USE OF WATER SPRAY COOLING SYSTEMS IN CONJUNCTION WITH HFP (HFC-227ea) TO PROTECT SHIPBOARD FLAMMABLE LIQUID STORAGE ROOMS

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INTRODUCTION

The Naval Research Laboratory (NRL) has conducted extensive intermediate [1] and full scale [2] Halon 1301 replacement tests. For the protection of shipboard Flammable Liquid Storage Rooms (FLSR), testing has included using heptafluoropropane (HFP, C_3F_7H, HFC-227ea) by itself and together with the NRL-invented Water Spray Cooling System (WSCS) [3, 4, 5]. Although HFP by itself has been proven effective in extinguishing low flash point liquid fuel fire scenarios, the amount of hydrogen fluoride (HF) produced during an HFP suppression is a safety concern. Furthermore, HFP produces very limited compartment cooling, as do all gaseous agents. Also, high compartment temperatures can result in increased fuel evaporation and reignition/reflash potential upon re-entry. The WSCS has been found to be beneficial in reducing HF production when initiated prior to agent discharge [6]. The WSCS also "scrubs" HF from compartment air and lowers compartment temperatures.

This effort identifies the usage parameters for protecting shipboard compartments containing low flash point liquids using HFP in conjunction with the WSCS. Initial testing using water mist technology has proven the potential for hazardous energetic reflashes [7]. To avoid energetic reflashes and facilitate potential system implementation, low pressure WSCS using pressures available in shipboard firemains will be used instead of high pressure water mist.

The tests are being conducted at the NRL Chesapeake Bay Detachment Facility (CBD). The program is designed to provide implementation guidance for increasingly larger compartments containing low **flash** point liquids. Initial tests were conducted in a **28** m^3 (1000 ft') test compartment similar in size to many smaller shipboard compartments. The results of the initial testing, reported herein, will serve as a learning process for designing and executing further tests to be conducted in a 126 m^3 (4460 ft') subcompartment constructed within a 300 m^3 (10,500 ft') test compartment. Testing in the 300 m^3 (10,500 ft') compartment may be conducted in the future.

The objective of the work presented here was to evaluate the use of the WSCS to improve the performance of HFP in terms **of** cooling and HF time-weighted exposure ("loading") in compartments up to 28 m^3 (1000 ft^3). The WSCS variables evaluated included nozzle type, water application rate, water application duration, and water initiation time relative to HFP discharge. Results include nozzle selection and guidance on the WSCS initiation time and application duration. This paper discusses the findings of this testing and provides preliminary recommendations for implementation of WSCS/HFP systems.

TEST COMPARTMENT AND MOCKUPS

Testing was conducted in a 3.0 x 3.0 x 3.0 m (10 x 10 x 10 ft) steel compartment designed to simulate a small shipboard flammable liquid storeroom. The compartment was equipped with a watertight door in the **aft** bulkhead and was fitted with storage racks along the port and forward bulkheads (Figure 1). The storage racks were composed of removable shelving sections that were approximately 66 cm (26 in.) in depth. Perforated shelves were positioned at heights of 61 cm (24 in.), 122 cm (**48** in.), 183 cm (72 in.), and 244 cm (*96* in.) above the deck. The total enclosed volume of the compartment was approximately **28 m^3** (1000 ft^3). Mock-ups consisting of **18.9** L (*5* gal) buckets were placed on the deck and shelving to challenge the suppression system by obstructing the agent distribution. With the compartment fully loaded with mock-ups, the adjusted compartment floodable volume became **19.8** m^3 (707 ft'). With limited mock-ups, the compartment floodable volume became approximately 23.9 m^3 (853 ft^3). While full mock-ups provide the maximum agent obstruction, testing was performed with limited mock-ups to provide sufficient obstruction while minimizing the increase of agent concentration.

The HFP discharge system consisted of a single overhead nozzle positioned in the center of the compartment. A design concentration of 10.6% HFP based on the compartment's total floodable volume of 28 m^3 (1000 ft^3) was used for these tests. Refer to "Test Plan for Evaluating HFP Gaseous Agent System with a Water Spray Cooling System in Compartments with Low Flash Point Liquids" [8] for more details and for drawings of the discharge system.

