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Conducting Real Scale Halon Replacement Tests Aboard the ex-USS SHADWELL: Overall Test Design

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Real scale tests are being conducted aboard the *ex*-USS SHADWELL in Mobile, AL, to address issues specific to total flooding system optimization and implementation. These tests are part of the Naval Research Laboratory's (NRL's) Halon 1301 Replacement program.

Initial real scale testing (Phase 1) was concerned primarily with agent suppression effectiveness and the levels of decomposition products generated. Heptafluoropropane, HFP (HFC-227ea, manufactured by Great Lakes Chemical Corporation as FM-200), was proposed as the most effective clean replacement agent for Halon 1301 currently available for U. S. Navy shipboard applications.

Further testing (Phase 2) was designed to determine the optimum hold time prior to venting following an HFP extinguished lire, as well as to optimize the compartment reentry time. The Phase 1 discharge system network was modified to accommodate several configurations. Non-standard Navy (or modified) hardware for the discharge system was also used to identify whether more rapid discharge times can be achieved. The modified components included the agent tank valves, check valves, and flexible hoses. The effect of doubling the number of agent discharge nozzles on agent concentration inhomogeneities was also investigated since homogenous agent distribution is critical to the agent's tire suppression performance. **A** number of these results can impact on current Halon 1301 discharge system design and use.

Prior to Phase 2 tests, significant modifications were made to the test setup and running procedures in order to achieve the above listed objectives. The compartment volume was reduced by half, still large enough to see agent inhomogeneities while requiring less agent. The ventilation system was also modified. Test instrumentation was augmented from that used in Phase 1. The tire scenarios were also changed from those used in Phase 1 by using a different fuel, larger fire sizes, and a longer preburn time. The test matrix included background or control fires (with no agent discharge), cold agent discharges (with no fires). and fire suppressions (agent discharges with fires). **A** water spray cooling system was installed with the purpose of cooling the space and reducing acid by-product concentrations.

This paper details these the changes between Phase 1 and Phase 2, and includes an explanation of the test matrix which was performed.

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Phase 1 Testing

Objectives

These real scale tests (RSC) were performed in order to identify a suitable replacement agent for Halon 1301. The test space was designed to simulate a typical machinery space on U.S. Navy ships. There were two agents which were evaluated: C_3F_7H (Heptafluoropropane, manufactured by Great Lakes Chemical Corporation as FM-200) and CF_3H (manufactured by DuPont deNemours and Co. as FE-13). In addition, baseline tests were conducted with Halon 1301. Agent discharge times and design concentrations were varied in order to better characterize the suppression system performance envelope.

Experimental Setup

The test compartment had overall approximate dimensions of 17 m long by 8.5 m wide by 6.1 m high (56 x 28 x 20 ft). After initial testing, mock-ups of diesel engines and reduction gear, a gas turbine engine, and ventilation ducts were installed to simulate a more realistic environment. The total compartment volume was 840 m^3 (29700 ft^3) while the actual floodable volume was 755 m^3 (26700 ft^3). 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. The agent discharge network was composed of 2 tiers and 9 nozzles.

Compartment instrumentation was used to monitor temperature, gas concentrations and pressure. Thermocouples were used to measure gas and fire temperatures. Continuous gas analyzers reported oxygen, carbon monoxide. carbon dioxide, and agent concentrations at 4 locations in the space. A Fourier Transform infrared (FTIR) spectrometer measured the agent and acid concentrations “real time”. Two types of grab samples were taken at several locations in the compartment at specified times. One set of these samples was analyzed for agent, oxygen, carbon monoxide, and carbon dioxide concentrations using a gas chromatograph. An ion chromatograph was used to analyze the other set of samples to determine acid concentrations. Pressure transducers were used to measure the compartment pressure and the fuel supply pressure to the spray fires.

The discharge system was instrumented so that the 9 nozzle pressures and temperatures could be measured during agent discharge. Similar measurements were also taken at two agent locations in the piping system. Load cells were used to determine the mass loss from two of the cylinders and a decibel meter was placed in the compartment to measure the sound level during agent discharge.

There were 5 fire locations. Three of these fires consisted of a spray/pan fire combination, and the other two were pan fires. Total fire sizes were either 2.5 MW or 8.5 MW depending on the scenario. Two tests were conducted with F-76 diesel fuel while the remaining tests used n-Heptane. There were also 29 n-Heptane telltale fires. Further details regarding the experimental design can be found in Reference 1.

