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# The Effects of a Water Spray Cooling System on Real Scale Halon 1301 Replacement Testing and Post Fire Suppression Compartment Reclamation

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## 1.0 INTRODUCTION

The United States Navy is investigating fixed fire extinguishing systems for future use in applications where Halon 1301 total flooding systems have traditionally been used. Many candidate halon total flooding replacement chemicals were evaluated at NRL both via laboratory cup burner' and intermediate scale' 56 $m^3$ (2000 ft') fire extinguishment tests. Replacements can yield significant quantities of toxic and corrosive halogen acids during fire suppression.[2,3] After intermediate' and full scale testing (Phase 1),[3] NRL has recommended heptafluoropropane, (HFC-227ea, $C_3F_7H$, manufactured by Great Lakes Chemical Corporation as FM-200) as the clean agent of choice for the U. S. Navy's next ship.[4] Little information has been available for the quantification of post-fire suppression compartment reentry (by the firefighting team) and desmoking or venting for Halon 1301 systems. The reduced safety margins of the replacement agents along with the increased acids threat have generated a need for such testing. Phase 2 tests were performed in accordance with the Test Plan[5,6] to help provide guidance on halon replacement system optimization and implementation.

## 2.0 TEST OBJECTIVES

Phase 2 full scale machinery space tests were conducted aboard the ex-USS SHADWELL located at Little Sand Island, Mobile, AL. The tests were performed with HFP, with limited baseline comparison tests performed with Halon 1301. A NRL designed Water Spray Cooling System (WSCS) was utilized to enhance fire suppression and reignition performance, reduce compartment temperatures, reduce acid decomposition product generation, and enhance acid concentration decay rate. Although the objectives of Phase 2

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testing were numerous, the focus of this paper will be on the performance and usage of the innovative WSCS.

## 3.0 TEST COMPARTMENT

The test compartment aboard the **ex-USS** SHADWELL was located at the 4th deck upper and lower levels between Frames 22 and 29 with catwalks on both levels (Figure 1). The approximate dimensions of the space were 8.5 m (28 ft) long from frames 22 to 29, 6.1 m (20 ft) high from keel to 3rd deck and 8.5 m (28 ft) wide (port to starboard) at frame 29 narrowing to 7 m (23 ft) wide at frame 22. The enclosed volume was approximately 395 $m^3$ (13,950 ft'). With the LM-2500 gas turbine mock-up occupying approximately 7% of the air space, the adjusted compartment volume became 370 $m^3$ (13,000 $ft^3$). The primary supply and exhaust ventilation system in the test space provided approximately **55** air changes per hour. A second exhaust system, the acid exhaust system, was used for venting decomposition products.

The nomenclature used to identify a location in the test compartment, e.g., (4-22-3: 0.6m), was level first (4 or 5 for upper or lower) followed by the frame number (22-29) and then by its athwart ship position (0-4). Zero (0) refers to centerline, 1 and **3** to starboard, and 2 and 4 to port, with **3** and 4 being farthest away from centerline. In general, the height was expressed in meters from the level's deckplate. Thermocouple tree heights, however, were all measured from the lower level deckplate.

## 4.0 AGENT *AND* WATER SPRAY COOLING SYSTEMS

The two gaseous agent extinguishing systems used (Figure 1) in the tests described below were designed by MPR with the computer code TFA.[7] Each system, one for HFP and one for Halon 1301, consisted of 4 discharge nozzles divided into two tiers.

The Halon 1301 system used standard Navy 4 hole (horizontal-cross) nozzles. The HFP discharge system used similar nozzles. However, because of the increased agent volume required to deliver effective concentrations of HFP, the nozzle diameters were larger than the standard Navy. All nozzles in all tests were oriented in the forward / aft position.

The Water Spray Cooling System (WSCS) was made out of 1 inch stainless steel tube and compression fittings. The looped system had 13 TF10FC nozzles, manufactured by Bete Fog Nozzle, Inc. The nozzles have a 120" degree full cone mist pattern. The brass nozzles had 1/4 inch male pipe connections. The WSCS was located in the compartment overhead just below the overhead stiffeners. Water for the WSCS was supplied by a 1 ½ inch standpipe connection to the firemain.. The WSCS Application Rate (WSCSAR) for Class A fires[8] was determined by:

$$\text{WSCSAR (gpm)} = \text{Compartment Volume } (ft^3)/270$$

This WSCSAR was then doubled for Class B fires.[9] For a Class B fire in a compartment volume of 13000 $ft^3$, the WSCSAR is 96 gpm. The WSCS flow rates were controlled by the firemain pressure. The system delivered 60 gpm at 80 psi.

