FAA/Wright report). Given that typical events with ARFF vehicles have involved the use of a fraction of the halon 1211 on those trucks, it was deemed acceptable by FAA to allow a 460 lb charge of Halotron I to replace 500 lbs of halon 1211 on the ARFF vehicles. A similar scaling factor is permitted for 150 lbs cylinders.

In these tests and others, the USAF had a goal to establish a one-to-one replacement for halon 1211. This was not accomplished in these tests, and to this day, more than 15 years later, a gaseous clean agent has yet to be identified as an equivalent, one-to-one drop-in replacement to halon 1211.

5.2 FAA-Approved Aircraft Rescue and Firefighting Use

In spring of 1995, the U.S. Federal Aviation Administration (FAA) approved Halotron I for use in airport firefighting. This approval was based on, among other factors, full-scale tests conducted at Tyndall AFB, Florida as described above. These tests addressed fires in an engine, fuel spill fires, fires involving tires and hydraulic fluids, and running fuel fires. CertAlert 95-03, dated June 1995, specifies that Halotron I can be used as a replacement for halon 1211 in ARFF vehicles. This use can meet formal requirements specified by FAA for airport ARFF vehicles [Federal Aviation Administration, 1995]. **No other halocarbon-based, clean agent, currently commercially available, has this type of certification. Approximately 100 airports have 460-500 lb Halotron I systems on their ARFF vehicles.**

Specifications for large cylinders are provided by AMPAC [American Pacific Corporation, 2008]. Descriptions of large ARFF use in the field are available in the general literature [Huffman, 2009].

5.3 Aircraft Onboard Clean Agent Extinguishers

On June 17, 1993, through the Federal Register, the Federal Aviation Administration (FAA) announced it was embarking on the development of a halon replacement program. This program was used to determine a test protocol to certify halon 1211 replacement handheld extinguishers for use onboard commercial passenger aircraft [Federal Aviation Administration, 1984]. The development of the test program was a joint industry/government effort that resulted in the *Minimum Performance Standards for Handheld Fire Extinguishers as a Replacement for Halon 1211 on Civilian Transport Aircraft*. Subsequent fire tests to this standard demonstrated that Halotron I can provide a similar level of protection as halon 1211 and will not represent a hazard to passengers or crew based on neat agent concentration or by-products when used properly [Colton and Gibson, 2002]. The Halotron I unit represented the first extinguisher containing an environmentally-acceptable agent to have fully satisfied these requirements.

5.4 NRC of Canada Portable Extinguisher and Operator Exposure Tests

The National Research Council of Canada (NRC) conducted Class B fire tests of clean agent portable fire extinguishers [Su and Kim, 2002]. The objective was to observe Class B fire suppression effects and the resulting threat to extinguisher operators. Handheld FM-200, FE-36, CF3I and Halotron I extinguishers with 2B:C, 5B:C and 10B:C ratings were tested for extinguishing Class B heptane pool fires in small and large enclosures (45, 120 and 21000 m³). The fire test sizes were 0.372, 0.836, and 1.49 m² pan fires corresponding to 2B, 5B, and 10B ratings, respectively. For the small enclosure tests, a 0.580m² pan was used in place of the intermediate size pan. Test results showed that the Halotron I and CF3I extinguishers performed better than the FE-36 and FM-200 extinguishers. Halotron I also had less acid gas production resulting from Class B fire extinguishment than the FM-200 and FE-36 extinguishers.

Summarizing, numerous small-, medium-, and large-scale fire tests have been conducted with Halotron I. For small fires, the mass of Halotron I needed is similar to halon 1211. While more agent is needed for large fires, Halotron I has been commercially designed and accepted to meet hazard performance criteria for portable fire extinguishers and fixed/vehicle hose line systems. No other streaming agent alternative has widespread approval for hose line applications. It has superior or equivalent fire extinguishing performance compared to other clean streaming agent alternatives.

6.0 USE AND EFFECTIVENESS OF HALOTRON I IN THE MARKETPLACE

When the Montreal Protocol was ratified, it was assumed that technological advancements and competition in the marketplace would drive the development of environmentally-benign, clean agent, halon 1211 alternatives. While halon 1211 is certainly the most effective portable fire protection agent, it is also one of the most potent ozone depleters. The fire tests described in the previous sections describe the degree to which Halotron I has been tested for fire performance. It also points out the limitations of alternative agents. The following outlines the degree to which Halotron I has gained market acceptance, and the substantial equipment certification and listing processes which are part of this market acceptance. Actual fire incident data is also provided to show its effectiveness in actual field use.

6.1 Listings, Certifications, and Approvals

To enter the marketplace, agents and associated discharge equipment must be approved by various listing and approval agencies. In the United States, this includes Underwriters' Laboratories, which approves extinguishers for general use under the Class A, B and C rating methodology. Additionally, they list extinguishers as appropriate for marine use, subjecting equipment to marine environmental conditions. Individual markets may impose additional requirements. For example, for certification of aircraft portable extinguishers, the FAA requires extinguishers to be both UL 5B:C rated and approved in accordance with their Minimum Performance Standard (MPS), DOT/FAA/AR-01/37 [Speitel, 2006].

Halotron I has the following listings, certifications, and approvals which demonstrate the widespread use of this fire extinguishing agent:

- U.S. Environmental Protection Agency – Halotron I is approved under the Significant New Alternatives Policy (SNAP) Program as “HCFC Blend B” with unrestricted approval as a streaming agent for non-residential use [U.S. Environmental Protection Agency, 1994].
- Underwriters Laboratories – Halotron I has 24 UL listings through four of the five major USA-based extinguisher manufacturers: Amerex, Badger, Kidde and Buckeye. The 150 lbs units are rated 10A:80B:C, the highest-rated portable halon alternative extinguisher available in the marketplace. DOT approved tanks are available in 250, 500, and 1250 lbs capacity for large volume use [American Pacific Corporation, undated].

