THE USE OF A SIMULANT FOR CERTIFICATION TESTING OF A HALON 1301 SYSTEM FOR AIRCRAFT CARGO COMPARTMENTS

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Abstract

Federal Aviation Regulation (FAR) 25.855 requires certification tests of fire suppression systems to be installed onboard Class C aircraft cargo compartments. This regulation is to certify the operation of the system and to ensure adequate concentration of the extinguishing agent in the compartment during the certification tests. On March 1998, the FAR was modified to include the conversion of Class D cargo compartments into Class C versions. It is expected that the aviation industry will be discharging quantities of Bromotrifluoromethane (Halon 1301) into the atmosphere to comply with the certification tests of the converted cargo compartments since halon is the preferred agent. In favor of reducing the atmospheric ozone depletion caused by the use of halons, the International Halon Replacement Working Group formed a task group to identify an agent that could simulate halon during these and future certification tests.

This paper describes the testing and results of the evaluation of pentafluoroethane (HFC 125) and sulfur hexafluoride (SF_6) as Halon 1301 simulants for cargo compartment certification testing. Results indicate that based on similarities in concentration profiles, decay rates, and metering system agent concentration, SF_6 is the better of the two agents evaluated to mimic halon as a fire suppressant simulant in an aircraft cargo compartment.

INTRODUCTION

Purpose

The purpose of this document is to describe the testing and results of the evaluation of pentafluoroethane (HFC 125) and sulfur hexafluoride (SF_6) as simulants for Bromotrifluoromethane (Halon 1301), the agent of choice in aircraft total flooding fire extinguishing systems. The idea behind the use of a simulant is to reduce the amount of halon, an ozone-depleting agent, discharged in the atmosphere during the certification testing of aircraft Halon 1301 total-flooding fire suppression systems.

Background

On April 15, 1997, the International Halon Replacement Working Group (IHRWG) organized a new task group to evaluate candidate Halon 1301 simulants. The thrust behind the creation of this new task group was the fact that the Federal Aviation Administration (FAA) was planning to release Notice of Proposed Rule Making (NPRM) 97-10 to change existing regulations regarding aircraft cargo compartments. The NPRM upgraded the fire safety standards for cargo compartments in aircraft by eliminating the Class D cargo compartment configuration in existing and future aircraft fleets; i.e., large cargo compartments without active fire detection and suppression systems. By the year 2001, all aircraft operating under Federal Aviation Regulation (FAR) Parts 121 and 135 are required to have a fire protection system installed in their Class D cargo compartment (FAA, 1997), thus converting them to a Class C compartment. FAR 25.855 requires certification tests of fire suppression systems to ensure their proper operation and that adequate concentration of extinguishing agent is maintained. This means that each Class D cargo bay configuration and each unique fire protection system will have to be certified by the FAA. Halon 1301 continues to be the agent of choice in the aviation community. Even though the production of Halon 1301 ceased in the industrialized world in 1994, the U.S. Environmental Protection Agency has not yet restricted its usage in civil or military aviation operations (EPA, 1995). It is expected that large quantities of Halon 1301 will be discharged into the atmosphere during certification testing in order to meet the new requirement before the year 2001. The goal of the IHRWG task group is to minimize or eliminate the usage of the Halon 1301 ozone-depleting gas during the certification testing of aircraft cargo compartment fire protection systems.

Aircraft Cargo Compartment Fire Suppression System Certification

Currently there is no advisory circular to direct an acceptable means to conduct these certification tests to comply with FAR 25.855. Even though there is no written guidance, a common procedure, based on years of testing and experience, has been used by aircraft certification engineers to approve certificates. Briefly, the applicant needs to demonstrate to the FAA that the cargo fire extinguishing system works as designed by performing a combination of flight testing and analysis. The aircraft flight test conditions are at a steady-state cruise profile with a maximum cabin-to-ambient pressure differential. The cargo compartment is empty with the ventilation system set as indicated in the airplane flight manual for a fire situation. If the system is designed for Halon 1301, a 5% by volume minimum concentration is required for initial knockdown of the fire and a sustained concentration of 3% by volume is required for the duration of the flight, typically 60 minutes for normal non-Extended Twin-Engine Operations (ETOP) aircraft. The certification engineers examine the system interface such as the connection between the fire suppression system and the smoke detection system. They also review the flight crew interface and system feedback, such as crew cockpit view of the fire alarm and usability of the control panel. Other certification considerations include system redundancy, fire squib debris blockage, system freezing effects, and squib power source (Lam, 1998).