## 5.0 INSTRUMENTATION

The suppression agent discharge systems were instrumented to measure temperature and pressure at each of the 4 nozzles as well as 2 locations in the piping. Pressures were also measured at one cylinder valve and check valve on the manifold. One bottle was attached to a load cell to measure mass loss. In addition, the test space was instrumented to measure gas, fire and bulkhead temperatures. Compartment and fuel pressures were also monitored. A continuous gas sampling system measured oxygen, carbon dioxide, carbon monoxide, and agent concentration at 2 locations in the space, and in the supply and acid exhaust ducts. Grab samples were taken at specified times and locations during each test. One type of grab sample (4 locations) was analyzed using a Gas Chromatograph (GC) to determine agent, oxygen, carbon dioxide and carbon monoxide concentrations. The other type of sample (4 locations) was analyzed using an Ion Chromatograph (IC) to quantify the concentration of halide acids in the space. Seven continuous acid analyzers (CAA) were also used at different locations in the compartment for "real-time" measurements of acids via electrochemical cells.

## 6.0 FIRES AND TEST SCENARIOS

There were 3 fire locations in the machinery space. Table 1 lists the fire specifications used for the Phase 2 tests described in the paper. In addition, to the three main fires there were 17 telltale fires (about 3 kW each) located throughout the compartment.

| Fire | Pan Sire (m x m) | Pan Area ($m^2$) | Pan Fire Sire (MW) | F-76 Diesel Spray Flow Rate (lpm) | F-76 Diesel Spray Fire Size (MW) |
|---|---|---|---|---|---|
| 1 | 2.44 x 0.91 | 2.23 | 4.5 [a] | 5.7 - 7.9 | 3.3-4.7 [a] |
| 2 | | | | 0.7 - 0.8 | 0.09-0.1 |
| 4 | | | | 0.7 - 0.8 | 0.09-0.1 |

## 7.0 TEST SERIES

The Phase 2 testing consisted of seven series of tests. Series' particulars are listed in Table *2* and particulars for the tests analyzed in this paper are listed in Table **3.** Fire suppression tests used HFP at 10.1% design concentration (Series 3-5), or Halon 1301 at 5.2% design concentration (Series 6).

## 8.0 RESULTS

### 8.1 Fire Suppression and Reignition Prevention

All fires were extinguished for each scenario tested. A preliminary summary of Series 3-6 test results is shown in Table 3. These data are based on visual observation of IR video. Reignitions were attempted at Fires 2 and 4. The attempts were performed every minute until a successful reignition occurred. **No** attempts were made after the first 5 minutes of venting.

Preliminary results indicate that WSCS introduction prior to agent discharge as well as during the venting enhances reignition protection. Also, at the agent design concentrations tested Halon 1301 provided better reignition protection than HFP.

Although there was no dramatic difference in overhead relative temperature decreases (see Section 8.2 Temperature Reduction) between Tests 4.2 and Test 3.6 (no WSCS), the introduction of the WSCS during venting prevented a sustained reignition (Test 3.6) and resulted in only a brief reignition lasting **3** seconds.

## 8.2 Temperature Reduction

8.2.1 WSCS Not Used

Figure 2 shows the measured temperatures from the aft thermocouple tree during Test 3.6. The introduction of the agent in the compartment (flash cooling) and the suppression of the fires reduced the ambient temperatures. The maximum measured temperature (aft thermocouple tree) did not decrease to 100°C until 180 seconds after agent discharge initiation.

8.2.2 WSCS Initiated At Same Time As Agent Discharge

For Test 4.5 (Figure 3) the WSCS was initiated simultaneously with the gaseous agent discharge. The WSCS was run for 60 seconds at a WSCSAR of 60 gallons per minute (gpm). Within 40 seconds after discharge initiation all aft thermocouple tree temperatures were below 50°C. The cooling effect of the WSCS is clearly visible.

8.2.3 WSCS Initiated Before Agent Discharge

During Test 5.2 the WSCS was initiated 60 seconds before agent discharge for a 120 seconds application, and at 780 seconds after discharge initiation for a 60 seconds application. Figure **4** shows the measured temperatures from the aft thermocouple tree. The peak temperature from the aft thermocouple tree was measured 320°C just prior to WSCS activation. The most dramatic temperature reduction is observed in the upper level of the compartment. At agent discharge (60 seconds after WSCS initiation) the peak measured temperature was 60°C. Within 20 seconds after agent discharge initiation the measured aft thermocouple tree temperatures were all below 40°C. In a real shipboard fire, the introduction of the water spray prior to agent discharge would drastically limit **flame** spread and reduce damage by reducing compartment temperature. Similar WSCS effectiveness is expected when used with other halon-like agents.

