INTERMEDIATE-SCALE (645-ft^3) FIRE SUPPRESSION EVALUATION OF NFPA 2001 AGENTS

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INTRODUCTION

Halon 1301 production will effectively cease at the end of 1993. Consequently, replacement agents will be substituted for Halon 1301 in applications where recycled halon is not available for use. This paper describes the testing and evaluation effort undertaken by the Center for Global Environmental Technologies (CGET) to compare the most promising near-term Halon 1301 replacements for occupied areas. The candidates were selected based on the preliminary decision by the National Fire Protection Association (NFPA) Technical Committee on Alternative Protection Options to Halons (NFPA 2001) that only agents with cardiac sensitization threshold levels above the design concentration are suitable for use in areas where human contact is possible. Thus, the only candidates that might meet this criterion are HFC-23, HFC-227ea, FC-3-1-10, and HCFC Blend A (Tables 1 and 2). The NFPA Standard (2001) on these agents is still in draft form and has not been approved or issued at this time.

The testing and evaluation protocol entailed assessing the agent fire suppression performance on a number of fire scenarios inside a nominal 645 ft^3 test chamber. Two sizes of pool fires, a diesel spray fire, and a Class A wood crib fire were examined. Fourier Transform Infrared (FTIR) Spectroscopy was used to measure agent concentration and decomposition product formation.

Agent discharge time was minimized to less than 7 seconds in order to minimize decomposition products (toxics). The amount of agent was also varied to minimize formation of toxics. Accordingly, for the smallest pool fires, it was determined that the design concentration being considered in NFPA 2001 (cup burner plus 20%), in most cases, was adequate to extinguish the fire but the level of toxic decomposition byproduct formation was excessive. During, larger fires toxics were always very high. In general, if the amount of agent was increased above the "design concentration," to cup burner plus 40% and the extinguishment time was short (< 5 seconds), decomposition products were kept to a minimum. No substantial fire extinguishment performance differences were observed between the candidates tested. The candidates generated a 10-fold increase in HF concentrations when compared with Halon 1301. Also, significant COF_2 was observed with the NFPA 2001 agents; no COF_2 was detected with Halon 1301 in any of the tests.

TABLE 1. NFPA 2001 OCCUPIED-SPACE AGENTS.

Chemical	Supplier	Tradename
[a]HFC-23	Dupont	FE-13
[a]HFC-227ea	Great Lakes Chem.	FM-200
[b]FC-3-1-10	3M	PFC-410
[c]HCFC Blend A	North American Fire Guardian	NAF-SIII

[a]Hydrofluorocarbon (HFC)
[b]Fluorocarbon (FC)
[c]As designated by the NFPA and the US Environmental Protection Agency (EPA) Significant New Use Alternatives Policy (SNAP) Program; Hydrochlorofluorocarbon (HCFC).

TABLE 2. AGENT CHARACTERISTICS.[a]

	Halon 1301	HFC-23	HFC-227ea	FC-3-1-10	HCFC Blend A
Chemical Formula	CF_3Br	CHF_3	CF_3CHFCF_3	C_4F_{10}	HCFC Blend
Molecular Weight	148.9	70.01	170.03	238	92.9
Heat of Vaporization, cal/g	28.4	57.3	31.7	22.8 @ -2 °C	54.3
Boiling Point, °C	-57.8	-82	-16.4	-2.2	-38
Vapor Pressure, MPa	1.47 @ 21 °C	4.83 @ 25 °C	0.405 @ 21 °C	0.330 @ 32 °C	0.669 @ b.p.
Critical Temperature, °C	67	25.9	101.7	113.2	125
Critical Pressure, MPa	3.97	4.84	2.91	2.32	6.65
Vapor Density, kg/m^3	6.26 @ 21 °C	—	—	9.94 @ 25 °C	—
Liquid Density, g/m^3	1.57 @ 21 °C	1.52	1.42	1.52 @ 20 °C	1.2 @ 25°C
Ozone Depletion Potential (ODP)	16	0	0	0	0.04
Atmospheric Lifetime, yrs	—	400	43	2600	7
[b]LOAEL, %	7.5	50	—	>40	—
[c]NOAEL, %	5	[d]30	9.7	40	10
[e]Cup Burner Ext. Conc., %	2.9	12.6	6.3	5.0	[f]8.6

[a]Values from the NMERI Halocarbon Database©
[b]Lowest observed adverse effect level.
[c]No observed adverse effect level, extinguishment design concentration must be lower than this value.
[d]Without supplemental oxygen; 50% with supplemental oxygen.
[e]NMERI 5/8-Scale for n-heptane.
[f]This is the manufactures design concentration, the NMERI cup burner value is 11.6%.