The WSCS was first evaluated aboard the ex-USS SHADWELL [6]. Limited WSCS testing in conjunction with HFP was also conducted in the Compartment in 1996 [9]. Testing has shown that the WSCS reduces compartment temperatures and weakens the fire through energy abstraction and dilution from water vapor generation [4]. This aids in limiting the production of HF. When HF is produced, the water supplied by the WSCS also lowers HF levels and ultimately reduces the time for compartment reclamation [5]. A single WSCS nozzle was used in the compartment due to its 3.0 x 3.0 m (10 x 10 ft) floor dimensions. Ten different types of nozzles (Table 1) were examined, with different application rates and droplet size distributions. The two nozzles that provided the best results will be used for future testing in larger compartments. In expected shipboard use, water will be supplied to the WSCS from the ship's firemain, operating at 10.2 bar (150 psi). Because of this, the WSCS system was designed to operate at 10.2 bar (150 psi) to allow shipboard implementation without the use of an additional pump. Given the constant supply pressure, the WSCS application rate was only a function of nozzle type and orifice size.

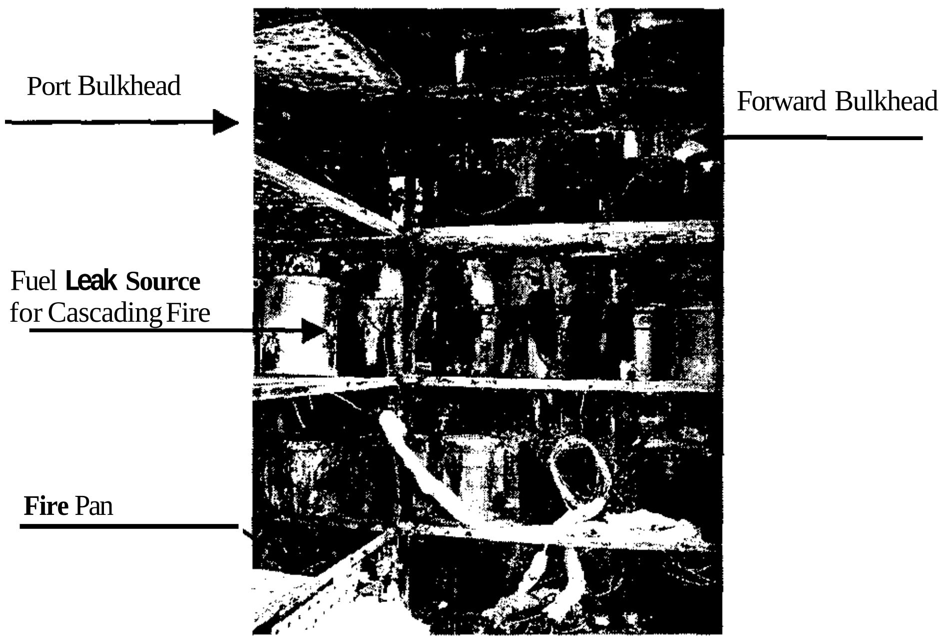

Figure 1. Interior view of the test compartment from the aft door.

FIRE SCENARIOS

The flammable liquid fuels used were methanol and n-heptane. Methanol, usually present aboard ships especially for use in Landing Craft Air Cushion (LCAC) operations, was selected as a test fuel because of the high HFP concentration required to extinguish methanol fires. n-Heptane was chosen because it is representative of other flammable liquids found in shipboard FLSRs. Each fuel has different burning characteristics and extinguishment requirements. Two fires in the shelving burned simultaneously during each test. The pan fire was located approximately 38 cm (15 in.) above the deck in the forward port corner of the compartment. The fuel for the 3-dimensional cascading fire was introduced 1.2 m (48 in.)

above the deck in the forward port corner of the compartment above the pan fire. The fuel dripped downward through the perforated shelving onto and around the 18.9 L (5 gal) containers. The combined fire sizes ranged from 175 to 400 kW. The cascading fire was more dynamic and more obstructed than the pan fire, presenting more of a challenge for the HFP and WSCS to suppress; therefore, we set it to be a larger percentage of the total heat release rate. Preburn duration, defined as the time between fire initiation and HFP discharge, was based upon response scenarios expected in the Fleet. Several preburn durations ranging from 30 sec to 2 min were evaluated.

