LOW-PRESSURE WATER MIST, FINE WATER SPRAY, WATER SOURCE, AND ADDITIVES: EVALUATION FOR THE ROYAL NAVY*

Mike Edwards, Steve Watkins
Ministry of Defencc. Ships Support Agency
Foxhill, Bath BAI SAB
UNITED KINGDOM

James Glockling
Loss Prevention Council
Borehamwood, Hcrts
WD16 2BJ UNITED KINGDOM

ABSTRACT

The Royal Navy's firefighting section, ME225 is conducting a programme of work to research the use of water mist and develop its application as a possible alternative to halon in the challenging environment of warship machinery spaces. Previous worh has been covered by papers published in the proceedings of the Halon Options Technical Working Conferences in 1996 [1] and 1997 [2] and explored tlie limitations of a rangc of systems with different operating pressures. The results indicated that lower prcssure systems. possibly using additives. may offer particular **advantages** for surface warship protection where enclosure and control of ventilation cannot always he guaranteed. As a result. a phased development programme for this type of technology is being undertaken for ME225 hy the Loss Prevention Council: progress to date is summarised in this paper.

INTRODUCTION

The Ministry of Defence Ships Support Agency (MoD/SSA) is the support procurement authority for the Royal Navy. Undcr the Directorate of Marine Engineering, ME225 provides technical support for in-service firefighting cquipment and is responsible for the research and development of halon alternatives suitable for warship applications. The Royal Navy uses Halon I211 and 1301 in primary fire-extinguishing systems on the majority of its vessels including surface warships. Royal Fleet Auxiliaries, and some submarines. Following the ban on halon production by the Montreal Protocol. ME225 has been researching alternatives as replacements for existing cquipment and for specification in future designs. It is of primary importance that such systems do not unduly compromise the firefighting effectiveness currently afforded hy halon or introduce unacceptable safety risks when used. Support to current, approved essential **use** systems is from a bank of recycled halon. A summary of ME225's strategy to achieve these aims is given in a rcccnt paper by the LPC [3].

BACKGROUND

ME225's assessment of halon alternatives has concentrated on the two areas considered most appropriate for warship compartmcnt protection: gaseous agents and water mist systems. With many of thc current chemical alternatives there are increasing concerns over toxicity. environmental implications. inability *to* remove heat from hot surfaces, and. importantly, the potential to release significant quantities of toxic breakdown products. This final point has serious implications in a warship, whcrc conipartmcnts must be re-occupied and become operational again as soon as possible, especially in time of conflict. It is for these reasons that our main area of research and development continues to be water-based systems that have the potential to provide fire protection in a safe and effective way ideally suited to naval applications.

SCOPE

This paper will update the reader on the programme of work in hand to develop water-based technologies specifically to suit the requirements of war-fighting vessels. Following encouraging results in earlier work an 8-phase programme of work was planned. It was decided to further investigate systems that would operate at the water pressures typically available on board ship, nominally 7 bar, and also investigate the performance of a range of additives with water mist. Before starting this work it was considered sensible to create a baseline for the performance expected of the potential replacement systems using typical existing naval firefighting media. Therefore Phase 1 of the programme tested a Halon 1301 system, a CO_2 system, and a typical existing RN sprinkler in the Loss Prevention Council's test compartment. This compartment had been used for previous RN work as well as other established halon alternative research programmes. Phase 2 began the search for a selection of low-pressure nozzles most likely to have the required characteristics for RN applications and also included a review of additives that could be used with such nozzles. This initial literature search resulted in the selection of six promising nozzles. which were then taken forward to Phase 3. Here they were further screened for distribution and heat removal ability using a technique specially developed by the LPC and described in more detail later in this paper. Phase 4 compared water source performance using sea water and freshwater and a range of additives to find the most suitable for use with the nozzle types being investigated. Phase 5, the last to be covered by this paper in detail, included rigorous testing of the best nozzle and additive combination on a range of Class **A** and B fires.

NAVAL APPLICATION CONSTRAINTS

The following are the main constraints that a warship application may place on a fire protection system. These result in a unique combination of requirements making the selection of halon alternatives an extremely challenging problem.