RATING SIZE/CONFIGURATION (ratings listed are with the minimum agent charge weights: additional higher charge weight extinguishers are available with similar performance ratings as those below, but are now manufactured sparingly)

1-B:C 1.4 lbs (0.63 kg)/Fixed Nozzle
2-B:C 2.5 lbs (1.13 kg)/Fixed Nozzle
5-B:C 5.0 lbs (2.27 kg)/Fixed Nozzle
5-B:C 5.5 lbs (2.72 kg)/Hose/Nozzle
1-A:10-B:C 11 lbs (5.0 kg)/Hose/Nozzle
2-A:10-B:C 15.5 lbs (7.0 kg)/Hose/Nozzle
4-A:40-B:C 65 lbs (29.5 kg) Hose/Nozzle
4-A:60-B:C 65 lbs (29.5 kg) Hose/Nozzle
10-A:80-B:C 150 lbs (68 kg) Hose/Nozzle

- Underwriters Laboratories of Canada –

RATING SIZE/CONFIGURATION

2-B:C 3.0 lbs (1.36 kg)/Fixed Nozzle
5-B:C 6.0 lbs (2.72 kg)/Hose/Nozzle
1-A:10-B:C 12 lbs (5.44 kg)/Hose/Nozzle
2-A:10-B:C 18 lbs (8.16 kg)/Hose/Nozzle

- U.S. Federal Aviation Administration – CertAlert 95-03 [Federal Aviation Administration, 1995]
- U.S. Federal Aviation Administration – Halotron I is now certified and available from one equipment manufacturer for use onboard aircraft as regulated by the FAA [e.g., Amerex, 2002].
- U.S. Coast Guard – Type B, Size I (5 lb, 5BC), Size II (15.5 lb 2A-10BC)

Environment and fire testing is only part of the process of fielding fire extinguishing equipment. Depending on the approval agency or end user, additional equipment or impact tests may be required. A wide range of material acceptability/compatibility assessments have been performed and are included in the Halotron I service manuals. The agent is compatible with all common metals and alloys and most plastics and paints. Extinguishing system parts using Buna, silicone, or natural rubbers, should not be used; acceptable o-ring and gasket materials have been identified. Halotron I has undergone the following representative equipment testing, certification, and maintenance evaluations:

- Testing of rubber seals: Certain elastomers are not compatible with Halotron I. Some types used with halon 1211 are incompatible with Halotron I. Hydrocarbon rubber (EPDM) is the common elastomer that is used for valve seating and o-rings with Halotron I. A neoprene-based material was also found to be acceptable for this service. These materials have been tested, and are described in the agent service manuals [American Pacific Corporation Halotron Division, 1999a];
- Aircraft corrosion testing: Halotron I has been subjected to the tests for compatibility with aviation structural materials and paint application, Boeing standard D6-17487. The agent was found to meet sandwich corrosion, immersion corrosion, and paint softening criteria, based on ASTM F502 [Scientific Material International Inc., 1993]. This data has been included in the Halotron I material data sheets [American Pacific Corporation, 2006a, 2006b];
- Paint compatibility: Through testing, Halotron I has been found to be compatible with the exterior paint of common automobile makes and models. No deterioration or discolorization has been found after a 30-second exposure to Halotron I in the liquefied state. The paints maintained their structural integrity and appearance [American Pacific Corporation Halotron Division, 1999b];
- Acid gas production- In an assessment by the FAA, related to potential acid gas production from a handheld extinguisher, Halotron I was found to create about two-thirds less HF and one half the combined HF+HCl than a comparable FE-36 extinguisher tested [Webster, 2002; FAA, undated]; and,
- Recovery procedures: Appropriate procedures for recovering unused Halotron from agent cylinders have been promulgated. The method uses similar equipment and procedures used to fill cylinders [American Pacific Corporation Halotron Division, 2006b]. Push and fill type configurations or pump based systems are used. There are more robust recovery systems that utilize tighter filter configurations in the market place and that are used by some U.S. distributors.

The fire testing, listing, and certification of agents and equipment is not a trivial matter. According to the 2005 TEAP IPCC report, “*Due to the lengthy process of testing, approval and market acceptance of new fire protection equipment types and agents, no additional options are likely to be available in time to have an appreciable impact by 2015*” [de Jager, 2005].

6.2 Field Use

Having been in service for nearly 15 years, Halotron I has established a track record of use and effectiveness. It is the clean agent of choice for U.S. commercial aviation aircraft rescue and firefighting use. Since it is the only halon alternative with large cylinder capability, it can be found with 150 lb (68 kg) to 500 lb (227 kg) truck mounted units on crash rescue vehicles at over 100 airports in the U.S. **No other halon alternative is available for this use; if Halotron I was removed from the market, airport ARFF would have to revert back to carbon dioxide, or use dry chemical with its associated collateral damage potential.** An example of high-performance crash truck attributes which includes Halotron I is provided in the general literature [Huffman, 2009]. Table 4 provides a partial listing of U.S. airports using Halotron I.