INSTRUMENTATION

All data were collected via an Experiment Running Personal Computer (ERPC) located in the Mobile Control Room (MCR). The ERPC was a 600 MHZ Pentium III system with LabVIEW, Version 5.1 Full Development System data acquisition software utilizing a National Instruments modular interface.

Two vertical thermocouple trees were used to measure compartment air temperature in the test compartment. Additional thermocouples were used to monitor fire temperatures, telltale temperatures, and temperatures at each grab sample location. Gaseous grab samples were taken at the pan and cascading fires and at three other locations within the test compartment. The samples were analyzed via gas chromatography (GC) for O_2/Ar, CO, CO_2, N_2, and HFP. An SRI Instruments'' GC, configured with a Thermal Conductivity Detector (TCD), methanizer, and a Flame Ionization Detector (FID), was used to analyze the grab samples. Infrared (IR) analyzers quantified HFP and paramagnetic oxygen balances determined O_2 concentration in sample gas taken continuously at four locations within the compartment. Five Continuous Acid Analyzers (CAA) were used to measure airborne HF (gas and aerosol) concentrations throughout the compartment. A Fourier Transform Infrared Spectrometer (FTIR) was used to measure in situ HFP and HF gaseous concentrations. (Note: Carbonyl fluoride (CF_2O) generated in the compartment is quickly converted to HF and is measured by the CAAs. The FTIR measures CF_2O directly, which is included in the HF concentrations reported.) Videocassette recorders with time stamp generators located inside the MCR recorded the output from five video cameras, including two infrared cameras, used to monitor fire and test site activity.

TEST VARIABLES

Several variables were evaluated, including the WSCS nozzle type, water application rate, initiation time, and application duration. The WSCS simulated a shipboard system with a pump maintaining a supply pressure of approximately 10.2 bar (150 psi). Ten different nozzles were evaluated, with application rates ranging from 6.4 to 44.3 Lpm (1.7 to 11.7 gpm) (Table 1). The test compartment was equipped with one WSCS nozzle positioned in the center of the compartment. The WSCS initiation time, defined as the time between initiation of the WSCS and discharge of the HFP, was also evaluated as part of this test series. From previous testing, enhanced fire suppression effectiveness and reduced HF production were achieved when the WSCS was initiated prior to agent discharge [6]. The WSCS initiation times ranged from 15 sec to 1 min to evaluate the effect of initiation time on HF generation. During some tests, the WSCS was initiated a second time (after reignition and during venting) to help develop compartment reclamation doctrine for future larger compartment testing. To avoid compartment flooding and facilitate compartment reclamation, the shortest effective WSCS application duration was desired. A range of 2 - 5 min was evaluated to determine the effects of short and long WSCS application durations.

TEST PROCEDURES

Four different test scenarios were used to evaluate the individual effects of WSCS and HFP: (1) background tests (no WSCS or HFP); (2) preburn tests (WSCS only); (3) baseline suppression tests (HFP only); and (4) suppression tests (WSCS and HFP). Background, preburn, and baseline suppression tests were conducted prior to suppression tests with HFP and WSCS. Data from the baseline suppression tests were compared to data from the tests in which HFP and WSCS were both discharged to quantify the effects of the WSCS on the quantity of HF produced.

TABLE 1. WSCS NOZZLE TYPES AND APPLICATION RATES AT 10.2 BAR (150 PSI).