Identified Simulants

Published reports from the U.S. Navy and other entities identified two agents (SF_6 and HFC 125) that are excellent simulants for Halon 1301 fire protection systems used in shipboard machinery spaces (DiNenno et al., 1990) and aircraft engine nacelles (Grosshandler et al., 1995).

Sulfur hexafluoride (SF_6) is a stable, non-toxic, nonflammable, colorless, odorless, non-corrosive gaseous chemical and is not suspected of contributing to ozone depletion. This gas is used as a dielectric or insulating medium in electrical equipment due to its desirable electrical, physical, and thermal properties. The major industrial use of SF_6 is in the electric utility industry and in areas such as high-voltage circuit breakers, low-voltage switchgear, gas-insulated power stations and transmission lines, radar equipment, and Van de Graff and linear particle accelerators. It has also been used in non-electrical applications such as the blanketing of molten magnesium, leak detection, and dry processing in the semiconductor industry (Air Products, 1983). It has a relative vapor density of approximately 5.1, which is equal to that of Halon 1301. The drawback of this gaseous agent is that it has an atmospheric lifetime of 3,200 years with a 100-year, 500-year, and 1,000-year global warming potential (GWP) of 16100, 26110, and 32803, respectively (EPA, 1995). The U.S. Navy identified SF_6 as an excellent simulant for shipboard total-flooding Halon 1301 systems based on its physical properties, discharge rate, distribution through a piping network, leakage from a compartment (Carthart et al., 1989), air mixture (Carthart et al., 1991), and full-scale testing (DiNenno et al., 1990). In 1995, the EPA in its final Protection of Stratospheric Ozone ruling stated that "SF_6 is acceptable for use as a discharge test agent in military uses and civilian aircraft uses only."

HFC 125 is an acceptable total-flooding fire and explosion protection agent under the EPA’s Significant New Alternatives Policy (SNAP) Program, but due to its extinguishing design concentration, 14.2%, it is limited to unoccupied areas; it exceeds the EPA’s 7.5% No Adverse Observable Effect Limit. HFC 125 is used in applications such as military aircraft engine nacelles, dry bays, electronic and electrical cabinets, under floor spaces, turbine or engine compartments, as a Halon 1301 simulant for aircraft engine nacelle extinguishing systems, and as an explosion suppression agent in grain elevators (Dupont, 1995). Its relative vapor density is approximately 4.2. Grosshandler and Womeldorf (1995) concluded that HFC 125, filled in storage containers to 77% of the mass of Halon 1301, provides an excellent simulant for the nacelle's fire protection system. The Navy has promoted its usage in qualification testing on board the F/A-18E/F and V-22 (Department of Navy, 1998).

CARGO COMPARTMENT TESTS

The cargo compartment tests were to further evaluate SF_6 and to study HFC 125 in this type of scenario. The main objective of this evaluation program was to determine the decay characteristics of these simulants while exposing them to different air leakage rates and to compare the results with Halon 1301. SF_6 was further evaluated by running two series of tests utilizing a fire suppression metering system after the activation of the main total-flooding system. In this scenario, the comparison was based on the similarity of volumetric concentrations after activating the metering system.

Test Facilities

The evaluation tests were conducted in the Fire Safety Section facilities at the FAA William J. Hughes Technical Center; the test articles used in this study were two different size aircraft, a narrow-body aircraft and a wide-body aircraft. The narrow-body cargo compartment had a total cargo volume of approximately 625 cubic feet while the wide-body aircraft had a cargo volume of 2000 cubic feet. Both compartments had a ventilation system to control the leakage rate.

For economic reasons, the narrow-body compartment was divided into two sections; the section selected for this study had a volume of 300 cubic feet. This small cargo bay was equipped with a leak system, a modular total-flooding fire suppression system, an open-loop fire suppression metering system, pressure valves, blowout panels, gas sampling probes, and measuring instruments (Refer to figure 1). A variable-speed fan and a perforated duct controlled the leakage rate of the cargo compartment. The leak system was capable of providing a maximum flow of 21 CFM. The leakage rate of the cargo bay was set and measured using a digital anemometer (Omega Model HH-30). The L-shaped perforated duct had a height of 28", a width of 39", and a 3" diameter orifice. This duct had a total of thirteen 1/2" diameter holes. The holes on the horizontal leg were spaced 5" apart from each other while the holes on the vertical leg of the duct were spaced 2.5" apart. A Powerstat Variable Autotransformer (PVA) controlled the fan rotational speed. It was planned that three fan flow settings were going to be used during the testing program: 2 CFM, 11 CFM, and 21 CFM. The leakage rate of 2 CFM was obtained by opening two holes, one on each end of the duct legs; the remaining holes remained closed. The PVA was set to 40%. The 11- and 21-CFM leakage rates were obtained by opening all of the holes and removing the duct cap found at the top of the vertical leg. The only difference between their settings was how the PVA was dialed: 60% for the 11-CFM leakage rate and 100% for the 21-CFM leakage rate.