Anchorage, Alaska	Louisville, Kentucky
Amarillo, Texas	McCarran, Las Vegas, Nevada
Austin, Texas	Memphis, Tennessee
Bay City, Michigan International Airport	Miami, Florida
Boeing Field, Seattle, Washington	Minneapolis/St. Paul, Minnesota
Boston/Logan/Massport, Boston, MA	Mobile, Alabama
Bradley, Connecticut	Monterey, California
Buffalo, New York	New Orleans Int'l, Louisiana
Burbank/Glendale/Pasadena, California	Norfolk, Virginia
Capital City, Lansing, Michigan	Oakland, California
Cayman Islands	Ontario, California
Chattanooga, Tennessee	Orange County, California (John Wayne)
Chicago Midway, Illinois	Orlando, Florida
Chicago O'Hare, Illinois	Palm Beach, Florida
Cincinnati, Northern Kentucky	Palm Springs, California
Clearwater, Florida	Pensacola, Florida
Columbus Metro Airport, South Carolina	Pittsburgh, Pennsylvania
Dallas Love Field, Texas	Portland Jet Port, Maine
Dayton, Ohio	Portland, Oregon
Detroit Metro, Michigan	Richmond, Virginia
El Paso, Texas	Rochester, New York
Everett, Washington	Rockford, Illinois
FAA Tech Center, Salt Lake City, Utah	Sacramento, California
Federal Express, Memphis, Tennessee	San Antonio, Texas
Ft. Lauderdale/Hollywood, Florida	San Francisco, California
Ft. Wayne, Indiana	Sanford International, Sanford, Florida
Gillette-Campbell City Airport, Wyoming	Santa Barbara Municipal, California
Grand Forks, North Dakota	Sawyer International Airport, Michigan
Harrisburg, Pennsylvania	Shenandoah Valley Regional, Weyers Cave, VA
Hilo, Hawaii	Sikorsky, Bridgeport, Connecticut
Honolulu, Hawaii	South Bend, Indiana
Houston, Texas	Southwest Michigan Reg., Benton Harbor, MI

Ithaca, New York	St Louis, Missouri (Lambert Field)
Juniper, Florida (Sikorsky Aircraft)	Tampa, Florida
Key West, Florida	Trenton, New Jersey (Mercer County)
King County (Seattle), Washington	Tri-Cities, Tennessee
Kona International, Hawaii	Warwick, Rhode Island (T.F. Green Airport)
Lafayette Regional Airport, Louisiana	West Columbia, South Carolina
Lee County (Fort Myers), Florida	Westchester County, White Plains, New York
Los Allemandes, California	Wilmington, North Carolina
Los Angeles, California (LAX)	

Fire extinguisher distributors have supported international use of halon replacements in lesser developed countries. In 2008, H3R Aviation, Inc., makers of halon and halon-alternative portable fire extinguishers, sold 86 Halotron I wheeled, clean agent fire extinguishers for use by the United Nations at various airports and helipads throughout Haiti [H3R Aviation, Inc., 2009].

As of 2008, other countries where Halotron I is sold in some volume include Argentina, Brazil, Canada, China, India, Indonesia, Korea, Malaysia, Mexico, Pakistan, Philippines, and Singapore.

Successful use of Halotron I has been reported directly to the manufacturer. The following incidents are among those that attest to its effectiveness:

- Garfield Co. 2005 – In early 2005, a mechanic was servicing a Gulfstream jet at the Garfield County, Colorado airport. He noticed flames coming from the plane’s engine cowling. The fixed fire suppression system was activated, but failed to suppress the fire. After suppressing the ground fire with foam, he successfully suppressed the engine fire by discharging Halotron I in the engine exhaust. The jet’s \$3.5 M (US) engine was saved, and no further damage was sustained to the \$30 M (US) aircraft [Garfield County, 2005];
- Richmond, VA, August 2004 – The fixed system on an Embraer 135/145 regional failed to extinguish an engine fire. A Halotron I vehicle handline was used by ARFF to successfully extinguish the fire [Nilo, 2004];
- Memphis, 2002 – On January 18, the FedEx fire department in Memphis, Tennessee, responded to smoke and flames coming from the rear of a fully-loaded Airbus A-300 [ARFFWG, 2002]. The aircraft was preparing to push back from the gate when a fire started in the auxiliary power unit exhaust pipe. Using an extended boom vehicle having Halotron I capability, the fire was extinguished. Only minor damage to the aircraft was reported, confined to the exhaust system;
- Sikorsky, December 1, 2000 – A high-pressure hydraulic fuel leak, ignited by an electrical spark, occurred onboard a test helicopter. Arriving firefighters found heavy smoke in the cabin. Although flames were visible, the responders were hesitant to use foam since it is the “agent of last resort”. A vehicle-mounted Halotron I handline was

used to flood the compartment and extinguish the fire, with no re-ignitions. The clean agent was credited with limiting collateral damage which may have occurred with the use of foam or dry chemical [Reichwald, 2001]; and

- Lee County (Ft Meyers, FL) Port Authority, April 7, 1997 – ARFF responded to a Boeing 737 engine fire. A minor fire inside the exhaust was extinguished using a Halotron I vehicle-mounted handline. After extinguishing the fire, ARFF personnel assisted in evacuating the passengers. The aircraft was flown out later the same day, with no apparent damage from the fire or the extinguishing agent [Lee County Port Authority, 1997].

Summarizing, Halotron I has approvals from Underwriters Laboratories, Underwriters Laboratories of Canada, the U.S. Coast Guard, and the Federal Aviation Administration for use at both commercial airfields and aboard aircraft. A variety of both fire testing and material compatibility tests have been conducted to support use in a wide range of specialized applications and industries. The commercial success of Halotron I is demonstrated by its widespread use at airports; this success is supported by actual fire loss experiences where Halotron I has been effective. It is being increasingly used throughout the world. No additional clean streaming agent options are likely to be available in time to have an appreciable impact by 2015.

