# Total Flooding Agent Distribution Considerations

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## Introduction:

This paper addresses results obtained during Naval Research Laboratory's (NRL's) real scale Halon replacement testing aboard the **ex-USS** SHADWELL in accordance with the test plan.' A results matrix for these tests ***can*** be found in reference (2). The agents tested were Halon 1301, $CF_3H$ (HFC-23) manufactured by DuPont de Nemours and Co. as FE-13, and $C_3F_7H$ (HFC-227ea) manufactured by Great Lakes Chemical Corporation **as** FM-200. All agents tested were successful in extinguishing all the design fires. These tests were designed to realistically simulate shipboard machinery space fires. Figure 1 is **an** isometric view of the test compartment and mock-ups used for this test series.

The purpose of this paper is to illustrate the effects of agent discharge time on agent distribution (i.e. inhomogeneity) **as** well **as** the effects of over-pressurization with nitrogen on agent dilution. Discharge time is important because longer discharge times result in higher level of undesirable decomposition products.' Inhomogeneity is important because a fire located at an **area** of low agent concentration will yield higher levels of decomposition products and reduced fire suppression protection. Results presented in this paper were previously included in the US Navy report issues **January** 24, 1995, as NRL Letter Report 61**80/0049** "Agent Concentration Inhomogeneities in Real Scale Halon Replacement Testing Aboard the Ex-USS SHADWELL."

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## Testing and Results:

### Background:

NRL has investigated agent inhomogeneities in shipboard Halon 1301 total flooding systems in the past[4] and during intermediate scale (ISC) testing at Chesapeake Bay Detachment (CBD). Variations in distribution, for two identical test scenarios in the ISC 56 $m^3$ (2000 $ft^3$) test compartment, resulted in extinction times of 6 and 12 seconds. Figure 2 shows fire suppression agent concentrations low in the compartment during and after discharge.

### Discharge System:

The real scale (RSC) agent discharge system was a 9 nozzle two level system. The system was designed according to the standard Navy specifications for total flooding Halon discharge systems.[5,6] The nozzles used were the standard Navy 4-hole horizontal cross type although larger than what is currently in the fleet because of the greater volume of replacement agent requirements compared to Halon 1301. Nozzle orifices were oriented in the fore-aft position.

### Discharge Times:

Navy agent storage tank hardware is the discharge system bottleneck on flow rate. The discharge system installed and tested on ex-USS SHADWELL used the largest nozzle orifices possible without reducing nozzle pressures to unacceptable low levels. Lower fill densities and / or higher nitrogen pressurization *can* be used to effect shorter discharge times. Higher nitrogen pressurization was employed in this test to achieve the faster discharge. The baseline discharge time was 10 seconds, the fast discharge 6 seconds. A discharge time below 5 seconds would have been very difficult to achieve and would have had little effect on fire out time and acid production.

### Fire Locations:

There were 5 main fires (Figure 3) and twenty nine indicator fires (pool fires 2 inches in diameter). The fuel for the baseline and fast discharge tests discussed in this paper was n-heptane. Reference 2 lists the particulars of the tests performed with F-76 (Navy diesel).

**Agent Sampling Locations:**

The agent concentration data used for this analysis are from the agent grab samples. The grab samples are collected with pre-evacuated 1.7 liter bottles connected to solenoid valves. The valves are computer activated (at predetermined times) during the test. Figure 4 shows the locations of the agent grab samples and agent discharge nozzles. The following is a detailed description of sample locations:

- Location 1: Forward, fourth level lower, port, between the LM2500 Gas Turbine Engine mock-up and port bulkhead. Samples are located on grating. There is a supply duct (0.45 m diameter) located 1 m above the samples. Samples located 1 m from Fire 2 (0.05 - 0.075 liters per minute (lpm) spray with 0.3 m x 0.3 m pan) The closest agent discharge nozzle is located 2.4 - 3 m aft of the samples and some 0.15 m above the top of the duct. The forward agent jet from the nozzle is directed between mock-up, port bulkhead, 4th level solid catwalk, and duct.
- Location 2: Forward bulkhead, fourth level upper, 0.7 m port of centerline, 0.7 m from the overhead. Samples located 1 m from Fire 4 (Overhead Cable with 0.05 - 0.075 lpm spray and 0.5 m x 0.5 m pan)
  The forward upper port agent discharge nozzle is 4 m aft, 0.7 m from the port bulkhead, and 0.7 m below the overhead. The forward upper part of the LM2500 Gas Turbine Engine mock-up is between the samples and the nozzle. The forward agent jet from the nozzle is directed between the mock-up, port bulkhead, overhead, and 4th level solid catwalk.
- Location 3: Forward, forth level lower, starboard, at the base of Fire 1 (0.05 - 0.5 lpm spray with 0.8 to 1.5 $m^2$ pan).
  The forward lower starboard agent discharge nozzle is located 1 m above the fire pan.
- Location 4: Aft, fourth level lower, port, between the LSD41 Diesel Engine mock-up and port bulkhead. Samples are located on grating.
  The closest agent discharge nozzle is located 3 - 4 m forward of the samples and 0.3 m above the Reduction Gear mock-up. The aft agent jet from the nozzle is directed towards the LSD41 mock-up.
- Location 5: Aft bulkhead, fourth level upper, centerline, 1 m below the overhead.
  The discharge nozzle closest to the grab samples is located 1.2 m forward and

0.5 m below the overhead. The aft agent jet from the nozzle is directed towards the samples.

**Measured Agent Concentrations:**

Tables 1 and 2 contain the minimum and maximum measured agent concentrations, the locations they each occurred at, and the difference between the two concentrations.