The small compartment's fire suppression system consisted of two modular systems: a total-flooding system and a metering system. The total-flooding system consisted of a Fenwal fire bottle connected to a 7/8" manifold with a single nozzle at the end. The manifold was approximately 10' long. The fire bottle was activated using an electronic control head. The open-loop metering system comprised of a pressure-regulated cylinder, regulated to 40 psig, connected to a 0.25" copper tube that had a single nozzle with a 0.35" orifice at the other end; the metering system setting and size were arbitrarily selected. This system was activated manually.

There were two types of gas analyzers used in this test program: the Heat Technology Laboratory (HTL) Halonyzer and the Rosemount 880A analyzer. The Halonyzer, calibrated to detect the volumetric concentrations of HFC 125 and Halon 1301, offered a gas collection capability of 12 probes. This system was used in the small compartment and with HFC 125 and Halon 1301 only due to its temporary availability. Five Rosemount 880A analyzers, calibrated for HFC 125, Halon 1301, and SF_6, were available for both compartments; only one of the five analyzers was calibrated for SF_6. This equipment provided a gas collection capability of four probes that could be used for Halon 1301 or HFC 125 and one probe for SF_6. Even though there were five analyzers on hand, only one was used at a time during some of the testing in order to maintain the same flow conditions and gas dynamics when testing SF_6. When the Halonyzer was used at the beginning of this study, all 12 probes were used and where located in two different trees. Each tree had six levels spaced 7.5" apart vertically starting from the floor. The sampling probes, 0.25" copper pipes and equal in length, were designed to convey samples at a uniform flow rate from the sampling area to the analyzer units.

During the wide-body aircraft test series the entire 2000 ft^3 compartment was used. The ventilation system of this aircraft provided a leakage rate of 50 CFM. This bay was equipped with four main gas collection probes and eight backup probes. The fire suppression system consisted of an unbalanced banked system with five nozzles. A closed-loop fire suppression metering system was present but was not used during these tests.

Procedure

Discharge tests were conducted for all of the identified candidates as well as the baseline agent using the following procedures.

The installed fire bottle was charged with the desired agent to a weight that produced a 5% volumetric concentration in the cargo compartment; there is one exception to this initial concentration in the case of HFC 125. During the first series of testing with HFC 125 in the small compartment, the fire bottle was filled based on the equal liquid fill approach rather than the equal volumetric concentration approach; this resulted in an initial volumetric concentration of 4.7%. This liquid fill approach maximizes agent density at the point of discharge, provides a consistent energy source during discharge, conserves the amount of gaseous nitrogen, and results in equivalent nozzle discharge pressure (Grosshandler et al., 1995). This approach was later changed during the large compartment testing to produce an initial volumetric concentration of 5%. The amount of Halon 1301 and SF_6 used to achieve 5% in the small compartment was 5.8 pounds and 5.7 pounds, respectively. In the case of HFC 125, 4.4 pounds were transferred into the fire bottle to achieve 4.7% volumetric concentration in this compartment. The amount of agent for the large compartment testing was 38.5 pounds of Halon 1301, 31.0 pounds of HFC 125, and 37.7 pounds of SF_6. After charging the bottle with the agent, the bottle was pressurized with nitrogen gas to 375 pounds per square inch absolute.

After charging and plumbing the bottle, the leak fan was set to the appropriate leak rate. Once this was set, and the analyzer(s) was (were) ready, the fire bottle was discharged simultaneously with the activation of the data acquisition system. The data acquisition then collected the compartment's concentration history, temperature, ambient humidity, and leak rate.

During the tests that were designed to use the fire suppression metering system, the system was activated when the volumetric concentration dropped below 3%. Tests without the metering system ran for 30 minutes, and the tests with the metering system ran for 45 minutes.