7.0 ENVIRONMENTAL IMPACT OF CONTINUED USE

The ozone depletion potential and global warming potential for HCFC Blend B (Halotron I) was compared to that of halon 1211 and of the other alternative agents for streaming applications in Figures 4 and 5. However, as these are on a per unit mass emitted basis, and while useful in comparing the use of one agent over another, this may not reflect the overall effects on the environment. Wuebbles et al. [2009], in assessing the impacts of Halotron I on the environment, estimates the total production of HCFC-123 at 2500 metric tons per year. Half of this production, 1200 metric tons per year, is estimated to be utilized in refrigeration applications. Firefighting is estimated to account for 10% of this production, or 250 metric tons per year. The emissions of HCFC-123 through firefighting activities are estimated to make up half of the estimated 130 metric tons emitted per year [Wuebbles et al., 2009]. The IPCC/TEAP special report estimates a higher emission rate for HCFC-123 at 4,000 metric tons per year but attributes all of the difference to refrigeration and other uses [de Jager, 2005]. Emissions due to firefighting are estimated at 40 metric tons per year [de Jager, 2005], effectively the same as the 65 metric tons per year estimated by Wuebbles [Wuebbles et al., 2009]. For comparison, 310,000 metric tons of HCFC 22 (0.05 ODP), a common refrigerant, is estimated to have been emitted during 2004 [Wuebbles et al., 2009].

Utilizing the Effective Equivalent Stratospheric Chlorine (EESC) concentration as an indicator of ozone depletion, the World Meteorological Organization (WMO) estimates the total contribution of HCFC emissions to the EESC as 100 ppt (parts per trillion), most of which are attributed to HCFC-22 emissions [de Jager, 2005]. The total EESC is estimated at 3000 ppt [World Meteorological Organization, 2007]. The contribution of HCFC-123 emissions is estimated at 0.001 ppt [Wuebbles et al., 2009; World Meteorological Organization, 2007]. Half this amount or 0.0005 ppt would be attributed to HCFC Blend B (Halotron I).

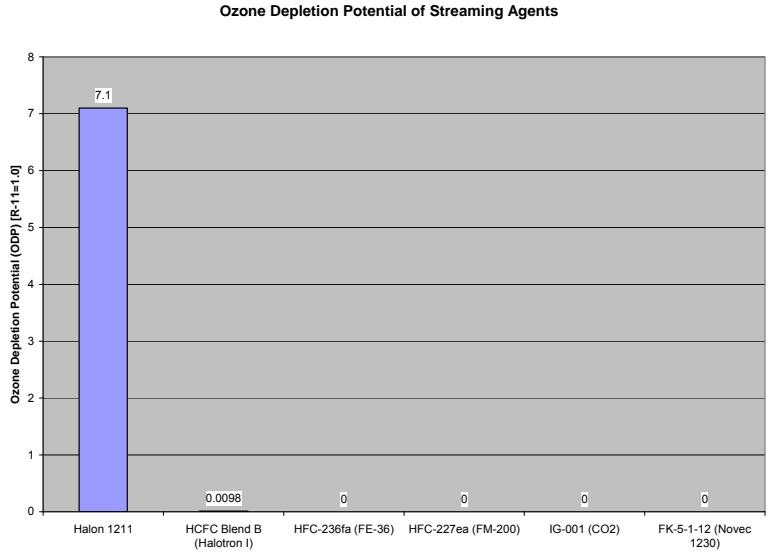


Figure 4 – HCFC Blend B (Halotron I) Ozone Depletion Potential Comparison to Halon 1211 and Other Alternatives

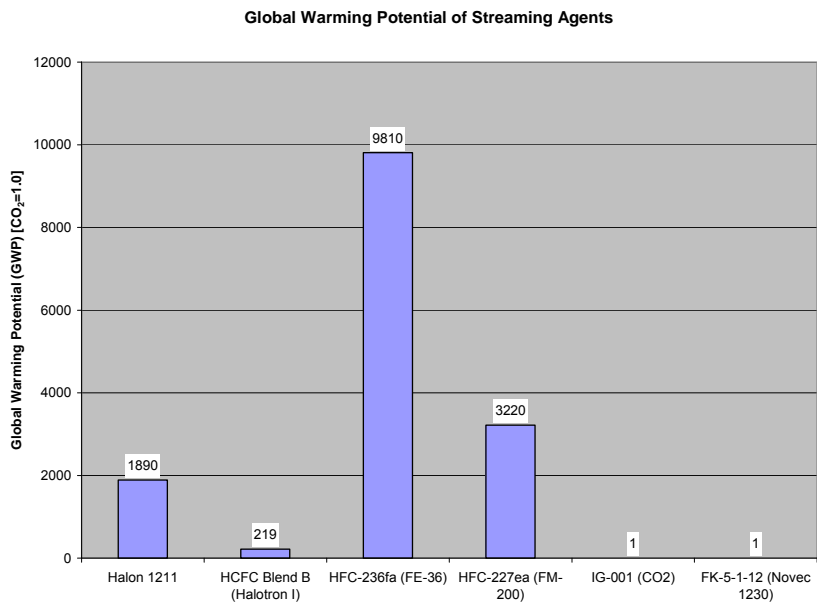


Figure 5 – HCFC Blend B (Halotron I) Global Warming Potential Comparison to Halon 1211 and Other Alternatives

Robin [2009], in an assessment of the impact of DuPont’s family of firefighting agents, estimated the total emission of HFC and PFC compounds during firefighting in carbon dioxide equivalents (mass emitted multiplied by GWP). This is estimated to be less than 0.03% of the total green house gas emissions. The analysis shown in Figure 6 was derived from the HARC HFC emission-estimating program data which did not included HCFC Blend B (Halotron I) [Robin, 2009]. Including HCFC Blend B (Halotron I) would not materially impact the percentage of the total green house gas emissions. Green house gas emissions associated with HCFC Blend B are estimated to be 14,200 metric tons of CO₂ equivalents per year. This

amounts to approximately 2% of the 681,000 metric ton of CO₂ equivalents per year estimated for HFC emissions in fire fighting applications [HARC, 2007].

