COMPARISON OF THE FIRE SUPPRESSION PERFORMANCE OF HALON REPLACEMENT AGENTS

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ABSTRACT

HFC-227ea and HCFC Blend A were evaluated using full-scale fire tests to obtain information on their fire suppression performance, drop-in capability, thermal decomposition products and physical behaviour of the agent such as its flow characteristics in the piping system. Also, full-scale tests were conducted with Halon 1301 to provide a basis for comparison.

Halon 1301, at concentrations of 5% to 7.5%, showed effective total-flooding fire-extinguishing performance for all test scenarios. HFC-227ea, at a design concentration of 7.6% or higher, and HCFC Blend A, at a design concentration of 12%, extinguished all fires in the test facility, however, these agents produced higher concentrations of acid gases than Halon 1301. The quantity of the acid gases generated during fire suppression was dependent on agent concentration, agent discharge time, fire type and size as well as extinguishment time.

INTRODUCTION

Halon 1301 is an excellent fire suppressant, however, it contributes significantly to stratospheric ozone depletion, and it has been phased out of production according to the Montreal Protocol (1987, London Amendments 1990, Copenhagen Amendments 1992).

To meet the fire suppression needs of the Department of National Defence Canada (DND) in the post-halon era, the National Research Council of Canada (NRC) and DND jointly set up a research program to address major questions concerning the fire suppression performance of currently-available halon replacements and alternatives.

DND's initial concern was with the potential replacement agents for use on their Halifax-class frigates. Based on an extensive review [1] of Significant New Alternatives Policy (SNAP) agents listed by the U.S. Environmental Protection Agency (EPA) as suitable for occupied spaces, HFC-227ea and HCFC Blend A were identified as having the most potential for replacing Halon 1301 on the frigates. This was based on their physical characteristics as well as their weight and volume requirements. These two agents were selected for further evaluation by full-scale testing to obtain information on their fire suppression performance, drop-in capability for the piping system on the frigates, thermal decomposition products and physical behaviour of the agent, such as its flow characteristics in the piping system. Full-scale tests were conducted in the same system with Halon 1301 to provide a basis for comparison. This paper describes the full-scale testing, and provides the test results as well as a comparison of the performance of HFC-227ea and HCFC Blend A with Halon 1301.

TEST SET-UP AND EXPERIMENTATION

Test Room

The full-scale testing of the halon replacement agents was performed in a 121 m^3 compartment constructed to simulate Radar Room No. 2 on the DND Halifax class frigates. The test room was an irregular-shaped, rectangular room with dimensions 9.7 m by 4.9 m and 2.9 m high, with a corner (2.9 m by 2.2 m) removed. A plan view of the room is shown in Figure 1.

The test room had a 2 m by 0.9 m door in the north wall. The room also had a 0.5 m by 0.5 m pressure relief vent in the south wall near the floor. The pressure relief vent was purposely located near the floor, rather than at the ceiling, to better simulate fire conditions in a compartment during the pre-burn and the agent discharge portions of the tests.

Piping System

Two different piping systems were used in the full-scale testing. In the first series of tests (Series A1), the existing Halon 1301 piping system used in Radar Room No. 2 on the Halifax Class frigates was used (see Figure 1). This piping system was designed to deliver a 7.5% halon concentration to the compartment. The fire suppression performance of the replacement agents discharged through this piping system was evaluated to determine the potential drop-in capability of the agents. For comparison, tests were also conducted with Halon 1301 using this piping system.

In the second series of tests (Series A2), tests were conducted using an optimal piping system designed for each of the two replacement agents (HFC-227ea and HCFC Blend A). These tests provided information on the possible use of the two agents to protect spaces in which new piping systems can be installed.

Instrumentation

The instrumentation consisted of thermocouple trees, pressure gauges and a sound meter in the test room to monitor the room temperature and pressure changes during the tests. Thermocouples were placed at each fire location to monitor the flame and to determine extinguishment times. The locations of the instrumentation are shown in Figure 1. In addition, fire gases and thermal decomposition products (TDP) of the agent in the test room were sampled through heated sampling lines and analyzed using a Fourier Transform Infrared Spectrometer (FTIR).

Seven pressure transducers and thermocouples were installed at strategic locations in the piping system to monitor the liquid/gas phase of the agents and their friction losses in the pipe. The mass loss rate of the agent in the cylinder was measured using a weigh scale and timer.