8.2.4 WSCS Initiated After Agent Discharge

The effects on compartment temperature of the WSCS initiation after fire suppression are demonstrated in Test 4.2 (Figure ***5).*** For this test the first WSCS application was initiated 300 seconds after agent discharge initiation and lasted 60 seconds. A second application, for 120 seconds, was initiated simultaneously with compartment venting at 900 seconds. The first WSCS application reduced overhead temperature from 70°C to below 40°C with 20 gallons of water within 20 seconds. The second WSCS application, in conjunction with the venting, reduced the temperature from 35°C, to below 25°C within 20 seconds compared to a decrease from 65°C to below 55°C in 100 seconds for Test 3.6 (no WSCS used).

## 8.3 HF Generation and Mitigation

8.3.1 WSCS Not Used

The reported peak measured values are from one of the Continuous Acid Analyzers

(CAA) located in the upper level of the compartment. HF values for HFP tests without the WSCS were 5000 parts per million (ppm) for Test **3.6** and 4100 ppm for Test 4.2. For the Halon 1301 Test 6.1 the measured peak was 1100 ppm. The higher HF generated values associated with HFP are consistent with Phase 1 testing.

8.3.2 WSCS Initiated At Same Time As Agent Discharge

The initiation of the WSCS at the same time as agent discharge (Test 4.5) limited HF generation to a peak value of 1800 ppm, compared to values over 4000 ppm for tests without WSCS.

| Series No. | Agent | Discharge System | Number of Nozzles | Fires | WSCS Application | | | Hold Time (time prior to venting) (min) |
|---|---|---|---|---|---|---|---|---|
| | | | | | Before Agent Discharge | During Agent Discharge | Priori During Venting | |
| 1 | No | No | No | Yes | No | No | No | |
| **2** | HFP | Standard Navy | 4,8 | No | No | No | No | 30 |
| 3 | HFP | Standard Navy | 4 | Yes | No | No | No | 5, 15, 30 |
| 4 | HFP | Standard Navy | 4 | Yes | No | Yes | Yes/No | 15 |
| *5* | HFP | Standard Navy | **4** | Yes | Yes | Yes | Yes/No | 15 |
| **6** | Halon 1301 | Standard Navy | 4 | Yes | Yes/No | Yes/No | Yes/No | 15 |
| *7* | HFP | Modified[a] | 4 | Nu | No | NO | No | 30 |

or HFP Tests Series 3-5, and Halon 1301 Tests Series 6

| Test No. | WSCS Initiation (min:sec) (t=0 @ discharge) and Duration (min:sec) | | | | WSCS AR (gpm) | Fire Extinguishment Times (min:sec) [a] | | | Peak HF Conc.[b] (ppm) | Agent Conc. at Fire 1 @ 5 and 15 sec. (%) | Peak Comp. Temp. (°C) | Peak Comp. Temp. @ Venting Initiation (°C) | First Successful Sustained Reignition[c] (Venting Initiated @ 15:00 min) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | First Application | | Second Application | | | | | | | | | | | |
| | Initiation | Duration | Initiation | Duration | | 1 | 2 | 4 | | | | | Fire 2 | Fire 4 |
| 1.16 h | N/A | N/A | N/A | N/A | N/A | d | d | d | N/A | N/A | 400 | N/A | N/A | N/A |
| 3.6 | N/A | N/A | N/A | N/A | N/A | 0:10 | 0:09 | 0:04 | 5000 | 4.4/ 8.9 | 420 | 70 | No | |
| 4.2 | 5:00 | 1:00 | 15:00 | 2:00 | 60 | 0:09 | 0:12 | 0:08 | 4100 | 3.8/ 10.5 | 390 | 40 | e | e |
| 4.5 | 0:00 | 1:00 | N/A | N/A | 60 | 0:09 | 0:11 | 0:16 | 1800 | 3.5/ 10.2 | 320 | 50 | No | 17:00 |
| 5.2 | -1:00 | 2:00 | 13:00 | 1:00 | 60 | 0:07 | 0:05 | 0:04 | 200 | 3.2/ 9.3 | 330 | 40 | e | 16:00 |
| 5.3 | -2:00 | 3:00 | N/A | N/A | 60 | 0:08 | 0:05 | -0:36 | 1300 | 4.6/ g | f | f | No | 17:00 |
| 5.4 | -1:00 | 2:00 | 15:00 | 2:00 | 40 | 0:09 | 0:12 | 0:07 | 2000 | g | f | f | No | 18:00 |
| 6.1 | N/A | N/A | N/A | N/A | N/A | 0:09 | 0:11 | 0:06 | 1100 | g | f | f | No | 18:00 |
| 6.2 | -1:00 | 2:00 | 15:00 | 2:00 | 60 | -0:06 | 0:04 | -0:46 | 200 | g | f | f | No | 19:00 |

a - Times are determined from visual observations of IR video.
b - HF peaks from Continuous Acid Analyzers.
c - Reignitions attempted for the every minute from agent discharge until a successful reignition was achieved, up to 5 minutes after venting initiation.
d - Fuel to spray fires was secured 10 seconds after discharge initiation would have occurred (control fire- no suppression agent used).
e - None attempted due to equipment failure.
f - Data currently being processed.
g - Data not available.

