Large Scale (840 m^3) HFC Total Flooding Fire Extinguishment Results

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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. Gaseous hydrofluorocarbon replacement candidates have clean halon-like physical properties. Intermediate tests have shown that these agents are effective in extinguishing Class B fires.[1] However, they have been shown to produce very high concentrations of decomposition products, primarily toxic and corrosive hydrogen fluoride, during fire suppression.[1] In order to determine if these agents are suitable for use in shipboard machinery spaces, tests were performed in a machinery space mockup in accordance with a detailed test plan.[2] These full scale machinery space tests were conducted onboard the ex-USS SHADWELL located at Little Sand Island, Mobile, Alabama.

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Objective:

The main objectives of the full scale tests were to select the agent of choice while determining if the replacement agent system characteristics are satisfactory for shipboard use. 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. These characteristics include fire suppression effectiveness and reflash protection, toxic and corrosive decomposition products formed during fire suppression, agent distribution, flow/discharge characteristics, and materials compatibility. As described in the test plan, the tests were divided into 4 series. Series 1 tests were fire tests without agent discharge or mockups. Three cold agent discharge tests without mockups or fires were performed in Series 2. Series 3 consisted of 1 cold discharge test which was conducted after the mockups had been installed. Series 4 tests were agent fire suppression discharge tests with mockups.

Test Compartment:

Overall dimensions of the test compartment are approximately 18 x 9 x 6 m (56 x 28 x 20 ft.). It is located on the 4th deck upper and lower levels between Frames 22 and 36 with catwalks on both levels (Figure 1). The agent discharge system consisted of 9 discharge nozzles which were divided into two tiers. After Series 2 tests were completed, mockups simulating diesel engines and reduction gears, a gas turbine engine, and ventilation ducts were installed in the space to create a more realistic obstructed environment. The primary supply and exhaust ventilation system in the test space provided approximately 20 air changes per hour. A second exhaust system was installed for venting decomposition products.

Discharge System:

The agent discharge system was a 9 nozzle two level system (Figure 2) with a 20 cylinder capability manifold (Figure 3). The system was designed according to the standard Navy specifications for total flooding Halon discharge systems. The nozzles used were the standard Navy 4-hole horizontal cross type. The baseline discharge time was 10 seconds, the fast discharge 6 seconds.

Instrumentation:

The discharge system was instrumented to measure temperature and pressure at each of the 9 nozzles as well as at 2 locations in the piping. Two bottles were attached to load cells to measure the mass loss. A decibel meter was located in the compartment to determine the sound level during agent discharge. In addition, the test space was instrumented to measure gas, fire and bulkhead temperatures, and compartment and fuel pressures. A continuous gas sampling system measured oxygen, carbon dioxide, carbon monoxide, and agent concentration at 4 locations in the space. Grab samples were taken at specified times and locations during each test. One type of grab samples (5 locations) was analyzed using a Gas Chromatograph *(GC)* to determine agent and oxygen concentrations, The other type of samples (4 locations) was analyzed using an Ion Chromatograph (IC) to quantify the concentration of halide acids in the space. A "real-time" measurement of agent and acids was determined using a Fourier Transform Infrared Spectrometer (FTIR).

Fires:

There were five fire locations in the machinery space (Figure 4). Specifications of the fire used can be found in Table 1. In addition, there were 29 telltale fires (about 3 kW each) located throughout the compartment. These fire locations were selected to indicate how effectively the agent reaches all areas of the space.

There were two basic scenarios (A and B) which primarily involved changing the size of Fire 1. Fires 1, 2, and 4 each included a fuel spray as well as a pool fire.

Full Scale Test Particulars:

The scope of the four test series are listed in Table 3. Computer and visual data gathered during Series 1 tests were used to refine the fire scenarios to be used during Series 4 tests. In particular, fire sizes and preburn times were determined.

Series 2 results showed that the discharge system produced a well-mixed environment in the test space. Actual discharge system characteristics were compared with values predicted using the computer code $TFA_{HFC-227ea}D4$ which was developed by MPR Associates, Inc.[3] These characteristics included temperatures and pressures in the piping and at the nozzles. The predicted values agreed well with the measured values.

Results from Series 3 showed that the mockups did significantly affect the agent distribution characteristics.

Series 4 Tests: Tests 4.1 and 4.2 were baseline fire suppressions with Halon 1301. Tests 4.3 to 4.9 and 4.14 were with FM-200, and 4.10 to 4.12 were with FE-13. All fires were extinguished for each scenario **tested.** Test 4.13 was deleted from the test plan and test 4.14 was added (different nozzles). Table 2 shows which of these scenarios was used in Series 4 tests.

