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Full Scale Tests of Water Mist Fire Suppression Systems for Navy Shipboard Machinery Spaces: Phase I - Unobstructed Spaces

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Full scale tests of candidate water mist systems were conducted in a simulated machinery space on the ex-USS *Shadwell.* There were no obstructions in the space and the fire threats were both pan and spray fires of up to 10 MW. These tests demonstrated the potential ability of water mist to extinguish both shielded and unshielded Class B fires in full scale, relatively uncluttered machinery space applications. Of particular importance from the standpoint of minimization of damage is the rapid reduction in the temperature of the space almost immediately after mist system activation. These tests also demonstrate the differences in firefighting capabilities of the candidate systems tested. While these results are extremely encouraging, modifications to the systems will be needed to shorten the extinguishment times and minimize potential fire damage. These modifications will be included iin the Phase II tests.

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FULL SCALE TESTS OF WATER MIST FIRE SUPPRESSION SYSTEMS FOR NAVY SHIPBOARD MACHINERY SPACES:
PHASE I - UNOBSTRUCTED SPACES

1.0 BACKGROUND

The U.S. Navy is conducting an ongoing investigation into the use of water mist as a replacement for Halon 1301 total flooding systems which are currently installed in shipboard machinery spaces. Intermediate scale tests have demonstrated the potential capabilities and benefits of water mist technologies for machinery space applications [1]. In addition, full scale tests have been conducted in a simulated machinery space aboard the ex-USS SHADWELL (Fig. 1) in Mobile, Alabama, as follows:

Phase I - These tests were conducted in any empty, i.e., unobstructed machinery space with the water mist nozzles installed at one level, high in the overhead of the space. The primary objective of these tests was to verify the results of the intermediate scale tests and identify any concerns associated with scaling these preliminary results to full scale applications.

Phase II - These tests were conducted in the Phase I machinery space which was fitted with mock-ups of equipment to further evaluate the firefighting capabilities of the water mist systems in a more realistic machinery space environment. Initially, the nozzles were installed in the overhead at one level as in the Phase I study. Then, in an attempt to improve the performance of the systems, the nozzles were installed on two levels as is the practice with the current Halon 1301 total flooding systems.

This report addresses the results of the Phase I tests conducted in accordance with the approved test plan [2]. The Phase II results will be covered separately [3].

2.0 OBJECTIVE

The objective of this program was to develop an environmentally acceptable replacement for Halon 1301 for new ships, starting with the LPD-17. Water mist is particularly attractive for this application since, unlike Halon 1301, water has zero ozone depletion potential, zero global warming potential, is non-toxic, non-corrosive and has tremendous cooling capacity.

The evaluation focussed primarily on the firefighting capabilities of the "state of the art" water mist technologies as applied to machinery space applications. An assessment of water mist system parameters (i.e., flow rates, pressures, nozzle spacings, etc.) was also conducted to optimize the firefighting capabilities of each system as well as to add robustness to the system's performance. Ultimately, a performance criteria and design specification will be developed.

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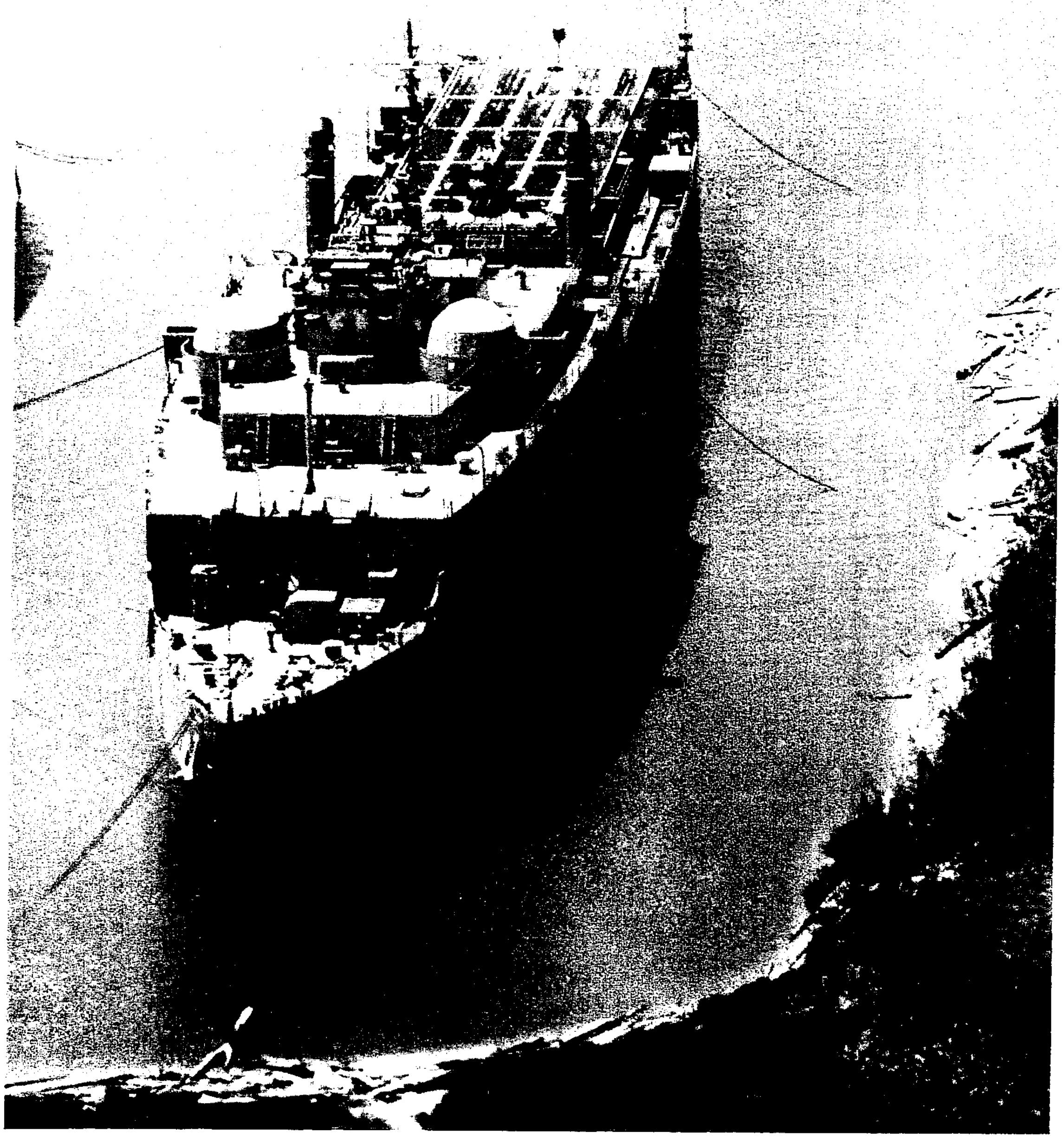


Fig. 1 - ex-USS SHADWELL

Other, more specific objectives include the following:

1. evaluate the system's firefighting capabilities against a range of fuel types and fire scenarios including Class A fires and Class B pool, cascading, and spray fires;
2. evaluate the system performance as a function of fire location within the protected space (i.e., corners, high elevations, etc.); and
3. determine the limits of the system with respect to shielding and fire obstruction(s).

3.0 WATER MIST OVERVIEW

3.1 Background

In general, the efficiency of a particular water mist system is strongly dependent on the system's ability to not only generate sufficiently small droplet sizes, but to distribute "critical concentrations" of droplets throughout the compartment. It is worth remarking that a widely accepted "critical concentration" of water droplets required to extinguish a fire is yet to be determined. Factors that contribute to the distribution of this critical concentration of water mist throughout the compartment consist of droplet size, velocity, the spray pattern geometry as well as the momentum and mixing characteristics of the spray jet, and the geometry and other characteristics of the protected area. Hence, water mist must be evaluated in the context of a system rather than as an extinguishing agent.

3.2 Current Water Mist Technologies

There are currently over twenty manufacturers of water mist hardware, some of which are commercially available as fire suppression systems while others are still under development or being used in other applications. For the purpose of more general discussion, these candidate systems can be broken down into three distinct categories: single-fluid low-pressure, single-fluid high-pressure, and twin-fluid systems. The droplet size distributions produced by similar technologies fall into discrete ranges. These ranges are shown as the volumetric mean droplet diameter (D_{V50}) in Fig. 2. All three system categories have been demonstrated as effective fire suppression technologies [1]. A brief description of the three general categories is given in the following paragraphs.

3.2.1 Single-fluid Low-pressure Systems

Single-fluid low-pressure systems operate at or below 12 bar (175 psi). Because of this relatively low operating pressure, these systems often utilize the same piping and materials as conventional sprinkler systems. This translates into a relatively simple, lower cost system. The lower pressure nozzles also utilize larger orifice sizes to produce the same water flow rates. This increased orifice size is less susceptible to clogging and can be an advantage in reducing the need for corrosion prevention and water supply filtration (to some extent).