System capability-complete extinguishment of all fires allowing rapid re-activation and re-occupation of the compartment. If complete extinguishment cannot be achieved, extended control and suppression of the fire until manual firefighting can be employed must be achievable.
Fire sources-diesel fuel, aviation fuel, lubricating or hydraulic oils in pool and spray fires possibly soaked into insulating material; electrical cable fires.
Compartments — ranging in volume from around 300 to 2500 m^3 (but typically around 500 m^3 for most machinery space applications), constructed of steel, having a high degree of equipment clutter and obstruction, varying deck heights, and extensive bilge areas.
Ventilation—conditions cannot be guaranteed. Normally forced draught systems are crash stopped on discovery of a fire with hatches, doors, and dampers quickly secured. However, in a wartime scenario, battle damage may result in the creation of a number of ventilation paths of unknown size and location.

Occupancy—-machinery spaces of current vessels are normally unoccupied but are visited regularly on watch-keeping rounds. This changes during action stations when they are manned. The policy for future reduced manned vessels is towards more automation and unmanned spaces.
Existing firefighting systems—the majority of ships are fitted with **Halon** 1301 compartment drench systems, backed by conventional overhead sea water sprinklers, which can he used with or without an AFFF additive. **A** number of vessels are fitted with CO_2 compartment drench systems instead of Halon 1301. Manual systems include hoses (lay flat and centre fed reels), nozzles. branch pipes, AFFF inductors. and portable extinguishers of the CO_2, dry powder, and water/AFFF varieties. Most gas turbine and some diesel generator engine installations are contained in separate enclosures protected by stand-alone halon systems.
Firefighting philosophy—initially manual attack using an attack party with fire hoses operated at 7 bar from the sea water main system, AFFF is used depending upon the fire type. Use of fixed systems is a command decision following initial assessment of the fire. All crew members are highly trained firefighters. Future reduced manned vessels will require less reliance on manpower-intensive manual attack philosophy.
Dependability—firefighting systems must be highly reliable and. in the case of water-based systems, must be relatively simple, able to tolerate low quality sea water supply, resistant to accidental damage, able to tolerate a degree of variation in supply pressure without adversely effecting performance. and have reasonable maintenance requirements at low cost.

TEST PROGRAMME

An important feature of this test programme is to be able to compare objectively the various technologies being examined to ensure the advantages and disadvantages of each can he assessed fairly. In this way the strategy of building on well-defined experimental phases to identify the systems most suited to the requirements of naval fire protection applications can be successfully completed.

Test enclosure—the comparability required has been achieved by utilising the same enclosure for all tests throughout the programme. The enclosure is designed to give a highly controllable environment and is extensively instrumented. Figure 1 shows the enclosure, which measures 8 by 4 by 3 m giving an internal volume of 96 m^3. The 3 m ceiling height is representative of a smaller warship machinery compartment, although none of these series of trials was aimed at replicating such a scenario exactly as this will follow in Phase 8 (real-scale testing). Ventilation for the prehurn condition was provided by **an** inlet situated under the fire and an outlet at high level. This arrangement allowed the fires to burn with an upright plume and the enclosure to he ventilated. After preburn the inlet and outlets were closed and the enclosure became relatively well sealed (the only ventilation being through two 100 mm diameter water drainage holes at tloor level).
Instrumentation—this facility provides comprehensive instrumentation for temperature. pressure, and gas analysis. During appropriate tests, the small satellite fires were sited in the corners of the room, two high up and two at floor level. These tested the total-flooding ability of each system as well as reliance on global oxygen depletion. Each was monitored by separate thermocouples.
Fire types—Table 1 gives details **of** the fire sources used throughout the test programme. **As** indicated, **a** selection of these were used as appropriate to particular phases of work. The fires were a combination of the standard LPC test fires plus naval fuel sources. **All** were carefully