Fourier Transform Infrared Spectroscopy was used to measure the concentrations of the agents and their thermal decomposition products in the room during tests. Heated sampling lines were used for these measurements to reduce the condensation of sample gases in the sampling tube, which would result in lower concentrations. Three quartz sampling ports were placed at the same locations as the thermocouple trees (Figure 1). The sampling ports were placed at three different heights (0.8 m, 1.4 m and 2.8 m above the floor), to measure agent concentrations at different levels.

CO, CO_2 and O_2 concentrations in the test room were also measured during the tests using the FTIR and CO_2/CO and O_2 analyzers.

Fire Scenarios

Five test fires were used to evaluate the fire suppression performance of the agent: tell-tale fires (TT), small square-pan fires (SP), a large round-pan fire (RP), a small heptane fire inside a cabinet and a wood crib fire. Heptane was used as the fuel for the TT, SP and RP fires, and at least 30 s of pre-burn was allowed for all fires.

TTs were 75 mm diameter cans containing 20 mL of heptane fuel on a water base. The total heat output from the 7 TTs used in the tests was estimated to be 50 kW.

A 0.3 m by 0.3 m pan (0.093 m^2) was used for the SP fires. Each contained 425 mL of heptane fuel on a water base, and the three SPs used in the tests produced approximately 50 kW heat release rate.

A 0.7 m diameter round pan with an area of 0.385 m^2 was used for the RP fire. The pan contained 2 L of heptane fuel on a water base, and produced an approximately 400 kW heat release rate. The use of a large fire was essential in determining the fire suppression capability of the agents and the production rate of decomposition products.

TT fires, placed in the middle of a mock-up cabinet, were used to evaluate the ability of the agents to suppress fires inside electronic cabinets. The mock-up cabinets were made of polycarbonate plastic sheets. The three cabinets were the same size, measuring 0.81 m by 0.81 m and 1 m high. The mock-up cabinets had two small grill openings in each side wall. Two cabinets had a ventilation opening ratio of 5% (ratio of ventilation opening area over total surface area of the cabinet, excluding the bottom), and the third had a ventilation opening ratio of 2%.

The wood crib fire was used to determine the ability of the agents to extinguish Class A fires. The wood crib was made of 40 mm by 40 mm pine sticks in 6 layers, measuring approximately 0.6 m by 0.6 m and 0.24 m high.

In the full-scale testing of Halon 1301, HFC-227ea and HCFC Blend A, four different fire scenarios were typically used. The four scenarios were as follows:

Scenario-1. Seven TTs with 50 kW total heat output were placed strategically throughout the room. Two SPs were placed near the floor at the southeast corner and the northwest corner. Another SP was placed about midway up the wall in the southwest corner.

Scenario-2. Seven TTs were placed strategically throughout the room. Two SPs were placed near the floor in the northeast corner and the northwest corner. Another SP was placed about midway up the wall at the southwest corner. A large round pan (RP) was placed on the floor at the southeast corner of the room.

Scenario-3. This scenario was set-up to evaluate the ability of the agents to penetrate into cabinets and suppress fires. Two mock-up cabinets, each with 5% ventilation opening, were placed approximately 1 m from the southeast corner, one on top of the other. Another mock-up cabinet, with a 2% ventilation opening, was located near the north wall. Tell-tale fires were placed in the centre of each mock-up cabinet. A metal cabinet containing a short cable bundle and a TT was placed against the east wall, near the door. A wood crib was also placed at the southwest corner.

Scenario-4. This fire scenario was similar to Scenario-3, except that a shielded 0.7 m diameter heptane pool fire was used instead of the wood crib fire. The circular pan was placed near the southeast corner and was covered with a box made of perforated sheet steel to shield the fire from direct spray of the agent. The sheet metal mesh used for the sides of the box had an opening ratio of 33%, and the top of the box was covered with a layer of sheet metal with holes which constituted a 6% opening ratio.

The shielded fires were used to determine whether the agent acted as a total flooding agent and did not rely on dynamic mixing with the fire in the manner of a streaming agent. If the agent's ability to extinguish a fire depends on the dynamic mixing of the agent with the flame, its performance will be affected by any obstruction in the space.