Manufacturer	Nozzle Type	Spray Angle (deg)	Listed Application Rates (Lpm I gpm)
Spraying Systems Co.®	1/8G-5.6W	90	6.4 / 1.7
	1/4G-12W	90	14.0 *13.1*
	3/8G-17W	90	**18.2** 14.8
Bete® Fog Nozzle	TF6FC	**120**	10.612.8
	TFSFC	120	18.9/ 5.0
	TF1 OFCN	90	26.8 17.1
	TF10FC	120	***29.5 f1.8***
	TF12FC	**120**	44.3 / 11.7
GEM (ex-Grinnell)	AM4	90	10.6 12.8
AquaMist®	AM10	90	10.612.8

NOZZLE SELECTION FOR BACKGROUND AND PREBURN TESTS

The purpose of the preburn tests was to characterize the effects of the WSCS variables on the compartment temperatures and fire characteristics. The 10 nozzle types included as part of this test series were evaluated based on their application rate at 10.2 bar (150 psi), their effect on the temperature inside the compartment, and their effect on the flame sheet size and extinguishment time (determined visually from video recorded during the tests). Initial background and prebum tests showed that the six highest flow rate nozzles did not provide any advantage (and in some cases performed worse) in terms of compartment temperatures and fire knock-down (reduction in size). Based on these results and discussions with the US Naval Sea Systems Command, the four low flow nozzles (those with an application rate of 10.6 Lpm [2.8 gpm or less]) were selected for further evaluation. The lowest flow nozzle (6.4 Lpm [1.7 gpm] was found not effective at reducing the size of the flame sheet or the compartment temperatures and was eliminated. The other three remaining nozzles, with an application rate of 10.6 Lpm (2.8 gpm), significantly reduced the compartment temperatures and the size of the flame sheet.

Due to the need to limit the number of suppression tests conducted, two of the three remaining nozzles (Bete® TF6FC, GEM@AM4, and GEM® AM10) were chosen for further evaluation. The Bete® TF6FC nozzle was chosen because it was effective at reducing the size of the flame sheets in both 175 kW total methanol and 200 kW total n-heptane fires. Neither of the GEM@nozzles had an effect on the 175 kW total methanol fire. While the AM4 was more effective than the AMI 0 in reducing the size of the flame sheet in 200 kW total n-heptane fire, the AM10 was chosen over the AM4 because it was more effective in reducing the size of the flame sheet in the more challenging 350 kW total methanol fire.

NOZZLE SELECTION CRITERIA FOR SUPPRESSION TESTS

The Bete® TF6FC and the GEM® AM10, chosen for further evaluation in suppression tests, were evaluated based on their effects on the following parameters: peak HF concentration, HF time-weighted exposure ("loading"), time to fire-out, and the reduction of compartment temperatures.

The peak HF concentration was defined as the maximum HF concentration measured in the compartment by the CAAs and typically occurred within 15 sec of agent discharge. The decay of the HF concentration in the compartment over time was evaluated to determine the effects of the water application rate and application duration. The data collected from the CAAs was graphed for each test and the area under the curve between agent discharge **(t=0 sec)** and ventilation initiation (t=900 sec) was numerically calculated to estimate the HF "loading." Visible and infrared videos of both the pan and cascading fires allowed accurate determination of the fire events. Fire-out time was determined by reviewing the videotapes of the tests. The compartment temperatures after agent discharge were also examined to determine the cooling capacity of each nozzle.

WSCS EFFECTS ON HF CONCENTRATION

The I75 kW (total) methanol fire with a preburn duration of 1 min produced the highest HF concentrations in the test Compartment. This cascading / pool fire threat was used for subsequent experiments. To evaluate the effect of the WSCS nozzle type on the peak HF concentration, three baseline suppression tests with HFP only and four suppression tests with WSCS and MFP, two with each nozzle, were conducted. The WSCS with HFP suppressions had a WSCS initiation time of 30 sec prior to HFP discharge. The average peak HF concentrations for each nozzle are in Table **2.** It is difficult to draw conclusions from the data for CAA position I because the sampling point was located close to the flame sheet. The turbulence of the moving flame sheet caused large fluctuations at that sampling point, compromising its usefulness. CAA positions ***2*** and **3,** located near the FTIR, low and in the obstructions, suggest that both nozzles diminished the peak HF concentration equally well. The peak **HF** concentration at CAA position 4, located next to the aft bulkhead door, indicated that neither nozzle had an effect at that location. The CAA position 5, located in the exhaust stack, only provided HF concentration data during ventilation and is, therefore, not included here.

