LOCAL APPLICATION OF WATER MIST FOR MACHINERY PROTECTION

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INTRODUCTION

The United States Coast Guard (USCG) is responsible for establishing fire safety standards for U.S. flagged ships via 46 Code of Federal Regulations. The USCG is also active in establishing and enforcing rules for fire safety on vessels making international voyages through the International Maritime Organization (IMO). Both the USCG and the IMO have recognized that the phaseout of Halon 1301, due to its ozone depletion potential, has created a need for the development and implementation of alternative protection technologies.

One of **the** alternatives for fire protection of shipboard machinery spaces is fine water mist. Entire space (total flooding) protection, using fine water spray, is allowed under the IMO's Safety of Life at Sea **(SOLAS)** regulations. The requirements for total space protection are contained in the Maritime Safety Committee's (MSC) Circular 668 [1]. The MSC's Fire Protection (FP) subcommittee is currently considering requiring local application protection for high fire risk components, e.g., main engines, diesel generators, and fuel strainers and purifiers.

The local application protection being considered would be additional protection for these high fire risk components. This would supplement the existing required total flooding protection, be it a gas, fine water spray or high expansion foam. The goal of the additional requirement would be to provide protection at the source, in a quicker time frame, without functional loss of other items in the space, and to potentially aid in, or eliminate the need for, evacuation of the space. This could greatly aid in a casualty when the ship is navigating in a harbor or other limited maneuvering situations.

The USCG, as part of its regulatory authority, had a need to assess the benefits and feasibility of local protection, as well as determine an effective method of evaluating potential systems. The USCG Research and Development Center (R&DC) conducted the tests hereafter described at the request of U.S. Coast Guard Marine Safety and Environmental Protection (G-M) organization to address these needs.

TESTING OBJECTIVE

The testing conducted was designed to meet the following objectives:

1. Assess the feasibility of local application of fine water mist for component level protection.

2. Evaluate a range of fine water mist parameters, (i.e., large drops, small drops, high and low momentum mist, nozzle flow rate, and nozzle spacing over a variety of fire sizes and conditions).

3. Investigate key parameters that a test protocol should include to effectively evaluate candidate systems.

NOZZLES TESTED

Seven generic nozzles that produced a variety of mists were tested. These were off the shelf industrial spray nozzles selected for their spray pattern and characteristics, see Table 1. They represented the extremes of currently available water mist systems. One Underwriter's Laboratories (UL) listed National Fire Protection Association (NFPA) Chapter 15 (NFPA 15) [2] water spray nozzle was also tested for comparison purposes.

Table 1. Nozzle Characteristics

Nozzle Designation	Operating Pressure (bar)	k-factor (Lpm-bar’”)	Spray Angle	Spray Classification (NFPA 750)
UL/NFPA- 15	7	16.9	Wide	Sprinkler
Generic 1	5	4.3	Narrow	Class 3
Generic 2	70	1.0	Narrow	Class 1-2
Generic 3	10	3.2	Wide	Class 3
Generic 4	70	0.9	Wide	Class 1-2
Generic 5	35	0.4	Narrow	Class 1-2
Generic 6	70	1.9	Wide	Class 1-2

The generic nozzles produced wide and narrow angled low pressure Class **3;** and wide and narrow angled high pressure Class 1-2 sprays as defined by NFPA 750 [3]. The high pressure nozzles generated small droplets with a Dv_{90} of 100 to 400 microns. The low pressure nozzles generated larger droplets with a Dv_{90} of over 400 microns up to 535 microns. The UL listed NFPA 15 nozzle generated droplets with a Dv_{90} of 1200 microns.

TESTING CONFGURATION

The tests were conducted at the U.S. Coast Guard's Fire & Safety Test Detachment in Mobile, Alabama. This unique fire test facility allows large fire tests to be conducted onboard ship. The tests were conducted onboard the test vessel STATE OF MAINE. The test compartment was 10 x 10 x 5 m for a total volume of 500 m^3 and meets the requirements of other IMO machinery space test protocols including MSC Circular 668 [1].