Tests Conducted

The tests were divided by their objectives into 4 different series. Series 1 tests consisted of prebum fire tests with no agent discharge and no machinery space equipment mock-ups. The purpose of these fires was to develop a suitable preburn scenario for the agent discharge tests. Series 2 tests were agent discharges without fires and no mock-ups in place. Agent discharge tests with the mockups installed were conducted in Series 3 in order to determine the effect of the obstructions on compartment agent homogeneity. The last series, Series 4, consisted of fire tests with agent discharge and mockups installed. The purpose of these experiments was to determine how effective the tested replacement agents were at extinguishing the fires. Discharge times and agent design concentrations were varied as part of this evaluation.

Results

The results of the Series 2 tests show that the agent was well-mixed within the compartment [2]. However, once the mockups were installed. substantial inhomogeneities were measured in both Series **3** and 4. All fires were extinguished in each scenario. **At** the conclusion ofthis testing, heptafluoropropane (HFP) at a design concentration of' 12% at 20 °C (68 "F) was recommended as the replacement agent for the U.S. Navy's next ship [3]. This large factor of safety was incorporated to account for some ofthese inhomogeneities as well as to provide rapid fire suppression while maintaining HF generation at relatively low levels.

Phase 2 Testing

Objectives

Phase 2 tests had several goals. The optimum hold time following an agent discharge and required venting time needed to be determined. Currently. U.S. Navy Firefighting Doctrine specifies a hold time of 15 minutes following a Halon 1301 discharge [4]. Following this soak time, the compartment is ventilated for 15 minutes prior to reentry. Little data are available regarding how optimal these times are. Parameters which are critical to postfire compartment reclamation include reflash, thermal hazard, and toxic hazard potentials. Since HFP generates a much larger level of toxic gases (primarily hydrogen fluoride. HF), it is uncertain what the risk level will be if these same procedures are followed. **As** a result. a portion of these tests were devoted to varying the length of the hold time and the vent time. After the specified ventilation time elapsed, properly equipped safety personnel entered the space and took HF measurements using Dräger™ tubes. In conjunction with this, the use of a Water Spray Cooling System (WSCS) was investigated. This system was designed to reduce the compartment temperature rapidly, thereby making it more tenable for the firefighting team and reducing the possibility of a reflash. In addition, the system was expected to reduce the acid concentrations in the compartment which would reduce the required hold and venting times.

Modified (non-standard Navy) discharge hardware was also evaluated to determine if a shorter discharge time can be achieved. Shorter discharge times aid in minimizing agent inhomogeneities. These modified components included the agent tank valves, check valves, and flexible hoses. The effect of doubling the number of nozzles was also investigated.

Modifications *to* Experimental Setup

The test compartment volume was reduced by approximately half for these Phase 2 tests (i.e. the forward portion only of the Phase 1 test compartment was used). This modification lessened agent requirements while still leaving the space large enough to observe agent inhomogeneities. Overall dimensions were approximately 8.5 m long by 6.1 m high by 8.5 m wide (Figure 1). The full volume of the space was 395 m^3 (13950 ft^3). The gas turbine mock-up occupied about 7% of the air space which left a floodable volume of 370 m^3 (13000 ft^3). The ventilation ducts in the aft portion of the Phase 1 test compartment were blocked off so that only the Phase 2 test compartment was served by the ventilation system.

Similar basic instrumentation was used as in Phase 1 but with increased spacial resolution because of the reduced compartment volume. There were several additions to the compartment instrumentation used in Phase 1. An overview of the instrumentation on the upper and lower levels is shown in Figures 2 and 3, respectively. Additional thermocouples were installed to monitor the gas temperatures in the compartment and ventilation ducts and to determine fire extinguishment times more accurately. Bi-directional probes were placed in the supply and exhaust ducts to determine air flow rates. Two of the continuous gas sampling ports were relocated. One of these was placed in the supply duct and the other in the exhaust stack to measure agent leakage from the compartment.

Three fire threats were used. Two of these fires were on the lower level and one was on the upper level (Figure 4). One of the lower level fires was a combination pan/spray fire (Fire 1) while the other was only a spray fire (Fire 2). For the pan/spray combination fire, the prebum was designed such that the pan fire and the spray fire just overlapped in time. The upper level fire (Fire 4) was located in the overhead and consisted of a cable tray fire with a fuel spray impinging on it. Fires were fueled with F-76 diesel rather than the heptane used in Phase 1. Total fire sizes ranged from approximately 3.2 to *5.6* MW. Seventeen n-Heptane telltales were also used.

A Water Spray Cooling System was installed in the compartment overhead. It was constructed of **2.5** cm (1 inch) diameter stainless steel tubing with 13 Bete Fog TFlOFC nozzles. This system was designed as a low pressure system and was supplied by the ship's fire main. The system pressure was adjusted to flow from 40 to 65 GPM flow depending on the test scenario.