RESULTS

A total of 57 tests were conducted during the evaluation of HFC 125 and SF_6 as Halon 1301 simulants. Figures 2, 3, and 4 illustrate the gaseous agents' concentration histories at different leakage rates and compartment sizes. The decay rates and the maximum concentration relative differences were calculated for these curves. Table 1 shows the overall test results which include the average data scatter bandwidths, decay rates, relative differences in rates, and relative difference in concentration histories (normalized by the peak concentration).

Figures 2, 3, and 4 provide a qualitative comparison between the evaluated agents. For the first five minutes, these charts show that HFC 125 mimics very well the concentrations of Halon 1301, but after this period, the difference between these two agents increased significantly. These results provide additional evidence that HFC 125 is an excellent simulant for engine nacelle fire suppression systems certification testing which is of very short duration (0.5 second). As shown in figure 2, HFC 125 achieved concentrations that resulted in differences that were on the unsafe side (i.e., indicative of a higher halon concentration) when compared to the baseline agent; this difference increased with time and as the leak rate of the compartment decreased. One of the reasons for such a difference is the lower specific vapor density, 4.2, when compared to halon, 5.1. For these reasons HFC 125 was not evaluated in the metering system. SF_6 did not match halon's initial concentration as well as HFC 125 during the total flood discharge, but as time passed, the concentration difference was much better than that of HFC 125. According to Grosshandler *et al.* (1995), sulfur hexafluoride reached significantly higher pressures in the pipeline and vaporizes too quickly from the observable spray plumes. On a positive note, the difference that exists between the concentrations of SF_6 and Halon 1301 are on the safe side. This conservative difference indicates that the simulant concentration in the compartment may be lower than what the halon concentration would be during the certification tests, providing a margin of safety.

Table 1, specifically under the average data scatter bandwidth column, shows that the Halon 1301 decaying concentration scatter, from all of the tests conducted, is between 2% and 4% while HFC 125 and SF_6 are between 3% to 4%, and 2% to 9%, respectively. The fifth column of table 1, decay rate, shows that sulfur hexafluoride decay rates are similar to those of halon. With the exception of the decay rate calculated at 2 CFM, SF_6 had the lowest maximum relative difference when compared to the decay rate values obtained with HFC 125. SF_6 decay history at 2-CFM leak rate did not follow a typical exponential decay causing a higher difference. The maximum decay rate differences between SF_6 and Halon 1301 at different leak rates were 11.60% at a leak rate of 11 CFM, 1.60% at 21 CFM (with the gas probe at 22.5" from the floor), 0.40% at 21 CFM (with the gas probe at 45" from the floor), and 1.74% at 50 CFM. The maximum decay rate differences for HFC 125 were 41.50% at a leak rate of 2 CFM, 15.60% at 11 CFM, 12.00% at 21 CFM (with probe 22.5" from the floor), and 26.60% at 50 CFM. These decay rates were calculated using the Microsoft Excel exponential smoothing analysis tool. In the seventh column of this table, the maximum normalized concentration relative differences between the identified simulants and halon are presented. The period selected to calculate these differences was between the time at peak concentration and the time prior to the activation of the metering system or the time when the volumetric concentration reached 3%. Once again, SF_6 had the smallest difference between its concentration and that of Halon 1301. In this case, the resulting concentration maximum differences were 3.70% at a leak rate of 2 CFM, 2.14% at 11 CFM, 5.84% at 21 CFM (Probe at 22.5"), 9.02% at 21 CFM (Probe at 45"), and 20.23% at 50 CFM. The maximum values for HFC 125 were 14.96% at 2 CFM, 10.14% at 11 CFM, 16.56% at 21 CFM, and 19.52% at 50 CFM. The majority of these maximum values were found at the end of the normalized concentration history curves. When considering the test data scatter, some of these relative difference values would be negligible.

Figure 5 illustrates the concentration history of SF_6 and Halon 1301 after the metering system was activated. As mentioned, the discharge flow and pressure were arbitrarily selected; the main purpose of this setup was to compare the concentrations of the agents rather than to optimize the system. The system used had a 0.035" diameter nozzle and a discharge pressure of 40 psig. Qualitatively, the graph shows that SF_6 mimics very well the injected concentration levels of Halon 1301 using this specific metering system. Table 1 displays the maximum average concentration relative differences between these two agents at two distinct leak rates; they are 8.18% at 11 CFM and 7.38% at 21 CFM. These differences fall within the data scatter.

