DEVELOPMENT OF A HALOTRON™ I HANDHELD FIRE EXTINGUISHER FOR USE ONBOARD COMMERCIAL AIRCRAFT

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1. INTRODUCTION

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 [1]. A portion of this program was to determine a test protocol to certify halon 1211 replacement handheld extinguishers for use onboard commercial passenger aircraft. 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* [2]. This paper overviews the initial selection of halon 1211 for use onboard commercial aircraft and highlights events and testing for the Underwriters Laboratories (UL) listing and FAA approval of a Halotron™ I extinguisher that may be used onboard commercial aircraft.

2. APPROVAL OF HALON 1211 EXTINGUISHERS

In 1980, FAA Advisory Circular 20-42, *Hand Fire Extinguishers for Use in Aircraft*, was revised to 20-42A in order to update the standard to current technology [3]. Revision to the circular included the approval of halon 1211 and 1301 extinguishers, which allowed the use of extinguishing agents with a toxicity rating of five or higher in occupied areas. At the time, most planes were protected by a combination of water and dry chemical, or water and carbon dioxide (CO_2).

Around the time of the 20-42A issuance, the first of a series of incidents occurred in which a hijacker would carry aboard a flammable liquid and threaten to set the plane on fire [3]. For protection against terrorist activities, testing of various extinguishing agents was carried out by the FAA that would impact future revisions of the Advisory Circular. Agents evaluated were water, CO_2, dry chemical, halon 1211, and halon 1301. Table 1 presents data for the basic characteristics of the agents tested.

Table 1. Extinguishing Agent Basic Characteristics [1]

Agent	Minimum Agent Weight Necessary for 10 B:C Rating, Lb.	Minimum Agent Weight for 1 A Rating, Lb.	Agent Plus Extinguisher for 5 B:C Rating, Lb.	Around Object Capability	Corrosion Potential	Visibility in Confined Space	Nominal Range, feet	UL Toxicity Group [2]
Halon 1211	5	9	4-6.5	Good	No	Good	9-15	5
Halon 1301	13	N/A	No units commercially available	Good	No	Good	4-6	6
Dry Chemical (ABC)	2.5	2.5	5-10 [3]	Poor	Yes	Poor	5-12	Non-toxic
CO_2	10	N/A	12-20	Fair	No	Good	3-8	5
Water	N/A	10.4	N/A	Poor	N/A	Good	30-40	Non-toxic

1. This table is a reproduction of Table 11 in Reference 3.
2. The UL toxicity Group 6 is the least toxic grouping. Group 5 is considered of a higher toxicity than Group 6.
3. 10 B:C Rating

As can be seen in Table 1, Halon 1211 stood out from the rest of the agents as it had the capability to extinguish fires around objects, good visibility, no corrosion or clean-up problems, a good throw range, and a low weight requirement. Halon 1301 provided some of the same benefits as halon 1211, but had a shorter throw range and was not commercially available in handheld units.

Since halon 1211 was in a higher toxicity grouping than halon 1301, there was a concern about using it in occupied areas. It became important to document the expected level of exposure based on intended usage and ventilation rates. One test series involving human exposure was carried out by the United States Coast Guard on C-130 aircraft facing a 25-30 knot wind [3]. In the testing, representing an onboard major electrical fire, three 5 Lb. halon 1211 extinguishers were discharged within one minute of each other at various locations. The first discharge was in the forward cargo area, which was immediately behind the cockpit. The second discharge was inside the cockpit, with the third discharge in the rear cargo area. Per normal flight procedures, the forward hatch in the cockpit, and the side doors in the rear cargo area, were opened in order to dissipate smoke and fumes. In this case, no live fire was present. As expected, the cockpit area reflected the highest agent concentration due to its smaller size and lower ventilation rates. The average concentration of halon 1211 in the cockpit area for the first 4 to 5 minutes was less than 3,000 parts per million. The maximum time that was required for total halon disappearance was 41 minutes. "None of the five participants in the exercise had any adverse effects from exposure either acute or cumulative." It was noted that in actual flight, ventilation rates would have been greater than those used for this test, resulting in reduced agent concentration and exposure time.