With the fast discharge by 5 sec. (after discharge initiation) the lowest measured concentration in the compartment is 7.2% vs 3.7% for the regular discharge. With the fast discharge the highest measured concentration occurs at location 5 (aft upper centerline, 1.2 m from a nozzle). This concentration is measured at 5 sec. Because it is a 6 second discharge, the 8 second sample begins to show a decrease in agent concentration due to nitrogen dilution (Figure 5). This nitrogen dilution was also measured during intermediate scale testing. The location 5 then becomes almost consistently the one with the lowest measured agent concentrations decreasing to 7.6% at 16 seconds (design concentration was 9.2%).

With the 10 second discharge, the measured agent concentration inhomogeneity differential reaches its maximum of 7.0% at 11 seconds (end of discharge), and decreases to below 3.0% by 10 minutes. At 10 minutes, the lowest measured concentration is 9.0%. With the fast discharge the measured agent concentration inhomogeneity differential reaches its maximum of 7.5% at 5 seconds (6 second discharge), and decreases to below 3.0% by 31 seconds. At 31 seconds the measured low concentration in the compartment is 8.4%.

The nitrogen dilution associated with the fast discharge is detected throughout the compartment with lower peak and average concentrations (compared to the regular discharge) measured from 11 seconds on.

The fast discharge being more energetic provides better mixing in the compartment resulting in a more homogeneous environment. Dilution was more pronounced in the vicinity of nozzles and up in the overhead. Dilution occurred in the vicinity of nozzles since the majority of nitrogen was discharged after completion of the agent liquid discharge and up in the overhead because the lower density nitrogen (compared to the agent) remained relatively unmixed high in the compartment because of buoyancy. Air infiltration from the exhaust opening high in the overhead enhanced agent dilution and further reduced the degree of protection in that area.

**Nitrogen Content for Various FM-200 Storage Conditions:**

The weight ratios of nitrogen to FM-200 calculated by MPR[5] using the computer program TFA are listed in Table 3. The ratios are for two different fill densities and bottle pressures from 2.6 to 8.4 MPa (300 to 1200 psig). Nitrogen content in Halon 1301, for 2.6 and 4.2 MPa (300 and 600 psig) storage pressures are listed in Table 4. The agent dilution due to nitrogen is a function of the agent design concentration. For 4.2 MPa (1200 psig) storage pressure and 1155 $kg/m^3$ (72 $lb/ft^3$) agent fill density, Table 5 lists agent concentration dilutions for FM-200 design concentrations from 8.0% to 10.5%. Table 6 contain the agent concentration dilution due to conditions in Table 3. Given a 4.24 MPa storage pressure, with 802 $kg/m^3$ (50 $lb/ft^3$) agent (FM-200) fill density, a 10% design concentration (based only on agent mass) becomes 9.39% when nitrogen dilution is considered. For Halon 1301, at 4.24 MPa pressure, with 1155 $kg/m^3$ agent fill density, a 5% design concentration (based only on agent mass) becomes 4.97% when nitrogen dilution is considered. Although nitrogen is a fire suppressant agent, it is much less effective than FM-200. While nitrogen mixed with other agents gives increased protection, inhomogeneities and displacement of the primary agent can however greatly reduce protection locally.

**Agent Dilution Due to Leakage:**

Agent dilution due to leakage and air infiltration were measured during the cold discharge tests (no fires). Figure 6 shows agent concentration in the test compartment measured at a non-dampered exhaust duct. The measurements were taken with a Thermal Conductivity Agent Detector (TCAD); unit similar to ones used for shipboard certification of total flooding Halon 1301 and $CO_2$ systems. The graph illustrates the agent concentration dilution near the non-dampered exhaust duct. In the overhead, agent dilution resulted in reflashes (non-sustained reignitions) lasting up to 15 seconds. Suppressant concentration calculations should take into account air infiltration in order to maintain adequate agent concentration at all locations in the compartment for the given ventilation and discharge nozzle particulars.

**Protection Provided by Halon 1301:**

Agent inhomogeneities and reduced local protection concerns exist for Halon systems as well.[4,7] The greater volume of less efficient replacement agents, and possible toxicity concerns, will not allow safety margins as large as currently exist with Halon 1301 systems. The import is that systems for replacement agents need to be better designed from the start.

## Conclusions:

Nitrogen content should be taken into account when determining the amount of agent needed to obtain a given design concentration. Because of the reduced safety margins associated with the currently available replacement gases (compared to Halon 1301), agent dilution due to leakage and air infiltration should be reduced in order to provide and maintain the desired agent concentration. Supply and exhaust systems (HVAC and Smoke Control) should be equipped with dampers in order to reduce air infiltration and agent dilution. Low agent fill densities and / or nitrogen pressurization above 4.2 MPa (600 psig) should be avoided if alternative techniques can be used to achieve fast discharges. Higher nitrogen content will increase agent dilution and reduce protection in the overhead. A fast agent discharge time (less than 10 seconds) should be selected, to take advantage of minimizing inhomogeneities, but without the excess of nitrogen from super-pressurization. This also accomplishes minimizing HF.[3] Design concentration decisions should take into account the likely range of reduced agent concentrations due to distribution inhomogeneities.

References:


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3. "Halon 1301 Replacement Total Flooding Fire Testing, Intermediate Scale," Sheinson, R., Maranghides, A., Black, B., Friderichs, T. Proceedings Halon Options Technical Working Conference, May 3-5, 1994, Albuquerque, New Mexico, pp. 43-53.