CONCLUSION

These tests, in conjunction with the Navy's evaluation tests, have shown that SF_6, based on equal initial volumetric concentrations is the best of the two identified Halon 1301 simulants when used in certification testing of the aircraft cargo compartment fire suppression system. Results showed that SF_6 and Halon 1301 had similar decay rates and volumetric concentrations when submitted to various leak rates, cargo sizes, and metering. HFC 125 does not mimic halon very well in sustained total flood applications; after five minutes, its volumetric concentration tends to decay at a lower rate due to its lower specific vapor density. SF_6 is an excellent simulant when considering aircraft cargo leakage rate, stratification, and the integration of a suppression system with a metering system.

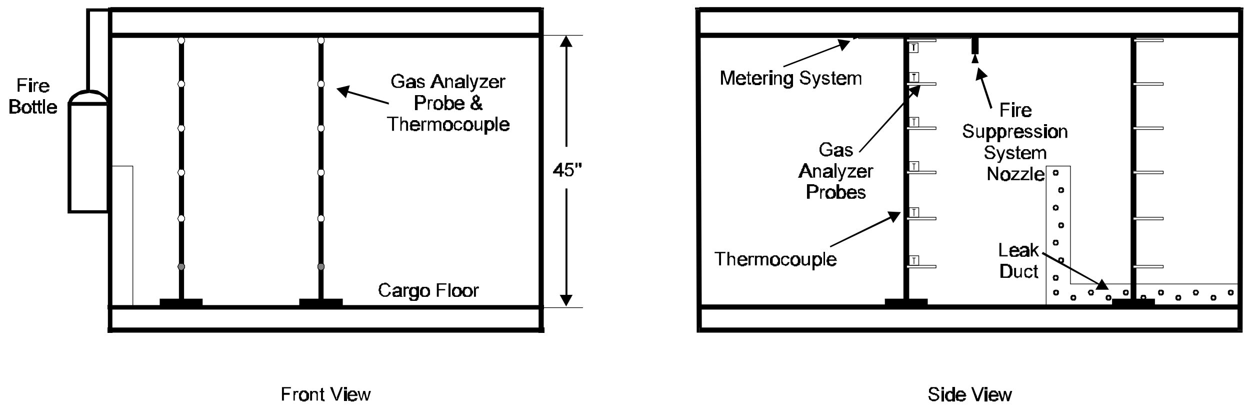

FIGURE 1. NARROW-BODY CARGO COMPARTMENT SETUP

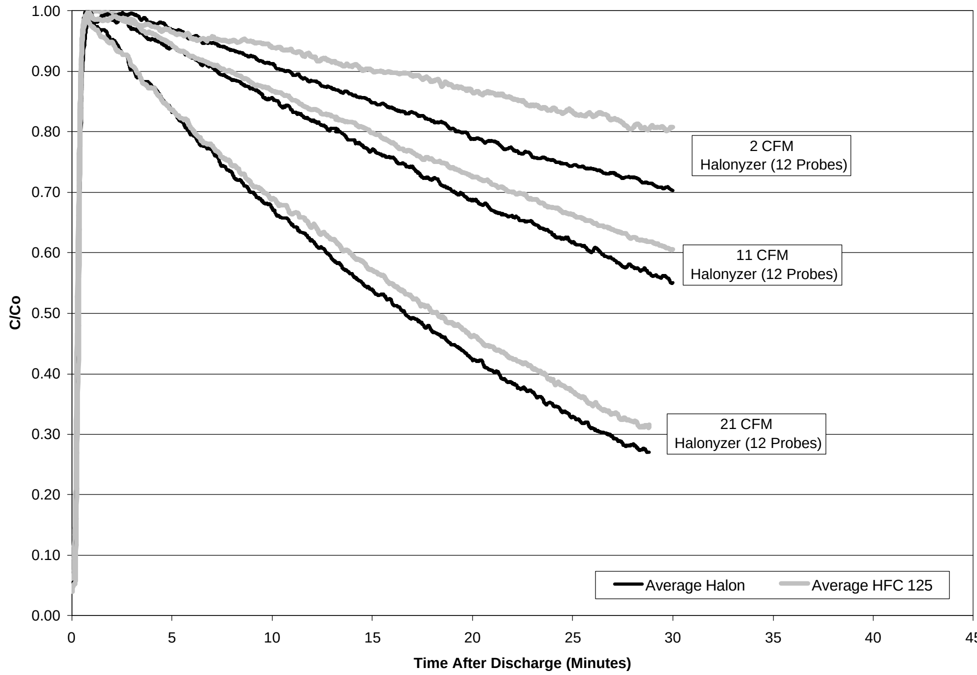

FIGURE 2. HALON 1301 VS HFC 125 CONCENTRATION HISTORIES AT VARIOUS LEAK RATES

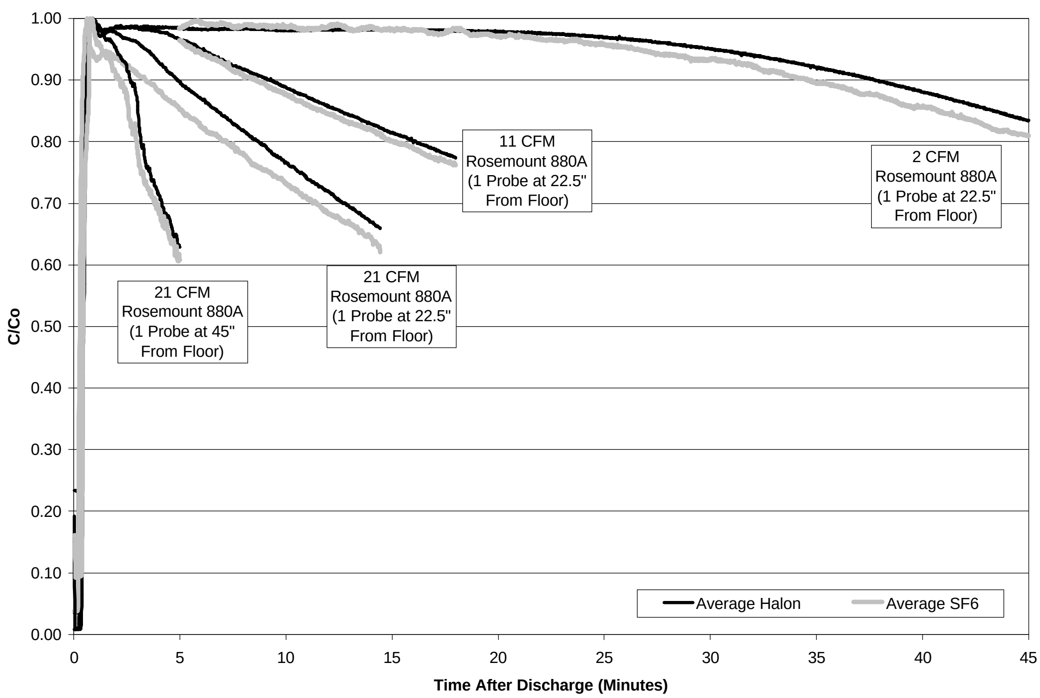

FIGURE 3. HALON 1301 VS SF_6 CONCENTRATION HISTORIES AT VARIOUS LEAK RATES

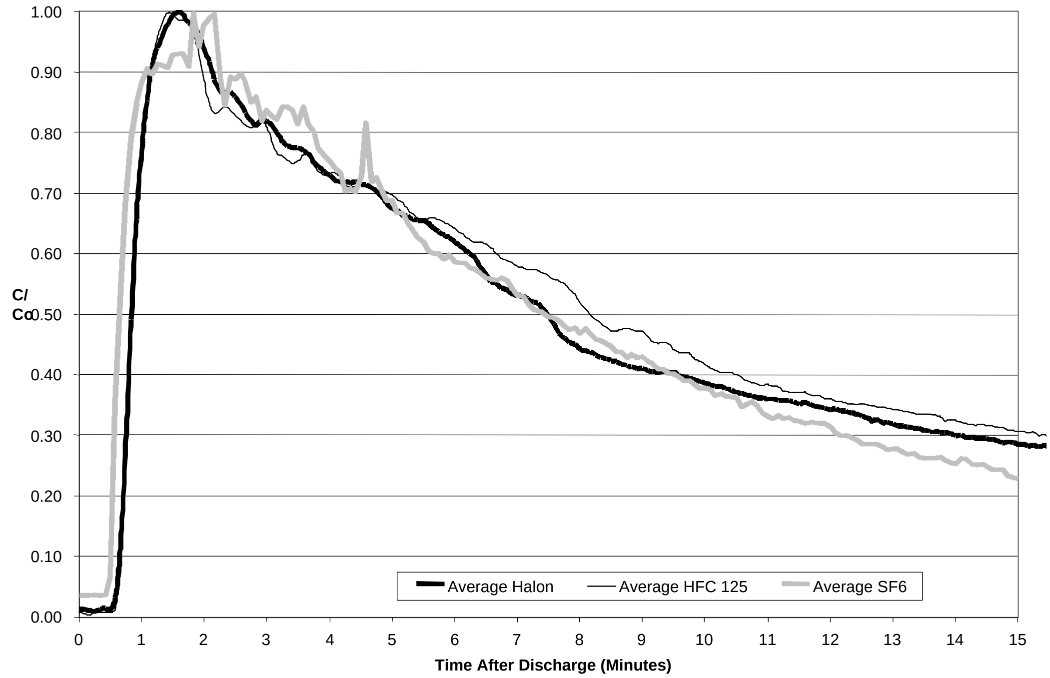

FIGURE 4. AGENT CONCENTRATION HISTORIES AT 50-CFM LEAK RATE

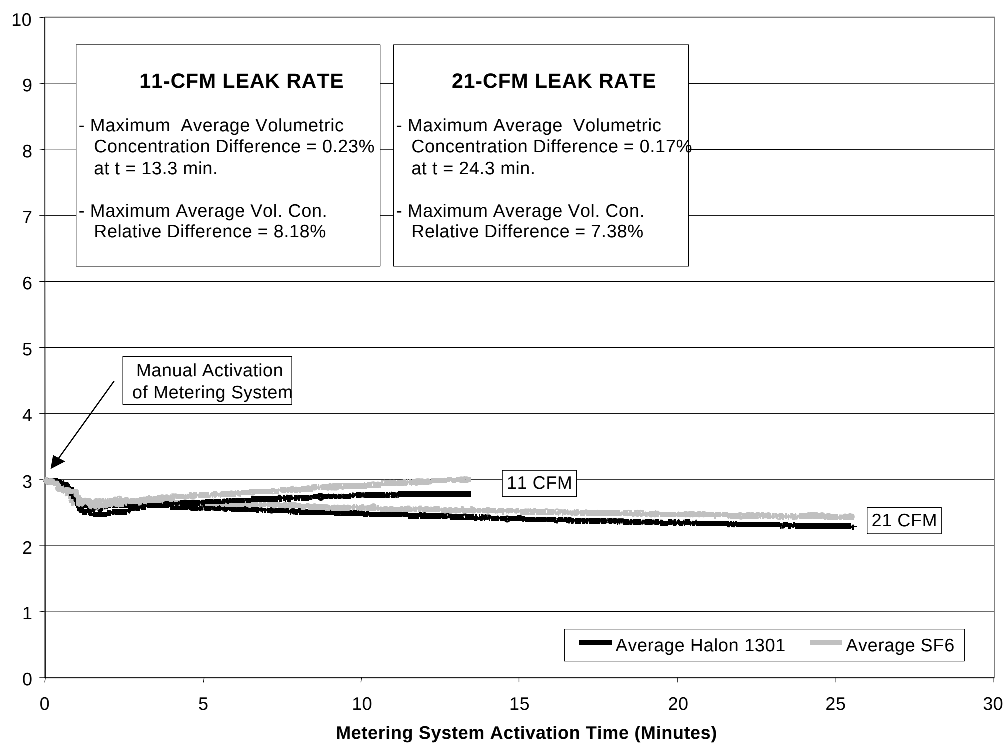