TEST RESULTS AND DISCUSSION

This study evaluated the fire suppression performance of Halon 1301 and its replacement agents (HFC-227ea and HCFC Blend A), as well as the hazards from their thermal decomposition products.

Fire Suppression

HCFC Blend A failed to extinguish several fires in the test room at concentrations less than 10%. It extinguished some fires when there was sufficient mixing of the agent with the fire, however, it failed to extinguish heptane pan fires located at floor level in the corners (50 mm away from the walls), due to a "floor-corner effect" which prevented mixing of the agent with the fire. Factors that governed effective mixing included the proximity of the nozzle to the fire, the shape of the discharge cone from the nozzle, and the local shielding conditions near the fires.

The fire test results suggest that, at concentrations below 10%, HCFC Blend A does not act as a total flooding agent but, rather, relies on dynamic mixing with the fire in the manner of a streaming agent. As such, its performance will be affected by any obstruction in the space.

Halon 1301, HFC-227ea at 7.6% and HCFC Blend A at 12% extinguished all test fires, regardless of their position in the room or the degree of shielding. Extinguishment times were less than 30 s in all cases. All heptane pool fires, including the shielded round pan, were extinguished within 15 s. Small fires inside cabinets took longer to extinguish, because it took some time for the agent to penetrate into the cabinets to react with the flames.

Re-ignition was attempted at 5 min, and at 9 min after the door was opened for 30 s. In most cases, there was a small flame at the hot re-ignition element, but the flame did not spread onto the fuel surface. The flame at the ignition element self-extinguished, once the ignition element was de-energized. It was assumed that there was no re-ignition since there were no lasting flames.

For all tests with Halon 1301 and HFC-227ea and for tests with HCFC Blend A at concentrations of 12% or higher, there was no evidence of a "floor-corner effect" indicating they acted as total flooding agents. The heptane tell-tale fires, shielded inside the simulated computer consoles with limited ventilation grilles, were extinguished within 30 s after the discharge was initiated. There was no provision for any turbulent mixing of agent with the small flames inside the cabinet. Further evidence of the total-flooding mode of extinguishment was provided by the fact that the tell-tale fires could not be re-ignited, after the initial extinguishment.

Room Pressure and Temperatures

When HFC-227ea and HCFC Blend A were discharged into the room, there was a rapid increase in pressure. The highest pressures were 400 Pa for the tests with HFC-227ea and HCFC Blend A with a 200 kW fire size. This is larger than the pressures measured with Halon 1301 (175 Pa).

The pressures and temperatures measured in the pipe while the agents were discharging were similar for all the agents tested. However, the temperatures at the nozzle outlets were different for tests with Halon 1301, HFC-227ea and HCFC Blend A. As shown in Figure 2, HFC-227ea and HCFC Blend A produced a substantial temperature drop (to as low as -60°C) near the nozzle. As the liquid agent evaporated into vapour, it substantially cooled the surrounding area due to its latent heat. Figure 2 clearly shows that most of the HFC-227ea and HCFC Blend A remained liquid in the pipe until it reached the nozzles, then flashed from liquid to vapour as it discharged through the nozzles. This substantial cooling from the evaporation of the agent could assist in the extinguishment of the fires by the agents. For Halon 1301, there was little enthalpy cooling at the nozzle. Fire extinguishment was achieved primarily by the chemical reaction of the agent with the fire.

CO/CO_2 Concentrations

The production of carbon dioxide (CO_2) and carbon monoxide (CO) was monitored using both the FTIR spectrometer and a CO_2/CO analyzer. In all tests, significant quantities of CO and CO_2 were produced. Figure 3 shows the CO concentrations in the room for the three agents for tests with a 600 kW fire. The maximum CO and CO_2 concentrations in the room varied with the fire scenarios and the agent tested. Typically in all tests, there was an increase in CO and CO_2 concentrations during the initial burning of the fuel in the pre-burn period. With the replacement agents, there was a sharp rise in CO and CO_2 levels shortly after the agent discharge, indicating that a substantial amount of CO and CO_2 was produced during fire extinguishment by the agents. This was most likely due to the thermal decomposition of the agents. There was also a substantial reduction in the O_2 level after the agent discharge, indicating that O_2 participates in the reaction of the agent with the flames during fire extinguishment.