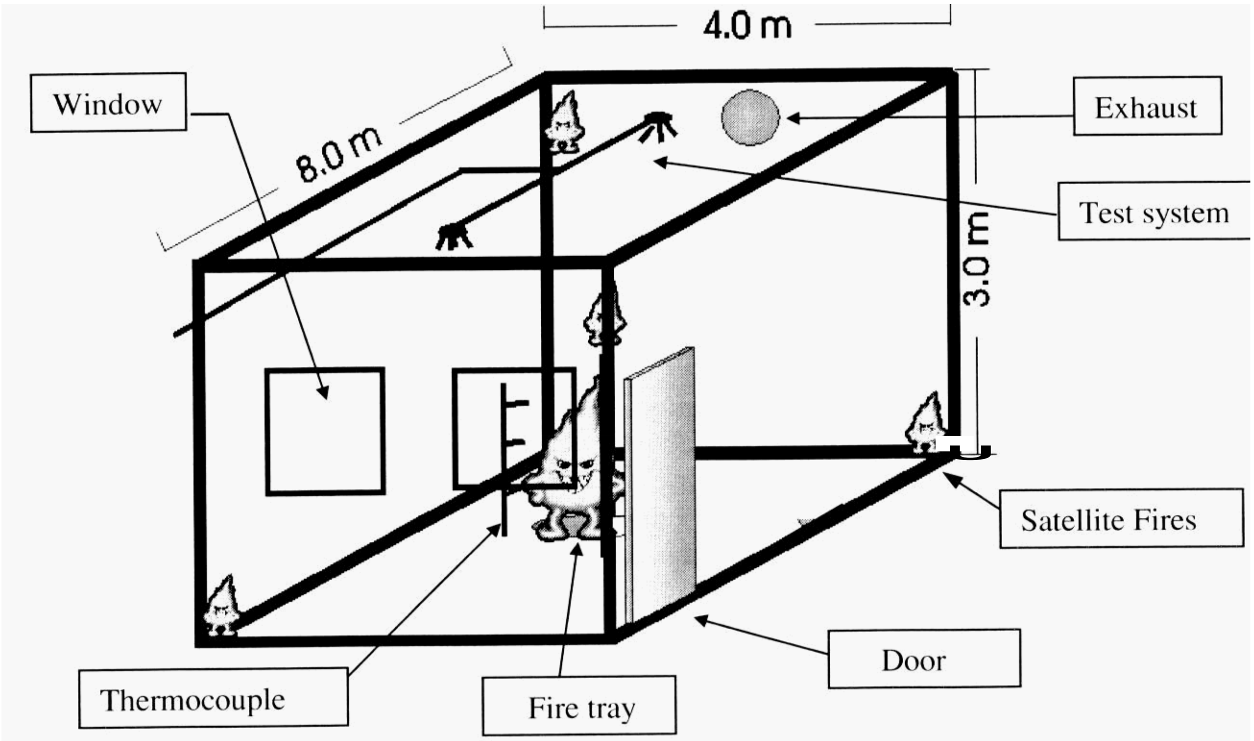

Figure 1. LPC Test Enclosure.

TABLE 1. FUEL DATA.

Fuel Class	Fuel Type	Description and Typical Uses	Flashpoint (°C)	Autoignition Temp (°C)	Approx Fire Size/Output (mW)
A	Small wood crib	Redwood 24 in no. (25 by 25 mm sticks)	—	—	0.20
	Large wood crib	Redwood 24 in no. (50 by 50 mm sticks)	—	—	0.40
	PVC cable crib	6 mm^2 PVC sheathed flat mains cable 72 by 280 mm strips in crib	—	—	1.1
B	Heptane	Commercial heptane	—	215	1.1
	Naval dieso F-76	Petrol distillate, diesels/gas turbines	61	240	1.0
	Naval avtur F-34	Kerosene derivative naval aircraft turbines	38	220	1.0
Hybrid A/B	Naval DSF	Dieso soaked insulation/ mineral fibre board	—	—	0.7

designed and tested to give a high degree of repeatability. The liquid fuels were contained in circular steel pans either 300 or 445 mm diameter giving small pool fires that were intentionally at the normal limits of water-mist system ability for the enclosure size (with water mist, the larger the fire the easier it is to extinguish due to fire-driven conversion of mist to steam and hence rapid local oxygen depletion).

Trials procedure — in each case the trials procedure involved ignition and a preburn period determined by the fuel type (Class A solid fuels, 100-270s depending upon size and Class B liquid fuels, 60s), the ventilation was then secured and the system under test activated. Extinguishment was confirmed visually through **a** viewing tube into the fire area, by temperature drop and use of a thermal imaging camera.

PHASE 1: BASELINE EXTINGUISHING PERFORMANCE OF NAVAL SYSTEMS

The aim of this phase was to develop baseline extinguishing performance data for existing naval fitted systems, consistent with those described for eight other gaseous extinguishing agents previously tested and documented in the LPC's LPR6 report [4].

Summary **of** Work

The following systems types were tested: current warship fitted sprinklers, CO_2 and Halon 1301 systems.

Water ***spray*** nozzles — It is important to clarify the range of terms applied to the many different types of water-based systems now available. Table 2 summarizes some of the more common terms including estimates of typical droplet sizes associated with them.

TABLE 2. WATER SYSTEM DESCRIPTIONS.