TECHNICAL APPROACH

Test facilities, equipment, and techniques were established. The extinguishment experiments were performed in a 645-ft^3 (18.27-m^3) test chamber. The experimental procedures developed were similar to those performed by other researchers investigating the performance of halon replacement candidates (References 1-8). The extinguishment experiments were designed to measure the fire suppression ability and decomposition product formation of the selected chemicals leading to a relative ranking and preliminary determination of performance characteristics. Sufficient testing was performed to allow characterization of the test apparatus for Class B fires. Limited Class A fires were also performed. This paper only presents the results of the Class B pool fire test series.

TEST APPARATUS

The test apparatus consisted of a test enclosure, data acquisition/control system, agent delivery system, fuel delivery and ignition system, and agent filling station (Figures 1 and 2). The "Test Enclosure" was a 8-ft x 8-ft x 20-ft steel ocean shipping container with a 3-ft by 6 ft-8 inch personnel door at the end of one side and large cargo doors, which completely cover the opposite end (Figure 2). A steel partition was placed in the center of the container, essentially dividing it in half. One half was used as the "Test Chamber" while the other was the "Agent Filling and Equipment Storage Room." The steel partition in the Test Enclosure was equipped with a 24-inch x 24-inch camera view port (1/2 inch thick clear Lexane) and pipe penetrations to provide inlets for the fuel and agent, pressure transducers, thermocouples, and sampling probes.

The internal dimensions of the Test Chamber were 95 inches high x 93.5 inches wide x 125.5 inches long with an internal volume of 645 ft^3. A baffle box was placed in the Test Chamber inside and upon which the fire pans were placed (Figure 2). The Test Chamber was equipped with an automatic ventilation system which was used to sustain the internal oxygen concentration to support combustion during agent testing. The ventilation system included a motorized exhaust fan and two motorized dampers. The ventilation system was initialized prior to fire ignition. The dampers were closed and the ventilator turned off prior to agent discharge.

The "Agent Filling and Equipment Storage Room" in the second half of the Test Enclosure (Figure 2) contained the Agent Delivery System and the Agent Filling Equipment. The Agent Delivery System consisted of a 60-lb (25 kg) Penwal Halon 1301 pressure tank with a volume of 0.656 ft^3 (18.6 L). Attached to the tank was a 600-lb/in^2 J.D. Gould solenoid valve, approximately 8-ft of 1-inch seamless 1000-lb/in^2 steel piping, and a Fenwal 1-inch halon discharge nozzle. Several changeable nozzle orifices were available for varying agent flow rate and, thus, discharge time.

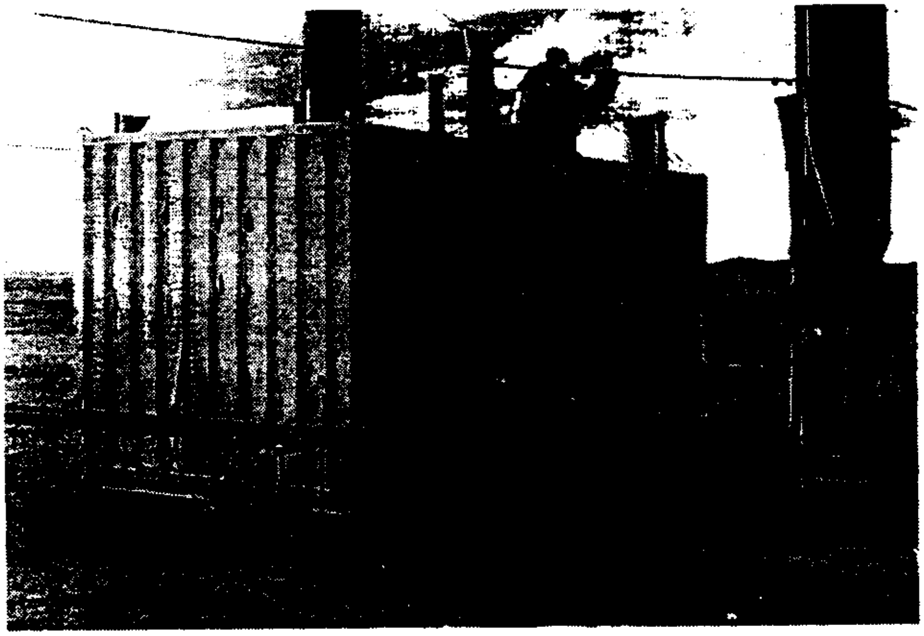

Figure 1. Photograph of the NMERI Field-Scale Test Enclosure.