Optimal Piping System

The test results show that there was no clear improvement in the fire suppression performance with the use of an optimal piping system compared to the halon piping used on the DND frigates. However, the quantity of thermal decomposition products was lower in tests with the optimal piping system. The Halon 1301 piping system used in this study was designed for 7.5% concentration instead of the typical 5% concentration. Therefore, the pipe for the halon system had a larger diameter than the optimal piping systems designed for HFC-227ea and HCFC Blend A with 7.6% and 12% target concentrations, respectively. The test results showed that the agent flow characteristics in both piping systems were similar with only a small difference in the pressure drops in the discharge pipes.

Thermal Decomposition Products

During fire suppression, halon replacement agents break down into fragments in the presence of flame and heat. These fragments react with the free radicals in the flame (such as H, OH and O), resulting in fire extinguishment. Fire suppression with the agents in these tests produced several by-products including HF, HCl and COF_2.

For tests at 12% concentration, HCFC Blend A produced average concentrations of 1,500 to 10,000 ppm HF and 1,500 to 5,000 ppm HCl in the room. The HF concentration produced by HFC-227ea was in the range of 700 to 6,300 ppm. These values for HFC-227ea are somewhat higher than the values obtained by others [2,3] for the same fire size per unit volume. However, the amount of TDP production depends not only on the fire size but also on the fire conditions and the air tightness of the test room. Halon produced HF in the range of 160 to 500 ppm, and HBr in the range of 150 to 400 ppm.

Figure 4 compares the HF levels produced by the three agents in tests with a 200 kW fire size (Fire Scenario 1). Halon produced the least amount of HF. Both HCFC Blend A and HFC-227ea produced more than double the amount of TDPs than produced with halon. The present study clearly shows that the amount of acid gases generated during fire suppression depends on agent type, agent concentration, agent discharge time, fire type and size as well as extinguishment times.

The test results showed that increasing the target concentration of HFC-227ea from 7.6% to 8.8% produced no clear improvement in the fire suppression performance of the agent using the same piping system. However, the production of thermal decomposition products was substantially reduced with increased agent concentration.

The HF and HCl concentrations produced in these test fires are dangerous even for brief exposures. Both are highly corrosive irritants to the eyes, skin and mucous membranes. The effects of individual irritants or irritant mixtures on escape behaviour, the degree of incapacitation and lung damage in humans are difficult to quantify. However, the SFPE Handbook [4] estimates the irritant concentrations at 120 ppm for HF, 200 ppm for HCl and 200 ppm for HBr. It also suggests that, for a 30 min exposure, 2900 ppm HF, 3800 ppm HCl and 3800 ppm HBr are likely to be lethal. The lowest HF concentration (LCL_0) in air which has been reported to have caused human death is 50 ppm for an exposure of 30 min [5]. The LCL_0 for HCl is 1,300 ppm in 30 min or 3,000 ppm in 5 min.

During most tests, the maximum CO concentrations were above 200 ppm, which is the U.S. Occupational Safety and Health Administration's (OSHA) short-term exposure limit (STEL). The lowest CO concentration in air which has been reported to have caused human death, LCL_0, is 4,000 ppm for 30 min exposure or 5,000 ppm for 5 min [4]. The LCL_0 for CO_2 is 9% for 5 min exposure or 10% for 1 min.

CONCLUSION

Halon 1301, at the tested concentration of 5% to 7.5%, demonstrated effective total-flooding fire-extinguishing performance for all test scenarios, and produced the least amount of TDPs. HCFC Blend A, at a design concentration of less than 10%, was not successful in extinguishing all fires. HFC-227ea, at a design concentration of 7.6% or higher, and HCFC Blend A, at a design concentration of 12%, extinguished all test fires. These replacement agents produced higher concentrations of acid gases than produced in fire suppression with halon. The quantity of the acid gases generated during suppression was dependent on agent type, agent concentration, agent discharge time, fire type and size as well as extinguishment time.