System Term	Typical Mean Drop Diameter (μm)	Operating Mode
Mist	100	Function of mist concentration suspended in a volume
Fine water spray	200-300	Floor coverage (mm min^{-1}) Plus suspended mist fraction
Sprinkler/spray	400-500	Floor coverage (mm min^{-1})

Two Wormald MV34 nozzles, typical of the range fitted in many RN ships. were tested in the LPC enclosure at two pressures, the system nominal operating pressure of 7.0 bar and at a reduced value of 3.5 bar to investigate performance should the system output become reduced as a result of failure or damage. The nozzles were tested with fresh water only at this stage. Table **3** gives a summary of the results. full details of which are contained in the Phase 1 report [5].

Carbon dioxide system — A system was designed to Naval Engineering Standard 357 pan 1 [6] to five a concentration of 40% within the LPC test compartment and discharge 85% of the stored gas within 2 min. This concentration must also be maintained in the compartment for at least 30 min. To achieve this, two 67.5-litre capacity cylinders were used, each charged with 35 kg of CO_2 at 58 bar.

Halon 1301 — A system supplied with recycled Halon 1301 from the MoD halon essential uses bank enabled completion of a test series previously run by the LPC [4] but with the additional naval fuels listed in Table 1. The system was designed to NES 357 Part 2 [7] and used one

TABLE 3. PHASE 1: RESULTS SUMMARY.

System	Fire Type	Extinguishing Time (sec)	Delivery Press. (bar)	O_2 min % @ Plume	Water Used (litre)	Satellite Fires Extinguished	Comments
MV34 Sprinkler	Dieso 445mm	75	7.0	20.2 I	41Y	3	Extinguished
MV34 Sprinkler	Dieso 445mm	NE	3.5	18.58		2	Not ext. Fuel out 1301s
MV34 Sprinkler	Dieso snaked Insulation	NE	7.0	20.16		3	Damage limited Fuel nut 682s
MV34 Sprinkler	Dieso soaked Insulation	NE	3.5	19.16		2	Not ext. Fuel out 730s
CO_2	Dieso 445mm	111	3x.4	11.78	NIA	4	Extinguished
CO_2	Dieso soaked Insulation	235	37.35	12.33	NIA	4	Extinguished
Halon 1301	Dieso 445mm	6	28.96	20.91	N/A	4	Extinguished
Halon 1301	Dicso soaked Insulation	6	27.21	20.89	NIA	4	Extinguished

NE = Not **extinguished** **N/A** = Not **applicable**

67.5-litre cylinder charged with 32 kg of Halon 1301 at 42 bar to give a 5% design concentration, achieved within 10 sec and held for 30 min.

Phase 1 Conclusions

The MV34 sprinkler was shown to have a good performance at its nominal operating pressure of 7 bar on most Class B fuels, but had difficulty with the more volatile heptane fires. At the lower pressure, performance was markedly reduced with no Class B fuels being extinguished. This indicated the importance of ensuring optimum pressure throughout the system to achieve the best performance. Water usage with these sprinklers was significant and required upwards of 6000 litres to extinguish the large wood crib fire (167 l/min per nozzle @ 7 bar). **As** these nozzles are normally used with AFFF it was recommended that they also be included in the additive trials in Phase 4 of this project. The data collected in these baseline tests reinforced the performance advantage? of Halon 1301, particularly with Class B fuels. This was demonstrated clearly by the short extinguishing times achieved on RN fuels including the difficult dieso-soaked fibre assembly. The CO_2 system also performed well and gave extended but consistent extinguishing times linked with the depletion of oxygen in the compartment.

PHASE 2: LOW-PRESSURE WATER MIST SYSTEM AND ADDITIVE SURVEY

The aim of this phase was to review commercially available low-pressure water-mist nozzles and suitable additives and select those that best suit naval parameters for further testing.

Summary of Work

A previous study [8] comparing the performance of high- and low-pressure water-mist systems concluded that for surface ships, low-pressure systems had the greatest potential for effective use because the enclosure of the affected compartment could not be guaranteed (e.g., battle damage), on-board sea water systems can provide up to 7 bar supply pressure and the larger orifice size of the LP nozzles reduces dependency on water quality while allowing the use of an additive. This phase of the project carried out a review of the nozzles likely to operate successfully at this pressure or below which also satisfy the other requirements of naval machinery space applications. A survey of additives suitable for use with such nozzle designs was also conducted.