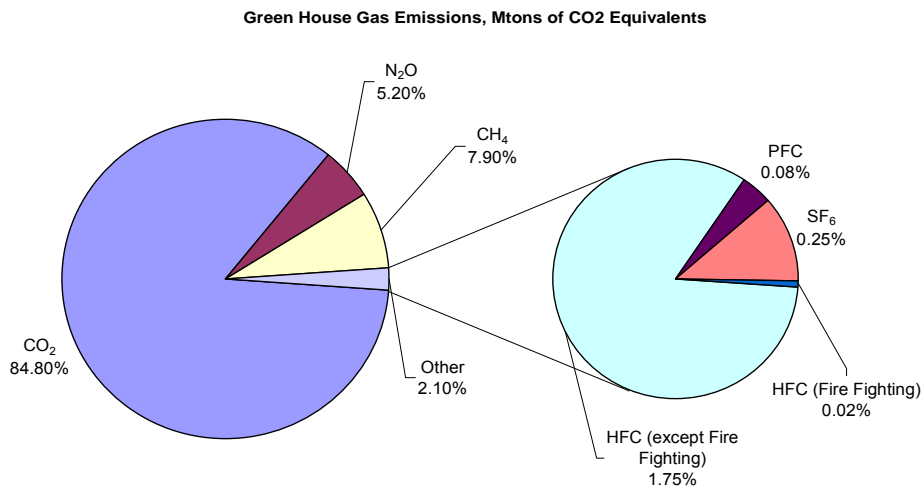


Figure 6 – Carbon Dioxide Equivalent Associated with Firefighting as percentage of Total Green House Gas Emissions

The impact on the amount of green house gas emissions of a withdrawal of HCFC Blend B (Halotron I) would depend on the replacement in its applications. After the production ban on halon 1211 was announced, many of the applications where it had been utilized shifted to non-clean agents like dry powder based extinguishers or water-based extinguishers, due to the increased cost of the alternative clean agents [Wickham, 2002]. Much of the re-examination of the need for a clean agent has already occurred, and it has been shown in this report that there are still applications where clean streaming agents are the preferred fire protection choice. If HCFC Blend B (Halotron I) was eliminated from the market, it would potentially be replaced in the market by another available clean agent. The potential candidates to replace HCFC Blend B (Halotron I) are HFC-236fa (FE-36), HFC-227ea (FM-200), IG-001 (CO₂) and FK-5-1-12 (Novec-1230). IG-001 (CO₂) and HFC-227ea (FM-200) do not have or have not demonstrated the Class A capability of HFCF Blend B (Halotron I). The inclusion of FK-5-1-12 (Novec 1230) is theoretical at this point as no UL-711 ratings have been obtained for portable or large-capacity extinguishers even though it has been commercially available for several years. This leaves HFC-236fa (FE-36) as the leading candidate to replace HCFC Blend B (Halotron I). However, as shown in Figure 7, if HCFC Blend B were to be replaced with HFC-236fa (GWP of 9810), the additional emission of HFC-236fa would represent 637,650 metric tons of CO₂ equivalents per year or approximately a 94% increase in emissions of CO₂ equivalents due to fire-fighting applications.

The withdrawal of HCFC Blend B (Halotron I) may also have the unintended consequence of increased emissions of HCFC Blend B. The usage bans of halon 1211 resulted in the unintended discharge of the chemical in greater quantities than expected. This was attributed to intentional or inadvertent discharges. Residual, existing materials which are outright banned may tend to be emitted, i.e., they may not be recovered.

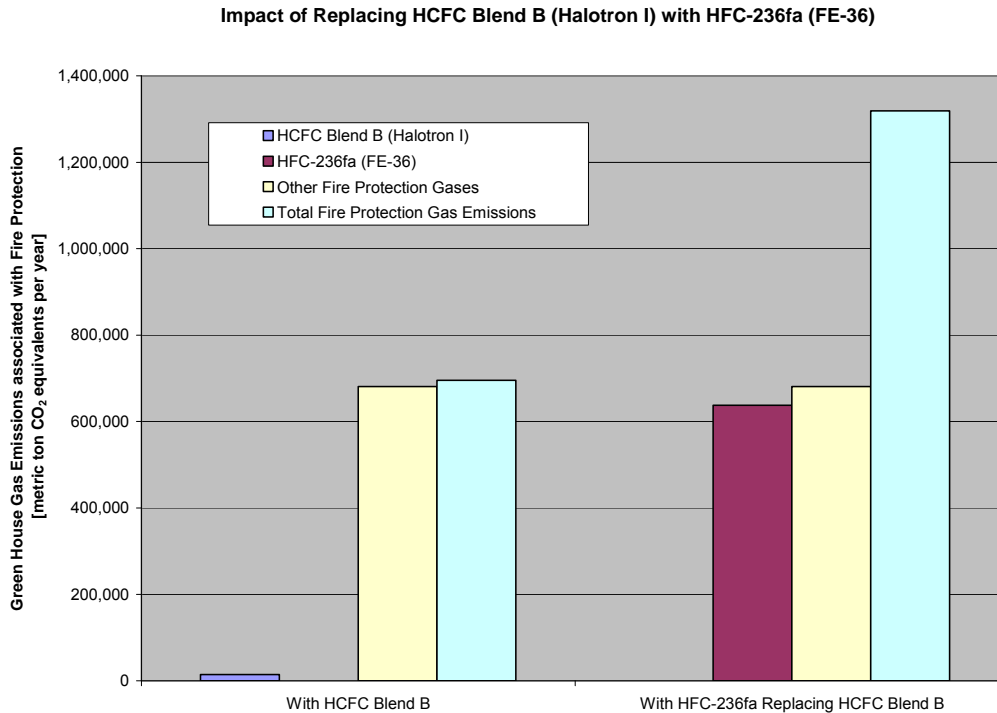


Figure 7 – Impact of replacing HCFC Blend B (Halotron I) with increased usage of HFC-236fa (FE-36) - leading candidate with both Class A and Class B UL-711 ratings