FIGURE 5. AGENT CONCENTRATION HISTORY WITH METERING SYSTEM ACTIVATED

TABLE 1. TESTS RESULTS

Agent	**Leak Rate (CFM)**	**Number of Active Probes**	**[a] Average Data Scatter Bandwidth**	**Decay Rate (1/min)**	**[b] Decay Rate **Relative Difference (%)**	**Max. Conc. [c] Relative Difference (%)**	**[c] Rel. Diff. (%) at 0.60 (3%) Concentration**
Halon 1301	2 [d] (150 min)	12	0.02	-0.0130, R^2 = 0.99	-	-	-
HFC 125	2 [d] (150 min)	12	-	-0.0080, R^2 = 0.99	41.50%	14.96% at t = 29.99 min	(14.96% at t = 29.99 min.)
Halon 1301	11 [d] (27.3 min)	12	-	-0.0211, R^2 = 0.99	-	-	-
HFC 125	11 [d] (27.3 min)	12	0.04	-0.0178, R^2 = 0.99	15.60%	10.14% at t = 29.97 min.	7.37% at t = 26.39 min.
Halon 1301	21 [d] (14.3 min)	12	0.03	-0.0435, R^2 = 0.99	-	-	-
HFC 125	21 [d] (14.3 min)	12	0.03	-0.0383, R^2 = 0.99	12.00%	16.56% at t = 28.74 min.	4.52% at t = 12.90 min.
Halon 1301	2 [d] (150 min)	1	0.02	-0.0004, R^2 = 0.75	-	-	
SF_6	2 [d] (150 min)	1	0.08	-0.0010, R^2 = 0.74	150.00%	3.70% at t = 43.60 min.	(2.99% at t = 45 min.)
Halon 1301	11 [d] (27.3 min)	1	0.02	-0.0155, R^2 = 0.99	-	-	-
Metered Halon 1301	11 [d] (27.3 min)	1	0.17	-	-	-	-
SF_6	11 [d] (27.3 min)	1	0.08	-0.0173, R^2 = 0.99	11.60%	2.14% at t = 17.18 min.	(1.37% at t = 45 min.)
Metered SF_6	11 [d] (27.3 min)	1	0.34	-	-	8.18% at t = 13.30 min.	-