The 9 nozzle Phase 1 discharge system for HFP was modified to a four discharge nozzle system, two on the upper level and two on the lower level (Figure 5). It was designed such that an 8 nozzle configuration could be easily implemented (Figure *6)*. **A** separate 4-nozzle system for Halon 1301 was installed. The nozzles were ***of*** the standard Navy 4-hole horizontal cross type. **A** further description of the test setup and running procedures may be found in Reference 5.

Tests Conducted

As summarized in Table 1, this phase of testing consisted of 7 series. The first of these was control fires with no agent discharge. As in Phase 1, the purpose of these tests was to characterize the compartment and find an appropriate preburn scenario. Series 2 tests consisted of HFP discharges with both 4 and 8 nozzles. no fires burning. Agent discharges with fires were performed in Series 3, and the hold times were varied to determine the optimum hold time. Series 4 was HFP discharges with fires and the water spray cooling system. Series 5 was HFP discharge tests with fires where the WSCS was activated prior to agent discharge, an NRL innovation. Baseline Halon 1301 fire tests both with and without the WSCS were performed in Series 6. Series 7 tests were HFP cold discharges with modified Navy hardware. All tests with HFP discharges had a design concentration of 10.1%. and Halon 1301 tests had a design concentration of 5.2%.

Results

All fires were extinguished in all scenarios. Preliminary results show that the WSCS was effective at reducing compartment temperatures rapidly. In tests using the WSCS, the upper layer temperature dropped from over 250 °C to less than 60 °C in 5 seconds after system activation [6]. In tests without the use of the WSCS. the average upper layer temperature reduction after agent discharge was only 130 °C. In one test in which the WSCS was activated prior to agent discharge. it was noted that the fire extinguished prior to agent discharge, indicating that the water put it out [7]. The modified hardware used to decrease the discharge time did produce improvements in agent inhomogeneity. No improvement was observed for the 8 nozzle discharge test [8].

Series No.	Agent	Fires	WSCS	Comments
1	NO	YES	YES/NO	Background/control fires
2	HFP	NO	NO	4 and 8 nozzle tests
3	HFP	YES	NO	Hold times varied
4	HFP	YES	YES	WSCS activated with or after agent discharge
5	HFP	YES	YES	WSCS activated prior to agent discharge
6	Halon 1301	YES	YES/NO	Halon 1301 baseline and WSCS tests
7	MFP	NO	NO	Modified Navy hardware used

References

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6. Sheinson, R.S., Maranghides, A., Black. B.H., and Peatross, M.J., "Real Scale Halon Replacement Testing - Post Fire Suppression Compartment Characterization: Preliminary Results," NRL Letter Report 618510009.1,February 1996.