## 9.0 DISCUSSION AND CONCLUSIONS

Results show that the innovative WSCS usage significantly reduced compartment temperatures. Overhead temperature was reduced from over 250°C to less than 60°C in less than 5 seconds from WSCS/agent discharge initiation. For comparison, the overhead temperature over the same interval dropped only 50°C with agent discharge alone. Results also showed that the WSCS dramatically reduced HF generation as well as accelerated the acid decay rate.

Phase 2 preliminary results show that the employed WSCS is a viable option for rapid reduction of compartment temperature. The low water pressure WSCS tested provided very rapid compartment temperature reduction in 15 seconds with less than 20 gallons of water. The ability of the WSCS to run off the ship's firemain or from its own pressurized water tank make it a viable system for shipboard installation.

Compartment reclamation initiation is a function of fire suppression, reignition potential, compartment temperatures and atmospheric acid product concentrations. The firefighting team reentry and compartment reclamation procedures depend on the particulars of a fire scenario: type of space, contents, and fire suppression system. Results show that the WSCS significantly reduced compartment temperatures and is particularly effective when initiated before agent discharge. The compartment temperature reduction as well as the reduced HF generation and subsequent mitigation concentration make the WSCS a viable supplement to a gaseous suppression system. Also, WSCS can enhance a gaseous agent's reignition protection and hence render the compartment safer during reentry and desmoking /venting.


## ACKNOWLEDGMENTS

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## REFERENCES


1. Sheinson, R. S., Penner-Hahn, J. E., and Indritz, D., "The Physical and Chemical Action of Fire Suppressants," Fire Safety Journal, vol. 15 (1989), pp. 437-450.

2. Sheinson, R. S., Maranghides, **A.,** Smith, W. D., Eaton, H. G., Burchell, H., Black, B. H., and Mitchell, C., "Halon 1301 Replacement Total Flooding Fire Testing, Intermediate Scale," Proceedings of the Halon Options Technical Working Conference, May 3-5, 1994, Albuquerque, NM, pp. 43-53.

3. Sheinson, R. S., Maranghides, **A.,** Eaton, H. G., Barylski, D., Black, B. H., Brown, R., Burchell, H., Byrne, P., Friderichs, T., Mitchell, C., Peatross, M., Salmon, G., Smith, W. D., and Williams, F. W., "Large Scale (840 m') HFC Total Flooding Fire Extinguishment Results," Proceedings of the Halon Options Technical Working Conference, May 9-11, 1995, Albuquerque, NM, pp. 637-648.

4. "Recommendations for the LPD-17 Main and Auxiliary Machinery Rooms Total Flooding Fire Suppression Systems," Sheinson, R. S., Maranghides, A., Friderichs, T., Black, B. H., Smith, W., and Peatross, M., NRL Letter Report 6180/0193.1, **24** July 1995.

5. "Test Plan for Halon Replacement Post Fire Suppression Compartment Characterization Testing on the **en-USS** SHADWELL," Sheinson, R. S., Maranghides, A., and Krinsky, **J.,** NRL Letter Report 618010592, 01 September 1995.

6. "Modification of the Test Plan for Halon Replacement Post Fire Suppression Compartment Characterization Testing on the ***Ex-USS*** SHADWELL," Sheinson, R. S., Maranghides, A., and Krinsky, J., NRL Letter Report 6185/00070, 27 February 1996.

7. Bird, E.S., Giesecke, H.D., Hillaert, J.A., Friderichs, T.J., and Sheinson, R.S., "Development of a Computer Model to Predict the Transient Discharge Characteristics of Halon Alternatives," Proceedings of the Halon Options Technical Working Conference, May 3-5, 1994, Albuquerque, NM, pp. 95-103.

8. Grimwood, Paul T., "FOG Attack", FMJ International Publications Ltd., United Kingdom, 1992, p. 88.

9. "U.S. Navy Salvage Ship Manual; Volume 3 (Firefighting and Damage Control)," S0300-A6-MAN-030, August 1, 1991, pp. 3-35.