Other tests with halon 1211 focused on the degree of layering that occurs with the discharge of handheld extinguisher [3]. Due to the reduced energy at discharge and considerably smaller degree of turbulence induced, the discharge of handheld extinguishers was found to have a layering effect as compared to a total flooding system. The handheld tests demonstrated that introducing halon 1211 into a volume by a streaming method resulted in significant concentration differences from the floor level to the nose level.

The FAA conducted a fire/toxicity test program focusing on a seat fire initiated by the ignition of a flammable liquid, with a final report being issued in 1982 [4]. The tests compared halon 1211 to water, CO_2, and dry chemical (monoammonium phosphate), and evaluated the decomposition products of halon 1211. These tests were carried out in a modified C-133. Modifications consisted of dividing the cabin into two sections by a galley partition and modifying the ventilation rates to match expected in-flight conditions. A triple-passenger airline seat was doused with 1 quart of gasoline and ignited. In these tests, water and CO_2 were unable to completely extinguish the fire. In the case of water, two extinguishers containing 1.5 quarts each were discharged for each test. In the case of the CO_2, over 10 Lb. of agent was discharged for each test. Halon 1211 and dry chemical both successfully extinguished the fire.

In these FAA seat fire tests, there were two sampling locations: one approximating the position that the extinguisher operator would be in front of the seat (sampling at 5 ft. 6 in. off the floor), and one located behind the seat (sampling at 1 ft. 6 in., 3 ft. 6 in., and 5 ft. 6 in. off the floor). The conclusions for halon 1211 from the sampling tests were:

- "Acid gases and 1211 concentrations were below 'dangerous' levels when a gasoline ignited seat fire, in a simulated in-flight aircraft, was extinguished with Halon 1211",
- "Acid gases and 1211 disappear due to ventilation, diffusion, and adsorption effects", and
- "Effective utilization of Halon 1211 to extinguish a severe seat fire in a transport passenger cabin is safe in term of agent decomposition."

The seat fire by itself produces toxic by-products. Both References 3 and 4 assert that if the fire is not quickly controlled that the hazard associated with the smoke and by-products will be much greater than the risk of a quick extinguishment with halon 1211.

2.1 DEVELOPMENT OF HANDHELD MINIMUM PERFORMANCE STANDARD

The FAA announcement in the 1993 Federal Register concerning their halon replacement program stated that they would focus on four applicable areas, one of which was “hand fire extinguishers” [1]. It was announcement that one of the tests “would be patterned after the in-flight fire which occurred on trans-Atlantic Delta L-1011 flight on March 17, 1991.” On this Delta flight, insulation batting, electrical wiring, flooring, and sidewall paneling caught fire and spread through debris and contamination from years of servicing. Halon 1211 was discharged blindly into air return grills, successfully extinguishing the fire beneath the floor and saving the 231 passengers and crew onboard.

There have been several incidents involving the successful extinguishment of hidden fires by halon 1211 handheld extinguishers. Because the demonstrated risk of these “hidden” fires, the FAA has specified that agents replacing halon 1211 must exhibit a similar degree of protection against these fires. The guidelines for the hidden fire and other testing are outlined in the *Minimum Performance Standards for Handheld Fire Extinguishers as a Replacement for Halon 1211 on Civilian Transport Aircraft* [2]. The standard requires a handheld extinguisher to pass two tests, the seat fire/toxicity test and hidden fire test, and have a 5B:C rating. The seat fire/toxicity testing is similar to that performed for halon 1211, but the hidden fire test is being newly introduced.

The origin of the hidden fire test fixture in the FAA minimum performance standard goes back to research that was funded by the Civil Aviation Authority (CAA) in the United Kingdom. A report, entitled “The Development of a Hidden Fire Test for Aircraft Hand Extinguisher Applications”, was published in 1995 for work that Kidde International had performed under contract [5]. The test fixture went through several configurations. Some of the changes made throughout the modification process were:

- Square test enclosure changed to tall, thin enclosure
- Minimal ventilation changed to sizeable cut-outs
- Two fire locations expanded to 20 locations
- Allowable ambient temperature fluctuations changed to temperature conditioning (70 ± 1.8 ^{o}F, 21 ±1 ^{o}C)
- High extinguisher discharge location to mid-height location
- Low baffles changed to only high baffles

The final variation was intended to reflect “the ‘infinite’ aspect of an aircraft cheek area” and to have a mid-height extinguisher discharge location to test for upwards dispersion. Even though the final variation had 20 fire locations possible, only 8 fires were lit at one time.