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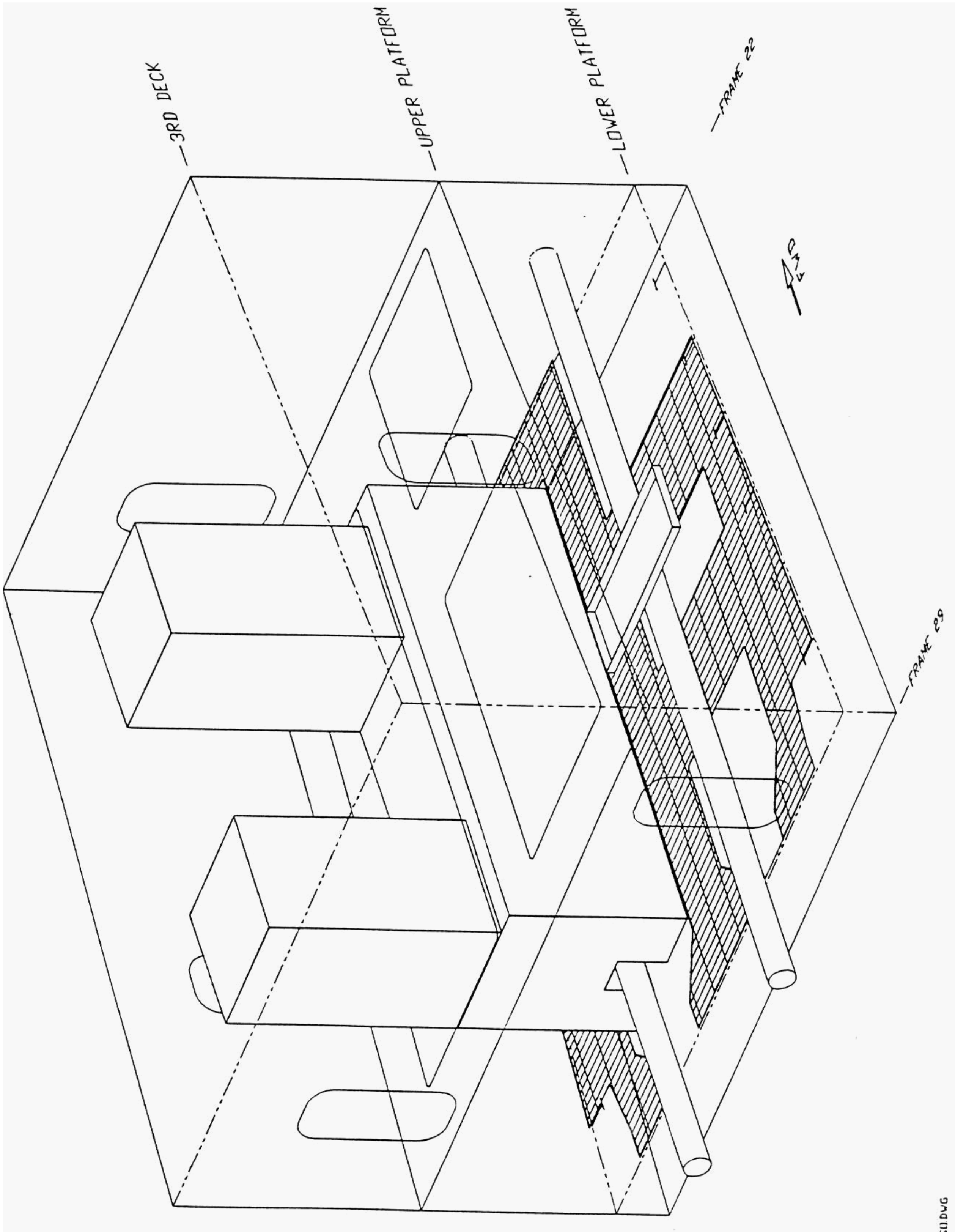
8. Sheinson, R.S., Maranghides, A., Black, B.. Friderichs, T., and Peatross, M. "Discharge System Modifications: Real Scale Halon 1301 Replacement Testing," Proceedings of the Halon Options Technical Working Conference, Albuquerque, NM, May 7-9, 1996.