A series of spray fires and pan fires were run against four or nine nozzle arrays in three different configurations. The four nozzle array was for the UL listed NFPA 15 nozzles, in accordance with their listing. The nozzles had either a 1 or 2 meter spacing and were typically evaluated 2 meters from the fire. Other distances (1 and **3** meters) from the fires were tested, but were found to be ineffective due to spray pattern deficiencies. The 2 meter distance provided the most uniform spray pattern. The fires ranged in size from 1 MW up to 6 MW. The test fuels were heptane and diesel.

The three test configurations consisted of horizontal nozzle arrays (Top and Low) located above the fire spraying vertically down, or a vertical nozzle array (Side) beside the fire spraying horizontally, as shown in Figure 1. While in practice, a local application system may completely surround the component and spray at multiple angles, this single direction spray approach was felt to be the most severe case. Two horizontal array locations were tested. The first was located just below the compartment's overhead (Top); the second was located a distance 2 meters below the overhead (Low). The Low configuration was established to reduce the effects of the nozzles entraining the vitiated fire products from the small ceiling layer that formed. These nozzles entrain a lot of air around the nozzle head from the spraying action.

The test compartment was kept well ventilated by a forced supply air system, and an open **6** m^2 exhaust stack located in the top of the compartment. The supply blower was sized to produce approximately 20 air changes an hour. Even with this high ventilation rate, a small ceiling layer was created with most fires. This layer generally was a thin layer of vitiated fire products moving across the overhead towards the exhaust stack.

The test compartment was instrumented to record compartment temperatures, pressure, heat **flux,** and gas concentrations at multiple locations. Probes at the fire location recorded fire temperatures and local oxygen concentrations. All oxygen measurements were paramagnetic oxygen concentrations of dried samples. The water distribution system was instrumented to record system pressure at various locations throughout the distribution network. Video cameras were used to monitor and record the tests.

Once the compartment ventilation conditions were set. The fires were ignited and allowed to bum for one minute. The fine water mist system was then actuated and allowed to run for up to 15 minutes. Fire extinguishment times and other instrument readings were recorded.

RESULTS

Ninety-three tests were conducted in this evaluation. Twenty-six tests were run with a vertical nozzle grid at the side location (Side - location as shown in Figure 1). Table 2 lists the results of those tests. Seventeen tests with the horizontal nozzle grid were run at the Top (Figure 1) location. The results are listed in Table **3.** Fifty tests were run with the lower horizontal nozzle grid in the Low location (Figure 1). Table 4 lists the results from those tests. For the purposes of this paper, the analysis of the results will be presented in terms of extinguishment times, when the fires were extinguished, or fire control, when the fires were not extinguished.