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6. "Total Flooding Real Scale Fire Testing with Halon 1301 Replacements," Sheinson, R., Maranghides, A., Eaton, H., Barylski, D., Black, B., Brown, R., Byme, P., Friderichs, T., Mitchell, C., Peatross, M., Salmon, G., Smith, W. and Williams, F., 1994 International CFC and Halon Conference, October 24-26, 1994, Washington,

7. "Halon 1301 Average Concentration Design and Test Criteria," MPR Serial 55-163, November 5, 1987, Lee, B.. DC, pp. 324-333.

Table 1.

FM-200 9.2 %, Agent Distribution

| Time' | Min. % (location) | Max. % (location) | Max. - Min. (%) |
|---|---|---|---|
| 5 sec. | 3.7 (1) | 5.7 (2) | 2.0 |
| 8 sec. | 7.0 (4) | 11.5 (1) | 4.5 |
| 11 sec. | 8.8 (4) | 15.8 (1) | 7.0 |
| 16 sec. | 9.5 (5) | 15.0 (1) | 5.5 |
| 31 sec. | 9.6 (5) | 12.8 (1) | 3.2 |
| 1 min. | 8.2 (5) | 12.5 (1) | 4.3 |
| 5 min. | 8.9 (5) | 12.1 (1) | 3.2 |
| 10 min. | 9.0 (5) | 11.4 (1) | 2.4 |
| 20 min. | 8.6 (2) | 11.0 (4) | 2.4 |

a

Table 2.

| FM-200 9.2 96, Agent Distribution<br>**Fast Discharge (6 sec), 8.4 MPa (1200 psi) bottle pressure** | | | |
|---|---|---|---|
| **Time[a]** | **Min. % (location)** | **Max. % (location)** | **Max. - Min. (%)** |
| **5 sec.** | **7.2 (3)** | **14.7 (5)** | **7.5** |
| **8 sec.** | **9.5 (3)** | **14.4 (1)** | **4.9** |
| **11 sec.** | **8.8 (3&4)** | **12.3 (1)** | **3.5** |
| **16 sec.** | **7.6 (5)** | **11.5 (1)** | **3.9** |
| 31 sec. | 8.4 (5) | 11.1 (1) | 2.7 |
| 1 min. | 7.9 (5) | 10.5 (1) | 2.6 |
| 5 min. | 8.4 (5) | 10.1 (1) | 1.7 |
| 10 min. | 7.7 (2) | 9.7 (1&4) | 2.0 |
| 20 min. | 8.9 (5) | 9.6 (1&4) | 0.7 |

a: time from beginning of discharge.

Table 3.

| Nitrogen Content for Various FM-200 Storage Conditions | | | | | |
|---|---|---|---|---|---|
| Storage Pressure' MPa (psig) | Agent Fill Density[b] $kg/m^3$ ($lb/ft^3$) | Weight of Agent' kg (lbs) | Weight of Nitrogen' kg (lbs) | Weight Ratio ($N_2$/FM-200) | Gas Volume Ratio ($N_2$/FM-200) |
| 2.6 (360) | 1155 (72) | 58.6 (129) | 0.91 (2.00) | 0.015 | 0.09 |
| 4.2 (600) | 1155 (72) | 58.6 (129) | 1.66 (3.65) | 0.028 | 0.17 |
| 7.3 (1050) | 1155 (72) | 58.6 (129) | 3.26 (7.18) | 0.056 | 0.34 |
| 8.4 (1200) | 1155 (72) | 58.6 (129) | 3.87 (8.51) | 0.066 | 0.40 |
| 2.6 (360) | 802 (50) | 40.6 (89.4) | 1.04 (2.28) | 0.025 | 0.16 |
| 4.2 (600) | 802 (50) | 40.6 (89.4) | 1.87 (4.11) | 0.046 | 0.28 |
| 7.3 (1050) | **802 (50)** | **40.6 (89.4)** | **3.56 (7.83)** | **0.088** | **0.53** |
| 8.4 (1200) | **802 (50)** | **40.6 (89.4)** | **4.17 (9.18)** | **0.103** | **0.62** |

a: Storage temperature is 21 C (70 F) for all cases.
b: Maximum fill densities are set by maximum cylinder pressure at 54 C (130 F) and cylinder rating. Use of 1155 kg/m$^3$ (72 lb/ft$^3$) at pressures above 4.24 MPa (600 psig) may require additional evaluation of cylinder ratings.
c: Weights of agent and nitrogen are for a size 5 cylinder currently in use in Navy Halon 1301 systems. The minimum cylinder volume is 0.0498 m$^3$ (1.788 f?).

Table 4.

| Nitrogen Con[illegible]e Conditions | | | | | |
|---|---|---|---|---|---|
| Storage Pressure' MPa (psig) | Agent Fill Density kg/m$^3$ (lb/ft$^3$) | Weight of Agent[b] kg (lbs) | Weight of Nitrogen[b] kg (lbs) | Weight Ratio ($N_2$/Halon 1301) | Gas Volume Ratio ($N_2$/Halon 1301) |
| 2.6 (360) | 1123 (70) | 56.8 (125) | 0.62 (1.36) | | 0.06 |
| 4.2 (600) | 1123 (70) | 56.8 (125) | 1.51 (3.33) | | 0.14 |

a: Storage temperature is 21 C (70 F) for all cases.
b: Weights of agent and nitrogen are for a size 5 cylinder currently in use in Navy Halon 1301 systems. The minimum cylinder volume is 0.0498 m$^3$ (1.788 ft$^3$).