Initial hidden fire tests using the Kidde/CAA test fixture were conducted with a constant-pressure generic discharge apparatus. Final tests were performed using a few commercialized halon 1211 extinguishers. In these tests, notable variations were observed in the percent of fires extinguished with handheld extinguishers of similar flow rates and starting agent weights. Table 2 reflects these test results and the importance of hardware, discharge time, discharge pressure, and agent quantity.

The hidden fire test prescribed in the new FAA minimum performance standard is similar to that described in the CAA report. The test fixture’s plastic view window was significantly enlarged and moved from the short side of the rectangular fixture to the long side of the unit for better viewing. There were two changes to the test protocol: (1) all 20 fire locations are ignited, instead of just eight, and (2) the fixture is allowed to be within a broader temperature range, 70 to 90 ^{o}F (21.1 to 32.2 ^{o}C), instead of 68 to 71.6 ^{o}F (21±1 ^{o}C). Figure 1 is a photograph of the FAA hidden fire test fixture.

Table 2. Halon 1211 Hardware Variations Tests for Kidde/CAA Hidden Fire Test [1]

Extinguisher	Pressure, psig	Agent Weight, Lb.	Mass Flow Rate, Lb./s	Percent of Fires Extinguished
Walter Kidde	130	2.0	0.31	40
Walter Kidde	100	2.5	0.22	40
First Technology	125	2.5	0.25	59
Water Kidde 'standard'	130	2.5	0.27	45
Walter Kidde	220	2.5	0.36	51
Walter Kidde	130	3.0	0.23	50
Kidde Thorn	130	3.3	0.32	60
Chubb	145	3.3	0.19	50

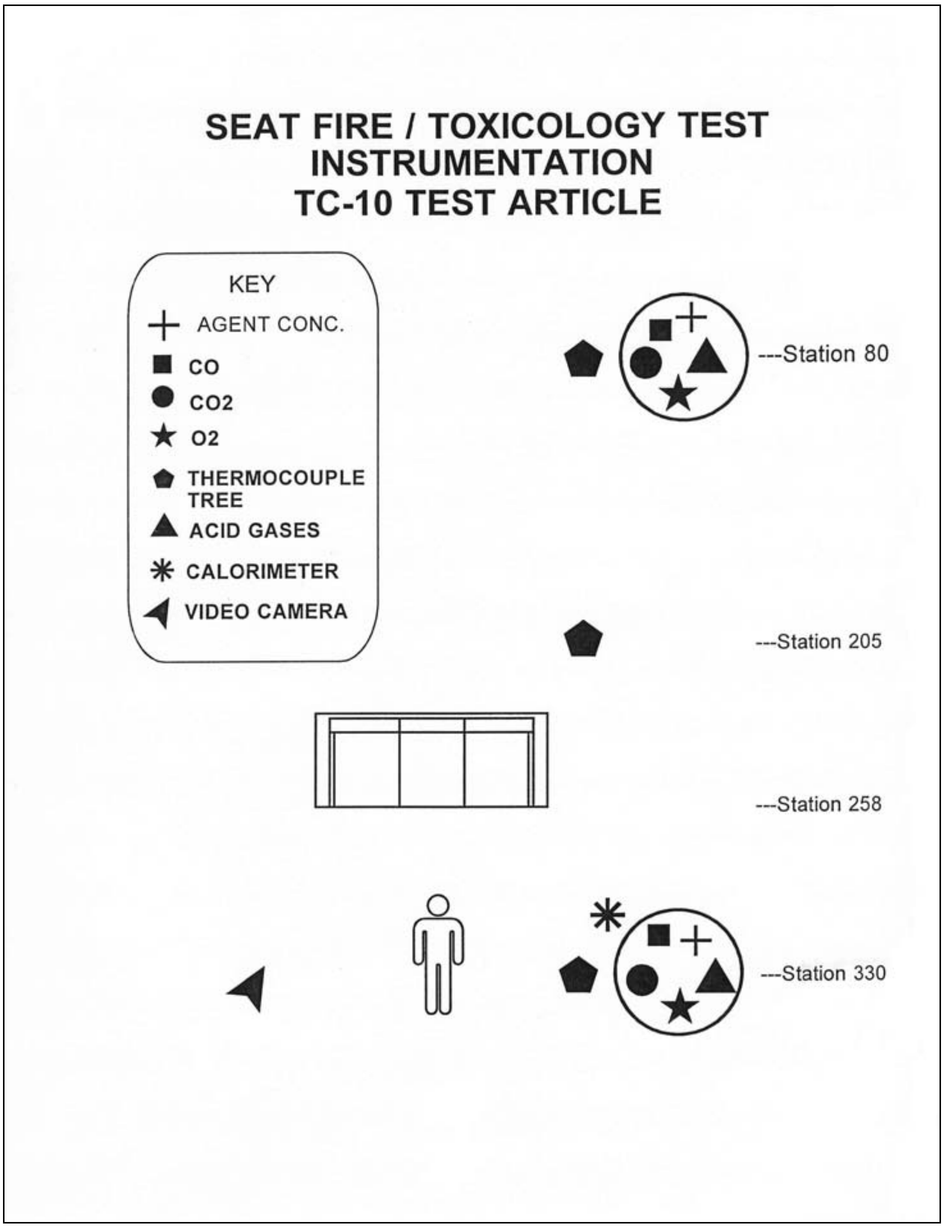
1. This table based on a compilation of information from Tables 4.2 and 4.3 in Reference 6.