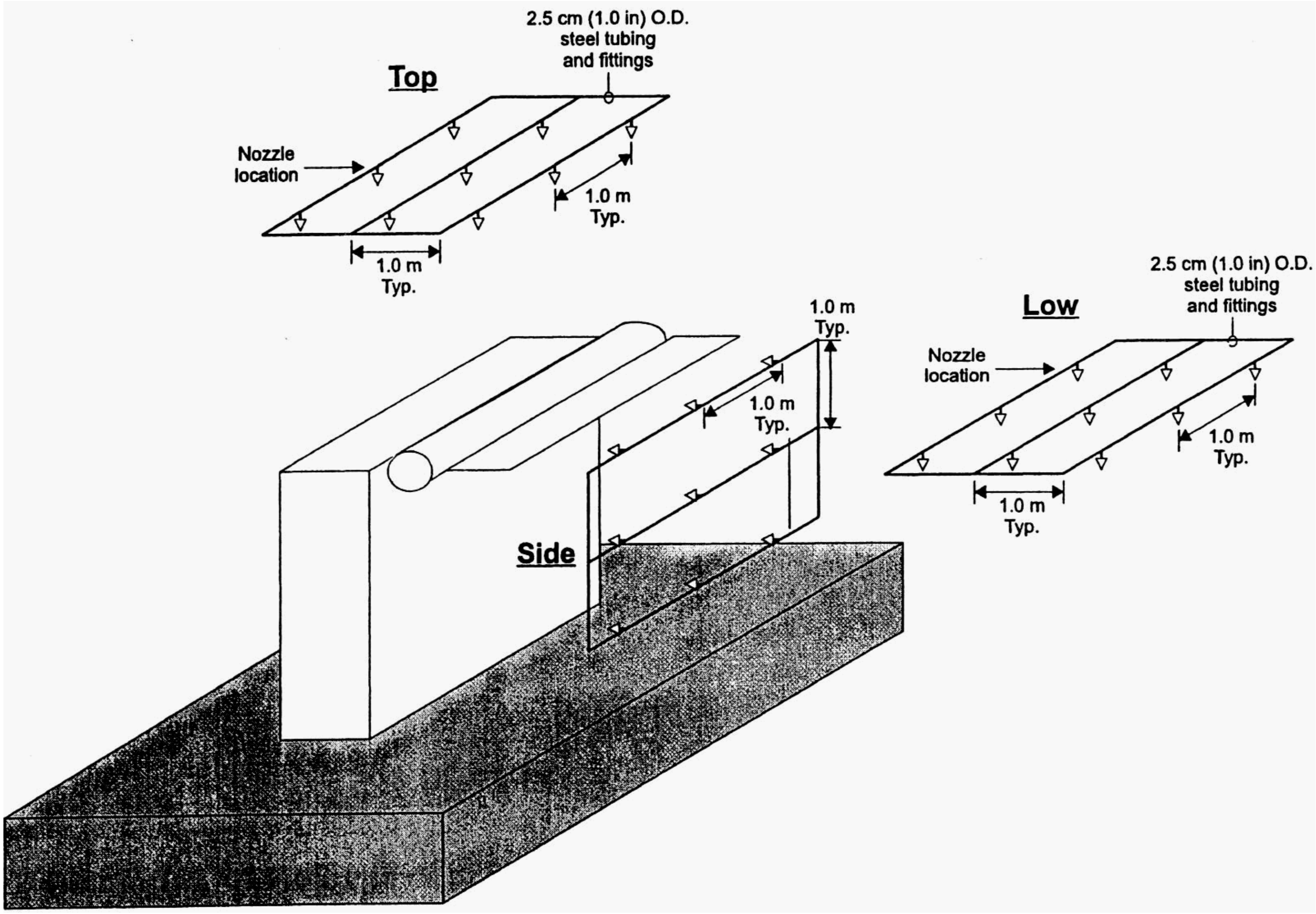

Figure 1. Local application water mist systems.

Table 1 Vertical Nozzle Grid - Side Location Results

Test No.	Nozzle Spray Direction	Grid Location	Nozzle	Pressure (bar)	Nozzle Dist. (m)	Nozzle Spacing (m)	Fire Size (MW)	Fire Type	Location (Figure 5)	Time (min:sec)
1	Horizontal	Side	NFPA-15	7	2	2	1.0	Diesel Spray	Side	No
		Side	NFPA-15	7	2	1	1.0	Diesel Spray	Side	No
3	Horizontal	Side	G-3	7	2	1	1.0	Diesel Spray	Side	No
4	Horizontal	Side	G-3	7	2	1	1.0	Diesel Pan	Side	2:30
5	Horizontal	Side	NFPA-15	7	2	2	1.0	Diesel Pan	Side	No
6	Horizontal	Side	G-1	7	2	1	1.0	Diesel Pan	Side	1:35
7	Horizontal	Side	G-4	70	2	1	1.0	Diesel Pan	Side	1:45
8	Horizontal	Side	G-2	70	2	1	1.0	Diesel Pan	Side	No
9	Horizontal	Side	G-2	35	2	1	1.0	Diesel Pan	Side	4:09
12	Horizontal	Side	G-2	35	2	1	1.0	Diesel Spray	Side	No
13	Horizontal	Side	G-2	35	2	1	1.0	Diesel Spray	Side	No
14	Horizontal	Side	G-2	35	2	1	6.0	Diesel Spray	Side	No
15	Horizontal	Side	G-4	70	2	1	6.0	Diesel Spray	Side	No
16	Horizontal	Side	G-4	70	2	1	1.0	Diesel Spray	Side	No
17	Horizontal	Side	G-1	7	2	1	1.0	Diesel Spray	Side	No
18	Horizontal	Side	G-1	7	2	1	6.0	Diesel Spray	Side	No
19	Horizontal	Side	G-3	7	2	1	6.0	Diesel Spray	Side	No
20	Horizontal	Side	G-3	7	2	1	1.0	Diesel Spray	Side	No
21	Horizontal	Side	NFPA-15	7	2	2	1.0	Diesel Spray	Side	No
22	Horizontal	Side	NFPA-15	7	2	2	6.0	Diesel Spray	Side	No
23	Horizontal	Side	G-4	70	2	1	6.0	Diesel Spray	Side	2:57
24	Horizontal	Side	G-4	70	2	1	1.0	Diesel Spray	Side	No
25	Horizontal	Side	G-2	35	2	1	6.0	Diesel Spray	Side	No
26	Horizontal	Side	G-2	35	2	1	3.0	Diesel Spray	Side	No
27	Horizontal	Side	G-3	7	2	1	3.0	Diesel Spray	Side	No
	Horizontal	Side	G-3	7	2	1	6.0	Diesel Spray	Side	No