3RD DECK
UPPER PLATFORM
LOWER PLATFORM
FRAME 22
FRAME 29

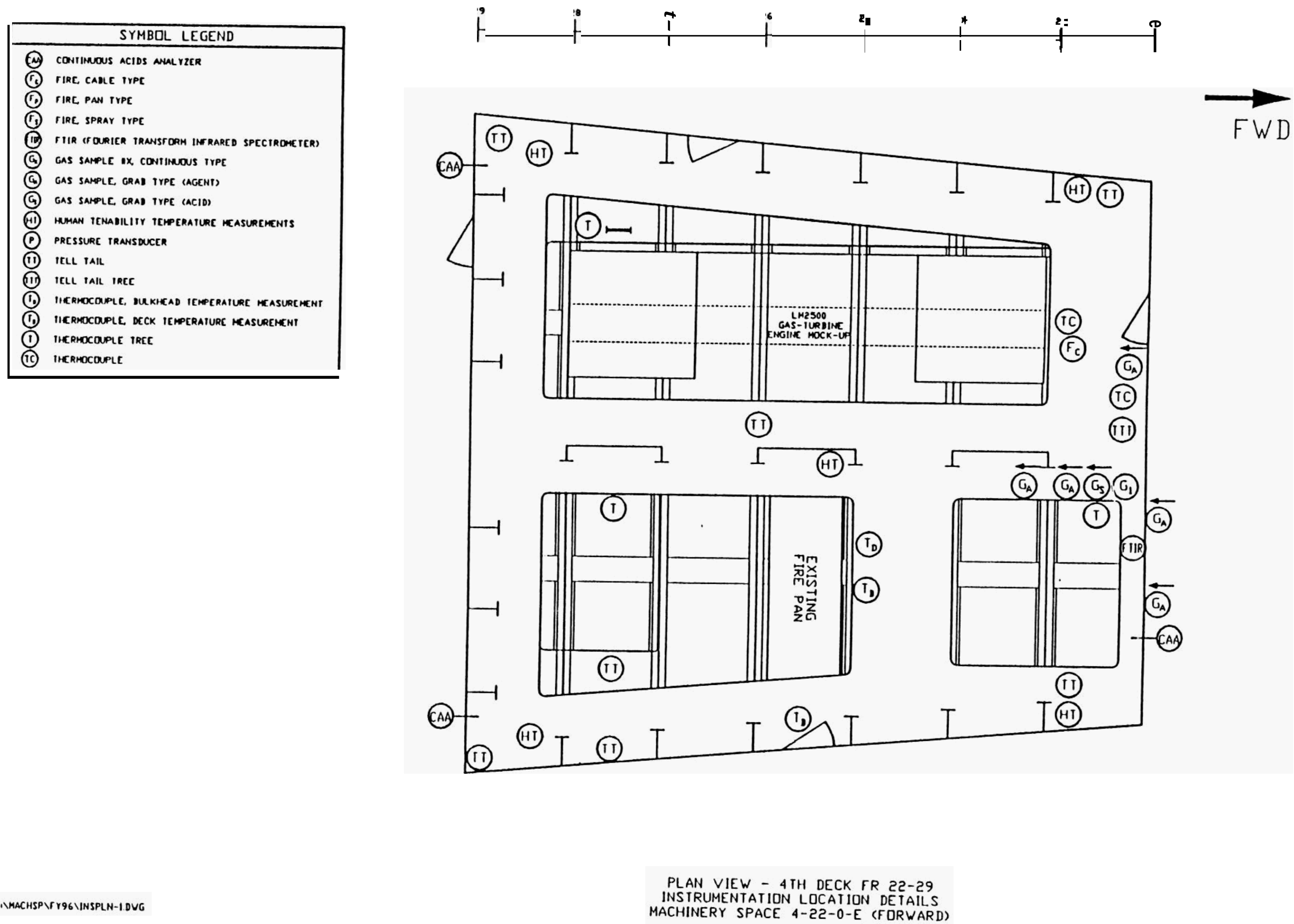
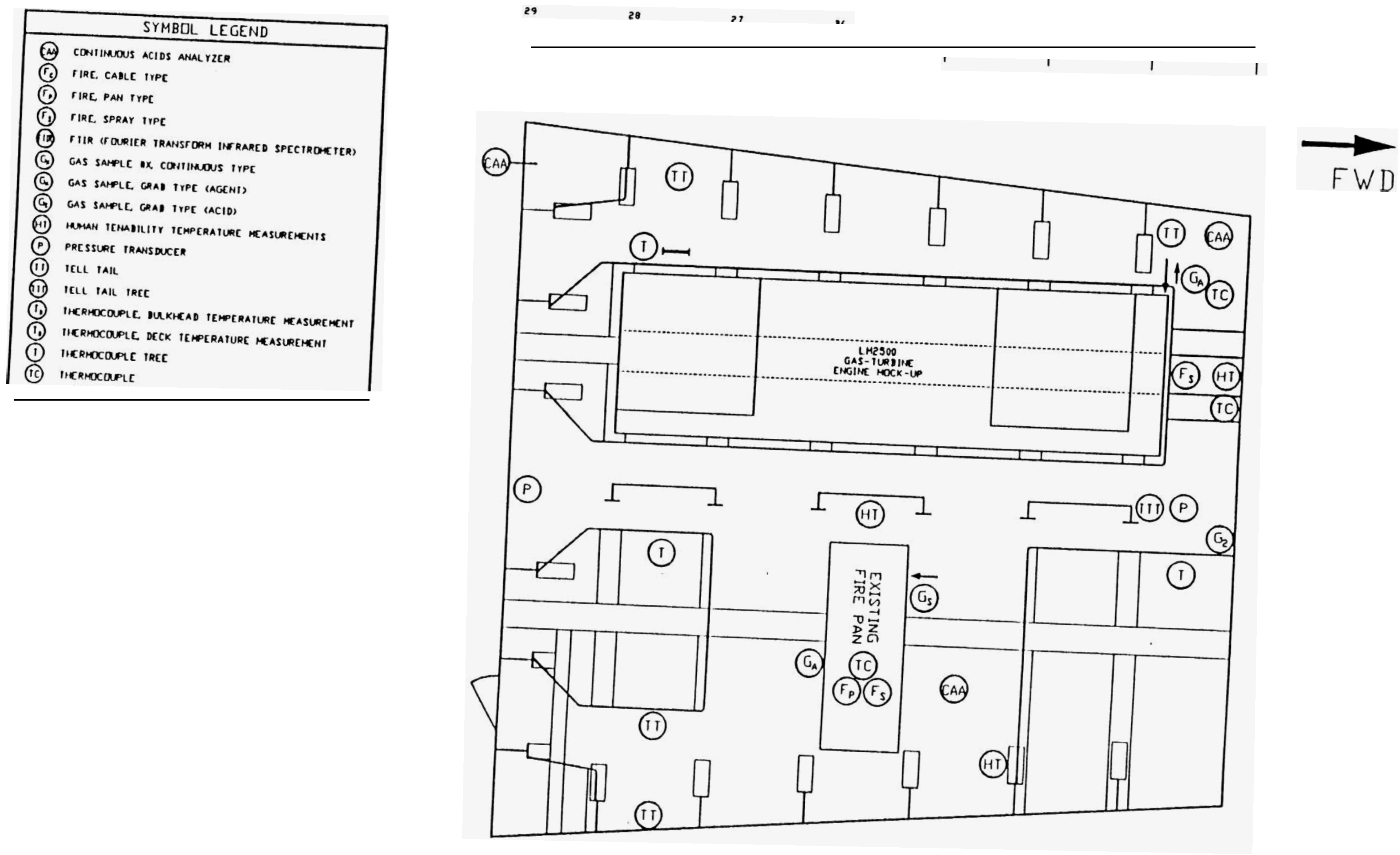