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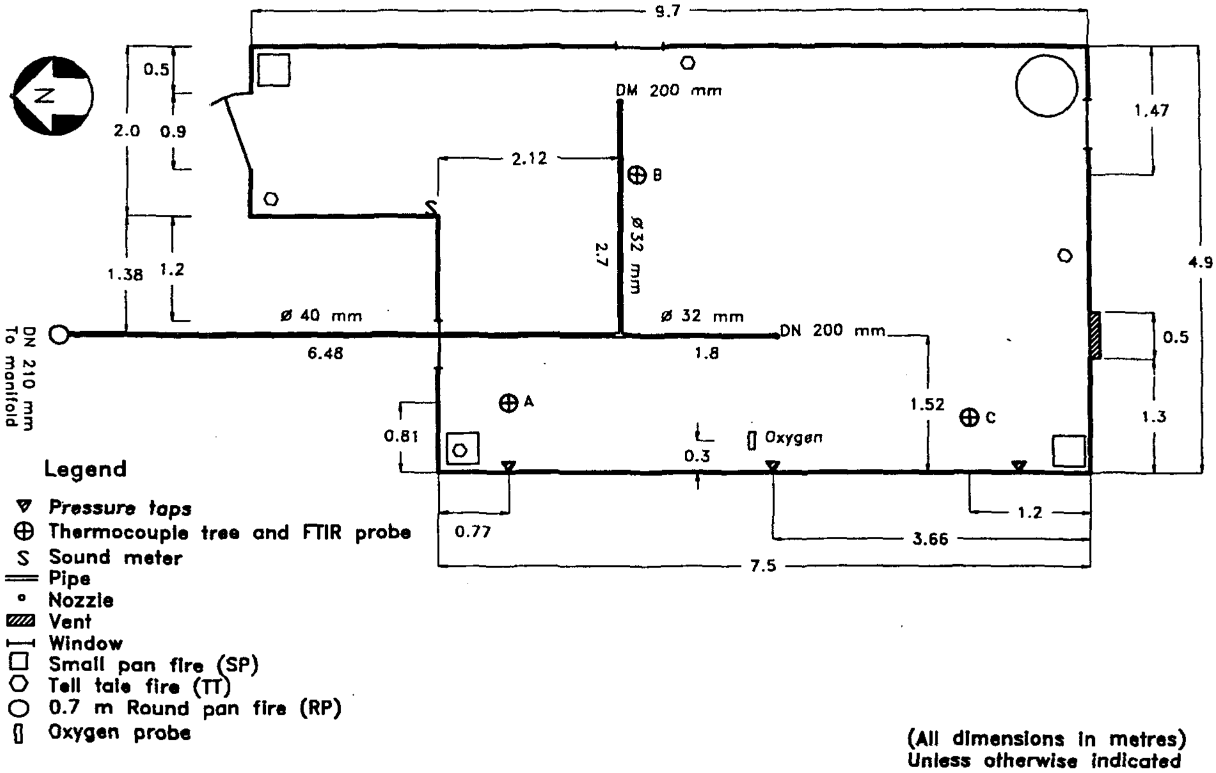

Figure 1. Room dimensions and piping arrangement (Halon piping)