Figure 1. Photo of FAA Hidden Fire Test Fixture

3. TESTING WITH HALOTRON™ I

In October of 1999, a standard 5B:C UL listed Amerex 5.0 Lb. Halotron™ I extinguisher was tested against a portion of the FAA draft of the minimum performance standard for handheld fire extinguishers. The 5.0 Lb. extinguisher was chosen because it already had the required 5B:C rating. The testing performed was the seat cushion/toxicity test, which is similar to that performed for the approval of halon 1211 (as described above in Section 2). Figure 2 represents a schematic of the test setup, reflecting the locations where the neat agent concentration and fire by-products are sampled. The sampling locations at each station were at 3 ft. 6 in. and 5 ft. 6 in. off the floor. The tests were conducted in the FAA TC-10 test fixture, which is an AFT section of a DC10. To pass this seat cushion/toxicity test, the seat fire must be extinguished with the associated levels of hazardous gases not exceeding dangerous levels. The hazardous gases include those generated by the interaction of the agent and the fire, as well as the neat agent. One quart of gasoline is poured over the seats, ignited, and allowed to burn for 30 seconds before discharging the extinguisher. Halotron™ I was able to easily extinguish the seat fires with just a portion of the agent in the extinguisher. The peak agent and by-product concentrations from these tests are summarized in Table 3.

When reviewing the peak neat agent concentrations in Table 3, these can be compared to the accepted industry practice of relating these values to the cardiac sensitization levels. The cardiac sensitization levels for Halotron™ I are 1.0%vol. for the No Observable Adverse Effect Level (NOAEL) and 2.0% for the Lowest Observable Adverse Effect Level (LOAEL). The highest concentration of neat agent in all tests never exceeded 0.1%vol, reflecting a high degree of safety margin against both the NOAEL and LOAEL. In Reference 4, the dangerous concentration range for HCl is identified as 1,000-2,000 ppm, 50 to 250 ppm for HF. In the minimum performance standard, Reference 2, the levels of HF should not exceed 100 ppm for a five minute period, nor shall the HF level exceed 200 ppm for a one minute period. Table 3 indicates that HCl and HF were both well below acceptable levels.



NOTE: This figure is a reproduction of Figure 1 from Reference 2

Figure 2. Seat Fire/Toxicological Test Instrumentation (TC-10 Test Article)

Table 3. Summary of Halotron™ I Seat Cushion/Toxicity Tests

Test Run	Agent Amount Required to Extinguish Seat Fire, Lb.	Comments on Fire Extinguishment	Peak Neat Agent Concentration, %vol.	Peak HCl, ppm	Peak HF, ppm
1	2.1	Small fire at seat top - required 2nd short discharge to complete extinguishment	0.10 (occurring at station 80, 5 ft. 6 in. probe)	11 (occurring at station 330, 5 ft. 6 in. probe)	28 (occurring at station 80, 5 ft. 6 in. probe)
2	2.0	Fire readily extinguished	0.07 (occurring at station 80, 5 ft. 6 in. probe)	22 (occurring at station 80, 5 ft. 6 in. probe)	29 (occurring at station 80, 5 ft. 6 in. probe)
3	2.3	Fire readily extinguished	0.10 (occurring at station 330, 5 ft. 6 in. probe)	12 (occurring at station 80, 5 ft. 6 in. probe)	24 (occurring at station 80, 5 ft. 6 in. probe)