Table 2. Horizontal Nozzle Grid - Top Location Results

Test No.	Nozzle Spray Direction	Grid Location	Nozzle	Pressure (bar)	Nozzle Dist (m)	Nozzle Spacing (m)	Fire Size (MW)	Fire Type	Fire Location (Figure 5)	Exting. Time (min:sec)
29	Vertical	High	G-4	70	2	1	1.0	Diesel Spray	Top	0:11
30	Vertical	High	G-4	70	2	1	6.0	Diesel Spray	Top	0:09
31	Vertical	High	G-4	70	2	1	1.0	Diesel Pan	Top	0:05
32	Vertical	High	G-2	35	2	1	1.0	Diesel Pan	Top	0:55
33	Vertical	High	G-2	35	2	1	1.0	Diesel Spray	Top	0:53
34	Vertical	High	G-2	35	2	1	6.0	Diesel Spray	Top	0:21
35	Vertical	High	G-3	7	2	1	1.0	Diesel Spray	Top	0:32
36	Vertical	High	G-3	7	2	1	6.0	Diesel Spray	Top	0:11
37	Vertical	High	G-3	7	2	1	1.0	Diesel Pan	Top	0:09
38	Vertical	High	G-1	7	2	1	1.0	Diesel Pan	Top	0:40
39	Vertical	High	G-1	7	2	1	1.0	Diesel Spray	Top	3:05
40	Vertical	High	G-1	7	2	1	6.0	Diesel Spray	Top	0:22
41	Vertical	High	NFPA-15	7	2	2	1.0	Diesel Spray	Top	No
42	Vertical	High	NFPA-15	7	2	2	6.0	Diesel Spray	Top	No
43	Vertical	High	NFPA-15	7	2	2	1.0	Diesel Pan	Top	No
75	Vertical	High	G-3	7	3	1	1.0	Diesel Spray	Side	No
76	Vertical	High	G-4	70	3	1	1.0	Diesel Spray	Side	No