Results:

A summary of Series 4 test results is shown in Table 4. Extinguishment times are listed for each fire, where applicable. Some of **this** data is based on visual observation while other data is based on thermocouple response. Agent concentrations reported **are** based on the GC analysis of the grab samples located near Fire 1. The **peak** hydrogen fluoride (HF) concentration was taken from measurements taken with the FTIR. Reignition was attempted for fires 1, 2, and 4 at **intervals** of at least **1,** 2, 3, 4, 5, 10, and 20 minutes following agent discharge. Tests 4.5, and 4.10-12 exhibited reignition phenomena at the large fire (Fire 1).

Agent and Discharge System Recommendations:

The recommendation at this time for this particular ship is HFC-227ea (FM-200). A major consideration in selecting FM-200 was the increased HFC-23 (FE-13) system volume and weight. The above FE-13 system limitations are due to the agent's low cylinder fill density necessitated by the high temperatures **that** *can* be expected on Navy ships (up to **66°C** (150°F)).

The desired FM-200 concentration ***at*** the base of the fire is **8.5%. This** concentration is based on achieving acceptable fire out times and acid generation. The recommended design concentration for FM-200 is determined by **first** adding 20% to the minimum **8.5%** agent concentration to account for observed inhomogeneities,' then by adding an additional 20% **as** a overall system engineering *safety* factor. **This** brings the agent concentration to 12.2%. The recommended design concentration is then specified **as 12.0%-13.0% *at* 20°C.**

The discharge time should **be** at most **8** seconds to enhance mixing and rapid fire suppression. Recommended system pressure is the current Navy Halon 1301 system pressure of 4.2MPa **(600psi).**[4]

Conclusions:

The recommended agent at this time for this ship (LPD-17) is FM-200.

A faster discharge time corresponded to shorter extinguishment times and lower HF concentration. The peak HF concentration increased with decreasing agent design concentration. With the larger fires, all extinguishment times were shorter and the peak HF concentration was higher. Decomposition product generation was substantially higher for FM-200 and FE-13 extinguished fires than for Halon 1301 extinguished fires. Reflashes and sustained reignitions occurred in several tests (function of agent concentration, location, time, and air infiltration).

References:

1. Sheinson, R. S., et al., "Halon 1301 Replacement Total Flooding Fire Testing, Intermediate Scale," Proceedings of the Halon Options Technical Working Conference, Albuquerque, NM, May 3-5, 1994.

2. Sheinson, R., Maranghides, A., and Krinsky, J., "Test Plan - Halon Replacement Agent Testing on the Ex-USS SHADWELL," NRL Ltr Ser 6180-0470.1, September 19, 1994.

3. 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, Albuquerque, NM, May 3-5, 1994.

4. Alexander Maranghides, Ronald S. Sheinson, Doug Barylski, Bruce H. Black, Tom Friderichs, Michelle Peatross, and Walter D. Smith, "Total Flooding Agent Distribution Considerations," Halon Options Technical Working Conference, Albuquerque, NM, May 9-11, 1995.

Table 1: Fire Specifications.

Fire	Pan Size	Spray Pressure (kPa)	Fire Size (kW)
1A	71 x 71 cm	280	1600
1B	114 x 114 cm	440	7000
2A	30 x 30 cm	280	500
2B	30 x 30 cm	440	600
3	30 x 30 cm	N/A	130
4A	30 x 30 cm	280	500
4B	30 x 30 cm	440	600
5	30 x 30 cm	N/A	130

Table 2: Series 1-4 Particulars.

Series #	Mockups	Fires	Agent Discharge
1	No	Yes	No
2	Yes	No	Yes
3	Yes	No	Yes
4	Yes	Yes	Yes

Table 3: Series 4 Fires Used.

Test #	Fuel	Fires used	Fire 1 Size (A or B)
4.1	heptane	1,2,3,5	A
4.2	heptane	1,2,3,5	A
4.3	heptane	1,2,3,5	A
4.4	heptane	1-5	A
4.5	heptane	1,2,3,5	A
4.6	heptane	1,2,3,5	A
4.7	heptane	1-5	B
4.8	F-76 (Navy diesel)	1-5	A
4.9	F-76 (Navy diesel)	1-5, crib	B
4.10	heptane	1-5, crib	A
4.11	heptane	1-5	A
4.12	F-76 (Navy diesel)	1-5, crib	B
4.14	heptane	1-5	B

Table 4: Results for Series 4 Tests.