Summarizing, continued use of HCFC Blend B (Halotron I) would have only a small impact on stratospheric ozone depletion due to its low ozone depletion potential, 0.0098, and its low emission rate, estimated at 65 metric tons per year. This continued use would also only have a small impact on global warming due to its low global warming potential, 219, and emission rate combined to represent approximately 2% of the total carbon dioxide equivalent emissions associated with fire protection. Replacement of Halotron I with the only clean agent candidate (defined as available in UL-listed hardware actively sold) to have both Class A and Class B UL 711 ratings, HFC-236fa, would dramatically increase the green house gas emissions associated with fire protection due to its high global warming potential (9810) from an estimated 695,000 metric tons of carbon dioxide equivalents per year (including Halotron I emissions) to 1,318,000 metric tons of carbon dioxide equivalents per year.

8.0 SUMMARY

Halon 1211, an effective firefighting streaming agent used in portable extinguishers and vehicle-mounted units, is being phased out because of its environmental impact. No environmentally “perfect” clean agent has been developed. The most effective and widely used alternative, Halotron I (HCFC Blend B), contains HCFC-123. Like halon 1211, Halotron I is a clean agent, leaving no residue, and is effective on Class A, B, and C fires. HCFC-123 faces a new production ban in 2030 as a Class II substance despite its near-zero ODP and extremely low GWP. Without Halotron I, users will be left with less effective, ineffective, and/or extremely high GWP alternatives in certain niche applications.

A wide range of testing, approvals, and actual field use have demonstrated its effectiveness as an alternative to halon 1211. An analysis on the impact of continued use of Halotron I shows that only a small impact on stratospheric ozone depletion and global warming would occur. Replacement of Halotron I with the only clean agent alternative (defined as available in UL-listed hardware actively sold) to have both Class A and Class B Underwriter Laboratories listings would dramatically increase green house gas emissions associated with fire protection.

Without Halotron I, users would likely be left with less effective, ineffective, and/or extremely high GWP alternatives. The environmental impact of continued use of Halotron I appears to be small and in fact appears beneficial when compared to alternatives that have similar approvals which might take its place, to the extent that can occur. As a reasonable need/impact trade off, regulators and policymakers should consider excluding HCFC Blend B from current 2030 production bans associated with HCFC-123.

9.0 ACKNOWLEDGMENTS

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10.0 REFERENCES

Aircraft Rescue & Fire Fighting Working Group (ARFFWG) (2002), "FedEx Memphis," *ARFF News*, May/June 2002, pp. 41.

Air Products and Chemicals, Inc (2004), "Material Data and Safety Sheet (2004) – Product: Carbon Dioxide," MSDS 300000000020, V1.2, Allentown, PA, September 27, 2004.

Amerex Corp. (2002), "Halotron, Model B394TS," Specification/Data Sheet.

Amerex Corporation Website (2008), October 21, 2008, <http://www.amerex-fire.com>.

American Pacific Corporation Halotron Division (1998), "Halotron™ I Health and Toxicity Summary Bulletin," Bul2/03.1998.v2 (Bul4).

American Pacific Corporation Halotron Division (1999a), "Halotron™ I Filling and Servicing Bulletin," Bul6.1999 v1.

American Pacific Corporation Halotron Division (1999b), "Halotron™ I – Automobile/Aircraft Paint Compatibility Bulletin," Bul 7.rev 0, July 1999.

American Pacific Corporation Halotron Division (2006a), "Filing Procedure Manual for 300–500 lb (136–227 kg) Type Fire Extinguishing Systems Manual, Revision 7," Halotron, Las Vegas, NV, February 2006.

American Pacific Corporation Halotron Division (2006b), "Portable Extinguisher Filling and Agent Recovery Manual, Revision 6," Halotron, Las Vegas, NV, January 2006.

- American Pacific Corporation Halotron Division (2006c), "Material Safety Data Sheet-Halotron I," Halotron, Las Vegas, NV, December 18, 2006.
- American Pacific Corporation Halotron Division (2008), "Halotron® I Clean Agent Airport Users – Large Scale Units 150 LB (68 kg) to 500 lb (227 kg) High Performance Truck Mounted Units," September 2008.
- American Pacific Corporation Halotron Division (undated), "Halotron® I Tank Specifications."
- Ansul Inc. (2006), "Cleanguard Clean Agent Hand Portable Extinguishers – Data/Specifications," Ansul Inc., Marinette, WI.
- Broder, J.M. (2009), "E.P.A. Clears Path to Regulate Heat-Trapping Gases for the First Time in U.S.," *New York Times*, April 18, 2009, page A11.
- Carpenter, D.J. Verdonik, D.P., DiNenno, P.J., and Williams, F.W. (1999), "US Navy Halon 1211 Replacement Plan Part I – Development of Halon 1211 Alternatives," NRL/MR/6180--99-8140, Naval Research Laboratory, Washington, DC, November 1, 1999.
- Commission of European Communities (2009), Draft amendment to Regulation (EC) No 2037/2000 of the European Parliament and of the Council on substances that deplete the ozone layer, with regard to the critical uses of halons, Brussels, 2009.
- Colton, B.A. and Gibson, J.M. (2002), "Development of A Halotron™ I Handheld Fire Extinguisher for Use Onboard Commercial Aircraft," *Proceedings of HOTWC-2002 12th Halon Options Technical Working Conference*, Albuquerque, NM, April 20–May 2, 2002.
- de Jager, D. et al. (2005), "Technical Summary," *Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons*, IPCC/TEAP Special Report, United Nations Environment Programme, 2005, pp. 17–82.
- Federal Aviation Administration, Offices of Airport Safety and Compliance (1995), CERTALERT No. 95-03, Airport Certification Program Inspectors, July 12, 1995.
- Federal Aviation Administration (1984), "Hand Fire Extinguishers for Use in Aircraft," Advisory Circular 20-42C, Washington, DC, March 7, 1984.
- Federal Aviation Administration (FAA) (undated), "Clean Agent Acid Gas Comparisons," Data from FAA Report DOT/FAA/AR-01/37 [Webster, 2002] and unreported data supplied to American Pacific Corporation from the FAA.
- Garfield County, CO (2005), *Newsletter From The County Manager To Garfield County Staff*, #8-3, appearing in *Green Acres*, March 20, 2005.