It should be noted that the Agent Delivery System was not optimized for any of the agents which were tested, including Halon 301. The objective was to design a cylinder/piping system which would accommodate all of the agents tested.

Two circular fire pans were used: 0.40 ft^2 and 1.67 ft^2. One-half inch of n-heptane was floated upon 2 inches of water in the fire pans. These pan sizes equate to values of 0.62 and 2.5 $ft^2/1000\ ft^3$ (surface area to volume ratio), respectively. While this ratio has been commonly used in the past, there is no theoretical basis to confirm its validity.

Data acquisition and equipment control were accomplished with a National Instruments Lab Windows software-based 486 33-MHz personal computer (PC) data acquisition and control system (DA/CS). There were eight sensor input and eight output control circuits. Test data was displayed on screen in real time for quick viewing and interpretation of results.

SAMPLING SYSTEM

Agent concentrations and combustion products were measured inside the test chamber during each test. The sampling system consisted of a Perkin Elmer System 2000 FTIR Spectrometer, 486-33-MHz PC, 4-feet of quartz sample tubing, a 10-cm glass gas cell, a vacuum pump, flowmeters, and miscellaneous tubing. Neat agent concentrations were determined to the nearest 0.5 percent. Products measured included CO, CO_2, COF_2, HF, and HCl. Reference 9 further discusses the sampling system.

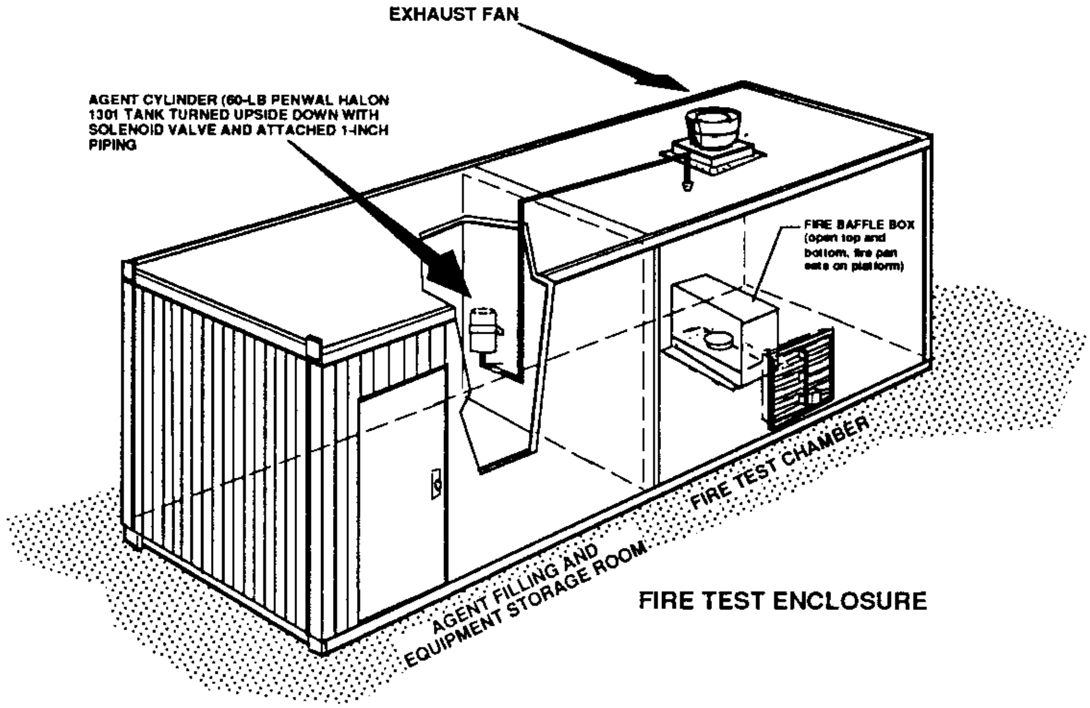

Figure 2. Sketch of the NMERI Field-Scale Test Enclosure.