TABLE 2. PEAK HF CONCENTRATIONS DURING SUPPRESSION IN PPM (VOL.).*

CAA Position	No WSCS	Bete® TF6FC	GEM® AM10
1	3400 **(3)**	2800	5400
2	I700	1100	1000 (1)
3	1600	960	970
4	*2500* **(3)**	2700	*2500*

* Results are the average of two **tests** unless otherwise specified in parentheses.

To further analyze the performance of the WSCS with respect to HF concentration, the effects of WSCS initiation time and application duration on HF loading were evaluated. WSCS initiation times ranging from I5 - *60* sec prior to HFP discharge and **WSCS** application durations of 90 and 270 sec were also evaluated. Table **3** contains the HF loading calculated for each CAA location for the 175 kW total methanol fire tests with a I-min preburn.

Two factors affecting the fire suppression performance of the WSCS are the compartment temperatures just prior to and during the **WSCS** discharge and the amount of water reaching the flame sheet. A hotter compartment will vaporize more water resulting in greater oxygen dilution. An obstructed (especially a smaller) fire will be exposed to fewer WSCS drops. **Less** water at the fire will reduce the effectiveness of the WSCS at inhibiting the fire by energy abstraction.

The data in Table **3** clearly demonstrate that the WSCS reduced the HF loading. The HF loading generally decreased as the initiation time increased from 15 to 45 sec prior to HFP discharge. An initiation time of *60* sec prior to HFP discharge reversed this trend, which is most probably due to the fire having time to recover after the initial "knock-down" from the water vapor generated by the WSCS. Since the ventilation was still operating, much of the water vapor diluted air was lost through the exhaust ducts. Subsequent to ventilation shutdown, less additional water vapor was produced because the compartment was cooled by the initial WSCS application. Therefore, the fire was able to recover before the discharge of the HFP. Although initiating the WSCS 45 sec prior to HFP discharge resulted in the greatest reduction of the HF loading (test WSCSl S2.8), an initiation time of 30 sec was recommended because implementation would not require any change to the current Fleet Firefighting Doctrine. In the Fleet, the ventilation system **is** secured 30 sec prior to HFP discharge for small FLSRs such as those simulated by the test compartment. Recommending a WSCS initiation time of 45 sec would require changing the time ventilation is secured to 45 sec prior to agent discharge. Both the 30 and 45 sec initiation times reduced the HF loading by about 75% when compared to the HF loading in non-WSCS scenarios in this compartment and fire scenarios. Despite the different nozzle spray angles, there is no statistically meaningful

TABLE 3. HF LOADING FOR DIFFERENT WSCS INITIATION TIMES AND APPLICATION DURATIONS.

Test Name	WSCS Initiation Time (sec)*	Water Application Duration After **HFP** Discharge (sec)	FTIR (ppm-secs)	CAA 1 (ppm-sec)	CAA2 (ppm-sec)	CAA3 (ppm-sec)	CAA4 (ppm-sec)
1s2.1	None	n/a	130,000	260,000	260,000	240,000	220,000
1S2.1rep	None	n/a	160,000	690,000	280,000	310,000	Data not available
1S2.1rep2	None	n/a	220,000	550,000	Data not available	Data not available	400,000
1S2.7rep†	-15	90	92,000	150,000	73,000	75,000	130,000
1S2.2†	-30	90	Data not available	210,000	50,000	68,000	100,000
1S2.3‡	-30	90	150,000	250,000	Data not available	28,000	130,000
1S2.8†	-45	90	140,000	130,000	51,000	48,000	83,000
1S2.9†	-60	90	Data not available	190,000	68,000	87,000	Data not available
1S2.10†	-30	270	210,000	63,000	73,000	48,000	110,000
1S2.11‡	-30	270	82.000	210.000	54.000	74.000	80.000

* WSCS IT is in reference to agent discharge; gaseous agent discharge is at t=0.
† Bete® TF6FC nozzle; ‡ GEM® AM10 nozzle

difference between the Bete® and the GEM® nozzles in reducing HF loading. HF loading reduction is fire scenario and sampling location specific.