- H3R Aviation, Inc. (2009), "H3R Aviation Halotron 1® Sale Supports United Nations Mission in Haiti," January 12, 2009.
- Halon Alternatives Research Corporation (HARC) (2007), "Report of the HFC Emissions Estimating Program, 2002–2005 Data Collection," HARC, Arlington, VA, November 2007.
- Huffman, J.P. (2009), "Mega Vehicles: PM Rides 5 of America's Largest Moving Machines," Oshkosh Striker 4500, *Popular Mechanics*, February 2009.
- Gann, R.G. (2007), "Next Generation Fire Suppression Technology Program (NGP) Collected Publications," NIST Special Publication 1069-1, Gaithersburg, MD, June 2007. <http://www.fire.nist.gov/bfrlpubs/fire07/PDF/f07028.pdf>
- International Civil Aviation Authority (ICAO) (2007), "Resolutions Adopted by the Assembly," *Assembly – 36th Session*, Montreal, September 2007.
- Korea Eco-Label (2003), "EL765.Fire Extinguishers," No. EL765-2006/1/2006-97.
- Lee County Port Authority (1997), Personal Communication to Robert Ferraro: Use of Halotron I – Boeing 737 Engine Fire, August 5, 1997.
- Marine Corps Air Station Beaufort (1992), "Halotron 1 Fire Fighting Evaluation," Rpt No. 11320 CFR/Ser 480, Beaufort, SC, November 23, 1992.
- Metz et al. (2005), "Safeguarding the Ozone Layer and the Global Climate System: Issues related to hydrofluorocarbons and perfluorocarbons," IPCC/TEAP 2005, Cambridge University Press, Cambridge, England, 2005.
- National Fire Protection Association (NFPA) (1990), "Standard on Halon 1211 Fire Extinguishing Systems," NFPA 12B, 1990 edition, National Fire Protection Association, Quincy, MA.
- National Fire Protection Association (NFPA) (2008), "Standard On Clean Agent Fire Extinguishing Systems," NFPA 2001, 2008 edition, National Fire Protection Association, Quincy, MA.
- Nilo, J. (2004), "Halon Usage?," email to Ronald Jackson of Emergency One regarding the successful use of Halotron I at Richmond International Airport, September 13, 2004.
- Rasky Baerlein Strategic Communications (2008), "New Minnesota Law on Reporting for Producers and Users of HFCs, PFCs, and SF6," FEMA Government Relations Committee, August 5, 2008.
- Reid, R.C., Prausnitz, J.M., and Poling, B.E. (1987), *The Properties of Gases & Liquids*, Fourth Edition, McGraw-Hill Book Company, New York, NY, 1987.

- Robin, M.L. (2009), "DuPont Fire Extinguishants, The Role of Hydrofluorocarbons in Global Fire Protection," DuPont, February 2009.
- Rochefort, M.A., Dees, B.R., and Risinger, C.W. (1993), "Halon 1211 Replacement Agent Evaluation-Perfluorohexane and Halotron I," WL-TR-93-3520, WL/FIVCF Tyndall AFB, November 1993.
- Reichwald, A. (2001), Letter from Rural/Metro Fire Department to American Pacific Corp. regarding helicopter fire, January 22, 2001.
- Scientific Material International Inc. (1993), "Boeing D6-17487, Revision K - Fire Extinguishing Foams and Liquids," SMI Ref. 9308002, August 9, 1993.
- Sea-Fire Marine Website (2008), October 21, 2008, <http://www.sea-fire.com/SF/ProductsSeaFire/Portable/FireExtinguisher/FireExting.html>.
- Skaggs, S.R., Tapscott, R.E., and Moore, T.A. (1992), " Technical Assessment for the SNAP Program", *Proceedings of the Halon Options Technical Working Conference 1992*, Albuquerque, NM, May 12-14, 1992.
- Speitel, L.C. (2006), "Handheld Extinguisher Draft Advisory Circular Summary," *Aircraft Systems Fire Protection Working Group Meeting*, Atlantic City, NJ, October 25–26, 2006.
- Su, J.Z. and Kim, A.K. (2002), "Suppression of Pool Fires Using Halocarbon Streaming Agents," *Fire Technology*, **38**, 2002, pp. 7–32.
- 3M Corporation, "Product Information: 3M™ Novec™ 1230 Fire Protection Fluid," 3M Corporation, St. Paul, MN, April 2009.
- Underwriters Laboratories (1990), "Standard for Fire Extinguishers, Rating and Fire Testing of," UL-711, Fourth edition, Underwriters Laboratories, Northbrook, IL.
- Underwriters Laboratories Inc. (1998), "HCFC Blend B (Halotron I) Clean Agent for Fire Extinguishers," *1998 Recognized Component Directory*, component listing issued June 3, 1997.
- Underwriters Laboratories Inc. (2009), "Withdrawal of the Fifth Edition of the Standard for Halogenated Agent Fire Extinguishers, UL 1093 and the Termination of New or Revised UL Listings under the categories of Liquefied Gas-type Extinguishers (GMBY) and Liquefied Gas-type Marine Extinguishers (GPGZ)," Subject UL 1093, March 12, 2009.
- U.S. Department of the Treasury, Internal Revenue Service (2009), Form 6627 "Environmental Taxes," Form 6627 rev. January 2009, <http://www.irs.gov/pub/irs-pdf/f6627.pdf>.