Table 5.

| Agent Dilution by Nitrogen for Different Design Concentrations | | |
|---|---|---|
| Agent Design Conc.' (%) | Actual Agent Conc.[b] (%) | Design - Actual Agent Conc. (%) |
| 8.0 | 7.73 | 0.27 |
| 9.1 | 8.74 | 0.36 |
| 10.0 | 9.57 | 0.45 |
| 10.5 | 10.0 | 0.50 |

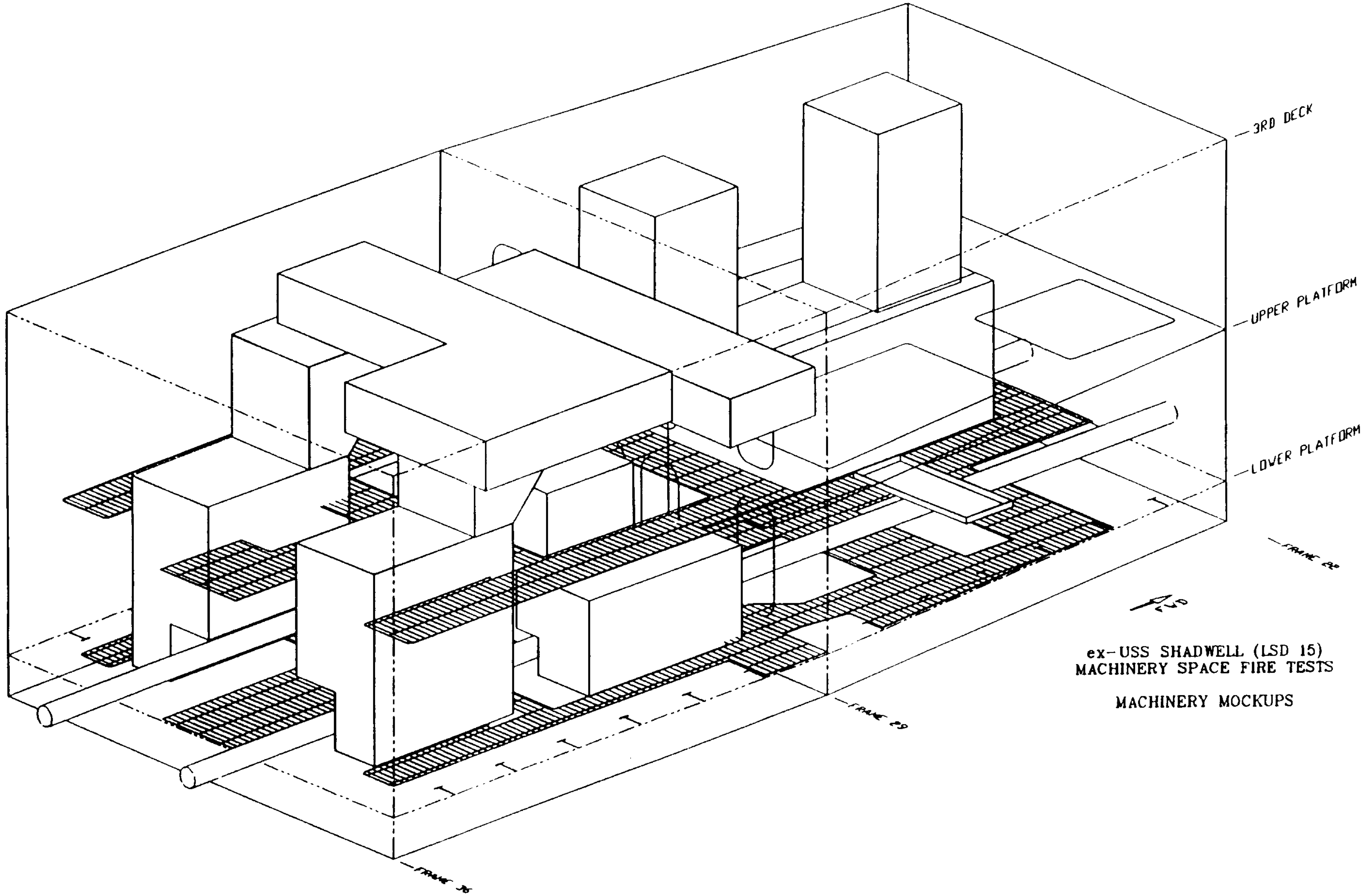
a: calculated based only on agent mass and compartment volume.
b: calculated accounting for dilution due to nitrogen. All the nitrogen is assumed to enter the compartment after all the agent has been discharged as a worst case scenario.

Table 6.

| Agent Dilution Due to Nitrogen for Various FM-200 Storage Conditions | | | | |
|---|---|---|---|---|
| Storage Pressure[a] MPa (psig) | Agent Fill Density[b] kg/m³ (lb/ft³) | Agent Design Conc.[c] (%) | Actual Agent Conc.[d] (%) | Design -Actual Agent Conc. (%) |
| 2.6 (360) | 1155 (72) | 10.0 | 9.91 | 0.09 |
| 4.2 (600) | 1155 (72) | 10.0 | 9.83 | 0.17 |
| 7.3 (1050) | 1155 (72) | 10.0 | 9.67 | 0.33 |
| 8.4 (1200) | 1155 (72) | 10.0 | 9.57 | 0.43 |
| 2.6 (360) | 802 (50) | 10.0 | 9.83 | 0.17 |
| 4.2 (600) | 802 (50) | 10.0 | 9.71 | 0.29 |
| 7.3 (1050) | 802 (50) | 10.0 | 9.47 | 0.53 |
| 8.4 (1200) | 802 (50) | 10.0 | 9.39 | 0.61 |

a: Storage temperature is 21 C (70 F) for all cases.
b: Maximum fill densities are set by maximum cylinder pressure at 54 C (130 F) and cylinder rating. Use of 1155 kg/m³ (72 lb/ft³) at pressures above 4.24 MPa (600 psig) may require additional evaluation of cylinder ratings.
c: calculated based only on agent mass and compartment volume.
d: calculated accounting for dilution due to nitrogen.