Figure 2. Plan view of upper level instrumentation



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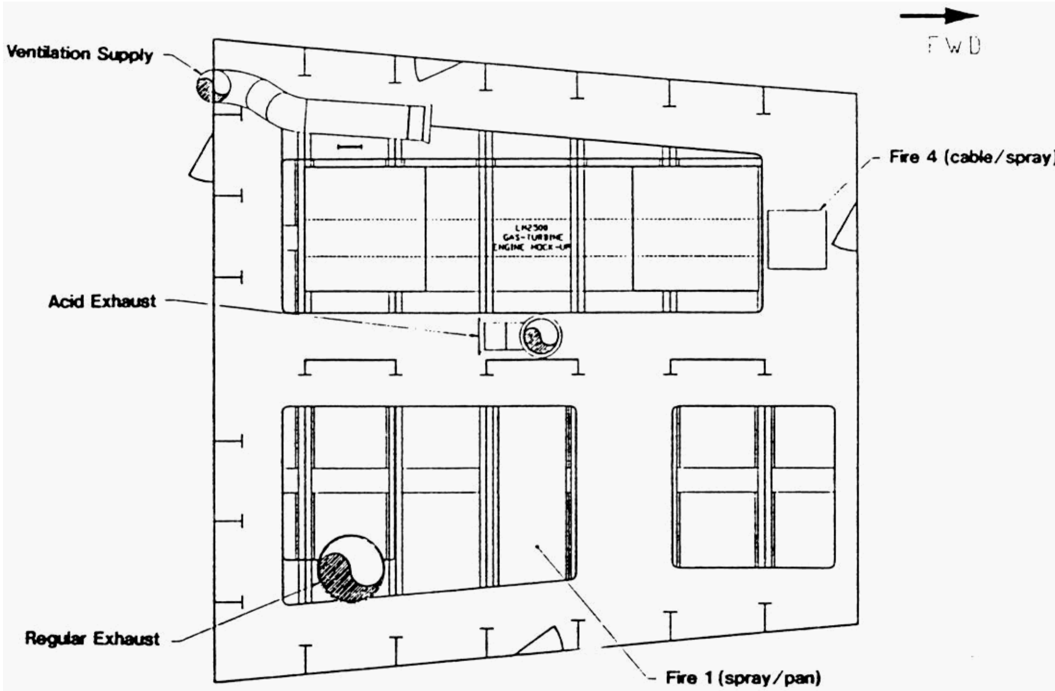
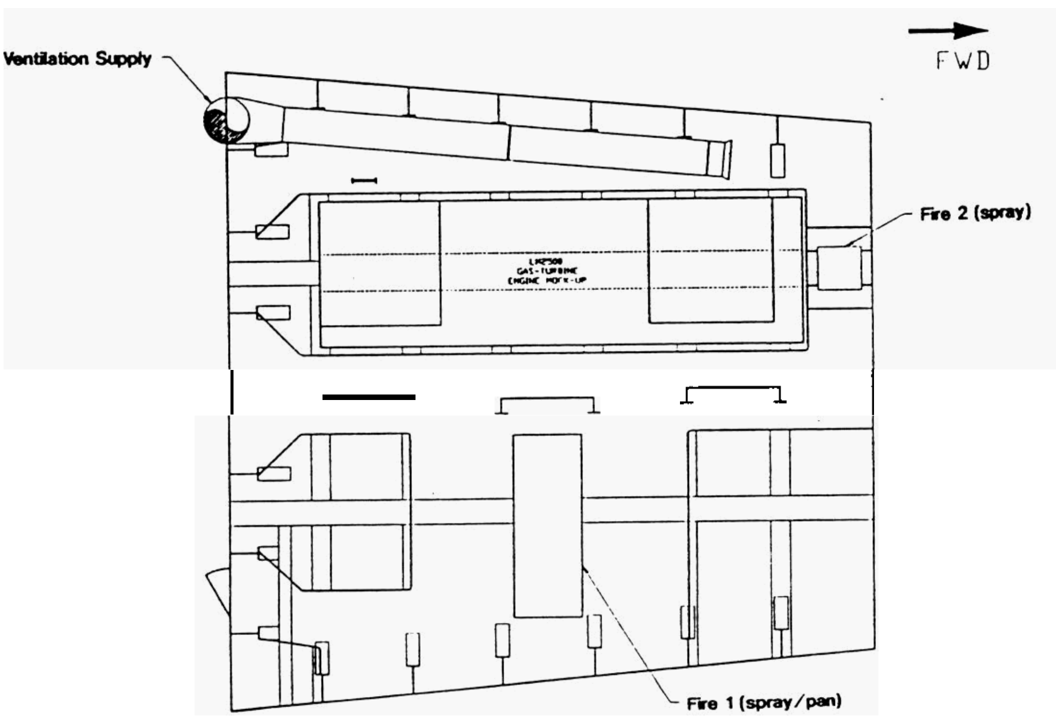
PLAN VIEW - HOLD LEVEL FR 22-29
INSTRUMENTATION LOCATION DETAILS
MACHINERY SPACE 4-22-0-E (FORWARD)