Phase 2 Conclusions

The review showed that two main groups of nozzles are available and are most likely to satisfy RN requirements: firstly. those purpose fully designed as low-pressure misting nozzles and secondly, modified spray nozzles, that may provide the required performance when operated at 7 bar or less. Of those surveyed 6 were selected for further testing. 3 mist or fine spray types (AM4, GW, MD), 1 single orifice spray nozzle (MV10), 1 multi-orifice spray nozzle (CL7), and 1 foam producing nozzle (SS). Full details are given in the Phase 2 report [9].

PHASE 3: PERFORMANCE SCREENING AND SELECTION OF NOZZLES

The aim of this work was to screen the range of nozzles identified in Phase 2 using distribution and calorimetry techniques to establish nozzles with the ability to carry additives to the fire while retaining mist producing ability. These would then be carried forward for full fire testing in Phases 4 and 5.

Summary of Work

Measurement and analysis of the following factors gave a good indication of the most suitable nozzles: area of coverage required by each nozzle. required water application rate. impact of the system on the fire size. and impact of the system on the environment (cooling/oxygen depletion).

Distribution measurements — The distribution profile of the nozzles was measured by collecting the water in an array of containers located 3 and 5 m below the test nozzle. which was mounted above one corner of the array to produce a quarter profile of the nozzle output. Each container was mounted on a load cell linked to a computer. which calculated the overall distribution profile including mean envelope diameter. mean coverage and maximum nozzle output. Particle sizing measurements were made using a Malvern 2600C laser particle sizer and are for guidance only as a more detailed investigation of the drop size distribution would be required to give a full picture of the spray envelope.

Calorimetry measurements — Calorimetric evaluation of the nozzle involved assessment of the ability of the spray to remove heat from a repeatable, calibrated fire source. The quantity of heat removed from the fire is a function of the application rate, droplet size, and the density of droplets. A calorimeter hood allowing a nozzle to fire to a height of 3 m was used. The fire source was a 445 mm diameter pan using 5 litres of heptane to give a stable repeatable fire of 193 kW heat output. Analysis relied on the following principles: effect on fire size, measured by monitoring the effect of the spray on the oxygen content of the combustion gases; effect on the environment, measured by determining the heat release rate of the fire with and without the spray: and vapour conversion ability. the ratio of steam produced under the calorimeter to the flow rate of each nozzle. The differences between nozzle characteristics were highlighted by these techniques. The sprinkler designs gave a large reduction in the heat output of the fire and little or no mist formation as indicated by low vapour conversion ratios. The Fine Water Spray (FWS) nozzles gave some reduction in the heat output of the fire and good mist formation. as indicated by significant vapour conversion ratios. Water-mist nozzles gave no reduction in the heat output of the fire (in some instances increasing heat output as the mist agitated the fire), and produced complete mist formation, as indicated by very high vapour conversion ratios. These measurements indicated that FWS type nozzles were the only type suitable for achieving the aims of this work, i.e., to identify nozzles with the ability to carry additive to the fire while retaining mist producing ability. Because of the assumptions accompanying this technique, the values obtained are not absolute; however, the technique does achieve its aim of enabling quick and easy comparisons among nozzles. A more detailed explanation of the processes involved is given in the Phase 3 report [10]. A summary of the most relevant results is shown in Table 4.

TABLE 4. **PHASE** 3: RESULTS SUMMARY.

System	Deliv. Pressure **(bar)**	Mean Coverage (l min^{-1})	Envelope Dia. @ 3m (m)	Mean Droplet Dia. (µm)	Change in Heat Release Rate (kW)	Vapour Conv. Ratio (%)
AM4	3.5	0.245	2.0	153	-14	14.28
	7.0	0.325	2.25	155	+5	19.44
GW K-15	3.5	1.384	3.0	200	-30	4.93
	7.0	1.856	3.5	258	-48	4.09
CL7	3.5	0.944	3.5	230	-5	4.97
	7.0	1.015	3.0	237	Extinguished	Extinguished
MV10	3.5	0.950	3.5	211	+5	5.60
	7.0	1.289	3.5	207	-113	1.86
MD	3.5	0.714	4.0	161	-33	3.97
	7.0	0.991	4.0	150	-24	4.40
SS	3 5	1.648	5+	383	-34	2.40
			5.0	246	Not tested	Not tested

Phase 3 Conclusions

These tests have shown marked differences in the factors affecting extinguishment over a range of nozzles, which encompass water mist, spray and sprinkler type technologies, and even between nozzles that have the same water application rate. Selection of the most appropriate system depends largely on the likely conditions existing at the time of operation and the result required (control or extinguishment). It has been demonstrated that true water-mist systems should be treated in the same manner as gaseous systems, where the maintenance of a well-sealed enclosure is fundamental to its successful operation. The use of such systems is therefore not entirely appropriate for the specific requirements of this programme where enclosure and control over ventilation cannot always be guaranteed. Of the nozzles tested four offered the most potential to satisfy these criteria by operating in a "hybrid" mode. These FWS nozzles combine the ability to produce fine mist droplets and larger spray droplets. potentially offering a combination of the benefits of low-pressure water-mist (volume filling, oxygen depletion, environmental cooling, and low water usage) and spray type (effective additive transportation, plume penetration, and surface wetting) systems. For these reasons the nozzles were selected for further evaluation in later phases of work.