Test No.	Agent	Design Conc. (%)	Discharge Time (s)	Fire Extinguishment Times (s)						Agent Conc. by Fire 1 @ 10 & 15 sec. (%)	Peak HF Conc. (ppm)
				1	2	3	4	≤	[illegible]		
4.1	Halon 1301	≤.7	11	2≤	9	11	-	7	-	6.4/6.7	600
4.2	Halon 1301	4.6	10	20	10	8	--	11	--	3.8/4.7	600[a]
4.3	FM-200	10.0	11	16	10	9	--	13	--	6.6/9.8	3800
4.4	FM-200	9.2	6	12	7	4	5	--	--	8.8/8.6	2400
4.5	FM-200	8.2	10	28	13	13	--	12	--	8.6/8.1	4500
4.6	FM-200	9.2	11	25	12	10	--	12	--	9.8/10.1	3800
4.7	FM-200	9.2	11	13	8	7	5	7	--	9.5/9.9	5200
4.8	FM-200	9.2	10	10	7	--	9	7	--	8.7/9.6	2500
4.9	FM-200	9.2	10	8	4	--	--	8	13	2.1/9.5[b]	7300
4.10	FE-13	18.0	10	9	6	--	6	4	9	16.3/16.6	3900
4.11	FE-13	16.0	10	12	5	11	6	5	--	16.2/17.1	5800
4.12	FE-13	18.0	10	8	5	5	--	5	8	18.2/21.0	5300
4.14	FM-200	9.2	10	12	8	--	5	9	--	7.4/9.1	3300