Initial suppression tests were conducted with a WSCS application duration of 90 sec after gaseous agent discharge. The HF concentration decayed slowly between the time the WSCS was secured and the time ventilation was initiated ("hold time" - approximately 15 min). For tests in which the WSCS was initiated 30 sec prior to gaseous agent discharge (WSCSlS2.2 and WSCS1S2.3), the average HF concentration in the compartment 5 min after HFP discharge was greater than 55 ppm. To determine whether a longer WSCS application duration would decrease the HF concentration during the hold time even further, tests WSCS1S2.10 and WSCS1S2.11 were conducted with a 270 sec WSCS application duration after gaseous agent discharge. The average HF concentration 5 min after HFP discharge in these tests was 30 ppm. The extended WSCS application duration decreased the average HF concentration to 30 ppm, the Immediate Danger to Life or Health concentration (IDLH) [I0]. The average HF concentration measured in the tests without the WSCS system was 300 ppm. As a result, an application duration of 270 sec after gaseous agent discharge (5 min total) was recommended (Table **4).**

TABLE 4. SUMMARY OF HF CONCENTRATIONS DURING HOLD TIME FOR TESTS WITH AND WITHOUT WSCS (60 SEC PREBURN).

Test **Name**	WSCS Initiation Time (sec)	**HF** Concentration at 5 min After **HFP** Discharge (ppm)	**HF** Concentration at Venting Initiation (ppm)
Without WSCS	n/a	300	70
2 min WSCS Application	-30	55	45
5 min WSCS Application	-30	30	30

Figure 2 compares the HF concentration over time as measured by the same CAA for two tests. Test WSCS1S2.1rep2 was a suppression test in which the WSCS system was not used. Test WSCSIS2.1I was a suppression test with WSCS. The WSCS system was initiated 30 sec prior to HFP discharge and was secured 5 min later at t = 270 sec. During both of these tests, ventilation was secured at t = -30 sec, HFP was discharged at t = 0 sec, and ventilation was initiated at t = 900 sec. Reignition of the pan and cascading fires occurred after ventilation was initiated in the test with WSCS. Only the cascading fire reignited in the test without WSCS because the pan reignition source failed during the hold time. The HF concentration in the test with WSCS decreased dramatically after the HFP discharge (Figure 2). At 5 min after HFP discharge, the HF concentration at this CAA location was still above 600 ppm in the test without WSCS, whereas it was 45 **ppm** in the test with WSCS. The HF concentration in the test without WSCS remained above 100 ppm throughout the hold time (0 - *900* sec). This trend was typical of those seen at all CAA locations. These results clearly demonstrate the increased HF reduction provided by a low flow (10.6 Lpm [2.8 gpm]) WSCS system. Table 5 summarizes the data presented in Figure **2.** Figure 3 compares the CAA data with the HF concentrations measured by the FTIR at the same location during a test without WSCS (WSCS1S2.1rep). The HF concentrations measured by the CAAs are higher because the CAAs measure both aerosol and gaseous HF whereas the FTIR measures only gaseous HF.