PHASE 4: IMPLICATIONS OF WATER SOURCE AND ADDITIVE ABILITIES

Having identified a water-based system philosophy with potential to satisfy the requirements of RN compartment drench applications, Phase 4 was designed to assess the effects of water source and additives on the performance of these FWS nozzles. The use of additive may nvercome the remaining difficulties that water-mist systems have in tackling small fires, particularly liquid fuels and where a degree of ventilation exists. The most promising nozzle from Phase 3. the GW LoFlow **K-**15, was used to test the two water sources and four additives selected. To complete the baseline tests conducted earlier, the MV34 sprinkler, typical of those already used in many RN ships, was also tested (it had been tested without additives in Phase 1).

Summary of Work

Fire testing was conducted in the LPC test enclosure as shown in Figure I. A single fire source was used for all tests; a dieso pool fire was selected **as** a typical naval fuel. The correct spacing of nozzles was investigated and a 3 by **3** m array of four nozzles suited all the FWS systems under test. The nozzle array was located in the middle of the 8 by 4 m compartment with the fire positioned at the centre of the array, the most challenging position. Because the FWS type nozzles rely less on oxygen depletion to extinguish small fires, focusing on an array within which the test occurs is a valid approach. In addition to the FWS nozzle chosen, the baseline MV34 sprinkler was reinstalled to naval standards as for Phase 1, with two nozzles 4 m apart on the centreline of the compartment.

Burnback testing — To assess the post-fire security afforded by each additive when applied through a spray nozzle, a burnback test procedure was specified. Initial testing within the enclosure to Defence Standard 42-40/1, more usually used for tests with handheld firefighting equipment. was problematic and the performance of the additives could not he compared fairly. **A** modified lest procedure was developed that considered the problems encountered with the standard under these circumstances while retaining **as** many of its parameters as possible. Details of this and all procedures and results are included in the report for Phase 4 [I1].

Additives tested — In general firefighting. additives can be divided in two categories: wetting agents and Aqueous Film Forming Foams (AFFF). The wetting agents reduce the surface tension of the water providing increased wetted area penetration; however. these are not able to form and maintain a foam blanket. The AFFF types both reduce surface tension and fonn a foam blanket over the fire and essentially starve it of oxygen. The additives chosen for this phase ranged from traditional foams already in cnmmon use to new, environmentally friendly formulations. The five types tested were additives I and 2 AFFF (to Mil Spec F2341C and Def Stan 42/40- **I** respectively) already employed in a variety of military applications: additive 3, **a** Film Forming Fluoro Protein (FFFP) which is a modified foam claiming enhanced performance by forming a thick self-healing skin; additive 4 (Fire Stopper) a relatively new wetting agent formulated to be more environmentally friendly than existing additives: and additive 5 (Fuel Buster) another relatively new product that acts as a wetting agent but with enhanced performance achieved by locking up fuel in small droplets surrounded by the agent. All additives were used at the manufacturers recommended concentration.

Water sources tested — Most previous tests have been conducted using fresh water for convenience. At this point it was decided to investigate whether using sea water either with or without additives had any noticeable effect on firc extinguishing performance or burnback resistance when applied through fixed spray nozzles. Each trial was conducted with both water sources, alone and with each additive at two supply pressures, 3.5 bar and 7 bar. The 445 mm dieso pan fire was used in each ease.