[a] value possibly higher, incomplete data analysis

[b] samples taken at 3 & 18 seconds

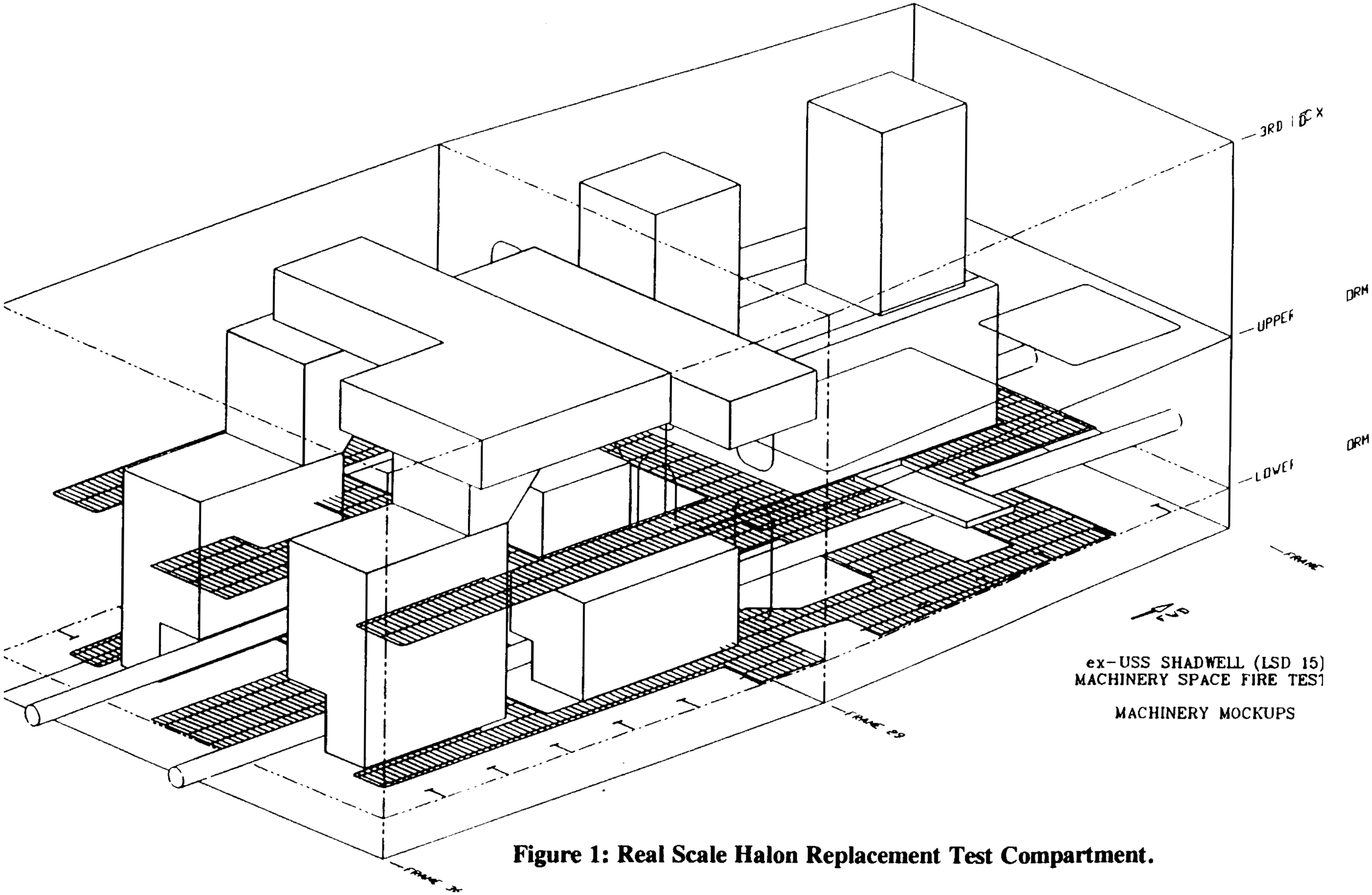

Figure 1: Real Scale Halon Replacement Test Compartment.