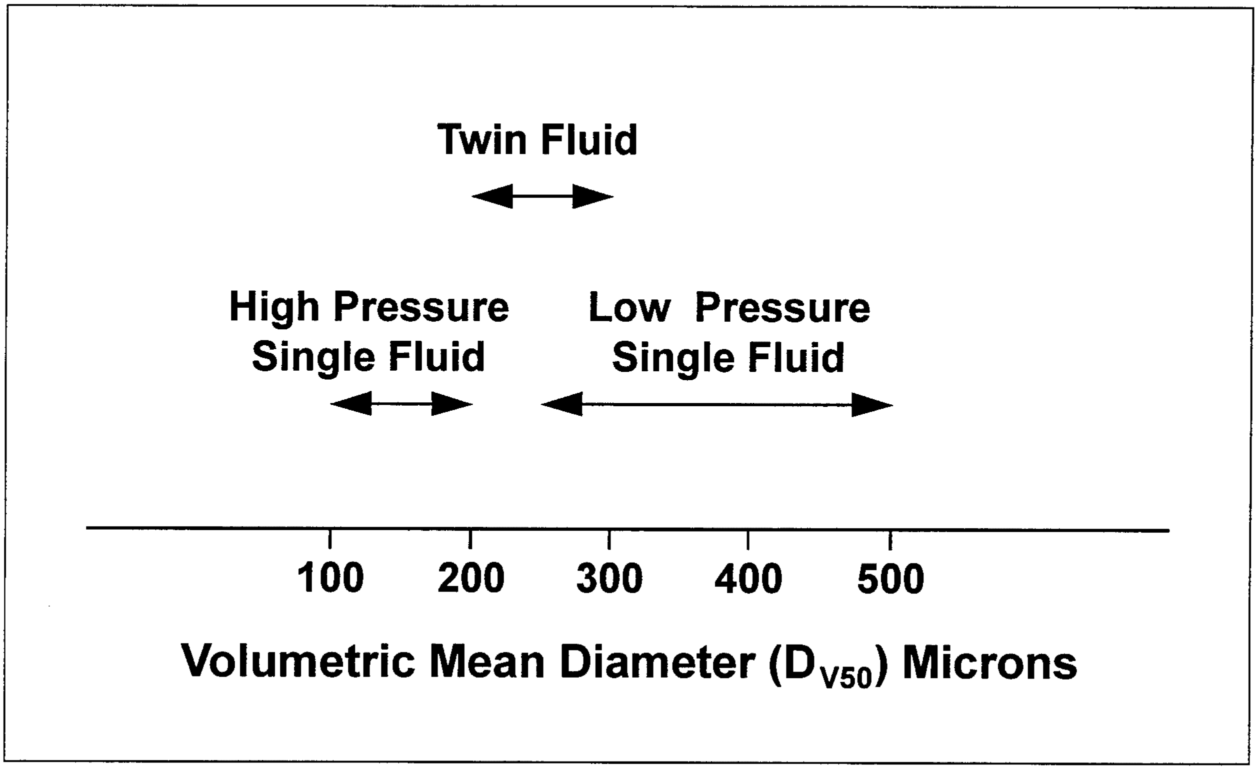


Fig. 2 – Droplet size comparison

The disadvantages of these systems are larger average droplet sizes and higher water flow rates. The larger droplets have a higher terminal velocity than smaller droplets due to the mass of water contained in the droplet. This results in a higher fall out rate of droplets from the mist. This fall out significantly reduces the amount of mist that effectively mixes throughout the space, especially in higher elevations and around obstructions. Consequently, these larger droplet sizes reduce the systems' capabilities against obstructed/shielded fires. The low pressure systems also utilize higher water flow rates in an attempt to negate these increased fall out losses.

3.2.2 Single-fluid High-pressure Systems

The single-fluid high-pressure systems, to date, have proven to be the most effective fire extinguishing mist system technology. The single-fluid high-pressure systems operate at pressures up to 210 bar (3000 psi). These high operating pressures provide an effective means of generating high concentrations of small droplets. The smaller droplet sizes exhibit more gaseous-like behavior and superior mixing characteristics. These characteristics increase the systems' capabilities against shielded/obstructed fires. The smaller droplets also have superior heat transfer characteristics due to greater surface area to volume ratios. This allows the high pressure systems to utilize water more efficiently and consequently use less water.

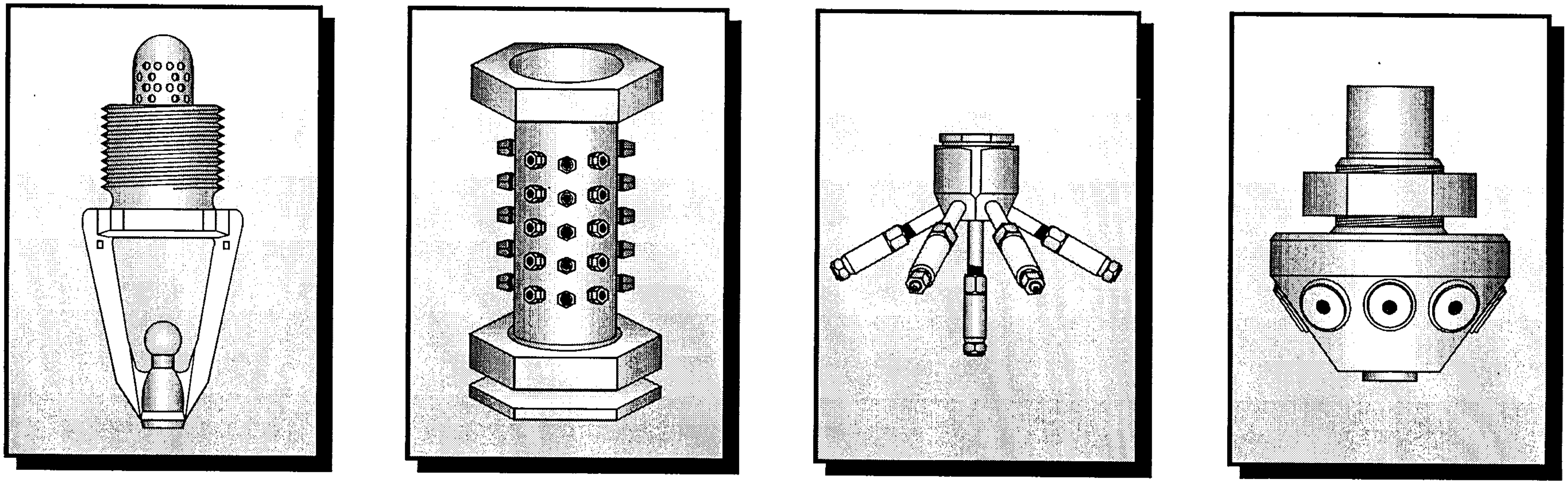
The disadvantage of these systems is an increased cost due to the need for high-pressure system components (i.e., pipes, fittings, valves, pumps, etc.). The power requirements associated with the high-pressure pumps may, in many cases, also prove to be a severe disadvantage.

3.2.3 Twin-fluid Systems

Twin-fluid systems require two fluids, water and an atomizing fluid, both being supplied to the nozzle using separate piping networks. These nozzles utilize a high velocity stream of air or nitrogen to shear the water into small droplets. This process usually takes place in or directly in front of the nozzle. One advantage of this technology is that it produces large quantities of small water droplets at low operating pressures, usually less than 7 bar (100 psi). The disadvantage of this technology is the additional piping, storage volume, and associated cost of the atomizing fluid.

3.3 Candidate Nozzles

Three commercially available water mist fire suppression systems and one generic system, produced using off-the-shelf industrial spray nozzles, were selected for this evaluation based on the intermediate scale tests [1]. The candidate systems cover the range from low to high pressure single-fluid systems. Twin fluid systems were not included in this evaluation due to the results of the intermediate scale tests (average performance) and due to the difficulty of running two pipes to each nozzle. The generic nozzles were evaluated to identify any variations in performance between the “state of the art” water mist technologies and ad hoc systems with similar droplet size distributions and water usage rates. The commercially available systems were evaluated at the manufacturer's recommended design parameters (i.e., pressure and flow rate, but not nozzle spacing). The systems evaluated during this test series include Baumac MicroMist, Grinnell AquaMist, Marioff Hi-fog, and a generic system produced using modified Spraying Systems nozzles. The candidate nozzles are shown in Fig. 3. A brief description of each system is as follows:



Grinnell
Aquamist
Nozzle
(AM-10)

Baumac
Micromist
Nozzle

HAI/NRL
Modified
Spraying Systems
Nozzle

Marioff
Hi-fog
Nozzle
(multipurpose)

Fig. 3 – Candidate water mist nozzles

3.3.1 Baumac MicroMist System

The Baumac MicroMist system was custom designed for this test series. The Baumac system is a single-fluid, high-pressure system which was evaluated at an operating pressure of 70 bar (1000 psi). The Baumac nozzles consist of 40 smaller nozzles configured in five rows of eight nozzles installed 45° apart in 2.5 cm (1 in.) stainless steel tubing (Fig. 3). Four smaller nozzle types/sizes (MX-8, MX-12, MX-15, and MX-20) were installed in this nozzle body and were varied during these tests. In its original configuration (all MX-8 nozzles), the nozzle has a nominal k-factor of 0.45 Lpm/bar$^{1/2}$ (0.03 gpm(psi$^{1/2}$)). The system was evaluated using a 2.4 m (8.0 ft) nozzle spacing with two nozzles installed at each nozzle location. This corresponds to a water mist application rate of 1.3 Lpm/m^2 (0.03 gpm/ft^2).

3.3.2 Grinnell AquaMist System (AM-10)

The Grinnell AquaMist system is a single-fluid, low-pressure system which has a operating pressure of 12 bar (175 psi) and is similar to a standard automatic sprinkler system in terms of system hardware and operating principles. The system produces small droplets by impinging a water stream on a spherical deflector plate. The relatively low-pressure AquaMist system substitutes efficiency in producing small droplets (produces larger droplets than the high-pressure nozzle) for the cost and commercial advantages of using standard hardware (hardware used by conventional sprinkler systems). The nozzle recommended for this evaluation (AM-10) has a nominal k-factor of 3.5 Lpm/bar^{½} (0.26 gpm/psi^{½}) and is typically installed with a 2.0 m (6.5 ft) nozzle spacing. During these tests, the nozzles were installed in the fire compartment with just over a 2.0 m (6.5 ft) nozzle spacing which corresponds to a mist application rate of 3.0 Lpm/m^2 (0.075 gpm/ft^2).