Phase 4 Conclusions

Tables 5 and 6 give a summary of the Phase 4 results. The MV34 sprinklers, as fitted to existing ships were tested with **AFFF** (its normal mode of operation), as an extension to the baseline trials. Significant improvements in extinguishing performance were noted over fresh water alone, which resulted in significantly reduced water usage. Phase I had already identified the significant benefits of operating at 7 bar (as opposed to 3.5 bar) with this nozzle despite its having a quoted minimum operating pressure of 1.4 bar. The FWS nozzle chosen had a K factor of 15 and consequently used around a quarter of the water of the MV34 system, even given that two FWS nozzles were required to protect the same space as each sprinkler. **As** with the MV34, the extinguishing performance of the FWS nozzle was dramatically improved with all the additives tested, the only exception being additive 5 (Fuel Buster). It appeared that this additive could not be mixed into the fuel as recommended by the manufacturer due to the relatively low momentum of the systems used and did not give acceptable extinguishing performance. Therefore, it is surprising that this additive gave the best single bumback result, but only after struggling to extinguish **all** fires. On this basis, additive 5 was not considered suitable for further testing. Overall, the best burnback performance was given by additive 3 **(FFFP),** closely followed by additives I and 2 **(AFFF).** Taking an overview of all extinguishing and bumback results the best all round

TABLE 5. PHASE 4: RESULTS SUMMARY.

System	Additive **Type**	Delivery Pressure (bar)	Water Used (l)	**Ext.** Time (sec)
Sprinkler (MV34)	None	**7.0**	419	75
	AFFF (MS)	7.0	201	36
	AFFF (MS)	3.5	245	61
	Add (FFFP)	3.5	205	51
	Add (FS)	7.0	120	30
	Add (FB)	3.5	**Nor** extinguished	Nor extinguished
FWS (GW K-15)	None	7.0	167	63
	AFFF (MS)	7.0	40	15
	AFFF (MS)	3.5	15	8
	FFFP	*3.5*	15	8
	FS	7.0	***26***	IO

TABLE 6. BURNBACK RESULTS.

Additive Type	Water Source	Burnback (min:sec)
AFFF (MS)	Sea	6:00
AFFF (DS)	Sea	1I **:00**
Add (FFFP)	Sea	12:00
FS	Sea	400
FB	Sea	NE
AFFF (MS)	Fresh	6:30
AFFF (DS)	Fresh	5:00
FFFP	Fresh	14:47
FS	Fresh	2:37
FB	Fresh	30:00+

performance is the FFFP closely followed by both AFFFs. However, because the use of AFFF is well established in RN applications and the benefits of FFFP appear marginal, AFFF has been taken forward for testing with FWS systems on a wider range of fire types in Phase 5.

While these results show that these FWS nozzles are able to transport additives into the fire very successfully, observations made during the tests suggest that the additive may bc affecting mist formation at this concentration, possibly by causing droplets to stick together. Consequently. it is intended to investigate the effect of additive concentration on mist formation, extinguishing, and burnback performance in a further phase of work. Regarding the comparison of sea and fresh water supplies, no clear pattern emerged with or without additives; sea water was selected for use in later phases for realism (as it is used in RN fire main systems). This work has shown that it is likely that other factors such as electrical conductivity would play a more important role in choosing between sea and fresh water than their effect on firefighting performance.

PHASE 5: LOW PRESSURE 'FINE WATER SPRAY SYSTEM' TESTING

The aim of this phase of the programme was to combine the most suitable nozzle systems, additives, and water source in a comprehensive series of fire tests against a full range of Class A and B fuels. It was considered important to test with and without additives in order to establish the firefighting effectiveness in both modes.

Selected systems — Four FWS type nozzles were carried forward from Phase 3, details of these arc given in Table 7. The selected additive was AFFF to Mil Spec F2341C together with sea water for the reasons described in the Phase 4 conclusions above.

TABLE 7. PHASE 5: NOZZLE SYSTEM PARAMETERS.

System	Bore (mm)	Output @ 3.5 bar (l mm^{-1})	Output @ 7.0 bar (l mm^{-1})	K-Factor	Rec. Delivery Pressure (bar)	Max. Nozzle Spacing (m)	Max. Spacing from Wall (m)
GW K-15	5.0	28.0	40.0	15	6.0 - 16.0	3.5	1.75
GW K-20	10.0	37.4	52.0	20	6.0 - 16.0	1.5	1.75
MVIO	5.1	30.0	42.0	15.9	1.4 - 7.0	Not available	Not available
CL7	7 by 1.0	20.0	41.0	15.5	0.7 - 7.0	Not available	Not available

Summary of Work

The tests were conducted under the Same conditions as previous work to ensure direct comparability. In doing this it was recognised that the nozzles selected from Phase 4 were ideally suited to transporting additives; therefore. their performance balance would be expected to favour this mode of operation even though they would he expected to perform satisfactorily with water only. On this occasion only one water pressure was used (7 bar), which is the nominal pressure specified for typical RN ship sea water main systems. Each systcm was installed in a 3 m^2 array of four nozzles following consultation with the manufacturers. The choice of a representative and challenging set of fires was important for this phase of work. The following were selected from those listed in Table 1: 445 mm dieso pan fire, 445 mm avtur pan fire, 300 mm heptane pan fire, large wood crib, 6 mm PVC cahle crib fire, and dieso-soaked insulation fire. The fire test procedures were not varied from previous test series conducted in this programme to ensure complete comparability with all results.