TEST CONDUCT

The testing was conducted in four steps: (1) control testing, (2) calibration and technique optimization, (3) baseline testing, and (4) agent evaluation (Table 3). Initially, a control test series was run to determine the threshold ignition energies required for reliable fuel ignition and to evaluate the optimum pool fire sizes. A calibration test series was then performed to optimize test techniques and the data were analyzed for reproducibility. When it was determined that results were reproducible and comparable to earlier work, experiments were run to develop Halon 1301 baseline data for comparison. Testing of the NFPA 2001 candidates then began.

TEST PROCEDURES

The following test procedures were developed and validated using Halon 1301: (1) The DA/CS was activated and initialized. Test information, including the test name, number, date, fuel type, agent type, and agent concentration were recorded. (2) The desired fuel scenario (Class A or B) was placed into the Test Chamber. (3) The agent was then loaded into the agent discharge cylinder. The agent bulk storage container was placed on the agent scale, and the tubing from the agent storage cylinder was connected to the liquid port. Nitrogen, for pressure transfer, was connected to the gas port on the agent bulk storage container. The agent scale was zeroed and valves opened until the desired amount of agent was placed into the agent discharge cylinder.

TABLE 3. TEST MATRIX.

Test Conduct	Test Series[a] ^{b}0.62	^{b}2.6	Totals
Control	5	2	9
Calibration	20	--	20
Baseline (Halon 1301)	4	3	10
Agent Validation			
HFC-23	4	3	10
HFC-227ea	7	3	13
FC-3-1-10	5	3	11
R-595	9	3	15

[a]Number of tests
[b]$ft^2/1000\ ft^3$

When the agent filling was completed, the agent discharge cylinder was pressurized with nitrogen to 360 ± 5 lb/in^2. In the case of HFC-23, no N_2 was used due to its high vapor pressure. (4) The fuel was loaded and the Test Chamber prepared for testing. The required vents were opened, and the liquid fuel was placed into the fire pan. The observation window and the ignitor electrodes were cleaned. The doors to the Test Chamber were closed. (5) The Test Director indicated that the test was ready to begin, and the DA/CS operator initiated the test sequence using the DA/CS. An established sequence of events followed: (i) the ignitor ignited the fuel; (ii) a 1-minute preburn was allowed; (iii) vents were closed; (iv) the agent solenoid valve opened and released agent into the Test Chamber; (v) fire suppression or non-suppression occurred; (vi) in the event of extinguishment, a "hold time" was determined by measuring the agent concentration over time within the Test Chamber and trying to reignite the fuel every 1 minute for 15 to 30 minutes; (vii) the vents were opened; and (viii) the data acquisition was terminated. (6) The Test Chamber was opened, prepared for the next test event, and the test sequence was repeated. (7) Test data were stored on 3-1/2 inch disks, and the operator had the option to plot and print the test data.

CONCENTRATION CALCULATIONS

The agent concentration was calculated using the test chamber temperature and information presented in the draft NFPA 2001 standard. The agent and decomposition byproduct concentrations were also measured "real time" with the FTIR spectrometer. In general, the test series started with the cup burner extinguishment value, and the agent concentration was increased until the decomposition product concentrations were minimized.

RESULTS

Control Testing --- During the control testing, 9 tests were performed. The automatic fan and vents operation was optimized. Fire characteristics were also determined (e.g., fuel ignition requirements, burn time, etc.). As a result of the control testing, it was determined that the largest fire that should be burned in the Test Chamber was 1.67 ft^2. Two pool fire scenarios were chosen: 0.4 ft^2 (0.62 ft^2/1000 ft^3) and 1.67 ft^2 (2.5 ft^2/1000 ft^3). The total burn times with the fan off and the vents closed were 13 and 8 minutes, respectively. A large fire equivalent to 6.0 ft^2/1000 ft^3 would only burn slightly less than one minute. Therefore, the largest fire tested was 1.67 ft^2.

Calibration and Technique Optimization --- At the beginning of the testing, the agent cylinder was rightside up with agent being discharged through a dip tube. However, test data indicated that agent was being held up inside the agent cylinder as shown in Figure 3. Measured versus calculated agent concentrations did not correlate. Therefore, the dip tube was removed and the agent cylinder was turned upside down, at which time the measured agent concentration using the FTIR matched the calculated concentration inside the test chamber (Figure 3). The results shown on Figure 3 ensured that the sampling system was accurately calibrated and baseline testing began.

Figure 4 shows a typical data plot generated by the DA/CS. From the data plots the discharge time (3.5 seconds for Figure 4) was determined. The discharge time is difference between when the nozzle pressure began to increase and the time at which the nozzle pressure returned to zero. The end of the discharge sound equates to the point at which the cylinder pressure returns to zero.