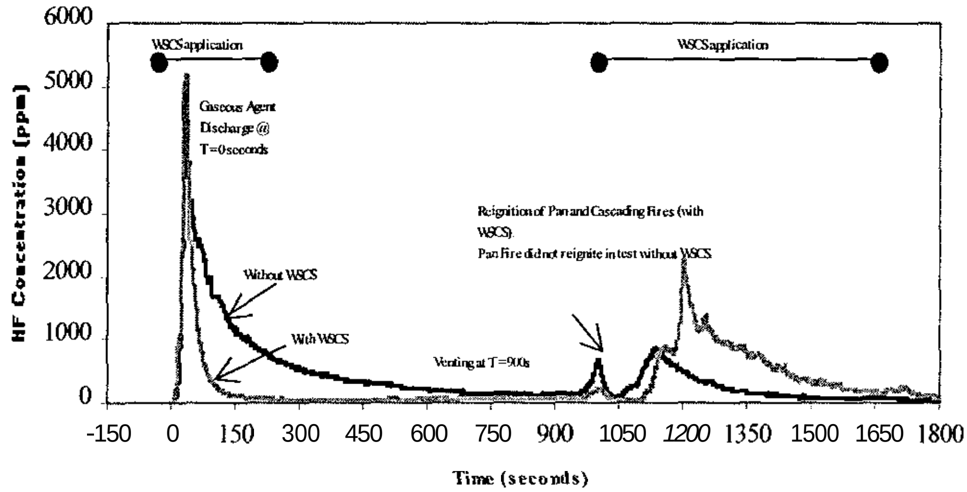

Figure 2. Continuous acid traces for tests with and without WSCS.

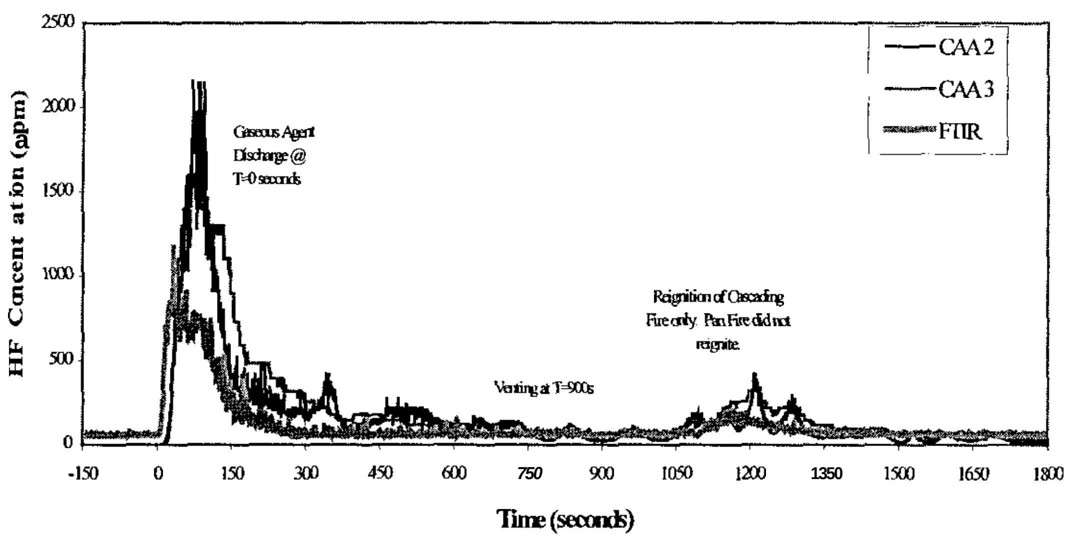

Figure 3. HF Concentration—CAA and FTIR—no WSCS.

TABLE 5. SUMMARY OF HF CONCENTRATIONS DURING HOLD TIME FOR TESTS.

Test Name	Fire Prebum Duration	WSCS Initiation Time (sec Prior to HFP Discharge)	WSCS Application Duration (sec)	HF Concentration 5 min After HFP Discharge (ppm)	HF at Ventila-tion Initiation (ppm)
WSCSl S2.I rep2	60	n/a	n/a	610	120
WSCS1S2.11	60	-30	300	45	40

WSCS EFFECTS ON FIRE-OUT TIME

The fire-out times for the 175 kW methanol fires (with and without WSCS) can be found in Table 6. The average fire-out times for pan and cascading fires with and without WSCS are within about 2 sec of each other. During two of the tests without WSCS (WSCS1S2.1rep and WSCS1S2.1rep2), a small amount of fire activity (i.e., flashing) was observed around the cascading hot rod for several sec after the fire was extinguished. Although the fire-out times are similar, the cascading fire flashing is eliminated with the addition of WSCS, indicating significant compartment surface cooling and reduction of fuel evaporation.