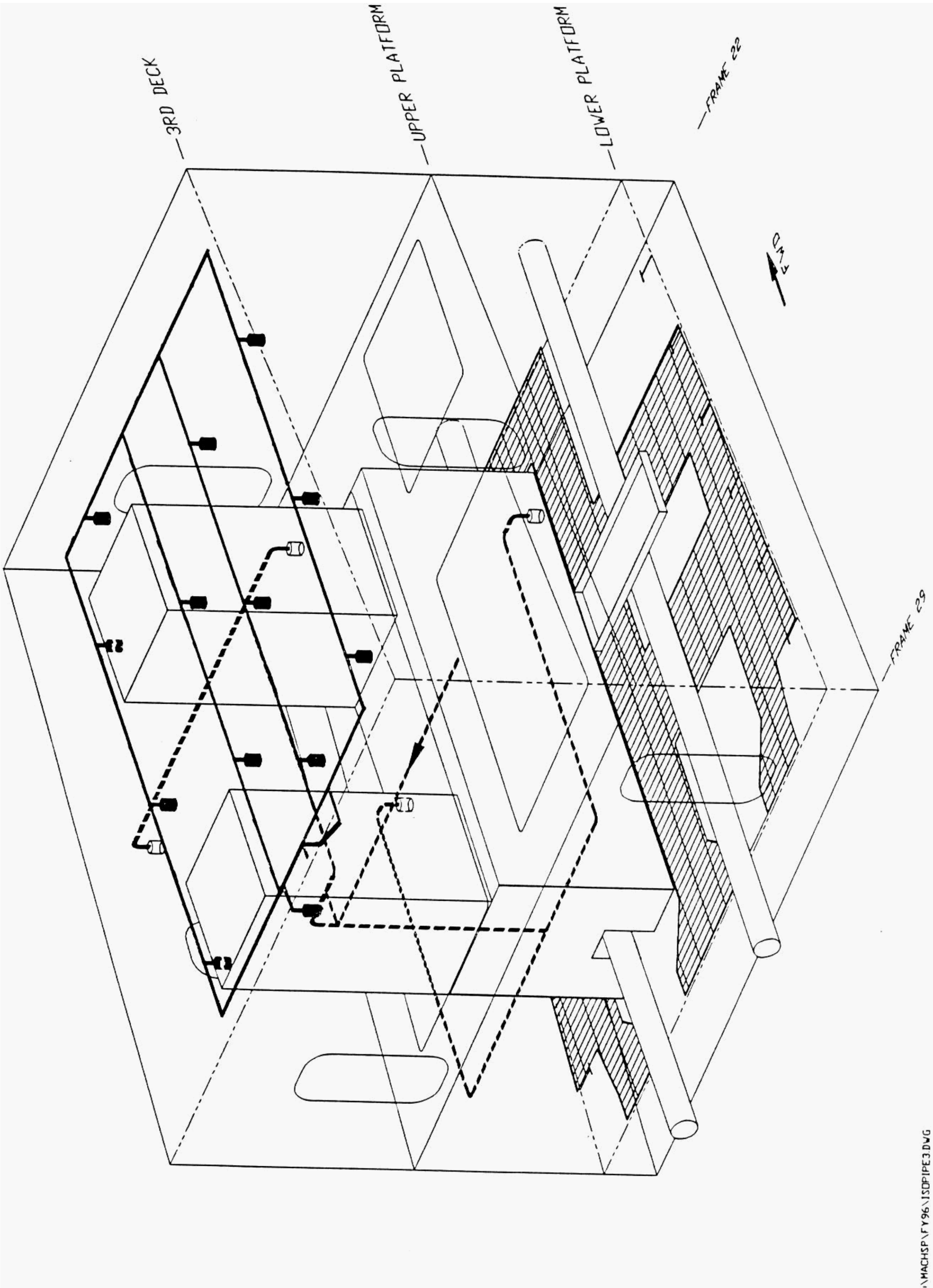
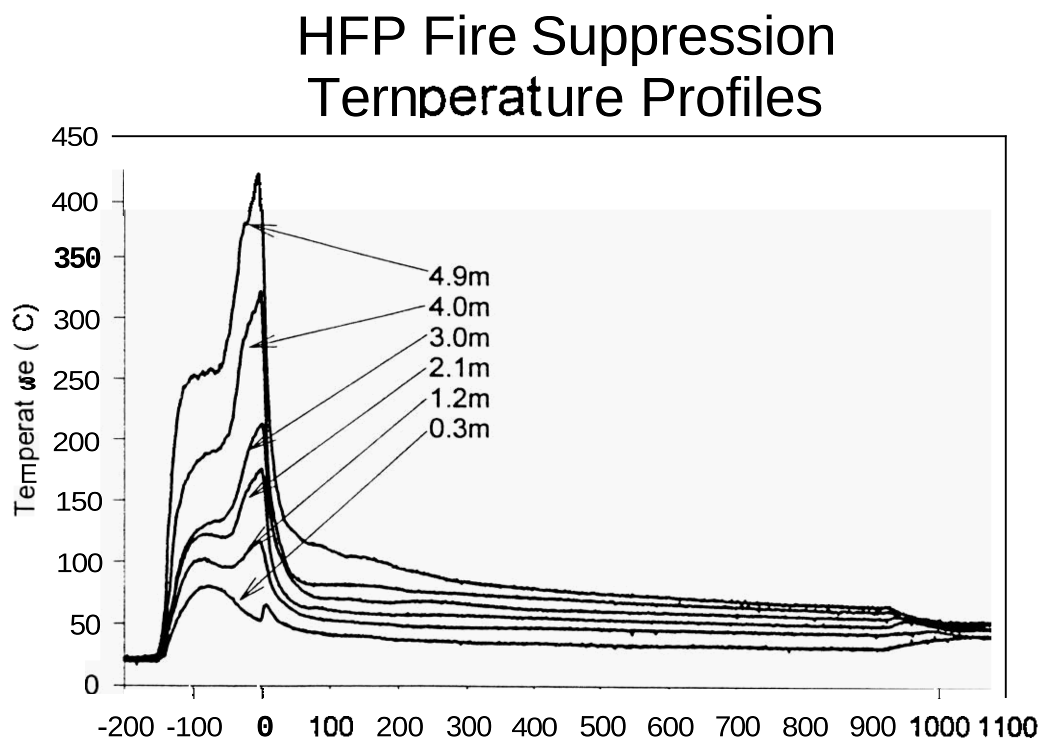