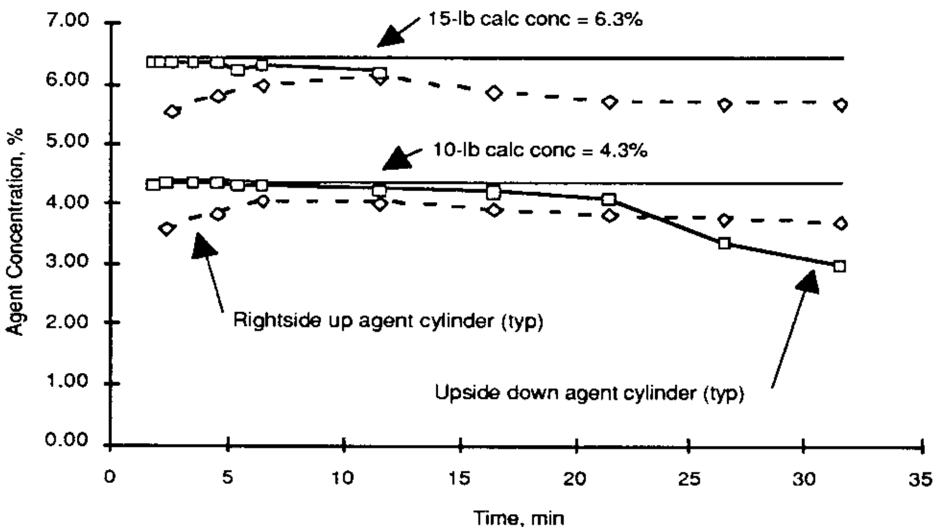

Figure 3. Plot showing the results of the calibration and technique optimization testing.

SYSTEM PRESSURES WITH NOZZLE AND FIRE PAN TEMPERATURES

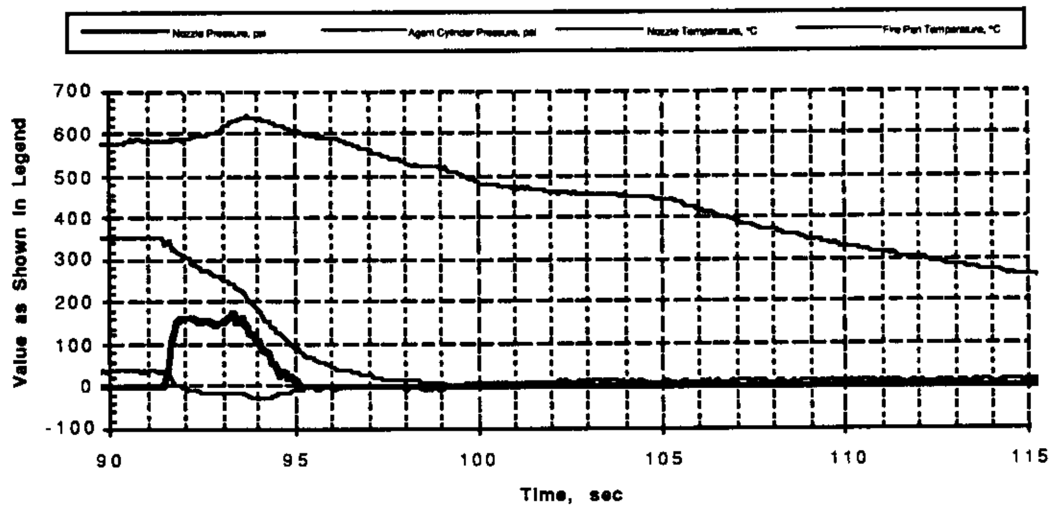

Figure 4. Example data plot generated by the data acquisition/control system.

Baseline Testing --- Ten baseline tests were run with Halon 1301. Figure 5 shows representative results for the two size pool fires. In general 4.0% (9 lbs) of Halon 1301 (cup burner plus 40%) was required for rapid extinguish and minimized decomposition byproduct formation. Extinguishment times exceeded 1-minute when the agent concentration was equal to the cup burner value. In the Halon 1301 baseline tests, the HF concentration steadily decreased to zero within 15 minutes after discharge (Figure 5), probably due to adsorption onto the chamber walls. The HF concentration for the larger pool fires was approximately 10 times greater than for the smaller pool fire.