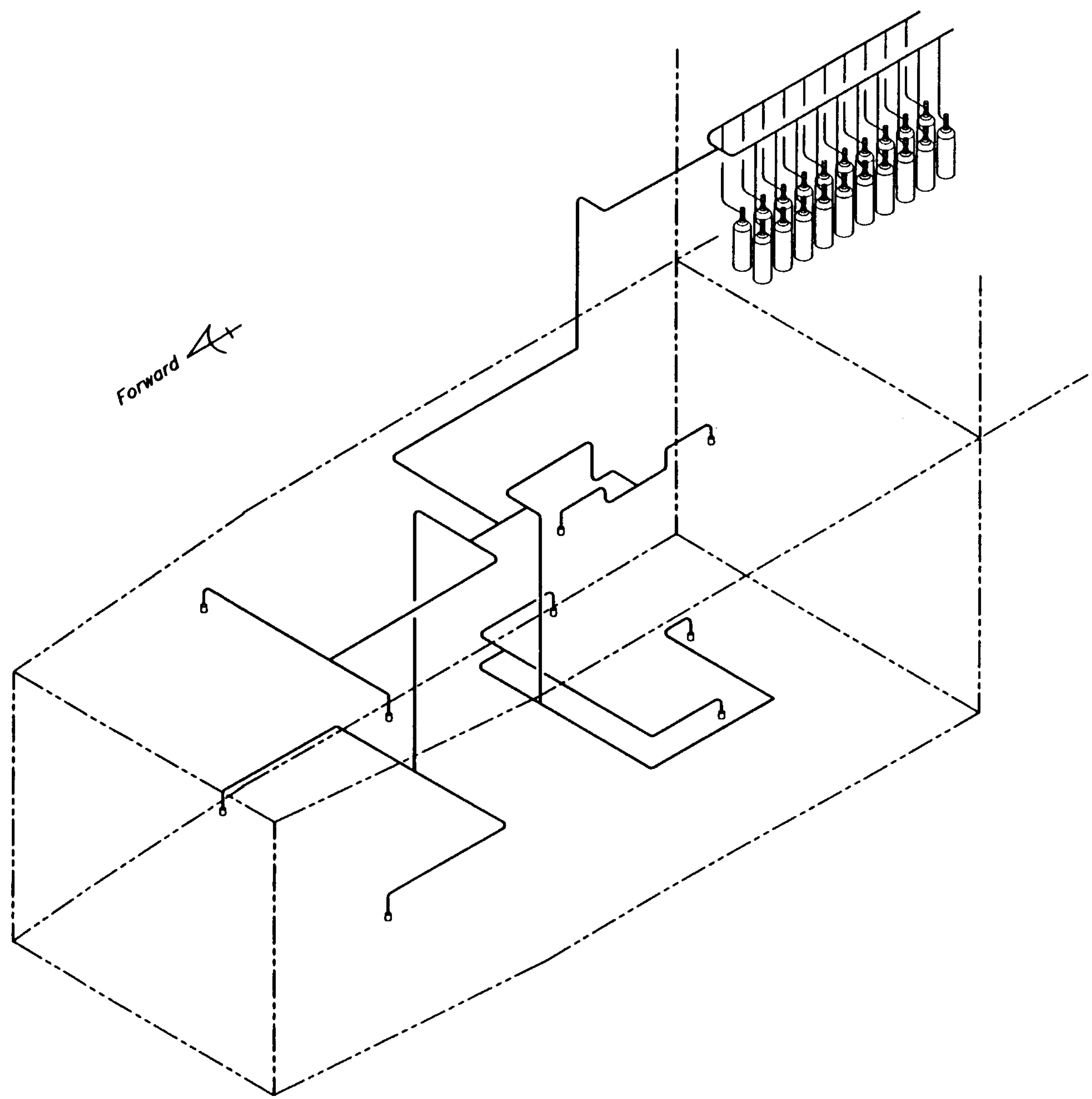

Figure 2: Agent Discharge System Piping.

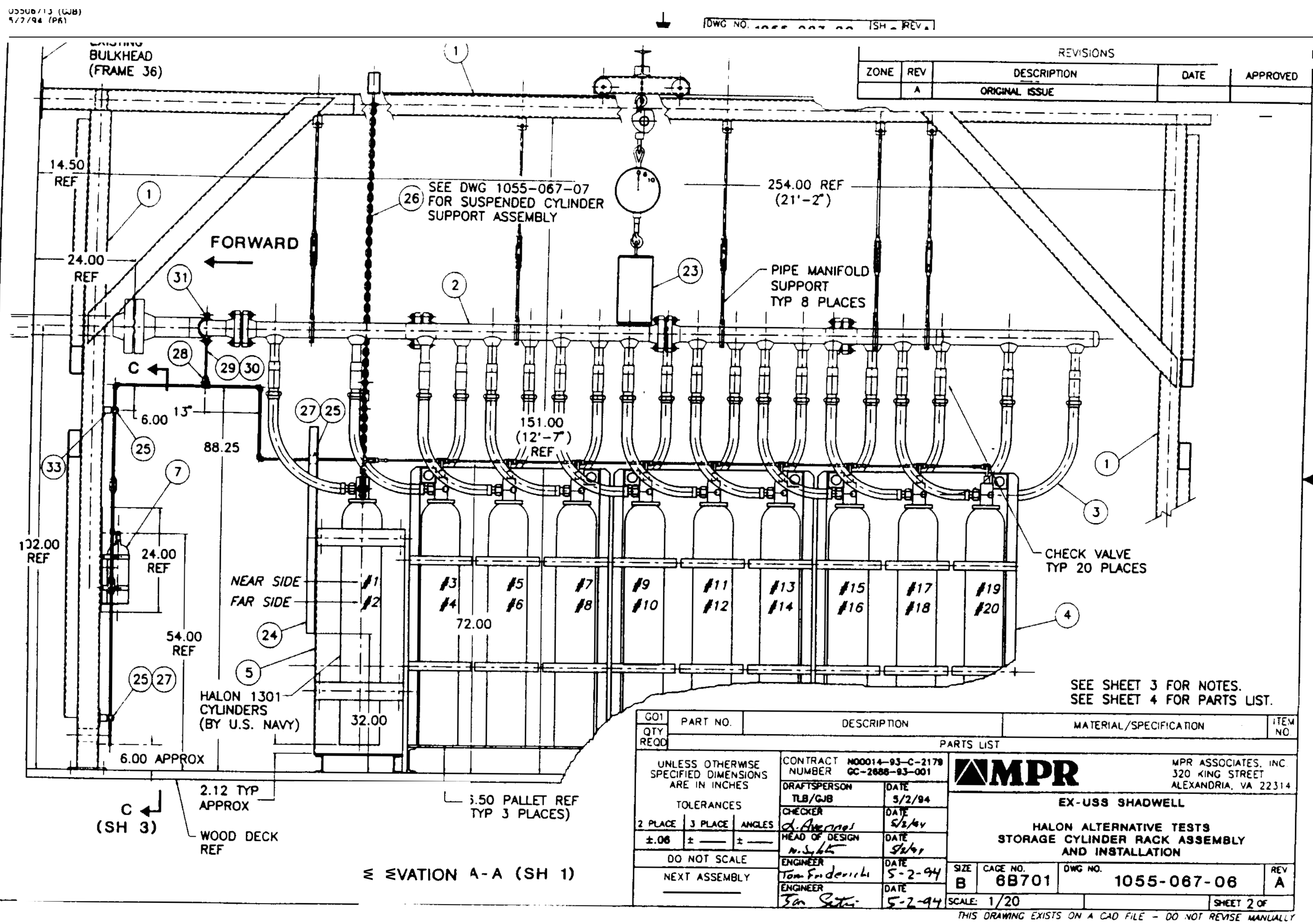

Figure 3: Agent Discharge System Manifold.