TABLE 6. FIRE-OUT TIMES (175 KW METHANOL FIRES).

Test Name	WSCS Initiation Time (sec)	Pan Fire-out Time	Cascading Fire-out Time (sec)
WSCSl s2.1	No WSCS	10	8
WSCS1S2.lrep	No WSCS	11	20, flashing to 30
WSCSlS2.1rep2	No WSCS	9	12, flashing to 25
WSCS1S2.2	-30	16	14
WSCS1S2.3	-30	10	12
WSCSlS2.7rep	-15	10	12
WSCS1S2.8	-45	13	13
WSCS1S2.9	-60	11	11
WSCS1S2.10	-30	13	13
WSCS1S2.11	-30	12	12

*WSCS IT is in reference to gaseous agent discharge at t=0.

WSCS EFFECTS ON COMPARTMENT TEMPERATURE

Unlike water, gaseous fire suppression agents do not provide much compartment cooling. Compartment temperatures for the 175 kW methanol fire tests with HFP and WSCS were approximately 10°C lower after fire extinguishment than those from the tests with HFP only. The temperatures in the 350 kW methanol fire tests with HFP and WSCS were approximately 20 °C lower after fire extinguishment than the temperatures from the tests with HFP only. Both the Bete® TF6FC and the GEM® AM10 nozzles provided similar cooling effects in the compartment.

Tests conducted during this test series consisted of short preburn durations, yielding cooler compartment temperatures than those observed in past test series. Short, realistic preburns were chosen to challenge the WSCS and gaseous agent systems via limited oxygen depletion and high HF concentrations. The WSCS produces more dramatic cooling effects in scenarios with higher compartment temperatures, such as those seen in previous testing conducted aboard the ex-USS SHADWELL [4]. The WSCS also produces more dramatic HF reduction, including production reduction, with larger, less obstructed fires.

FINAL NOZZLE SELECTION

Both the Bete" TF6FC nozzle and the GEM' AM10 nozzle provided desirable results throughout the test series. Neither nozzle performed significantly better than the other during fire suppression in terms of the reduction of HF, the time to fire out, or the reduction of compartment temperatures.

SUMMARY OF FINDINGS

These findings apply only to protecting compartments with a maximum volume of 28 m' (1000 ft^3), a maximum area of 9 m^2 (100 ft'), and a maximum height of 3 m (10 ft) with a combined HFP and WSCS system having a nominal HFP design concentration of 10.6% at 21 °C (70 °F). The WSCS system discharged through a single nozzle with a spray angle of 90-120 deg at 10.2 bar (150 psi). The higher flow rate nozzles evaluated in this test series did not provide added protection over the 10.6 Lpm (2.8 gpm) nozzles. **In** some cases, the higher flow rate nozzles provided reduced protection. Although other nozzles and application rates may provide adequate protection, only the Bete® TF6FC and GEM® AM10 were examined due to the limited number of suppression tests available. A WSCS initiation time of 30 secs prior to gaseous agent discharge provided about a 75% reduction in HF loading in our fire scenario. Although longer application durations may provide further reduction of the HF concentration, a 270 sec WSCS application duration after gaseous agent discharge is recommended here to limit the quantity of water discharged into the compartment. Shorter application durations (but at least 90 sec) may be acceptable if water availability or interactions are important considerations.

CONCLUSIONS

Tests of HFP with WSCS in the 28 m^3 (1000 ft^3) have demonstrated the performance advantages provided by the WSCS over an HFP only system. The HF loading reduction (by 75%) expedited compartment reentry and reduced HF exposure. The WSCS also lowered compartment temperatures and improved reignition protection. These advantages were achieved with a low pressure system flowing only 10.6 Lpm (2.8 gpm) for 5 min.

The diminished effectiveness of WSCS noted with higher application rates or longer periods of application prior to gaseous agent discharge provide significant input for optimizing water mist (only) suppression systems.

Additional implementation guidance and considerations for future testing include the following: the effects of WSCS usage during hold time, the effects of WSCS usage during ventilation, and reignition and reclamation issues.

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