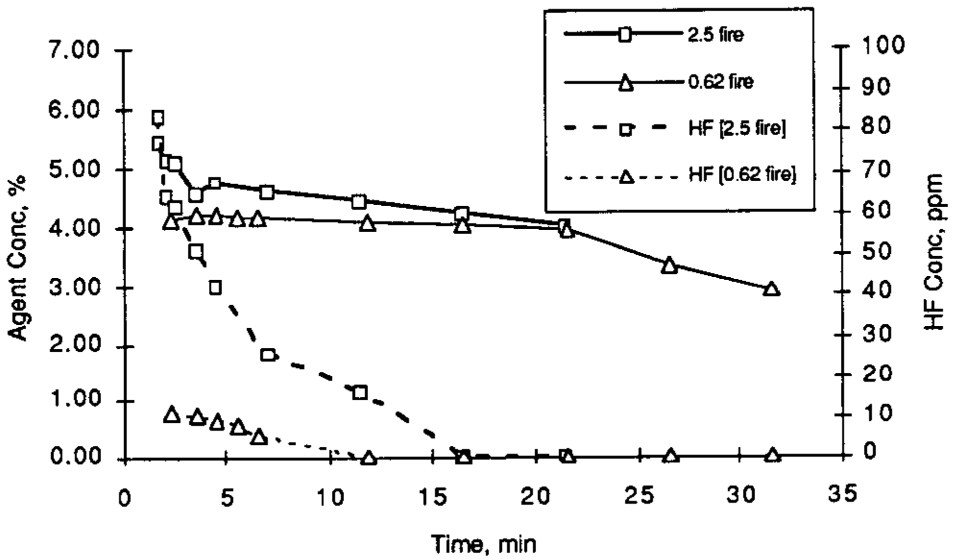

Figure 5. Plot showing the results of the baseline testing using Halon 1301.

Agent Evaluation --- A minimum of three tests were run per candidate agent per test series (Table 3). Representative test results for all the agents are shown in Figure 6. Rapid extinguishment (< 7 sec) and minimum decomposition byproduct formation required that the agent concentration be 40% greater than the cup burner value. Figure 6 shows the agent concentration values over time. The "hold time" for the agents generally exceeded 30 minutes. The difference in the agent concentrations required for extinguishment for the two pool fires shown in Figure 6 was due to the increased chamber temperature as a result of the larger fire (e.g., the same quantity of agent was discharged in each case).

Figure 7 shows the measured HF concentrations over 30 minutes. The baseline Halon 1301 results have been included for comparison. The HF concentrations generally drop by a factor of 10 within 15 minutes. In both pool fire sizes, the measured HF values for the tested agents are 10 times higher than for Halon 1301. Note, that this is for the best case (e.g., discharge time less than 7 seconds and extinguishment time less than 5 seconds). HF concentrations increased dramatically as the extinguishment time increased. In general, the test results for HFC-227ea and FC-3-1-10 compare similarly while HFC-23 and HCFC Blend A are similar at higher levels.

Figure 8 summarizes the best case (minimum toxic formation) test data for the 0.62 $ft^2/1000\ ft^3$ pool fire test series. As shown the agents tested required twice the amount of agent as Halon 1301 to achieve the same performance. This was also true for the larger pool fires. It should be noted that the HF concentrations were higher for HCFC Blend A and HFC-23 than for the other agents tested even when the extinguishment time was reduced to less than 7 seconds. Also, these two agents were the only ones in which COF_2 continued to be present even though extinguishment time was minimized. These two agents continued to exhibited the highest toxics formation throughout all of the testing. Additional discussions of the decomposition byproduct information derived during this testing is presented in Reference 9 (a companion paper also presented in these proceedings).

CONCLUSIONS

During this test and evaluation effort, an apparatus and test procedures were developed to assess the total flooding fire suppression and decomposition byproduct formation of potential Halon 1301 replacements. The NFPA 2001 agents tentatively acceptable for use in occupied spaces were tested. A summary of the test results for n-heptane pool fires have been presented herein. The FTIR sampling and analysis system proved to be very effective in identifying and quantifying agent concentrations and decomposition byproduct formation. Measured decomposition products included HF, CO, CO_2, and COF_2.