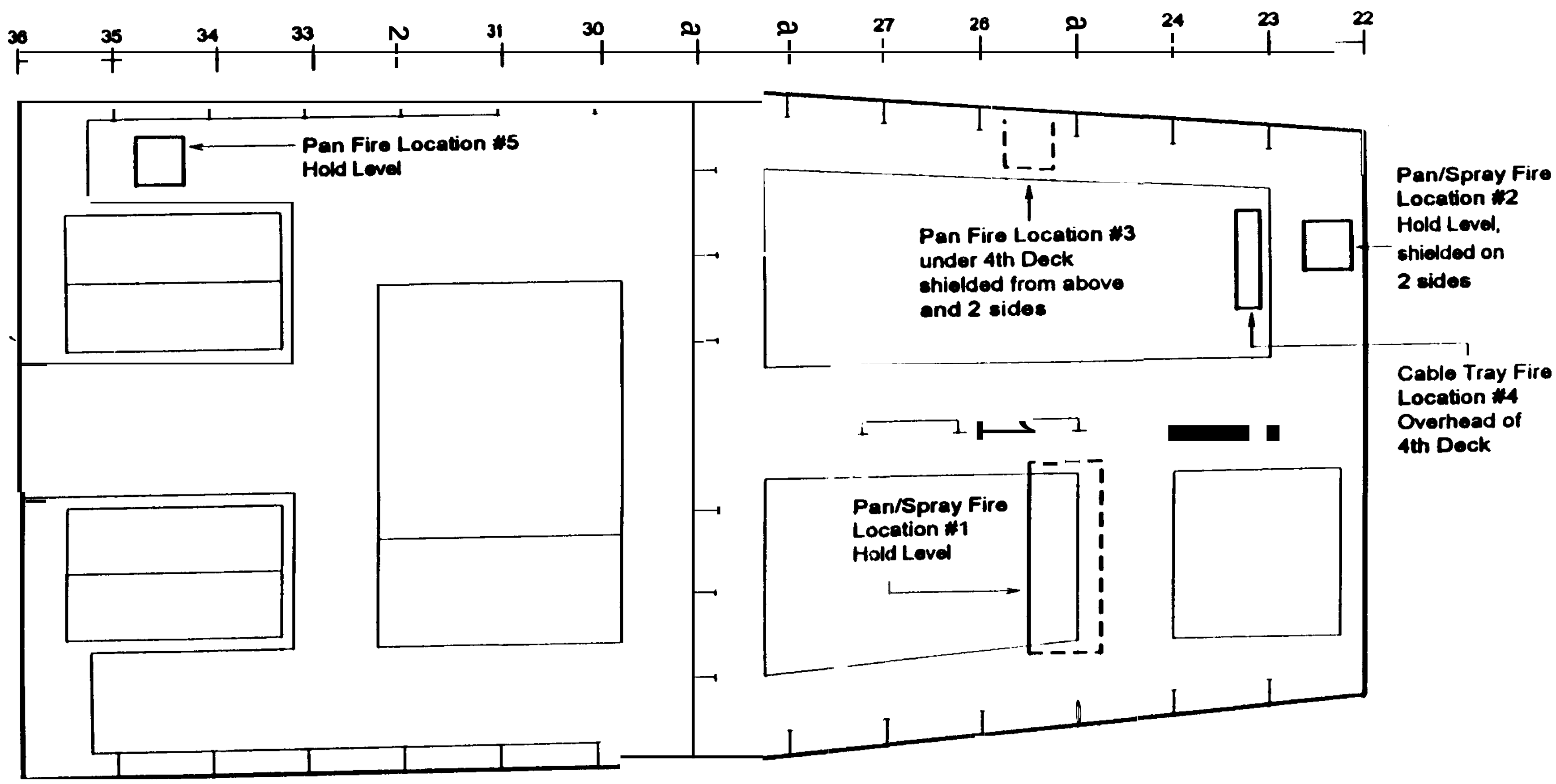

Figure 4: Real Scale Testing Fire Locations.