3.3.3 Marioff Hi-fog System

The Marioff Hi-fog system is a high-pressure single-fluid system which has an operating pressure of 210 bar (3000 psi), the highest pressure of any commercially available water mist system. This system produces small droplets with high momentum. Although Marioff has numerous nozzle designs and configurations, only the multipurpose nozzles were tested during this evaluation. Marioff's multipurpose nozzle contains seven orifices, one central orifice surrounded by six perimeter orifices. The nozzle has a k-factor of 0.9 Lpm/bar^{½} (0.06 gpm/psi^{½}) and has a recommended nozzle space of 3.0 m (10 ft). During these tests, the nozzles were installed in the fire compartment with a 2.0 m (6.5 ft) nozzle spacing which corresponds to a mist application rate of 2.3 Lpm/m^2 (0.054 gpm/ft^2).

3.3.4 Modified Spraying Systems 7N Nozzle

The modified Spraying Systems nozzle is a single-fluid, high-pressure nozzle which was evaluated at a pressure of 70 bar (1000 psi). The modified nozzle is comprised of a Spraying Systems Model 7N nozzle body with seven model 1/4LN nozzles installed on 7.6 cm (3 in.) long brass nipples. The six 1/4LN nozzles installed around the perimeter are Model 1/4LN4, and the one in the center is a Model 1/4LN8. The purpose of varying the size of these nozzles was to produce droplets of different size and momentum: the perimeter nozzles produce small droplets with low momentum, and the center nozzles produce larger droplets with high momentum which serves to mix the mist throughout the space. In this configuration, the nozzle has a k-factor of 1.1 Lpm/bar^{½} (0.08 gpm/psi^{½}). These nozzles were installed with a 2.4 m (8.0 ft) nozzle spacing, which corresponds to a mist application rate of 1.6 Lpm/m^2 (0.04 gpm/ft^2).

4.0 TEST PARAMETERS

4.1 Test Compartment

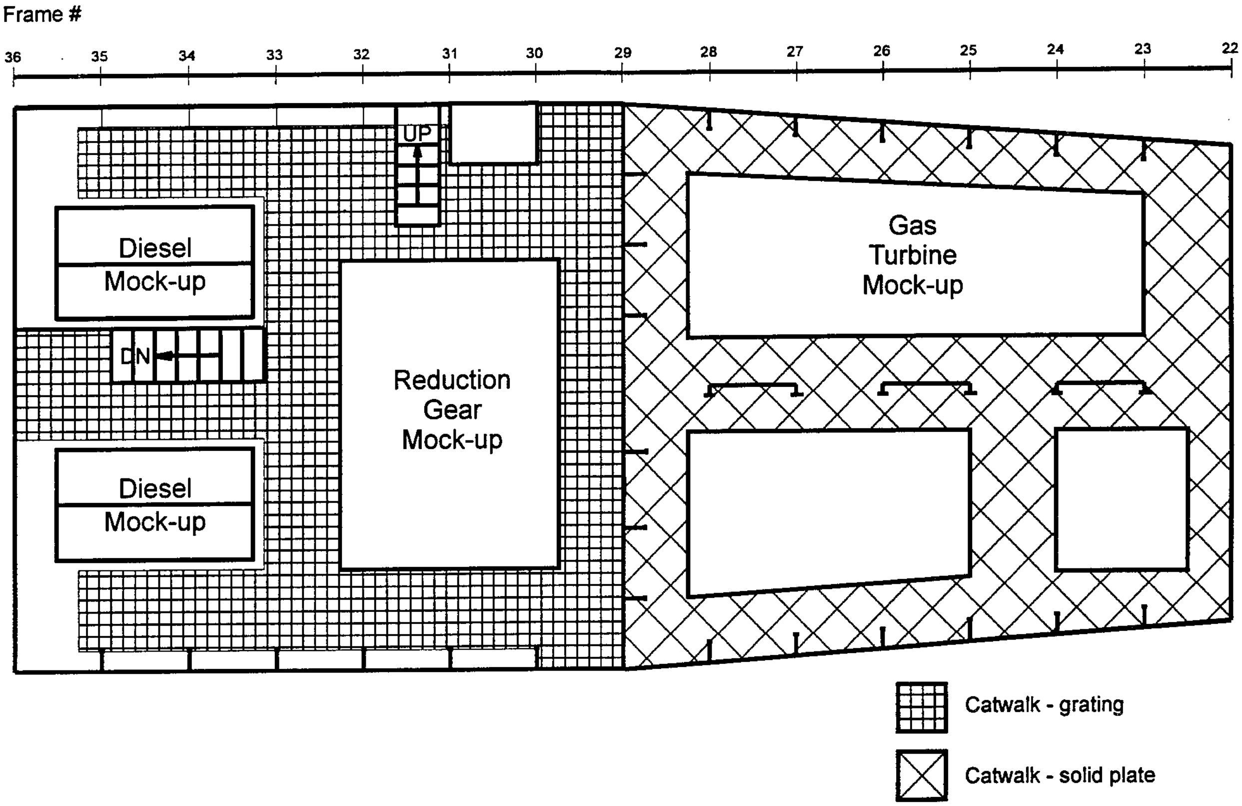
The Phase I tests were conducted in a machinery space aboard the ex-USS SHADWELL in Mobile, AL. An area forward in the ship between Frames 22 and 36, and between the bilge and the third deck was modified to simulate a "typical" machinery space (Fig. 4). The space is roughly 9 x 18 x 6 m (30 x 60 x 20 ft), producing a total volume of 962 m^3 (36,000 ft^3). Included in this space was an open bilge area approximately 1 m (3 ft) deep and two levels of catwalks shown in Figs. 5 and 6. The ventilation system onboard the ship was used to provide 20 air exchanges per hour, a value representative of actual machinery spaces. Both supply and exhaust fans were used to provide this ventilation. The space was instrumented for temperature, radiant, and total heat flux, optical density, and typical fire gas species (O_2, CO, and CO_2). Oxygen concentration was also measured at the base of each fire. All fires were instrumented for temperature to note extinguishment. Each test was videotaped using both a standard and an infrared video camera.

4.2 Water Mist System

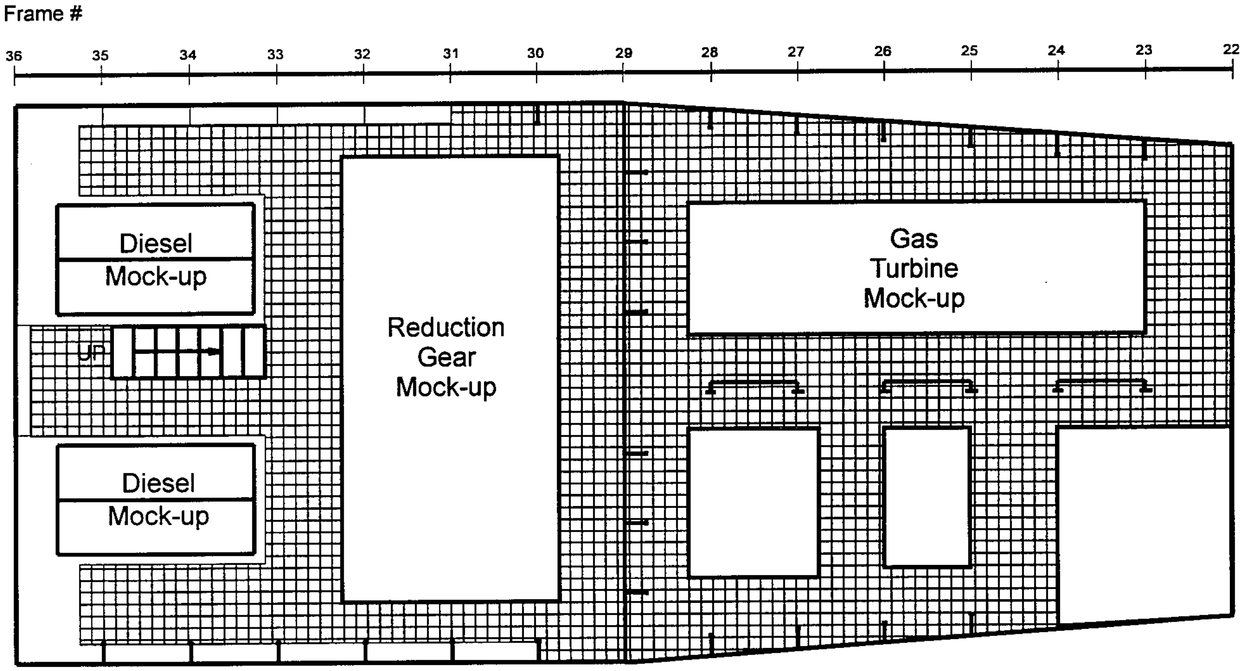
During this evaluation, the nozzles were installed with an uniform nozzle spacing at one elevation high in the space. The nozzles were installed in either of the two piping configurations shown in Fig. 7. It was originally intended to evaluate all four candidate systems in the same configuration. However, due to the compressed test schedule, Grinnell and Marioff both requested a tighter nozzle spacing, i.e., 2.0 m (6.5 ft) versus 2.4 m (8.0 ft), to ensure adequate results. The pipe network was constructed of 2.5 cm (1 in.) stainless steel tubing (AISI 316, with a 1.65 mm (0.065 in.) wall thickness) and connected together using stainless steel single-ferrule compression fittings. Stainless steel tubing and fittings were selected to prevent rust and/or corrosion from developing inside the piping network. As installed, this system has a working pressure of 200 bar (3000 psi) and a burst pressure of 800 bar (12,000 psi). The pipe network was supplied using ten 38.0 Lpm (10 gpm), 210 bar (3000 psi) pressure washers installed in parallel (Fig. 8). Each pressure washer was equipped with a pressure regulating unloader valve allowing the pressure/flow to be adjusted to the manufacturers' design pressure/flow requirements for each system. The pumps were supplied with rain water via the fire main of the ship. The water mist system was instrumented to provide the total system flow rate and nozzle pressure for each system.