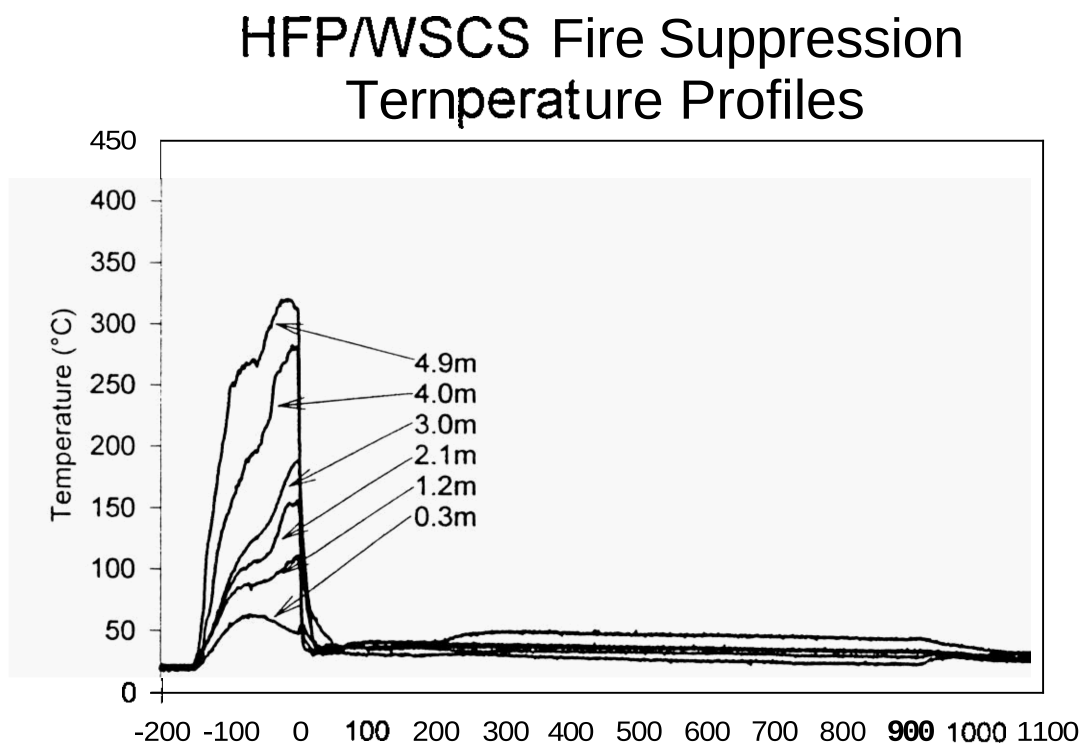