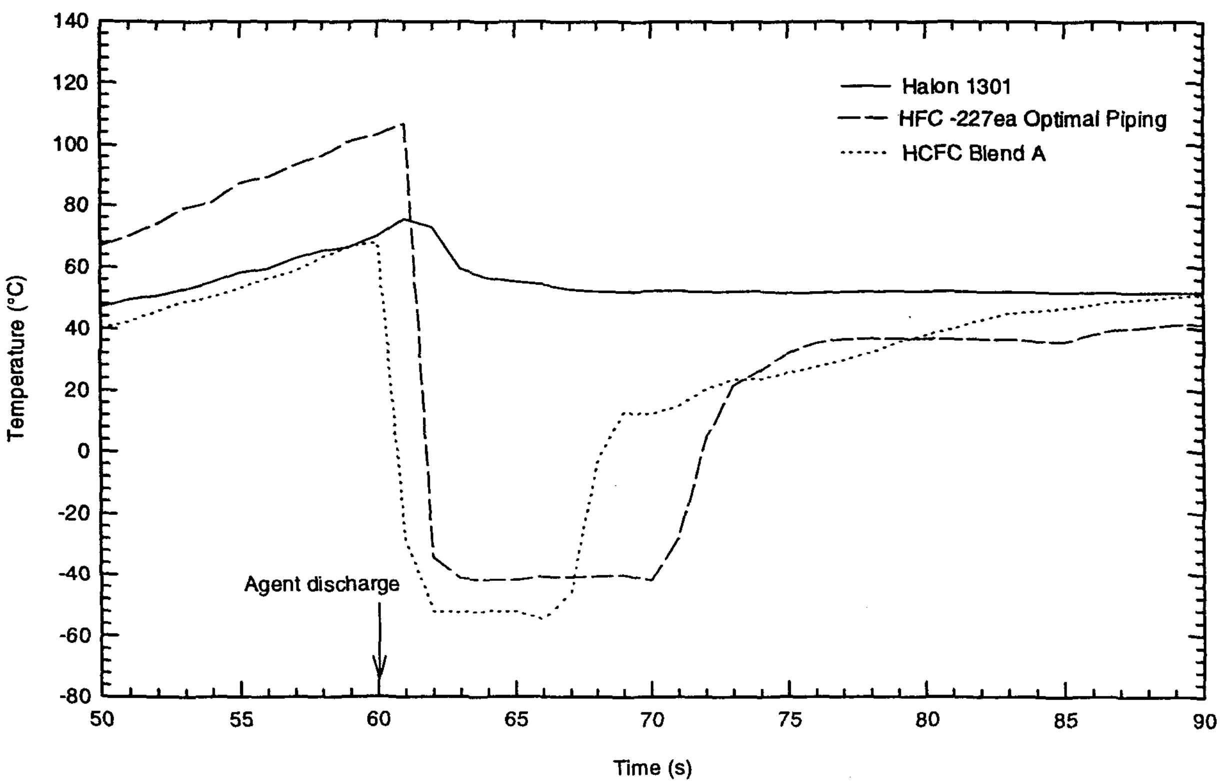

Figure 2. Temperature near east nozzle for test

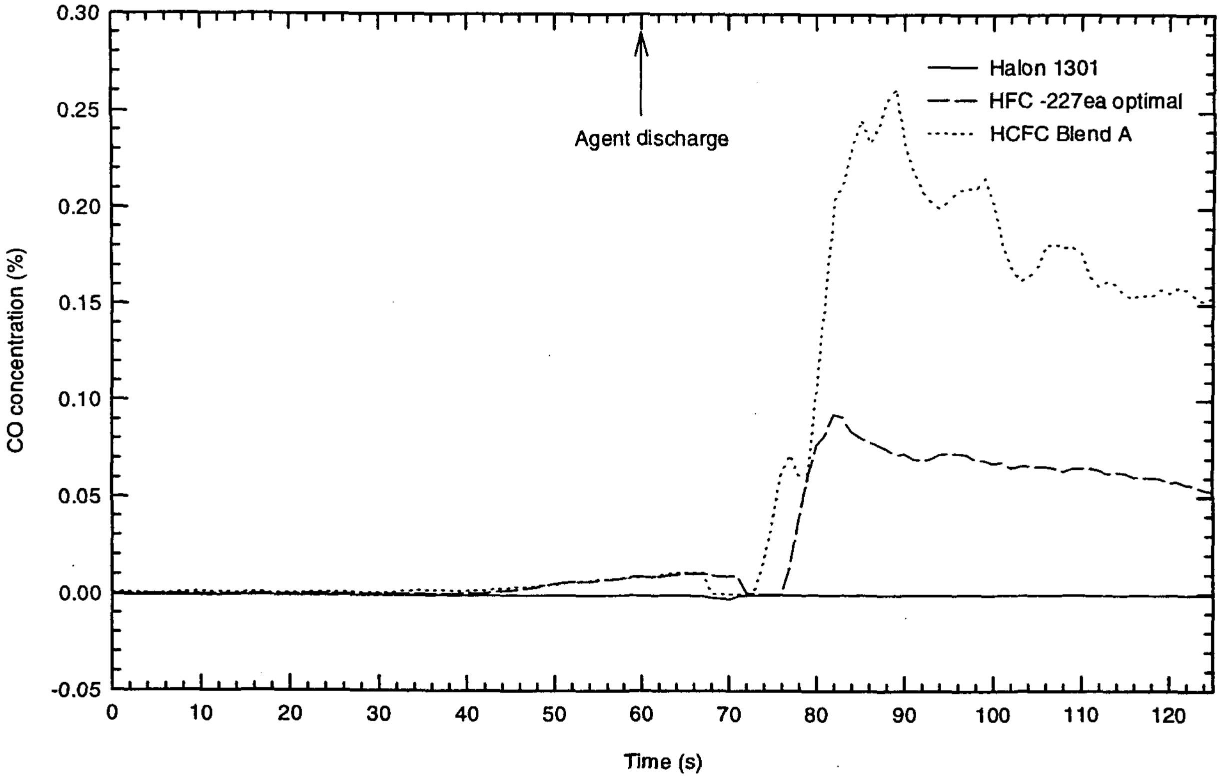