4.3 Fire Scenarios

The four candidate systems were evaluated against Fire Scenarios #1-5 listed in Table 1. The locations of the fires for each scenario are shown in Fig. 9. The total heat release rates of these fire scenarios were estimated to be 3.5, 4.5, 6.5, and two 7.5 MW. Each scenario consisted of a large spray fire (Fire #1, Fig. 9), a shielded spray fire (Fire #2, Fig. 9), and both a shielded and unshielded 0.3 x 0.3 m (1 x 1 ft) pan fire (Fires #3 and #5, Fig. 9). Due to time constraints, the cable tray fire (Fire #4) was not used in this evaluation. The net heat release rates of the five scenarios were varied by changing the size of the large fire (Fire #1). All of the above fires were produced using heptane as the fuel and were located between the ship's hold and the fourth deck. There were also 29 small heptane pan fires (Tell tales ~3 kW each) positioned at various locations throughout the compartment to evaluate the mist dispersion and extinguishing characteristics of the candidate systems. The first four fire scenarios were



Machinery space with mock-ups - Fourth Deck



Machinery space with mock-ups - Hold Level

Fig. 4 – Machinery space mock-up (plan view)

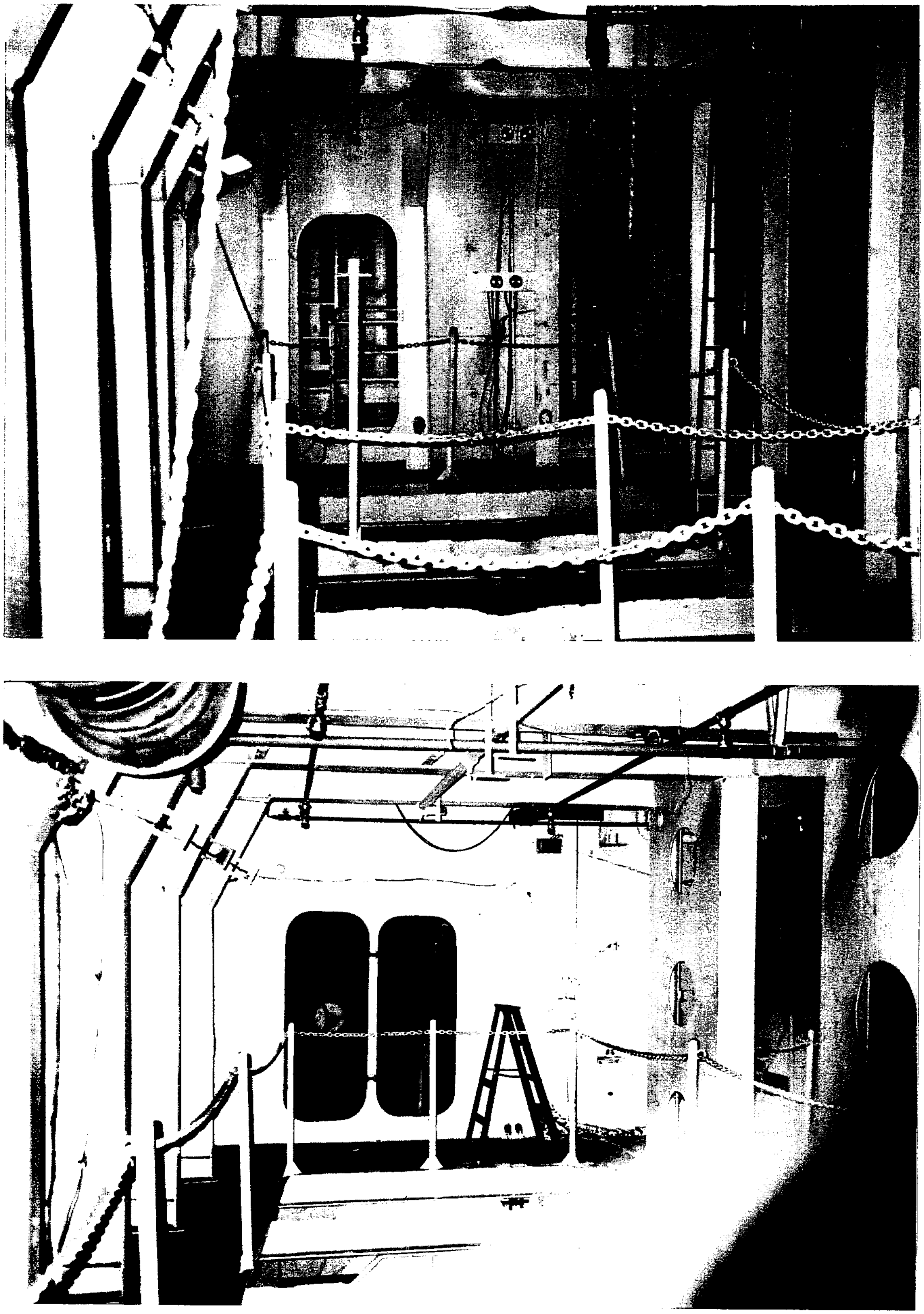


Fig. 5 - Machinery space mock-up (forward compartment, fourth deck)