- U.S. Environmental Protection Agency (U.S. EPA) (1994), “Ozone Layer Depletion – Alternatives/SNAP, Substitutes for Halon 1211 as a Streaming Agent,” current version, April 30, 2009, <http://www.epa.gov/Ozone/SNAP/Fire/Lists/Stream.html>.
- Webster, H. (2002), “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, U.S. Department of Transportation, Federal Aviation Administration, August 2002.
- Wickham, R.T. (2002), “Status of Industry Efforts to Replace Halon Fire Extinguishing Agents,” Wickham Associates, Stratham, NH, March 16, 2002.
- World Meteorological Organization (2007), “Scientific Assessment of Ozone Depletion: 2006, Pursuant to Article 6 of the Montreal Protocol on Substances that Deplete the Ozone Layer,” Report No. 50, August 18, 2006, pp. 8.7–8.12.
- Wright, J.A. (1995), “Full-Scale Evaluations of Halon 1211 Replacement Agents for Airport Fire Fighting,” DOT/FAA/AR-95/87, U.S. Department of Transportation, Federal Aviation Administration, October 1995.
- Wuebbles, D.J. and Patten, K.O. (2009), “Three-Dimensional Modeling of HCFC-123 in the Atmosphere: Assessing Its Potential Environmental Impacts and Rationale for Continued Use,” *Environ. Sci. Technol.*, **43** (9), 2009, pp. 3208–3213.

11.0 BIBLIOGRAPHY

- ASTM International (undated), “Standard Specification for HCFC Blend B (CF₃CCl₂H, Ar, and CF₄), Designation: D 7122 – 05.
- Badger Fire Protection (undated), “Halotron-1™ Stored Pressure Extinguisher Models,” *BadgerExtra*, BFPN0005.
- Banks, R.E. (1994), “Environmental aspects of fluorinated materials. Part 2*. ‘In-kind’ replacements for Halon fire extinguishants; some recent candidates,” *Journal of Fluorine Chemistry*, **67**, 1994, pp. 193–203.
- Boeing Commercial Airplanes (2008), “Withdrawal of UL 1093 Impact,” PowerPoint Presentation, November 17, 2008.
- Deletain, R./AIRBUS (2008), Personal Communication to Anne Collomby: Green Agent for Engine and APU Fire Extinguishing Applications, July 31, 2008.
- Floden, J.R., Scheil, G., and Klamm, S. (date unknown), “Final Firefighter Exposure Results: A Comparison of Halon 1211, HCFC123 and PFH,” for U.S. Air Force WL/FIVCF, pp. 645–658.

- Gibson, J. (1996), "Halotron I: Recent Developments A Manufacturer Update," in *Proceedings of International Conference on Ozone Protection Technologies*, Washington, DC, 1996, pp. 640–642.
- International Aircraft Systems Fire Protection Working Group (IASFPWG) (2003), "International Aircraft Systems Fire Protection Working Group User Preference Survey for Agents Used in Hand Held Extinguishers on Board Aircraft."
- MacGregor, L. (2006), "An Analysis of Emission Trading in Fire Protection: HCFCs for Halons," *Proceedings of HOTWC-2006 16th Halon Options Technical Working Conference*, Albuquerque, NM, May 16–18, 2006, pp. 551–569
- Military Specification MIL-B-387.1 (USAF) for Bromochlorodifluoromethane, Technical, July 30, 1965.
- Parsons, M.L. (1995), "A Second Look at HCFCs," *Proceedings of HOTWC-1995 Halon Options Technical Working Conference*, Albuquerque, NM, May 9–11, 1995, pp. 575–584.
- Sampey, T. and Wagner, T. (2008), "The Auxiliary Power Unit (APU)," *ARFF News*, **19** (5), September/October 2008, pp. 15–18.
- Speitel, L.C. (2008), "Handheld Advisory Circular Update," *International Aircraft Systems Fire Protection Working Group Meeting*, Atlantic City, NJ, November 19–20, 2008.
- Thomas, S.D. (1995), "Clean Streaming Agents," *Proceedings of HOTWC-1995 Halon Options Technical Working Conference*, Albuquerque, NM, May 9–11, 1995, pp. 335–344.
- Wright, J.A. and Risinger, C. (1994), "Full Scale Test Evaluations of Halon 1211 Replacement Agents for Airport Fire Fighting," *Proceedings of Halon Options Technical Working Conference*, Albuquerque, NM, 1994, pp. 295–306.
- United Nations Environment Programme (UNEP), "2006 Report of the Halons Technical Options Committee, 2006 Assessment," UNEP Ozone Secretariat, Nairobi, Kenya, 2006, <http://ozone.unep.org/teap/Reports/HTOC/index.shtml>
- United Nations Environment Programme (UNEP) (2007), "Montreal Protocol On Substances that Deplete the Ozone Layer," *2006 Assessment Report of the Halons Technical Options Committee*, January 2007.