With the completion of the seat fire/toxicity test, and with the UL 5B:C rating, the final test was the hidden fire test. The hidden fire text fixture was initially at the FAA Technical Center in Atlantic City, where preliminary Halotron™ I testing with Amerex extinguishers was completed in 2000. The test fixture was later moved to the UL Fire Test facility in Northbrook, IL. There is an agreement between the FAA and UL that UL will conduct the hidden fire tests. UL will provide a listing for agents that have: (1) previously passed the seat fire/toxicity test, (2) passed the testing to obtain a 5B:C, (3) passed the hidden fire test, and (4) are contained in an extinguisher that can pass the other operational tests required by UL Standards such as 2129, *Halocarbon Clean Agent Fire Extinguishers*.

The hidden fire tests with Halotron™ I were conducted at UL in December 2001. In performing these tests, it became necessary to modify the pressure and agent weight of Amerex's standard 5.0 Lb. Halotron™ I extinguisher. To successfully pass the hidden fire test requires extinguishing a minimum average of 9 cups out of 20 (45% of fires) over a series of five tests. A summary of the tests performed using the standard Amerex 5.0 Lb. cylinder, valve, and Halotron™ I nozzle design is provided in Table 4.

Table 4. Amerex Handheld Extinguisher Hidden Fire Tests with Halotron™ I

Line Number	Agent Weight, Lb.	Pressure, psig	Mass Flow Rate, Lb./s	Percent of Fires Extinguished
Preliminary FAA Technical Center Testing, Atlantic City, 2000				
1	5.0	100	0.48	35
2	5.0	150	0.55	45
3	5.0	125	0.50	35
4	5.0	150	0.50	45
UL Northbrook Facility Testing, 2001				
5	5.0	150	0.54	45
6	5.0	150	0.56	35
7	5.0	125	0.52	40
8	5.5	150	0.56	50
9	5.5	150	0.56	45
10	5.5	150	0.56	50
11	5.5	150	0.56	45
12	5.5	150	0.56	50

NOTE: Grey shading on Lines 8 through 12 reflect the series of five tests for the final extinguisher configuration.

Tests 8 through 12 represent tests of the final configuration that will receive UL listing/FAA approval. Due to the changes in agent weight and pressure, the final configuration had to be re-tested on the 5B fire, which it passed. As was observed in the CAA report on the development of the hidden fire test fixture, there can be variations of the number of cups extinguished, even with the same configuration.

Figure 3 represents the hidden fire locations that were extinguished by Halotron™ I in Tests 8 through 12 in Table 4. In general, these locations follow the typical locations that are extinguished by halon 1211 based on Reference 5. One exception is that the fire at the top left in the fixture (fire closest to the upper vent), which could sometimes be extinguished by halon 1211, was never extinguished with Halotron™ I. The difference in extinguishment of the top left cup is believed to be a reflection of the difference in boiling point between Halotron™ I and halon 1211. Halotron™ I has a boiling point of 80 ^{o}F (27 ^{o}C), compared to halon 1211 at 26 ^{o}F (-3.4 ^{o}C). The fires extinguished by Halotron™ I in these tests were extinguished by the end of the discharge or within a couple seconds thereafter. During the tests, a considerable amount of Halotron™ I pooled at the bottom of the test fixture. While the evaporation of the pooled agent was strongly evident, the size of the vents did not allow for this accumulated liquid to be available to extinguish further fires.