Figure 1: Real Scale Halon Replacement Test Compartment.



# FM-200 ($C_3F_7H$) 8.2%
## 2.5 $ft^2$ -Heptane Pan Fire
### 8" Navy Nozzle

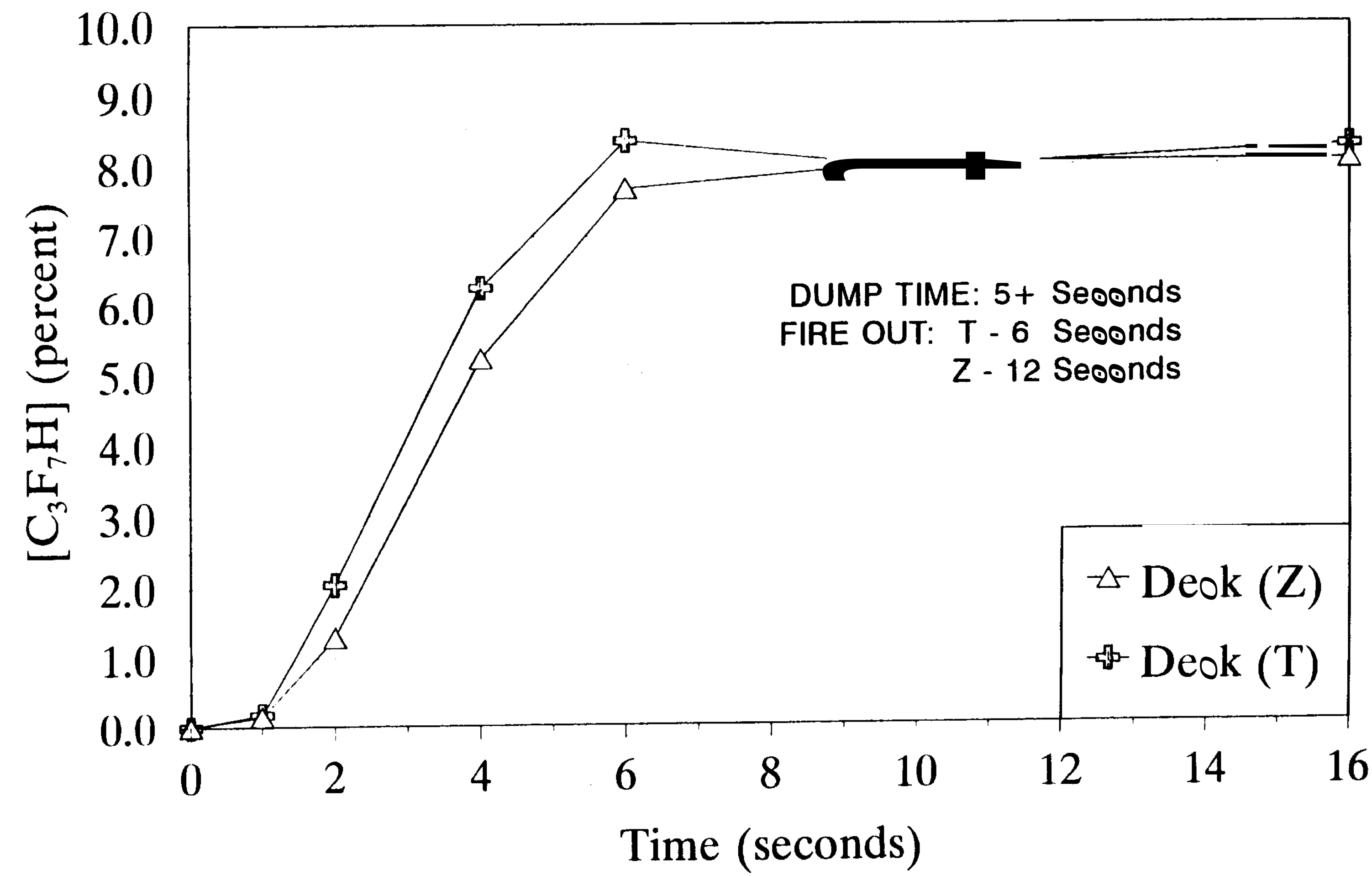



Figure 2: Intermediate Scale Agent Concentration Inhomogeneities