3RD DECK
UPPER PLATFORM
LOWER PLATFORM
FRAME 22
FRAME 29
FWD
C:\MACHSP\FY96\ISDPIPE3.DWG

Figure 1




**Time (seconds: agent discharge @ t = 0s)**
**(WSCS not Activated)**
**Figure** 2

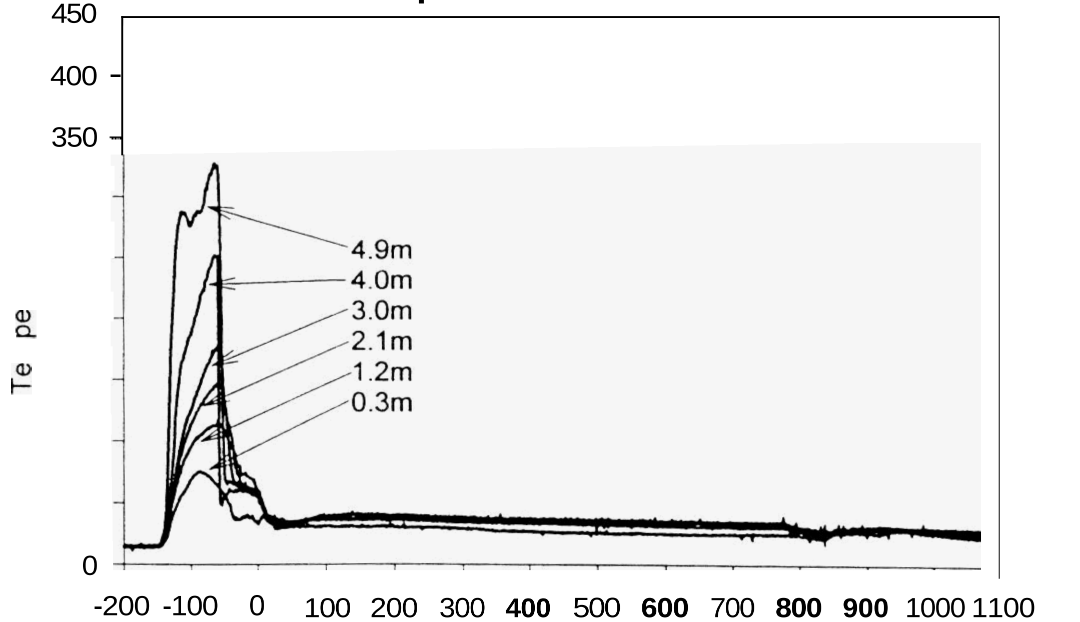
Thermocouple Tree 5-27-1
ex-USS SHADWELL
Phase 2 Test 3.6




**Time (seconds: agent discharge @** t = **0s)**
**(WSCS Initiated @** t = **0s** for 60s)
**Figure 3**

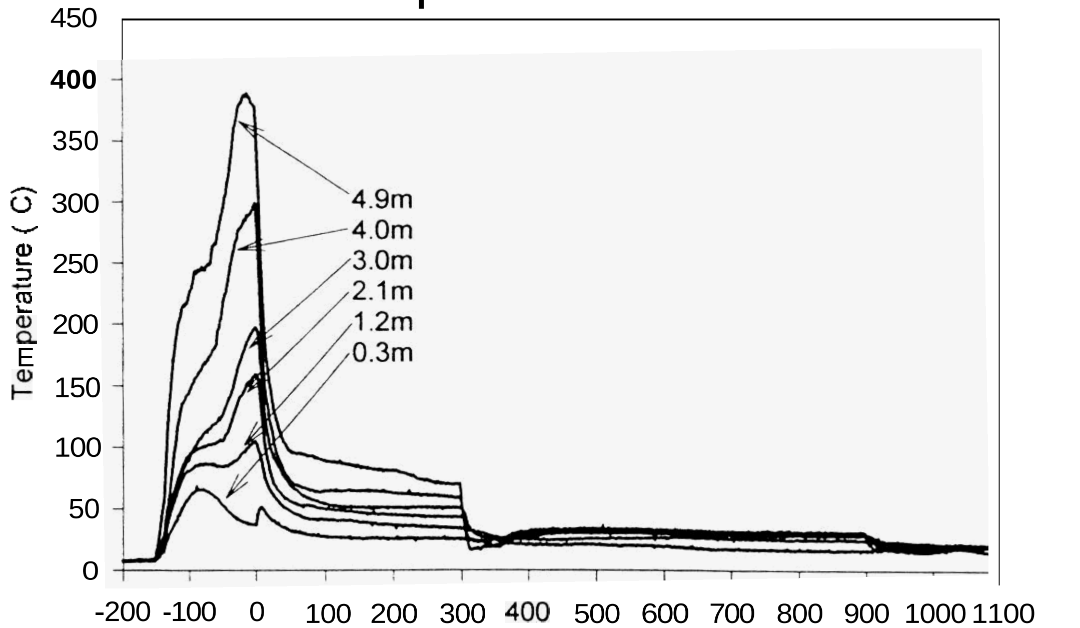
Thermocouple Tree 5-27-1
ex-USS SHADWELL
Phase 2 Test 4.5