Table 3 Horizontal Nozzle Grid - Low Location Results

Test No.	Nozzle Spray Direction	Grid Location	Nozzle	Pressure (bar)	Nozzle Dist (m)	Nozzle Spacing (m)	Fire Size (MW)	Fire Type	Fire Location (Figure 5)	Exting. Time (min:sec)
73	Vertical	Low	G-4	70	2	1	1.0	Diesel Spray	Low	4:24
74	Vertical	Low	G-3	7	2	1	1.0	Diesel Spray	Low	No
111	Vertical	Low	G-4	70	2	1	6.0	Diesel Spray	Low	0:41
112	Vertical	Low	G-4	70	2	1	3.0	Diesel Spray	Low	0:59
113	Vertical	Low	G-4	70	2	1	1.0	Diesel Spray	Low	3:01
114	Vertical	Low	G-4	70	2	1	6.0	Heptane Spray	Low	1:30
115	Vertical	Low	G-4	70	2	1	3.0	Heptane Spray	Low	1:25
116	Vertical	Low	G-4	70	2	1	1.0	Heptane Spray	Low	3:03
117	Vertical	Low	G-4	70	2	1	1.0	Diesel Pan	Low	0:09
118	Vertical	Low	G-4	70	2	1	1.5	Heptane Pan	Low	0:11
119	Vertical	Low	G-2	35	2	1	1.5	Heptane Pan	Low	0:07
120	Vertical	Low	G-2	35	2	1	1.0	Diesel Pan	Low	0:10
121	Vertical	Low	G-2	35	2	1	6.0	Heptane Spray	Low	0:31
122	Vertical	Low	G-2	35	2	1	3.0	Heptane Spray	Low	0:57
123	Vertical	Low	G-2	35	2	1	1.0	Heptane Spray	Low	3:19
124	Vertical	Low	G-2	35	2	1	6.0	Diesel Spray	Low	0:30
125	Vertical	Low	G-2	35	2	1	3.0	Diesel Spray	Low	1:01
126	Vertical	Low	G-2	35	2	1	1.0	Diesel Spray	Low	1:03
127	Vertical	Low	G-3	7	2	1	6.0	Diesel Spray	Low	2:40
128	Vertical	Low	G-3	7	2	1	6.0	Diesel Spray	Low	No
129	Vertical	Low	G-3	18	2	1	6.0	Diesel Spray	Low	0:45
130	Vertical	Low	G-3	18	2	1	3.0	Diesel Spray	Low	1:15
131	Vertical	Low	G-3	18	2	1	1.0	Diesel Spray	Low	3:35
132	Vertical	Low	G-3	18	2	1	6.0	Heptane Spray	Low	0:51
133	Vertical	Low	G-3	18	2	1	3.0	Heptane Spray	Low	2:04

Table 4. Horizontal Nozzle Grid - Low Location Results (cont.)

Test No.	Nozzle Spray Direction	Grid Location	Nozzle	Pressure (bar)	Nozzle Dist (m)	Nozzle Spacing (m)	Fire Size (MW)	Fire Type	Fire Location (Figure 5)	Exting. Time (min:sec)
134	Vertical	Low	G-3	18	2	1	1.0	Heptane Spray	Low	1:20
135	Vertical	Low	G-3	18	2	1	1.0	Diesel Pan	Low	0:07
136	Vertical	Low	G-3	18	2	1	1.0	Diesel Pan	Low	0:09
137	Vertical	Low	G-3	18	2	1	1.5	Heptane Pan	Low	0:09
138	Vertical	Low	G-3	18	2	1	1.5	Heptane Pan	Low	0:12
139	Vertical	Low	G-1	7	2	1	1.5	Heptane Pan	Low	0:35
140	Vertical	Low	G-1	7	2	1	1.0	Diesel Pan	Low	0:06
141	Vertical	Low	G-1	7	2	1	6.0	Heptane Spray	Low	1:21
142	Vertical	Low	G-1	7	2	1	3.0	Heptane Spray	Low	2:46
143	Vertical	Low	G-1	7	2	1	1.0	Heptane Spray	Low	No
144	Vertical	Low	G-1	7	2	1	6.0	Diesel Spray	Low	0:35
145	Vertical	Low	G-1	7	2	1	3.0	Diesel Spray	Low	1:00
146	Vertical	Low	G-1	7	2	1	1.0	Diesel Spray	Low	2:14
147	Vertical	Low	G-4	70	2	2	6.0	Heptane Spray	Low	No
148	Vertical	Low	G-6	70	2	2	6.0	Heptane Spray	Low	No
149	Vertical	Low	G-6	70	2	2	6.0	Diesel Spray	Low	No
150	Vertical	Low	G-6	70	2	2	6.0	Diesel Spray	Low	0:50
151	Vertical	Low	G-6	70	2	2	3.0	Diesel Spray	Low	0:48
152	Vertical	Low	G-6	70	2	2	1.0	Diesel Spray	Low	1:32
153	Vertical	Low	G-6	70	2	2	1.0	Diesel Spray	Low	2:55
154	Vertical	Low	G-6	70	2	2	1.0	Diesel Spray	Low	2:53
155	Vertical	Low	G-6	70	2	2	1.0	Diesel Spray	Low	2:51
156	Vertical	Low	G-6	70	2	2	6.0	Heptane Spray	Low	0:46
157	Vertical	Low	G-6	70	2	2	3.0	Heptane Spray	Low	1:05
158	Vertical	Low	G-6	70	2	2	1.0	Heptane Spray	Low	1:37