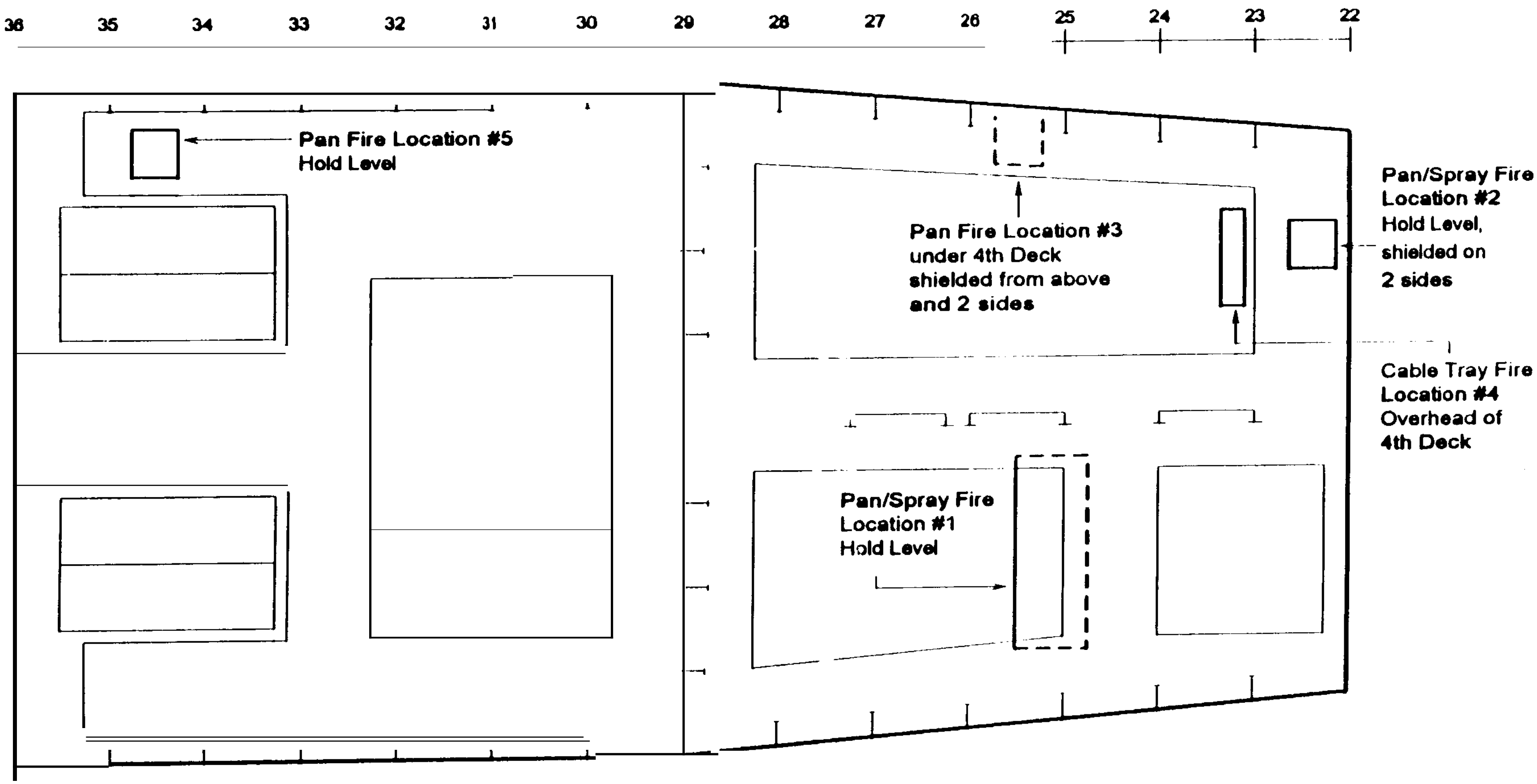
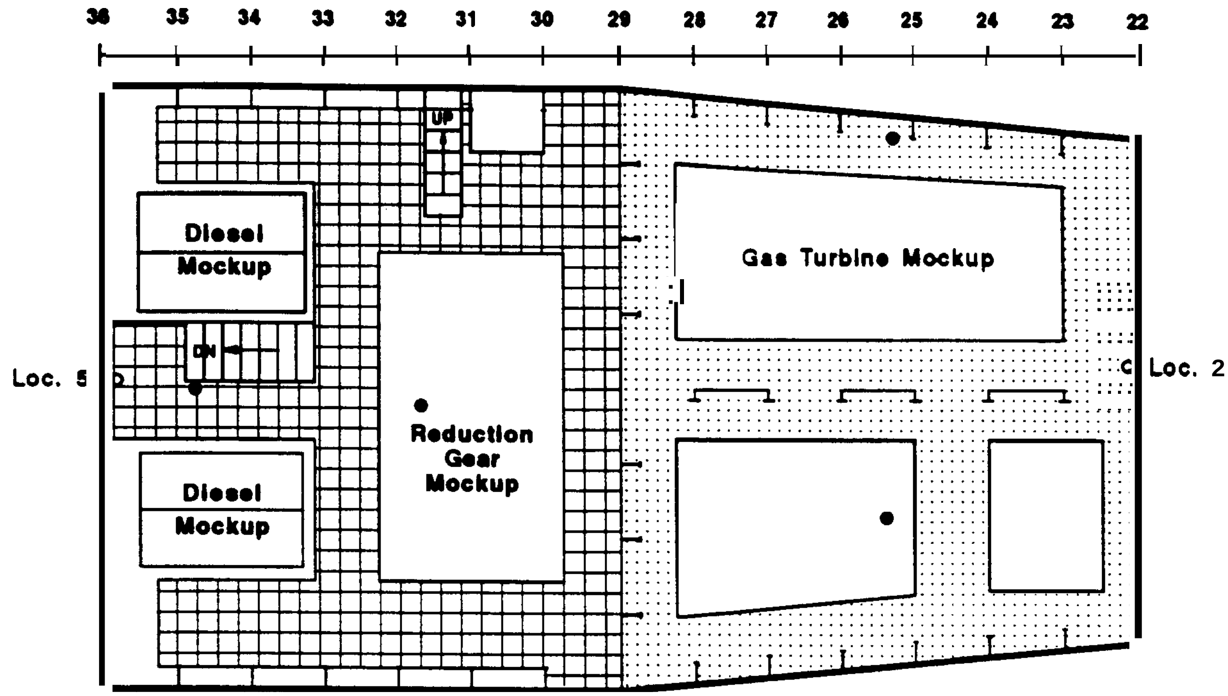
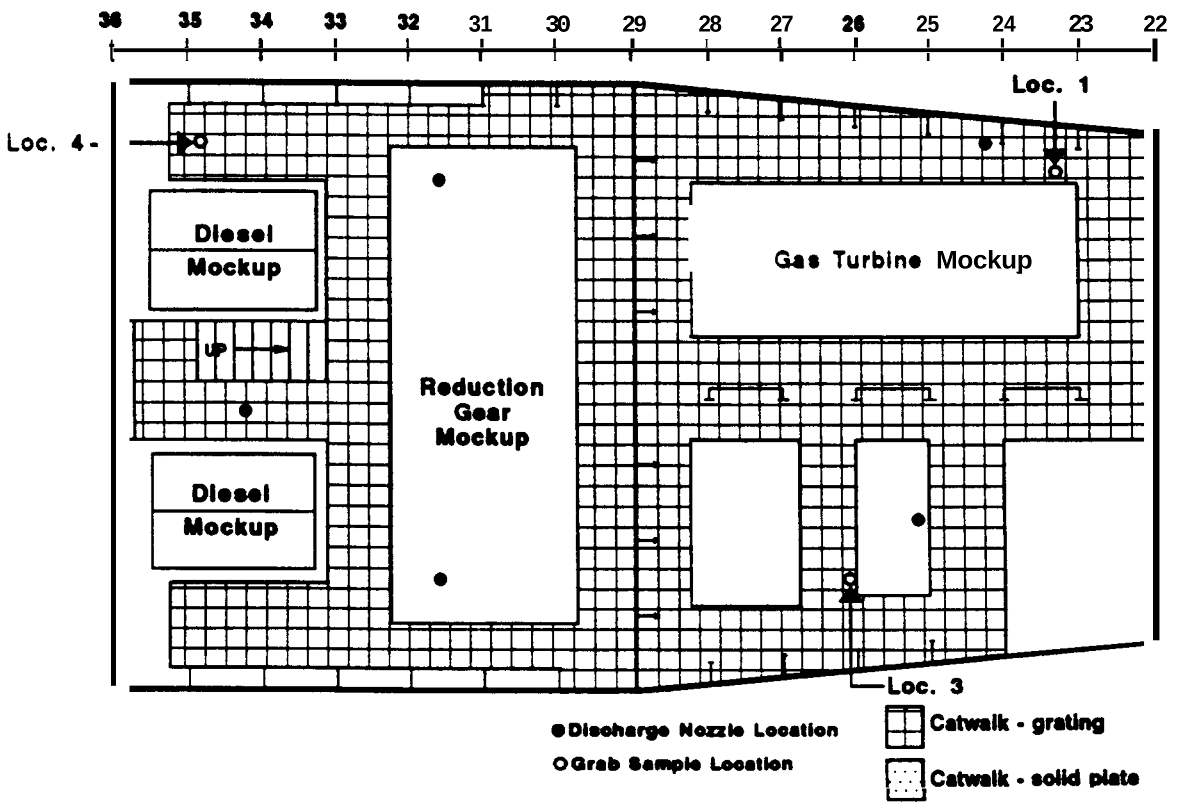