## HFPMSCS Fire Suppression Temperature Profiles



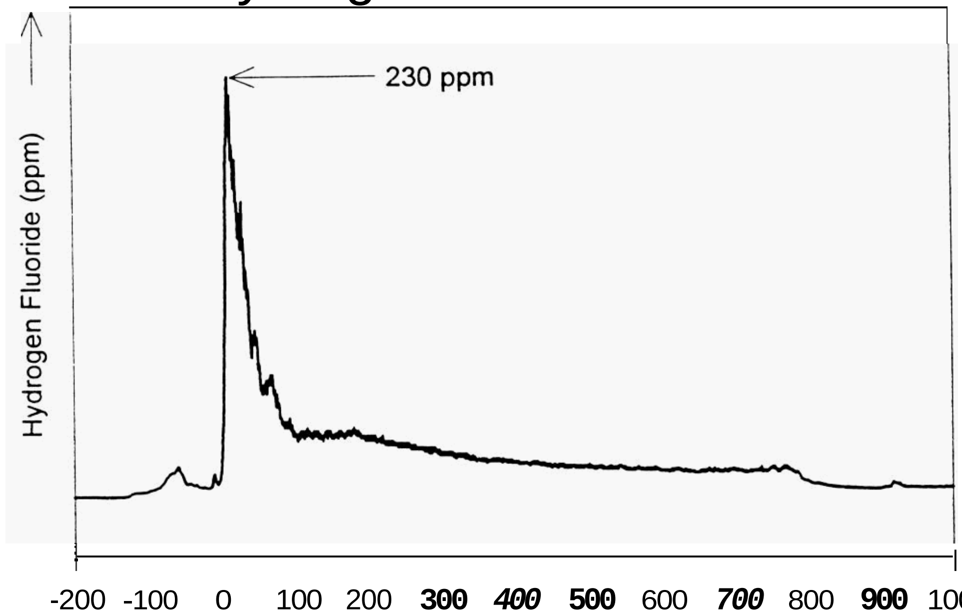

**Time (seconds: agent discharge @ t = 0s)**
(WSCS **Initiated @** t = **-60s for 120s & +780s for** 60s)
**Figure 4**

## HFPMSCS Fire Suppression Temperature Profiles




**Time (seconds: agent discharge @ t = 0s)**
(WSCS **Initiated @ +300s for** 60s **& +900s for 120s)**
**Figure 5**

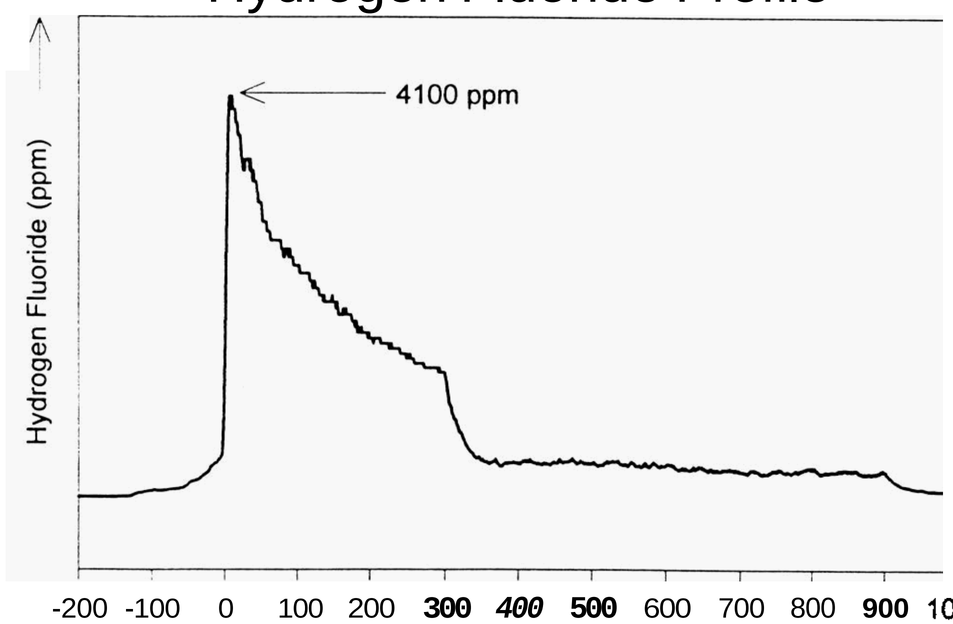
## HFP Fire Suppression
## Hydrogen Fluoride Profile




**Time (seconds: agent discharge @ t = 0s)**
***(WSCS* Initiated @ t = -60s for 120s & +780s for 60s)**
**Figure 6**

HF Analyzer: 4-22-3
ex-USS SHADWELL
Phase 2, Test 5.2

## HFP Fire Suppression
## Hydrogen Fluoride Profile




**Time (seconds: agent discharge @ t = 0s)**
**(WSCS Initiated @ t = +300s for 60s & +900s for 120s)**
**Figure 7**

HF Analyzer: 4-22-3
ex-USS SHADWELL
Phase 2, Test 4.2