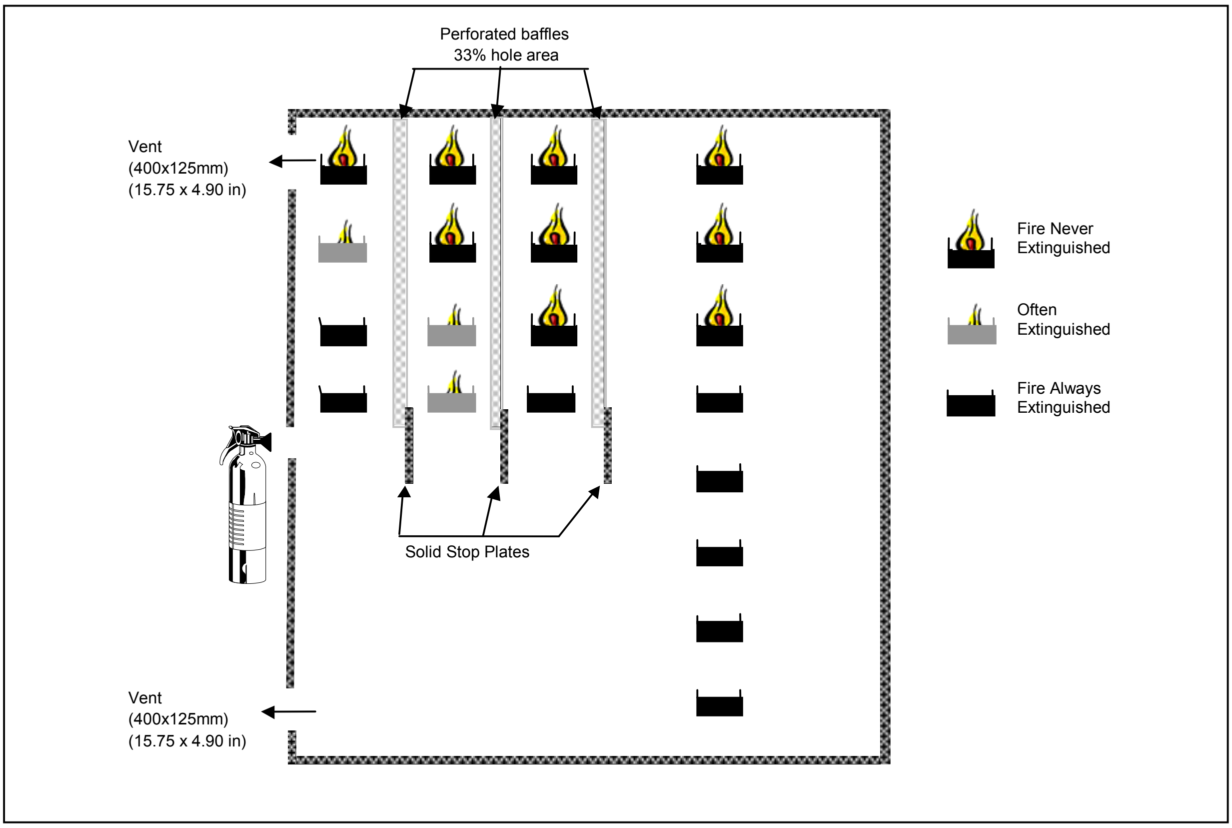


Figure 3. Fire Extinguishment Locations for Halotron™ I

4. CONCLUSION

The use of halon 1211 onboard aircraft was widely studied before its selection. Since the approval of halon 1211, its use has saved hundreds of lives onboard commercial aircraft. Some of the incidences in which halon 1211 successfully extinguished fires were fires hidden behind sidewalls or other hidden spaces. Because of the performance of halon 1211 in real fire situations, the FAA recognized early on that new agents must achieve the same level of performance. The approval process for agents replacing halon 1211 is more rigorous than that used for halon 1211.

A Halotron™ I handheld extinguisher has successfully completed all testing required by the FAA *Minimum Performance Standards for Handheld Fire Extinguishers as a Replacement for Halon 1211* *on Civilian Transport Aircraft*. The tests completed demonstrate 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. Final UL listing and FAA approval of the Amerex Halotron™ I handheld extinguisher discussed in this report represents the first extinguisher containing an environmentally acceptable agent to have fully satisfied the requirements to replace halon 1211 onboard commercial aircraft. Halotron™ I handheld extinguishers for use onboard commercial aircraft are anticipated as being commercially available in early Summer 2002. Halotron™ I handheld extinguishers are available from three other manufacturers in North America, and it is anticipated that there will be other UL/FAA approved extinguishers containing Halotron™ I in the near future.

5. ACKNOWLEDGEMENTS

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