Figure 3: Real Scale Testing Fire Locations.

Figure 4: Agent Discharge Nozzles and Grab Samples.




Agent dlschargo nozzles & agent grab samples - 4th Deck Upper Level




Agent dlschargo nozzles & agent grab samples - 4th Dock Lower Level

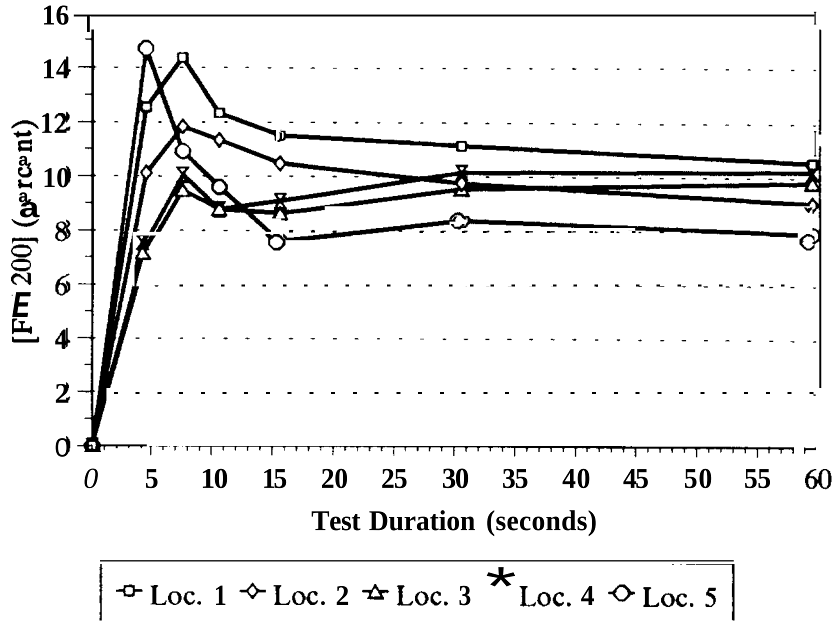



**Figure 5a: Real Scale Testing**
**Agent Concentration Profiles (fast discharge)**

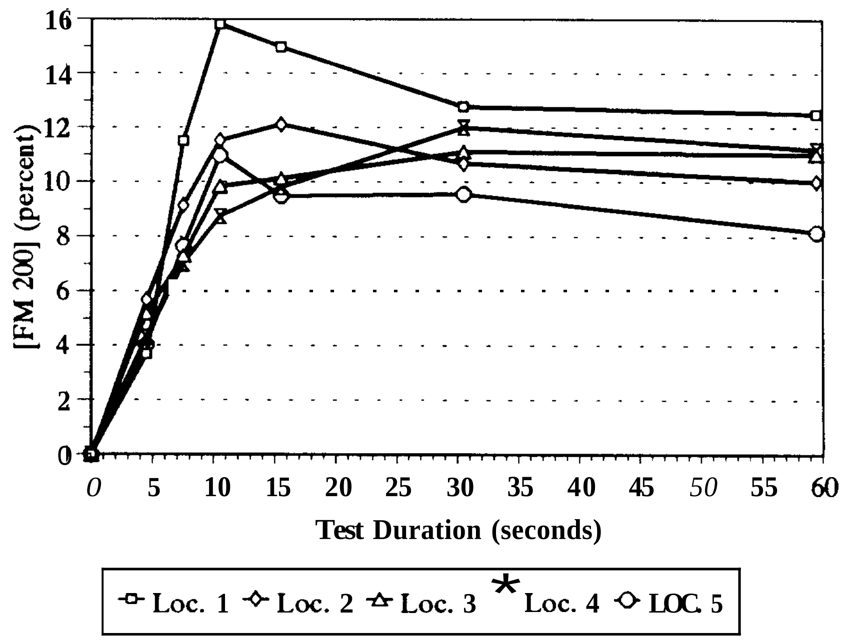
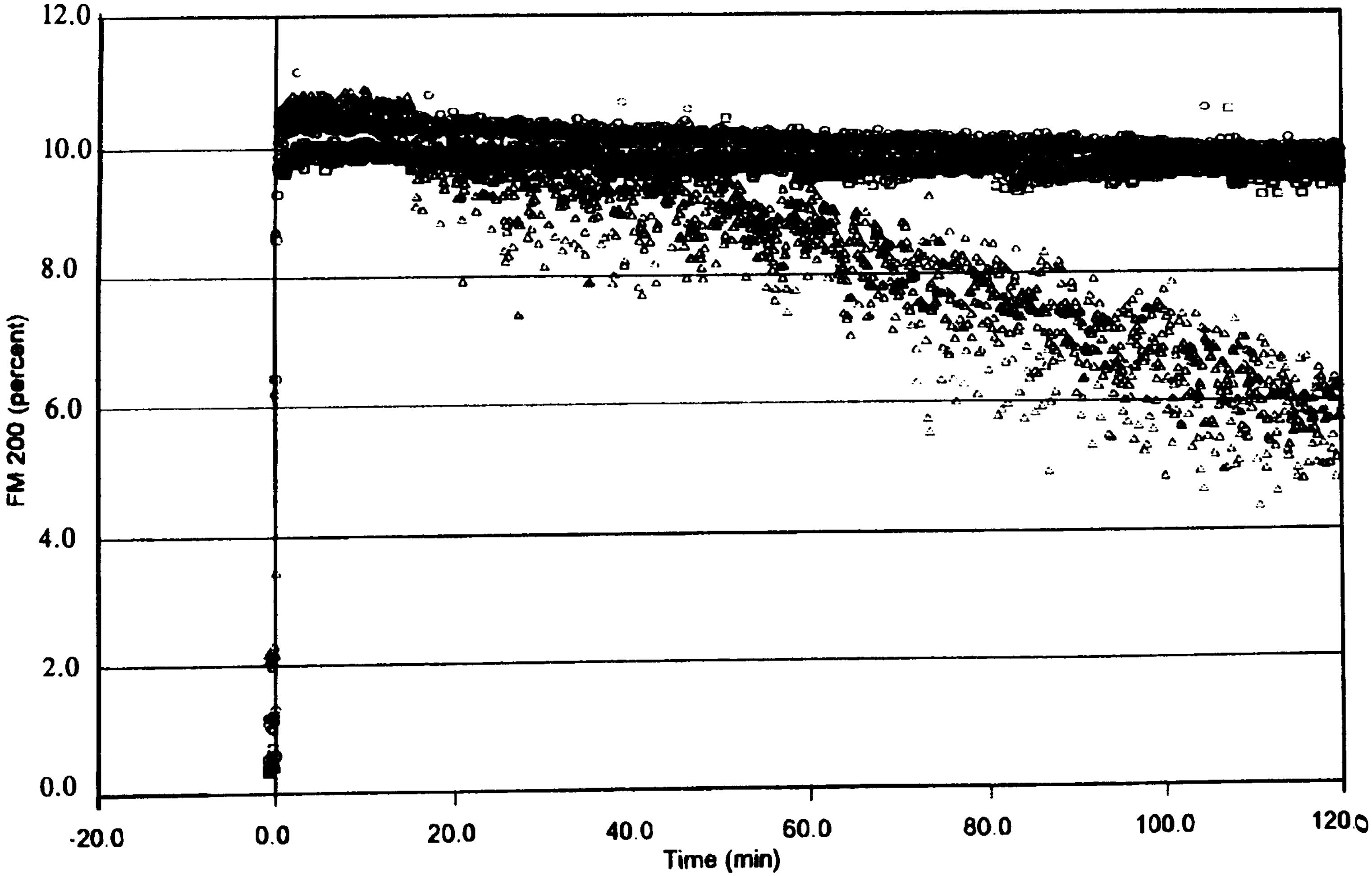



**Figure 5b: Real Scale Testing**
**Agent Concentration Profiles (regular discharge)**

## FM-200 Co Discharge




Δ Overhead at Exhaust Duct.
□ Slightly forward and 1.4 meters (4.5 feet) below duct.
○ Forward bulkhead, overhead.

Figure 6: Real Scale Testing: Agent Concentration Time Profiles.