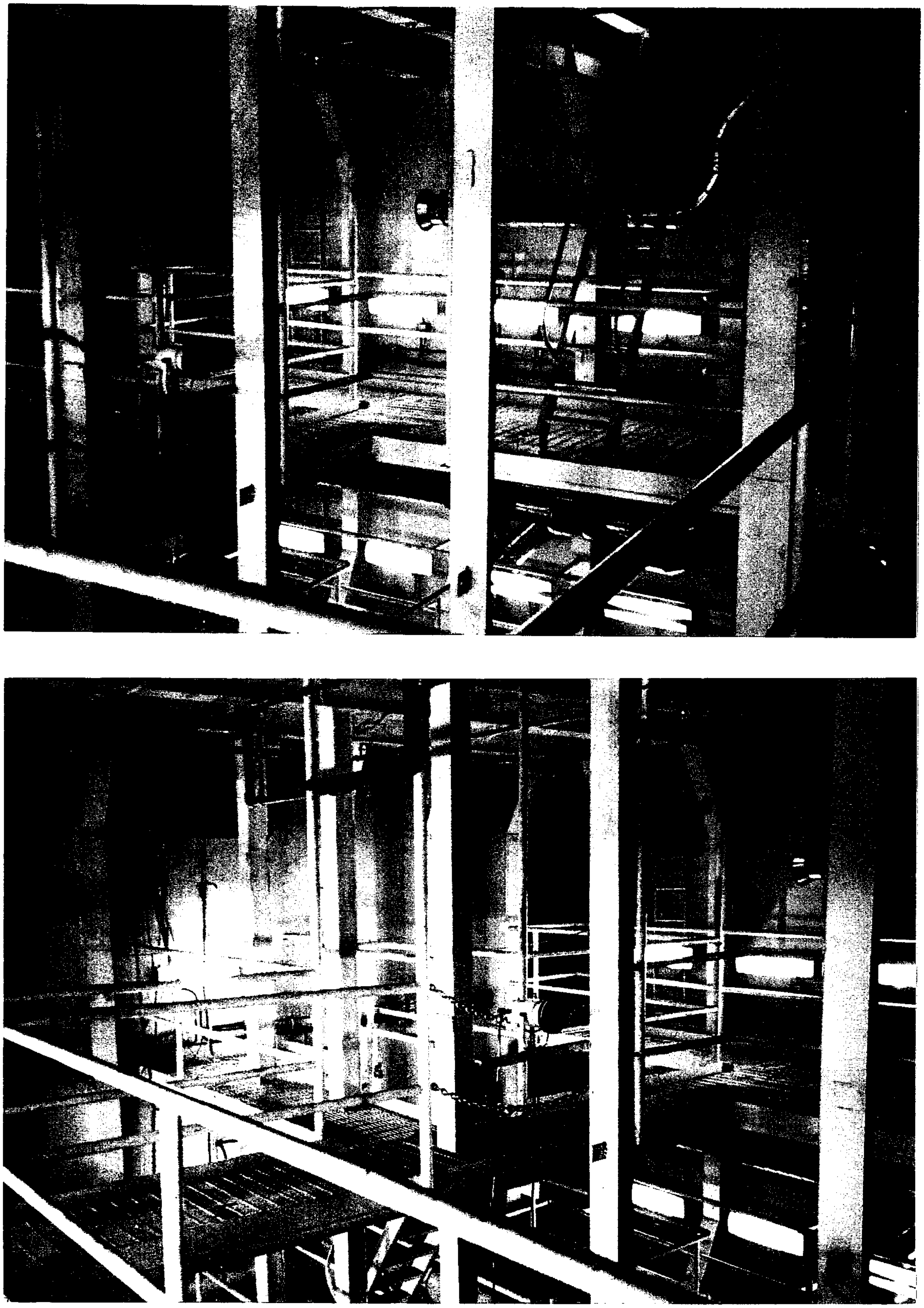
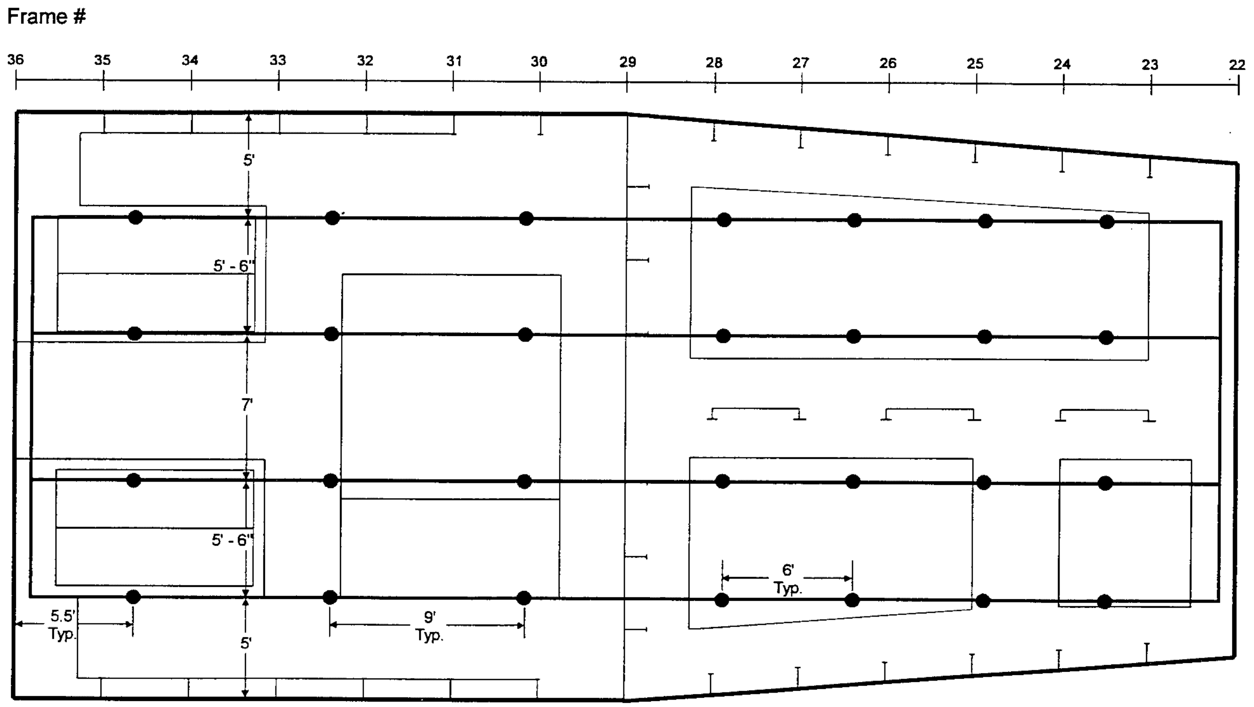
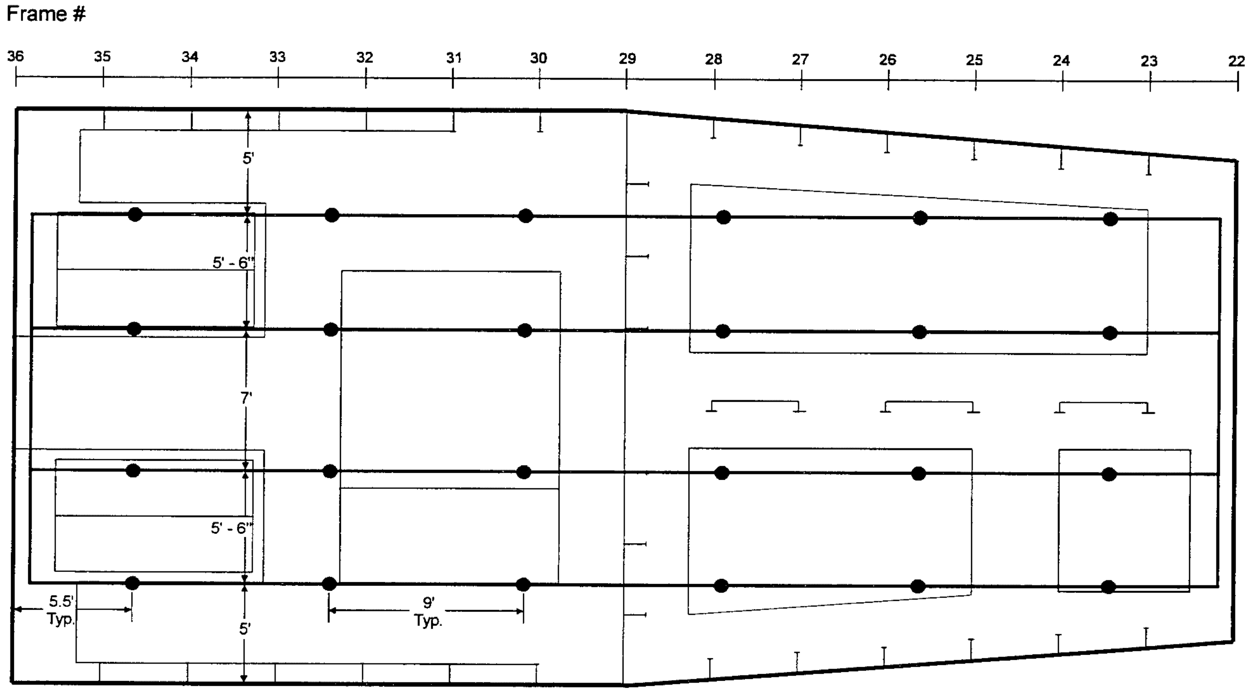


Fig. 6 - Machinery space mock-up (aft compartment, fourth deck)



Grinnell and Marioff nozzle spacing



Baumac and Spraying Systems nozzle spacing

Fig. 7 – Piping network with nozzle locations

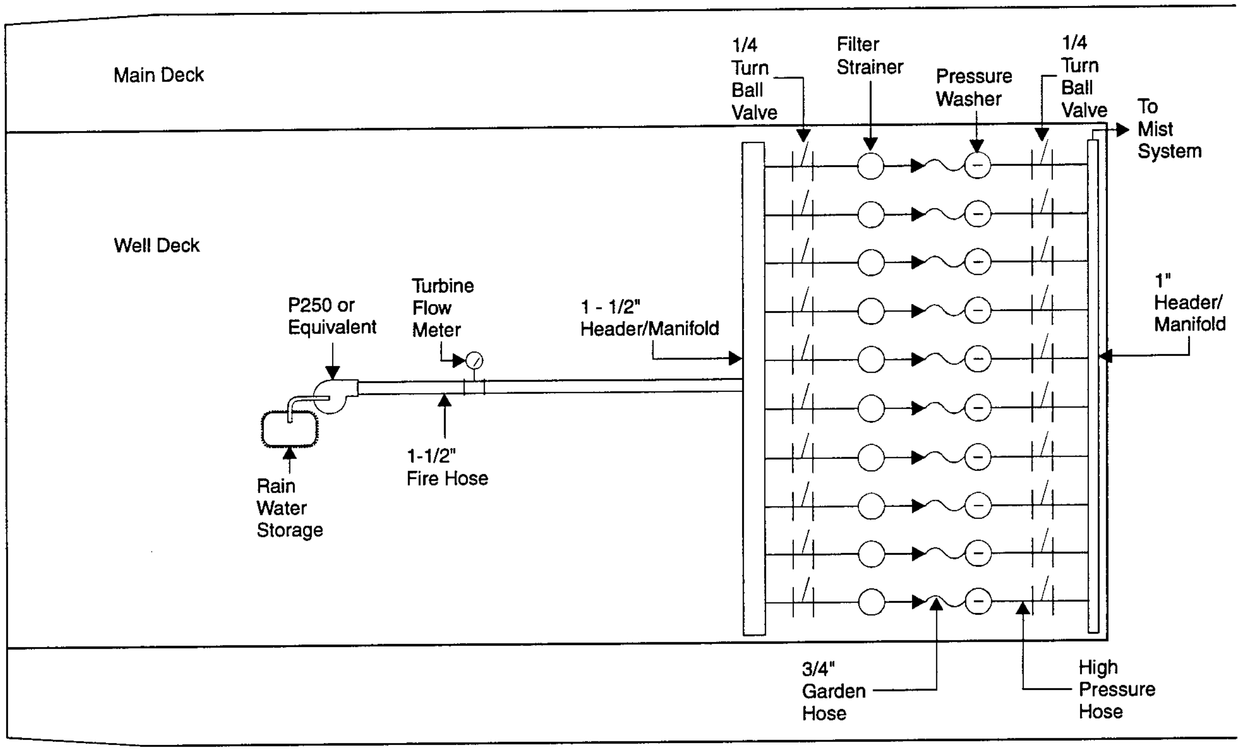
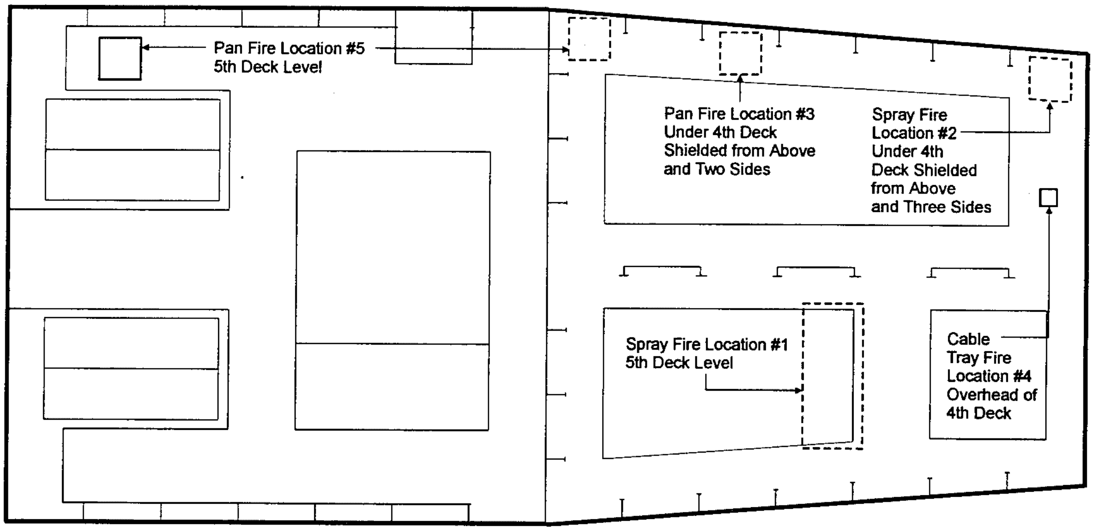
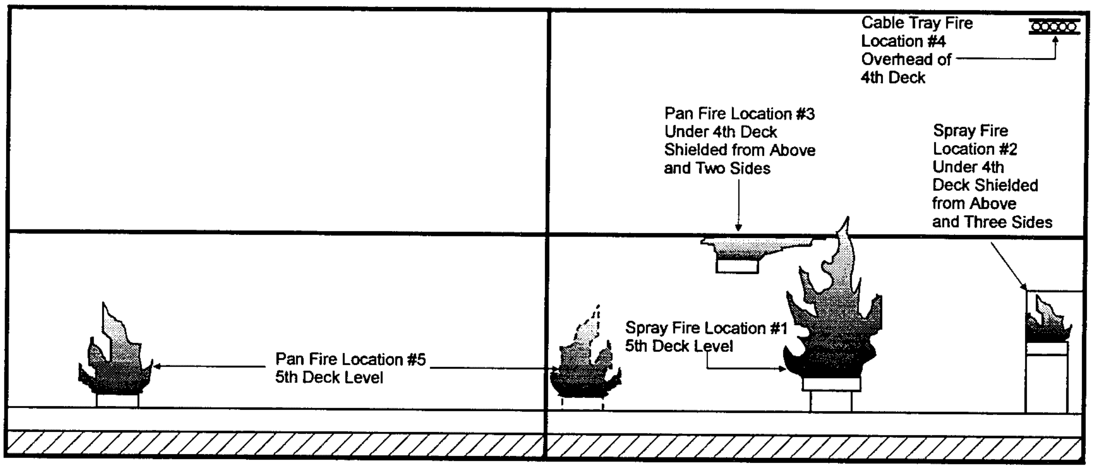