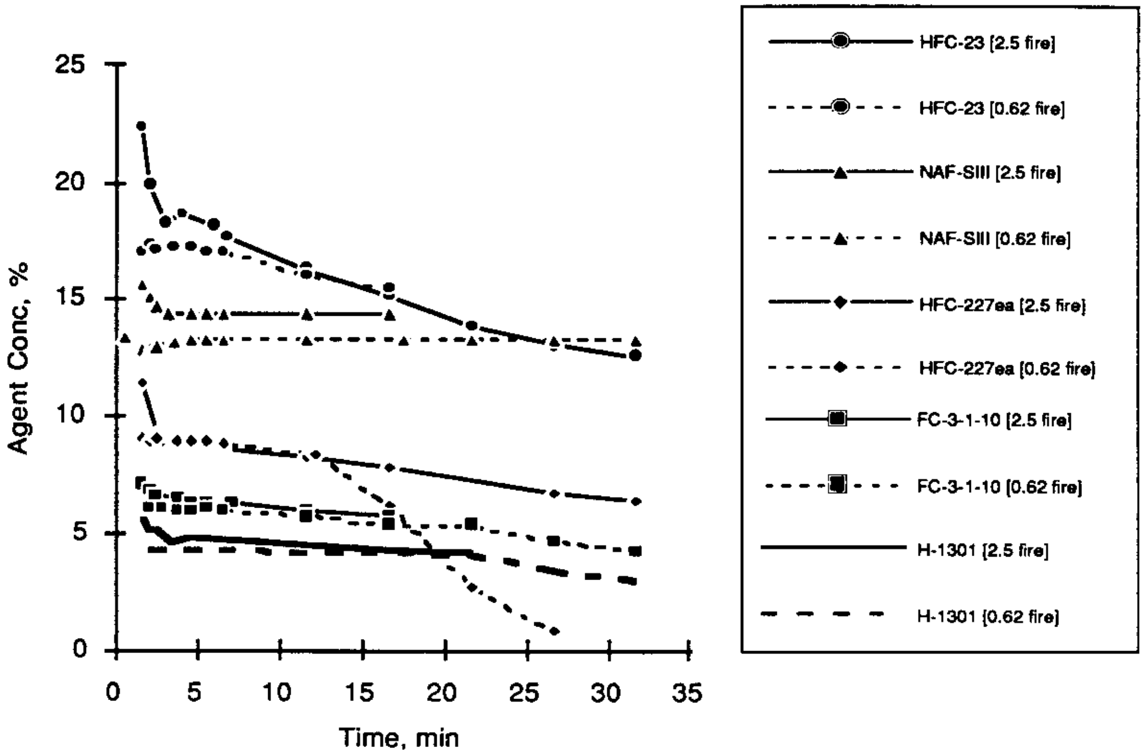

Figure 6. Agent concentration versus time for the agent evaluation testing. The agent concentrations shown are for those tests which were considered representative for each agent/fire size combination tested.

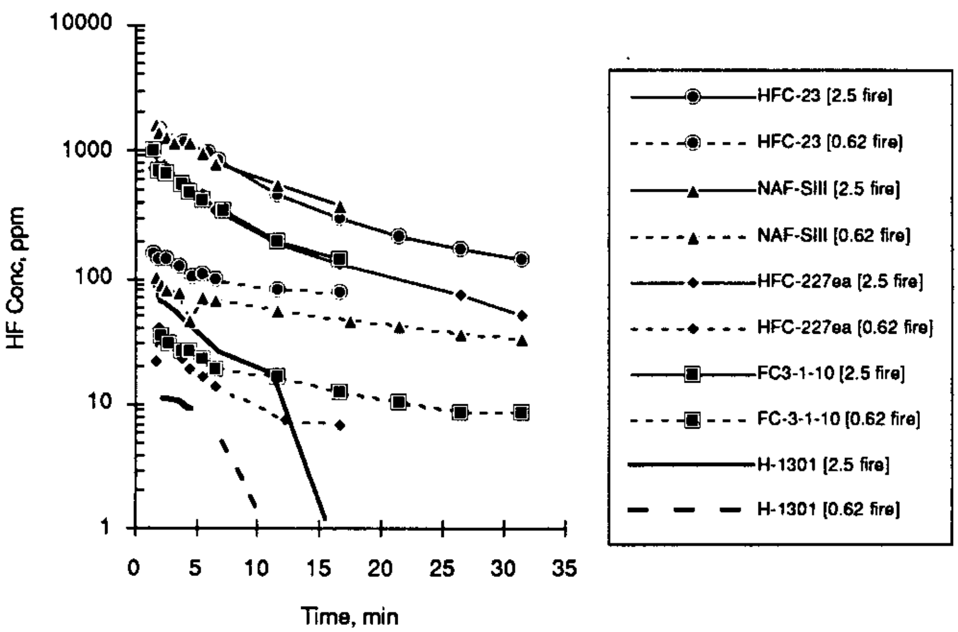

Figure 7. HF concentration versus time for the agent evaluation tests shown in Figure 7.