Halon 1301	21 [d] (14.3 min)	1 (at 22.5")	0.02	-0.0318, R^2 = 0.99	-	-	-
Metered Halon 1301	21 [d] (14.3 min)	1 (at 22.5")	0.05	-	-	-	-
SF_6	21 [d] (14.3 min)	1 (at 22.5")	0.02	-0.0313, R^2 = 0.99	1.60%	5.84% at t = 14.45 min.	(5.84% at t = 14.45 min.)
Metered SF_6	21 [d] (14.3 min)	1 (at 22.5")	0.14	-	-	7.38% at t = 13.30 min.	-
Halon 1301	21 [d] (14.3 min)	1 (at 45")	0.04	-0.1278, R2 = 0.96	-	-	-
SF6	21 [d] (14.3 min)	1 (at 45")	0.09	-0.1273, R2 = 0.98	0.40%	9.02% at t = 2.98 min.	3.18% at t = 5.00 min.
Halon 1301	50 [d] (40.0 min)	4	0.02	-0.1109, R2 = 0.98	-	-	-
HFC 125	50 [d] (40.0 min)	4	0.01	-0.0814, R2 = 0.94	26.60%	19.52% at t = 7.83 min.	3.69% at t = 6.25 min.
SF6	50 [d] (40.0 min)	4	-	-0.1128, R2 = 0.98	1.74%	20.23% at t = 15.00 min.	3.69% at t = 6.25 min.

[a] Computations made using normalized concentration data
[b] Relative difference with Halon 1301
[c] Difference within parenthesis means that the agent concentration did not reach 0.60
[d] Time for an air change in the compartment

REFERENCES

Air Products, 1983, "Sulfur Hexafluoride and Its Uses," *SF_6, An Applications and Technical Manual*, p. 1.

Carhart, H.W., Leonard, J., DiNenno, P., Starchville, M., Forssell, E., and Wong, J., 1989, "Tests of Halon 1301 Test Gas Simulants," NRL Memorandum Report 6424, Washington , DC, p. 38.