Fig. 8 – Pumping system



Plan View



Elevation View

Fire Scenario	Ventilation	Fire #1	Fire #2	Fire #3	Fire #4	Fire #5
#1 ~ 3.5 MW	Secured	2.5 MW Spray	0.25 MW Spray	0.2 MW Pan	N/A	0.2 MW Pan
#2 ~ 4.5 MW	Secured	3.5 MW Spray	0.20 MW Spray	0.2 MW Pan	N/A	0.2 MW Pan
#3 ~ 6.5 MW	Secured	5.5 MW Spray	0.30 MW Spray	0.2 MW Pan	N/A	0.2 MW Pan
#4 ~ 7.5 MW	Secured	6.5 MW Spray	0.20 MW Spray	0.2 MW Pan	N/A	0.2 MW Pan
#5 ~ 7.5 MW	Operating	6.5 MW Spray	0.25 MW Spray	0.2 MW Pan	N/A	0.2 MW Pan

Fig. 9 – Fire locations

conducted with the ventilation system (both exhaust and supply) secured prior to mist system activation and the fifth with the ventilation system operating (both exhaust and supply) for the duration of the test.

Table 1. Fire Scenarios

Fire Scenario	Description
#1	~3.5 MW (Ventilation Secured) 1 - 2.5 MW spray (P-80 @ 2.8 bar (40 psi)), vertical spray 1 - 0.25 MW spray (LN-8 @ 2.8 bar (40 psi)), horizontal spray 2 - 0.3 x 0.3 m (1 x 1 ft) pans, 3.8 L (1 gal) of heptane in each 29 - Tell tales with ~2.5 cm (1 in.) of heptane in each
#2	~4.5 MW (Ventilation Secured) 1 - 3.5 MW spray/pan (FF158145 @ 1.0 bar (15 psi)), horizontal spray 1 - 0.15 MW spray (LN-8 @ 1.0 bar (15 psi)), horizontal spray 2 - 0.3 x 0.3 m (1 x 1 ft) pans, 3.8 L (1 gal) of heptane in each 29 - Tell tales with ~2.5 (1 in.) of heptane in each
#3	~6.5 MW (Ventilation Secured) 1 - 5.5 MW spray (P-80 @ 2.1 bar (30 psi)), vertical spray 1 - 0.20 MW spray (LN-8 @ 2.1 bar (30 psi)), horizontal spray 2 - 0.3 x 0.3 m (1 x 1 ft) pans, 3.8 L (1 gal) of heptane in each 29 - Tell tales with ~2.5 cm (1 in.) of heptane in each
#4	~7.5 MW (Ventilation Secured) 1 - 6.5 MW spray (P-120 @ 4.1 bar (60 psi)), vertical spray 1 - 0.30 MW spray (LN-8 @ 4.1 bar (60 psi)), horizontal spray 2 - 0.3 x 0.3 m (1 x 1 ft) pans, 3.8 L (1 gal) of heptane in each 29 - Tell tales with ~2.5 cm (1 in.) of heptane in each
#5	~7.5 MW (Ventilation Operating) 1 - 6.5 MW spray (P-120 @ 4.1 bar (60 psi)), vertical spray 1 - 0.25 MW spray (LN-8 @ 4.1 bar (60 psi)), horizontal spray 2 - 0.3 x 0.3 m (1 x 1 ft) pans, 3.8 L (1 gal) of heptane in each 29 - Tell tales with ~2.5 cm (1 in.) of heptane in each
#6	~10.0 MW (Ventilation Secured) 1 - 6.5 MW spray (P-120 @ 4.1 bar (60 psi)), vertical spray 1 - 0.25 MW spray (LN-8 @ 4.1 bar (60 psi)), horizontal spray 2 - 0.3 x 0.3 m (1 x 1 ft) pans, 3.8 L (1 gal) of heptane in each 2 - 1 x 1 m (3 x 3 ft) pans, 18.9 L (5 gal) of heptane in each 29 - Tell tales with ~2.5 cm (1 in.) of heptane in each

An additional fire scenario (Fire Scenario #6) was conducted against the modified Spraying Systems nozzles. This fire scenario was produced by adding two 1 m x 1 m (3 x 3 ft) heptane pans adjacent to the spray fire in Fire Scenario #4. The estimated heat release rate of this fire scenario is approximately 10 MW. As with Scenarios #1-4, this test was conducted with the ventilation system secured just prior to mist system activation.

4.4 Test Procedures

The tests were initiated from the control room located on the 02 level. All key personnel were located in the control room during each test with the exception of two pump operators located in the well deck and a safety officer positioned near/outside the space. Also, two firefighters wearing protective clothing were positioned in the well deck. The water mist systems' pumps were started five minutes prior to each test. The machinery space ventilation system was activated and remained running during the initial stages (preburn) of each test. The tell tale fires were ignited two minutes prior to the start of the data acquisition system. The data acquisition system was activated one minute prior to ignition. The fires were allowed to burn freely for one minute before the ventilation system was secured and the water mist system was activated. The mist system was activated for five minutes during each test. At the completion of the five-minute discharge, the system was secured marking the termination of the test. After the test was completed, the ventilation system was activated to clear the space. Any remaining fires in the space were then either extinguished manually by the firefighting party or allowed to burn until all of the fuel was consumed. The space remained off-limits until cleared by the safety officer and the test director.

5.0 RESULTS AND DISCUSSION

A total of sixteen tests were conducted during this test series. The extinguishment times for each of the fires are listed in Table 2. Also listed in Table 2 are the operating pressures, total system water flow rates, and the nominal water mist application rate (flow per unit area) for each system. Mechanical difficulties prevented a fair evaluation of the Marioff System, and for this reason, it will not be included in this discussion.

During this evaluation, the Grinnell AquaMist system, Baumac MicroMist system, and modified Spraying Systems nozzles were each capable of extinguishing a majority of the test fires. The three systems were capable of extinguishing the large spray fire (Fire #1, Fig. 9) in each of the five fire scenarios (Fig. 10). Variations in system performance were observed when evaluating the system capabilities against the shielded spray fire (Fire #2, Fig. 9). The shielded spray fire was effectively obstructed on five of the six sides and was located in the corner of the space directly in front of a 30 cm (12 in.) supply vent. Only the modified Spraying Systems nozzles could consistently extinguish this fire during the unventilated fire scenarios (Fire Scenarios #1-#4, Fig. 11). During the unventilated fire scenarios, the Baumac MicroMist system and the Grinnell AquaMist system could only extinguish this fire approximately 50 percent of the time. The shielded spray fire was not extinguished by any of the three candidate water mist systems during the ventilated fire tests (Fire Scenario #5).

Throughout this test series, the modified Spraying Systems nozzles consistently out-performed the other systems, not only for extinguishment times, but also for water usage requirements (overall efficiency). This system was capable of extinguishing a majority of the fires within two minutes of activation using approximately 450 liters (118 gallons) of water. Both the Grinnell and Baumac systems required over three minutes to extinguish the same fires and required an additional 300-600 liters (75-150 gallons) of water to achieve these results. The performance of all three systems was significantly reduced by the presence of the forced ventilation in the space (Fire Scenario #5).