Diesel pan fires were easily extinguished during this evaluation. This was independent of the fire location or nozzle array location. Ninety percent (19/21) of the pan fires were extinguished. Extinguishment was usual within 30 seconds of mist activation. Spray fires were more difficult to extinguish. Only sixty percent (42/68) of the spray fires were extinguished.

Large spray fires were easier to extinguish than smaller spray fires. This may be related to the higher entrainment rates which are characteristic of the larger fires (re-entrainment of combustion gases and steam). The higher entrainment would draw more mist and other products into the combustion zone. The heptane fueled spray fires were slightly more difficult to extinguish than those with diesel fuel. This can be attributed to the lower flash point of the heptane verses diesel.

The fine water mist systems showed better extinguishment properties when the nozzles were above the fires spraying vertically (Top and Low configuration in Figure 1) down on the fire. With this configuration, 90 percent of the spray fires were extinguished verses 5 percent for horizontally spraying nozzles (Side configuration in Figure 1). This result can be attributed to the system entraining and redirecting a portion of the vitiated gases and steam hack into the combustion zone. This creates a localized lower oxygen concentration at the combustion zone.

Some observations noted during the tests were that any areas of lower/inadequate mist concentrations (and possibly lower drop velocities) would prevent a system from extinguishing the spray fires. When nozzles were moved further away from the fire, mist concentration holes would develop and poor extinguishment capabilities were noted. Likewise when the nozzles moved closer to the fire, the fire would extend through the mist/nozzles and burn on the backside (no mist) of the nozzle grid.

The vertically downward spraying nozzle systems were evaluated at two elevations. One directly below the test compartments overhead (Top); and the other 2 m below the overhead (Low). Although the compartment was well ventilated (20 air changes per hour) thin upper layers formed as the gases and smoke traversed to the exhaust stack. When the nozzles were directly below the overhead, they would entrain some of these products and redirect them back towards the combustion zone. When the nozzle grid was 2 m below the overhead (Side), there was no entrainment from this upper layer, which significantly lengthened the time to extinguishment (that is, 4:24 verse 0:11). Therefore, entrainment of vitiated gases significantly increases extinguishment capabilities.

When the systems were unable to extinguish the fires, there was a dramatic reduction in the seventy of the thermal conditions in the space. It was found, based on the large fire's (6.0 MW) theoretical heat release rates verses the actual measured rates (using oxygen calorimetry), that the mist systems reduced the fire size 10-50 percent depending on the system. However, for all the fire sizes, the amount of energy absorbed by the mist was between 30-70 percent of that theoretically released by the fire. The fire's radiation onto the compartment boundaries was typically attenuated 60-90 percent of that emitted.

CONCLUSION

Fine water mist was found to provide reasonable fire protection for high risk components when properly locally applied. Systems are highly dependent on nozzle spray characteristics (drop size and momentum), nozzle spray pattern, mist concentration, application rate, nozzle spacing, and offset distance. Even when **a** system was unable to extinguish a test fire, it did provide significant energy absorption and radiation reduction benefits. This reduction in the thermal assault should aid in limiting fire spread and manual intervention.

The systems tested provided the best protection when the nozzles where located above the fire and where not obstructed. The vertical nozzle array configuration did not provide good extinguishment, but did provide good thermal protection to the space.

The results of the testing were used in drafting **a** United States' information paper (FP 42-8-4) submitted to the 42nd meeting of International Maritime Organization's Fire Protection Subcommittee (FP 42). A complete report of these tests and some additional fine water mist design parameters' evaluations can be found in Reference **4.**

REFERENCES

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4. Back, ***G.G.,*** Beyler, C.L., DiNenno, P.J., Hansen, R.L., "Full-scale Water Mist Design Parameters Testing," in preparation, September 1997.