Figure 3. CO concentrations for tests

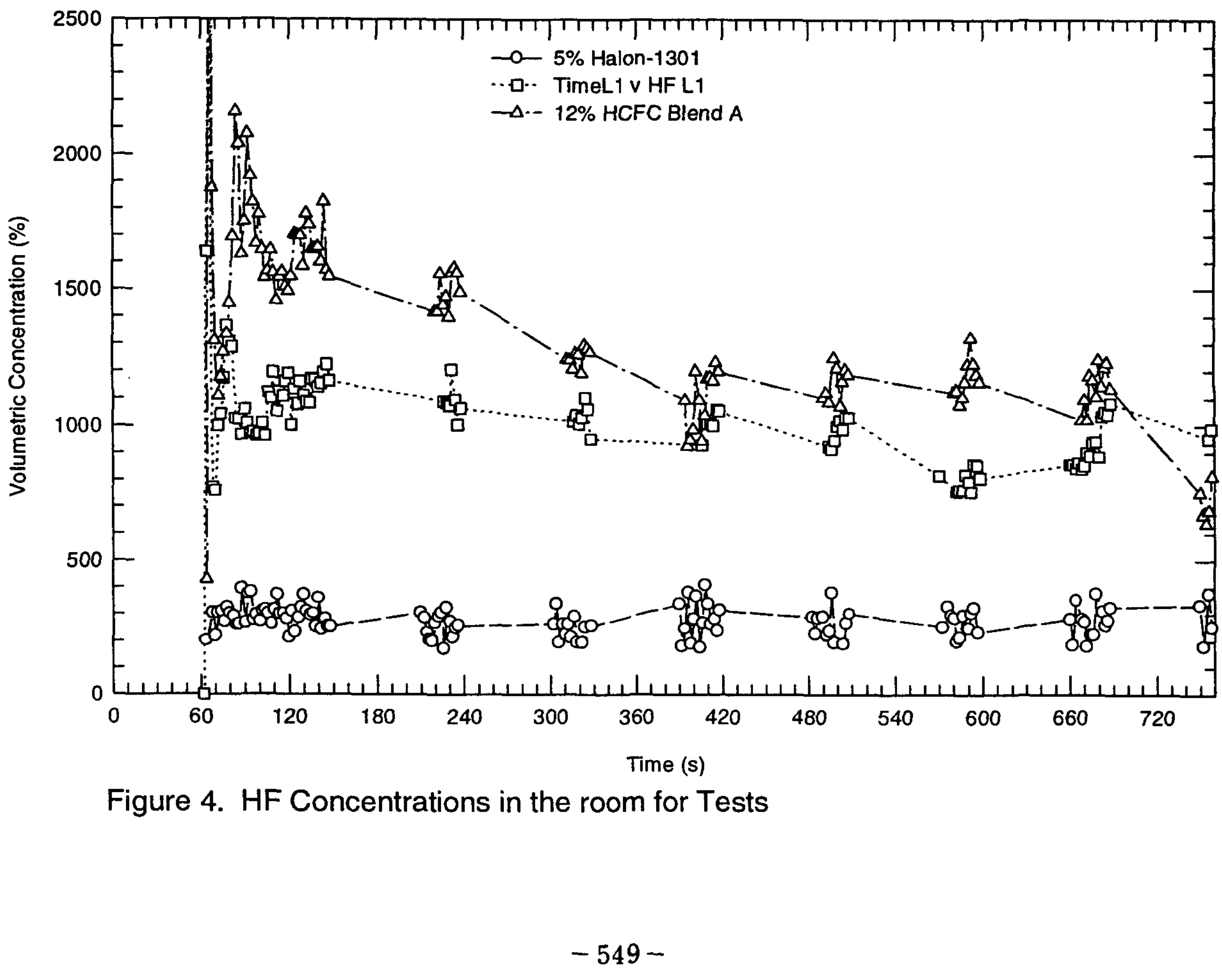

Figure 4. HF Concentrations in the room for Tests