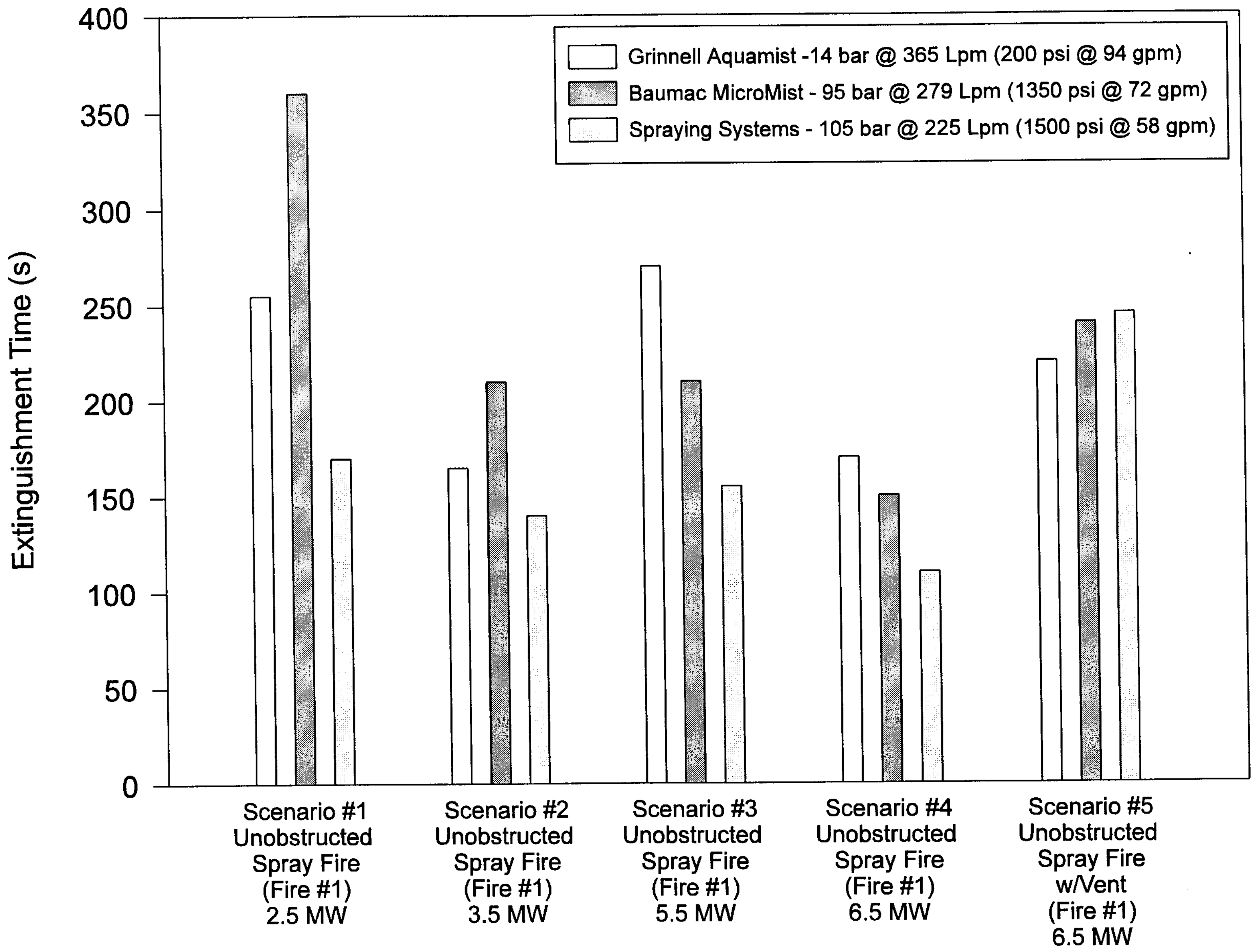


Fig. 10 – Large spray fire extinguishment summary

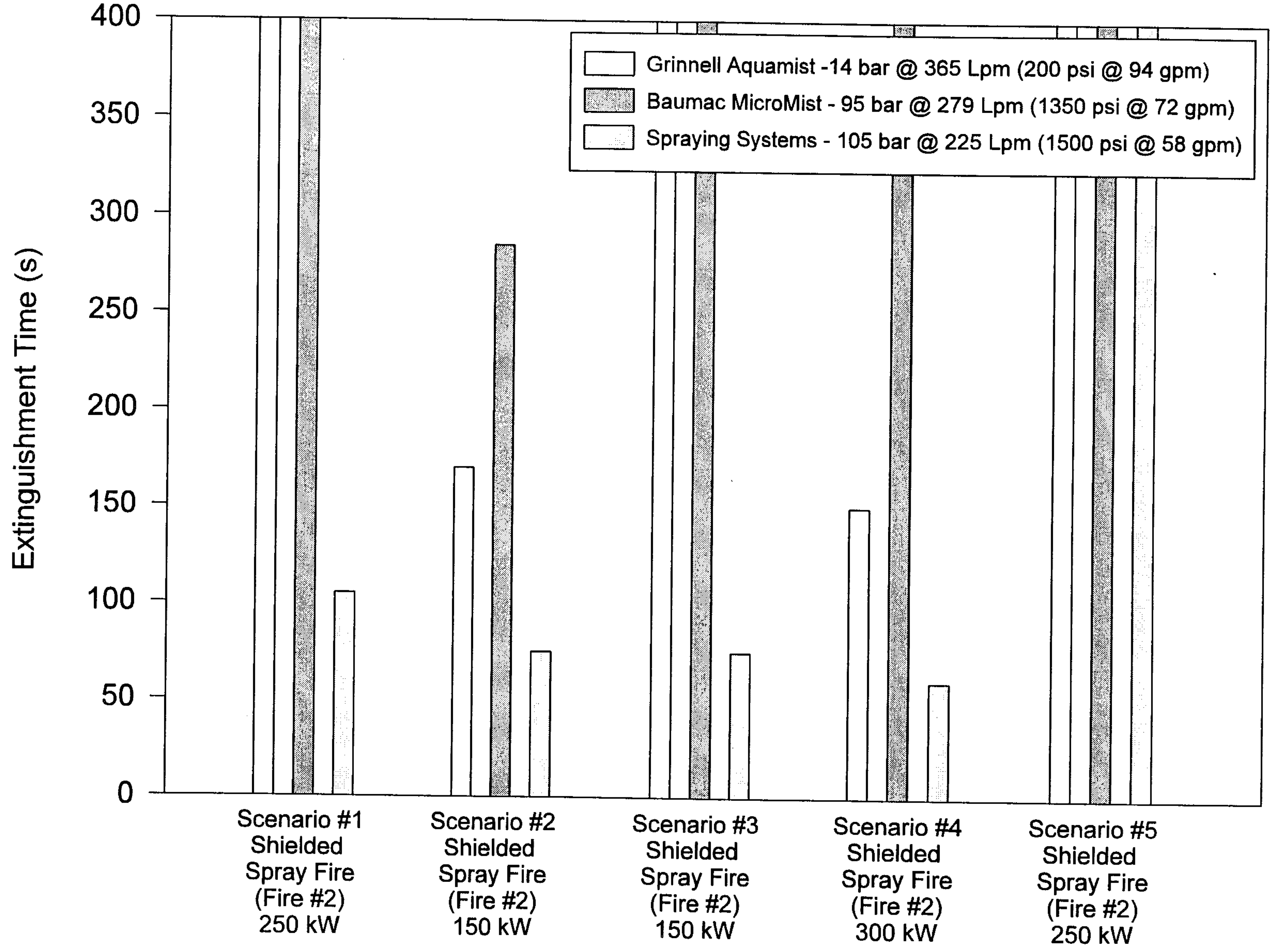


Fig. 11 – Shielded spray fire extinguishment summary

Table 2. Full Scale Test Results

Scenario	Extinguishment Time (min:s)		
System	Grinnell AquaMist	Baumac MicroMist	Spraying Systems
Nozzle	14 bar (200 psi	95 bar (1350 psi)	70 bar (1000 psi)
System Flow Rate	365 Lpm (94 gpm)	279 Lpm (72 gpm)	225 Lpm (58 gpm)
Application Rate*	3.0 Lpm/m^2 (0.075 gpm/ft^2)	1.6 Lpm/m^2 (0.04 gpm/ft^2)	1.6 Lpm/m^2 (0.04 gpm/ft^2)
Scenario #1 (3.5 MW)			
2.5 MW Spray	4:15	6:00	2:30
250 kW Spray (Shielded)	No	No	1:45
250 kW Pan (Shielded)	3:15	4:30	2:30
250 kW Pan	2:20	3:30	2:15
Scenario #2 (4.5 MW)			
3.5 MW Spray	2:45	3:30	2:00
150 kW Spray (Shielded)	2:50	4:45	1:15
250 kW Pan (Shielded)	1:45	1:45	1:30
250 kW Pan	2:15	3:30	2:15
Scenario #3 (6.5 MW)			
5.5 MW Spray	4:30	3:30	2:15
150 kW Spray (Shielded)	No	No	1:15
250 kW Pan (Shielded)	2:30	2:30	1:30
250 kW Pan	3:00	2:30	2:00
Scenario #4 (7.5 MW)			
6.5 MW Spray	2:50	2:30	1:30
300 kW Spray (Shielded)	2:30	No	1:00
250 kW Pan (Shielded)	2:00	1:40	0:45
250 kW Pan	1:50	1:15	1:00
Scenario #5 (7.5 MW)**			
6.5 MW Spray	3:40	4:00	3:45
250 kW Spray (Shielded)	No	No	No
250 kW Pan (Shielded)	1:45	1:45	No
250 kW Pan	1:45	3:20	2:00
Scenario #6 (10 MW)			
6.5 MW Spray and 2 Pans			1:20
250 kW Spray (Shielded)			1:15
250 kW Pan (Shielded)			1:00
250 kW Pan			1:15

* Based on the mist discharge rate (water flow rate) in the fire compartment.