Figure 3. Plan view of lower level instrumentation



PLAN VIEW - 4TH DECK FR 22-29
MACHINERY SPACE 4-22-0-E (FORWARD)



PLAN VIEW - HOLD LEVEL FR 22-29
FIRE AND VENTILATION LOCATION
MACHINERY SPACE 4-22-0-E (FORWARD)

Figure 4. Schematic of fire locations

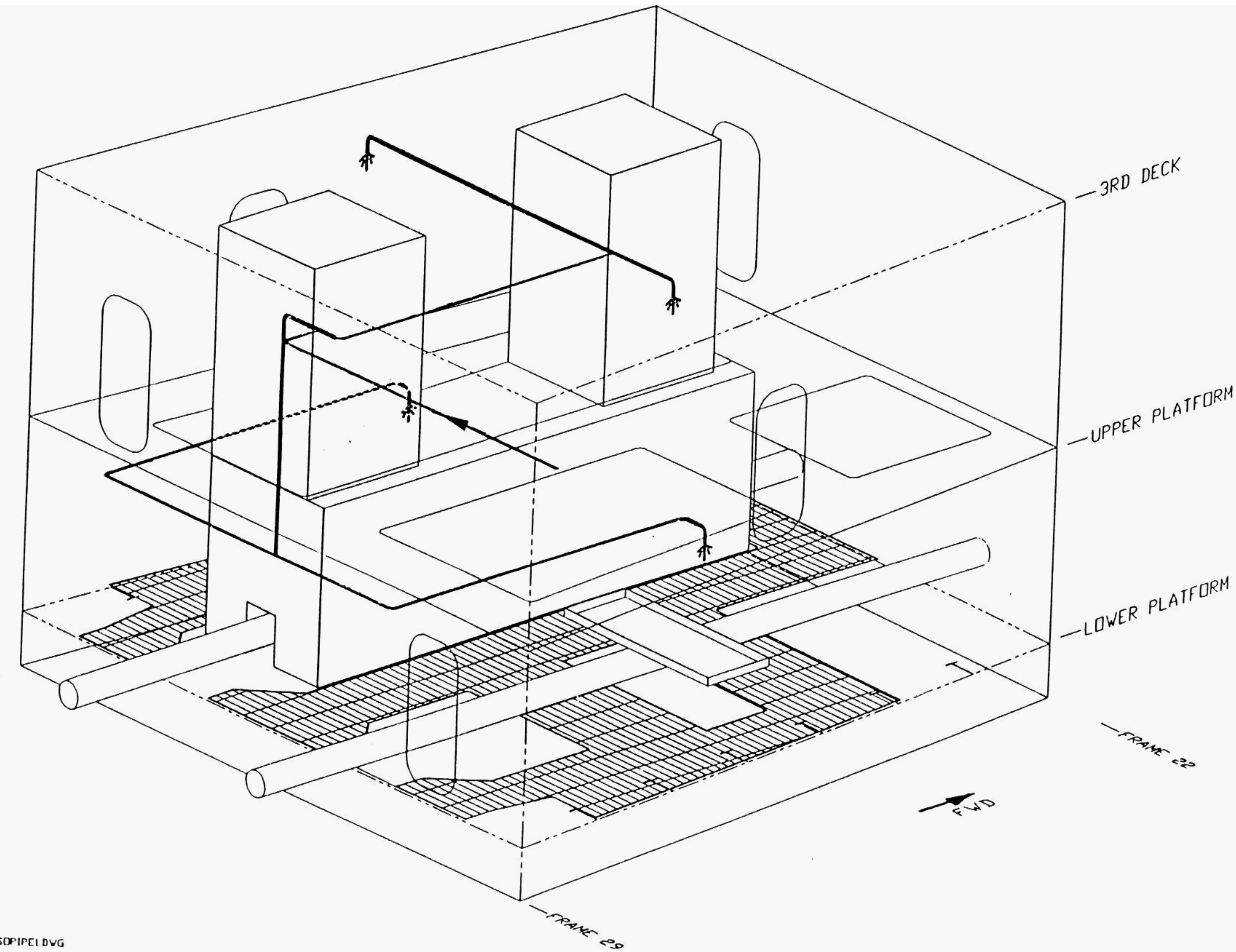


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Figure 5. Schematic of 4 nozzle gaseous agent discharge system

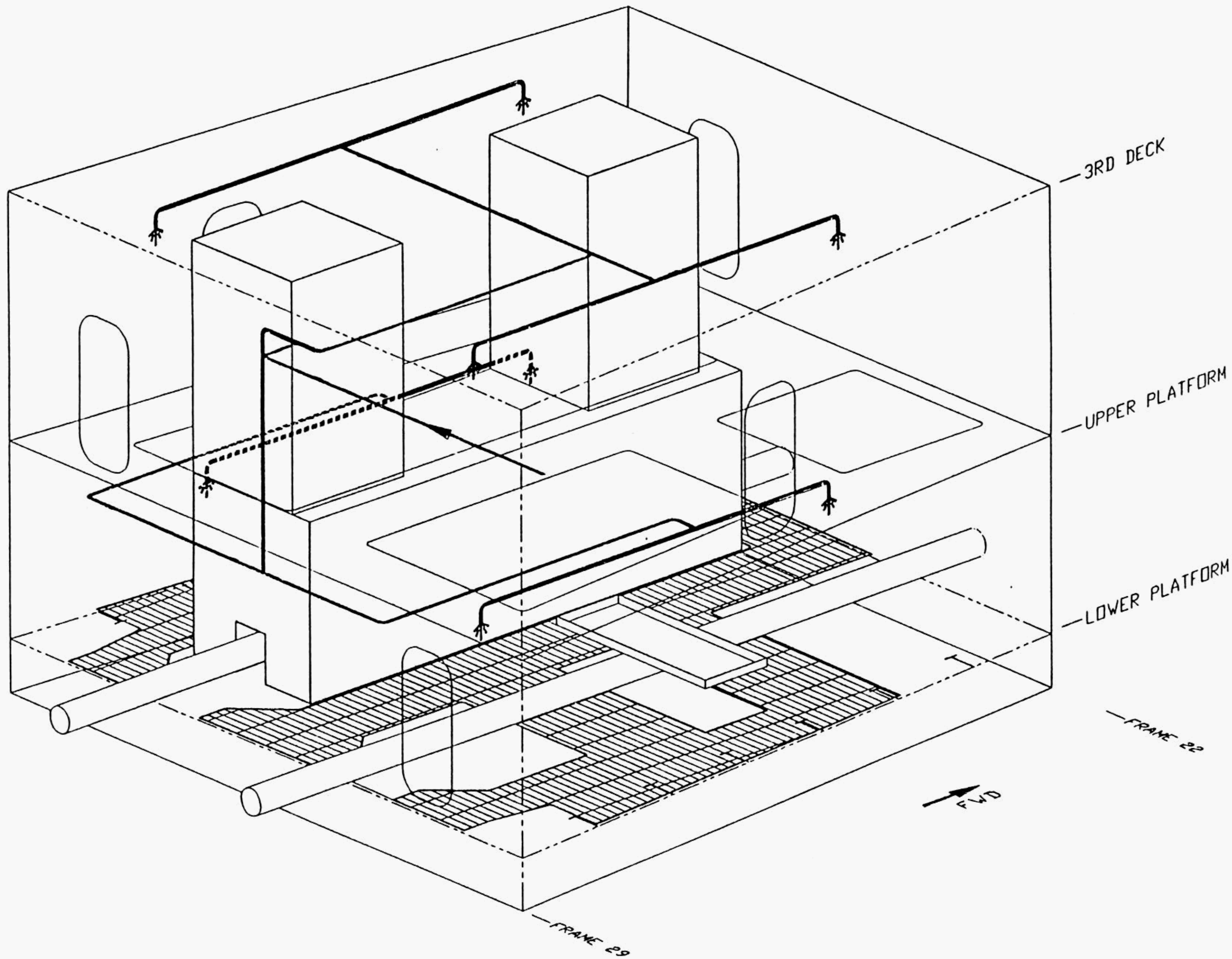

Figure 6. Schematic of 8 nozzle gaseous agent discharge system