Carhart, H.W., Leonard, J., DiNenno, P., Starchville, M., and Forssell, E., 1991, "Discharge System Tests of Halon 1301 Test Gas Simulants," NRL Memorandum Report 6898, Washington , DC, p. 92.

Department of Navy, 1998, "The Navy Defends Our Ozone Layer," http://home.navisoft.com/navyozone/navdef.htm, p. 1.

DiNenno, P., Forssell, E., Back III, G., Ouellette, R., Fulper, C., and Carhart,H.W., 1990, "Shipboard Tests of Halon 1301 Test Gas Simulants," NRL Memorandum Report 6708, Washington , DC, p. 37.

Dupont, 1995, "FE-25 Fire Extinguishing Agent," *Dupont Alternative Fire Extinguishants Technical Information*, Delaware, pp.1-2.

Environmental Protection Agency, 1995, "Protection of Stratospheric Ozone - Final Rule," 40 CFR Parts 9 & 82, Washington, DC.

Federal Aviation Administration, 1997, "Revised Standards for Cargo or Baggage Compartments in Transport Category Airplanes," Docket No. 28937, Notice of Proposed Rulemaking No. 97-10, p.1

Grosshandler, W.L. and Womeldorf, C.A., 1995, "Selection of A CF_3Br Simulant for Use In Engine Nacelle Certification Tests, Fire Suppression System Performance of Alternative Agents in Aircraft Engine and Dry Bay Laboratory Simulations," NIST Report No. SP 890, p. 605.

Lam, A., 1998, "Fire Suppression System Certification Protocol," E-mail message, pp.1-2