** Ventilation (exhaust and supply) was operating during this test only.

The superior firefighting capabilities of the modified Spraying Systems nozzles were attributed to the system's ability to produce smaller droplets with high momentum. The Grinnell AquaMist system produced somewhat larger droplets (characteristic of the low-pressure single-fluid systems) while the Baumac MicroMist system produced the smallest droplets with little or no momentum. The firefighting capabilities of the Grinnell AquaMist system may be enhanced by increasing the operating pressure of the system to produce smaller droplet sizes and higher momentum. The performance of the Baumac system may be improved by reorienting the nozzles to increase the downward momentum of the mist. (As configured and installed, the spray pattern momentum is strictly in the horizontal direction.) Adjustments to these systems will be included in the second phase of this investigation.

In general, the extinguishment times measured during these tests ranged from 1.5 to 6.0 minutes. This compares to approximately 30 seconds for the intermediate scale tests [1]. The lengthy extinguishment times observed during this test series suggest that oxygen depletion resulting from both the consumption of oxygen by the fire and from the displacement of oxygen due to the expansion of the mist to steam, significantly contributed to the extinguishment of these test fires. During the tests with the longer extinguishment times (4-5 minutes), the oxygen concentrations measured in the space were observed to drop to ≈14.0 percent (13.0 percent is the limiting oxygen index for most hydrocarbon fuels [4].

The relatively short extinguishment times and higher oxygen concentrations observed during the intermediate scale tests suggest that water mist systems can extinguish fires primarily by gas phase cooling and are not as dependent on oxygen depletion as the results of these tests seem to illustrate. This would suggest that the firefighting capabilities observed during the full scale tests could be significantly increased. The primary difference between the two test series must be the amount of mist reaching the fire and the momentum of the mist at the fire location. During the intermediate scale tests, the fires were extinguished with a mist application rate of 1.0 Lpm/m^2 (0.025 gpm/ft$^{2)}$, which was selected as the starting point for the full scale analysis. However, on a volumetric basis due to the increased ceiling height, this application rate would produce a water flow per unit volume about one-half that of the intermediate scale tests. This would suggest that the water mist discharge rate (total system flow rate) needs to be significantly increased. Increasing the system flow rate should increase the amount of mist reaching the fire and will be evaluated in the second phase of this investigation.

The spray characteristics of the system (i.e., droplet size and momentum) are also related to the amount of mist reaching the fire. Due to the geometry of the intermediate scale tests, the water mist nozzles were always located in close proximity to the fire (usually less than 1.0 m (3.3 ft) away). This geometry assures that the mist entering the fire has significant momentum. During the full scale tests, the nozzles were located over 3.0 m (10 ft) away, which significantly reduced the momentum of the mist. During the second phase of this investigation, nozzles will be installed at two levels to increase the momentum of the mist at the fire location.

For the unventilated fires, the extinguishment times were observed to decrease with increased fire size, independent of the mist system being evaluated. This was also attributed to the decrease in oxygen concentration produced by the larger fires. During Fire Scenario #5, when the ventilation system (supply and exhaust) remained activated and the oxygen concentrations decreased more slowly, the time required to extinguish the fires was dramatically increased. The overall decrease in system performance observed during the ventilated fire tests (Fire Scenario #5) suggests that if the Navy selects water mist as the halon alternative for machinery space applications, they should continue the practice of securing the space (closing all hatches leading into the space) and shutting down the ventilation system prior to activating the water mist system.

Throughout this investigation, the activation of the mist system dramatically reduced the temperatures in the space. Under the worst case thermal conditions (largest fire), the temperatures were observed to decrease from over 500°C (932°F) in the overhead of the space to below 50°C (122°F) uniformly throughout the compartment. This temperature reduction occurred within seconds of mist system activation (Fig. 12). The reduction of the temperature in the space may allow a firefighting party to enter the compartment and extinguish any remaining fires almost immediately after the mist system is activated. The reduction in temperature will also serve to minimize thermal damage and may prevent the spread of fire beyond the space. An additional finding of these tests was the ability of the Navy's handheld thermal imager (NFTI) to see the fire through the mist, which will also aid in manual intervention.

6.0 CONCLUSIONS

In summary, these tests have demonstrated the potential ability of water mist to extinguish both shielded and unshielded Class B fires in full scale, relatively uncluttered, machinery space applications. Also observed during these tests was a rapid reduction in the temperature of the space almost immediately after mist system activation. This reduction in temperature will aid in manual intervention, minimize thermal damage, and may prevent fire spread beyond the space. These tests also demonstrate the differences in firefighting capabilities of the candidate water mist systems. While these results are extremely encouraging, modifications to each system will be needed to shorten the extinguishment times and minimize potential fire damage. These modifications will be included in the second phase of this investigation.

7.0 REFERENCES

1. Leonard, J.T., and Back, G.G., “Small/Intermediate Scale Studies of Water Mist Fire Suppression Systems,” NRL Ltr Rpt Ser 6180/0869, December 19, 1994.

2. Leonard, J.T., “Test Plan - Full Scale Testing of Total Flooding Water Mist Systems,” NRL Ltr Ser 6180/0275.2, April 20, 1994.

3. Back, G.G., DiNenno, P.J., Leonard, J.T., and Darwin, R.L., “Full Scale Tests of Water Mist Fire Suppression: Systems for Navy Shipboard Machinery Spaces; Phase II - Simulated Machinery Space Evaluation,” NRL Memo Report in preparation.

4. Beyler, C., “Flammability Limits of Premixed and Diffusion Flames,” Section 1/Chapter 7, *The SFPE Handbook of Fire Protection Engineering*, National Fire Protection Association, Quincy MA, 1988.

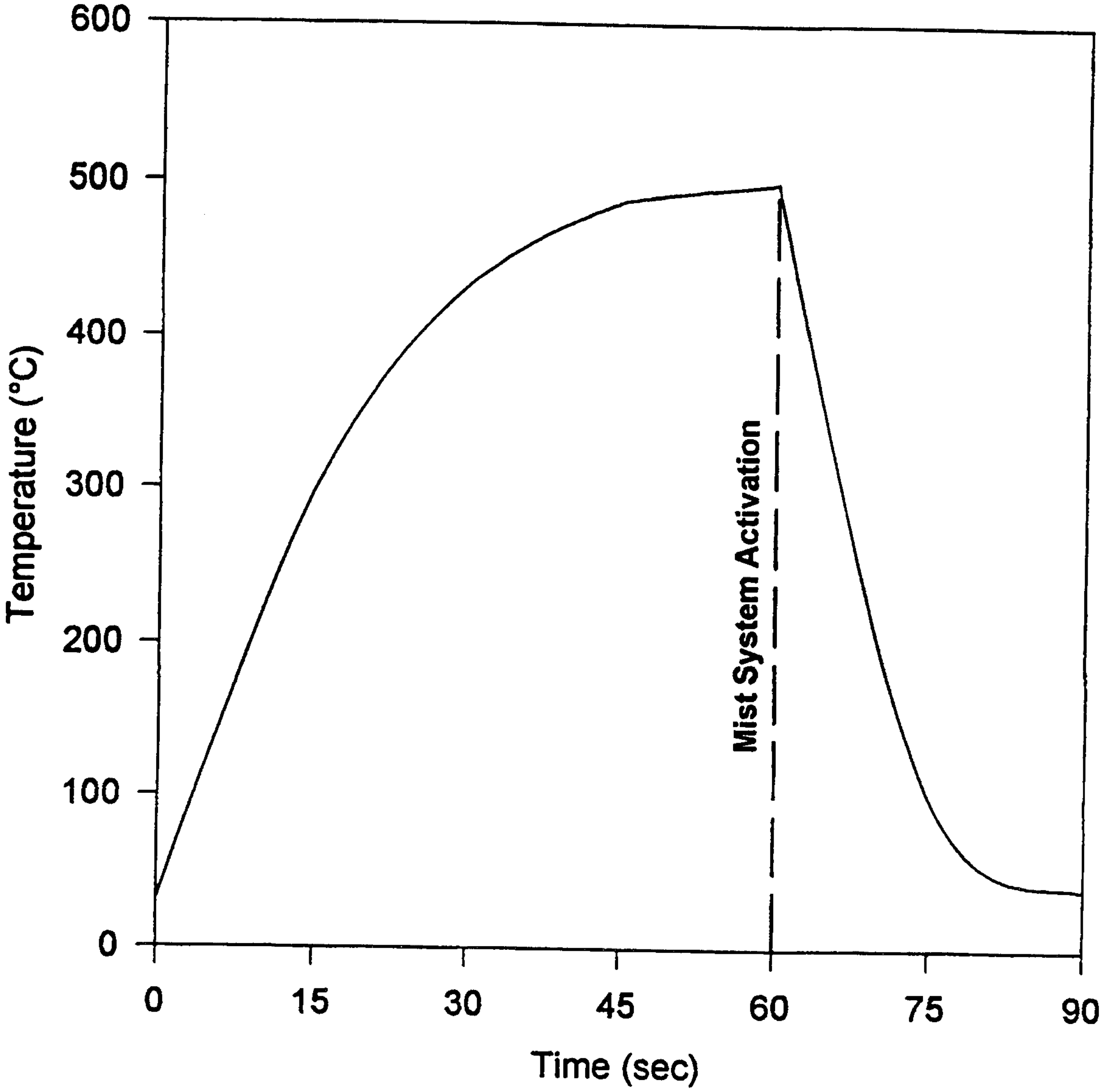


Fig. 12 – Compartment temperature reduction resulting from mist system activation