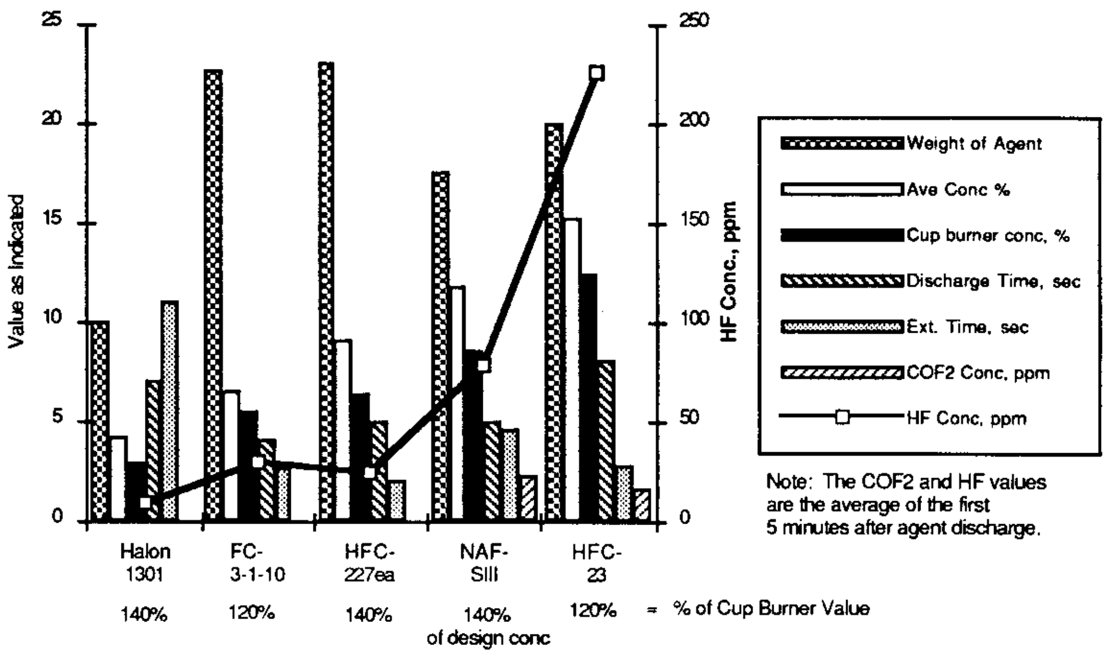

Figure 8. Summary of the agent evaluation test data for the 0.62 $ft^2/1000\ ft^3$ test series.

The test results indicate that the performances of the agents (HFC-23, HFC-227ea, FC-3-1-10, and HCFC Blend A) were approximately the same on an equivalent weight basis compared to each other. However, these candidate replacements required twice the amount of agent by weight to achieve the same extinguishment characteristics as Halon 1301. As a note, in the case of HCFC Blend A the agent requirement was the manufacturers stated design concentration plus 40%.

Approximately, a 10-fold increase in HF production was observed with the tested agents compared to Halon 1301. The decomposition product formation for these agents is also much more dependent on the time to extinguish and fire size than with Halon 1301. An extinguishment time less than 7 seconds was required to minimize decomposition products. To achieve an extinguishment time of less than 7 seconds, an agent concentration of the cup burner value plus 40% and a discharge time less than 5 seconds were required. These requirements may be due to the fire baffle box and agent discharge system used in this particular test series. HFC-23 and HCFC Blend A produced greater quantities of decomposition products than the other two agents. Where the extinguishment time was greater than 7 seconds, COF_2 was measured at concentrations in excess of 10 ppm. With Halon 1301 no COF_2 was detected in any test.

RECOMMENDATIONS

The following recommendations are made as a result of the testing presented herein:

- Agent discharge and extinguishment times must be kept to a minimum in order to reduce decomposition products.
- High performance detection with multiple sensors should be required to minimize fire size if the tested agents are ever used in an actual fire protection system.
- Agent concentrations of 140% of the cup burner are required to minimize extinguishment time and reduce toxics for scenarios in which a hidden (baffled) fire is expected, such as in this test series.
- An investigation of the 140% of the cup burner requirement should be considered using other fire scenarios in order to verify that the proposed NFPA 2001 120% value is applicable.
- The effects of optimizing the agent discharge system to the agent being tested should also be investigated.

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