Phase 5—Conclusions

The results in this phase (shown in Tables 8 and 9) extend those from Phase 4 to show clearly the large performance advantages of using an additive on a wide range of Class B fire types. On these liquid fuel fires reductions in extinguishing times in the order of 85% to 99% were experienced with the FWS nozzles when compared to the sea water-only mode of operation. Furthermore several fires were extinguished with additives that could not be without additives. It is important to note that while Class A fire risks are not as significant in machinery spaces, the extinguishing performances achieved with additives, while acceptable were in fact generally longer than those without. This is consistent with the design intent of the additives themselves, which is to improve performance against Class **B** fires, and so should not be unexpected. The complete set of results is given in the Phase ***5*** report [12].

TABLE 8. PHASE 5: RESULTS SUMMARY (EXTINGUISHING TIMES).

System	Additive Used	Extinguishing Time (sec)					
		Dieso	Avtur	Heptane	Wood Crib	Cable	Dieso-Soaked Insulation
GW K-15	No AFFF (MS)	175.0	Not extin.	Not extin.	22	226	620
		8.0	10	18	13	64	154
GW K-20	No AFFF (MS)	62.0	Not extin.	Not extin.	I6	61	754
		7.0	8	14	38	10X	83
MV10	No AFFF (MS)	95.0	450	228	41	24	Not extin.
		14.0	21	30	62	165	247
CL7	No AFFF (MS)	644.0	740	Not extin.	106	129	836
		15.0	6	11	14	I34	242

TABLE 9. PHASE 5: RESULTS SUMMARY (WATER USAGE).

System	Additive– Used	Water Used To Extinguishment (litres)					
		Dieso	Avtur	Heptane	Wood Crib	Cable	Dieso-Soaked Insulation
GW K-15	No AFFF (MS)	463.8	Not extin.	Not extin.	58.3	598.9	1643.0
		21.2	26.5	47.7	34.5	169.6	408.1
GW K-20	No AFFF (MS)	219.1	Not extin.	Not extin.	56.5	215.5	2664.0
		24.7	28.3	49.5	134.3	459.3	293.3
MV10	No AFFF (MS)	266.0	126.0	638.4	114.8	448.0	Not extin.
		39.2	58.8	X4.0	171.0	462.0	69I.6
CL7	No AFFF (MS)	1760.3	2022.7	Not extin.	289.7	352.6	2285.0
		41.0	16.4	30.I	38.3	366.3	661.5
MV34	No AFFF (MS)	419.0	4371.0	Not extin.	1088.0	754.0	Not extin.
Sprinkler		201.0	No test	No test	No test	No test	No test

CONCLUSIONS: PROGRAMME TO DATE

The programme started from a review of typical high- and low-pressure water-mist systems, which, while useful, proved somewhat inconclusive for application against the wide range of constraints placed on them hy warship fire protection. It was clear that generic high and low pressure systems had specific advantages and disadvantages for different scenarios, particularly when ventilation, enclosure and fire obstruction were considered. Pursuing the goals of the project. the programme evolved to look at the use of additives with low-pressure systems. This approach had potential to overcome the difficulties that all mist systems have in tackling small fires and large ventilated areas and, if successful at low pressures, could remove the need to install dedicated pumps or carry additional compressed cylinders on board as is required with higher pressure systems. When four such FWS systems were tested with additives. rapid extinguishing times were achieved, similar to inert gas system performance and far superior to existing warship sprinklers. The water usage was also dramatically reduced particularly with additives, despite the need for more nozzles than with some sprinkler installations. In summary. at Phase 5 the programme has shown that FWS nozzles operating at 7 bar or below can give high performance with additives. acceptable performance without additives. greatly reduced water usage over existing sprinkler systems and the potential to wet and cool surfaces in three dimensions. However, in order to quantitatively assess the effect of additive concentration on their mist-producing abilities and the balance between burnback protection and extinguishing time, further work needs to be undertaken. It is not the intention at this stage to select a single nozzle or system, rather to gain knowledge on generic system performance and test the developing system philosophy. It is believed that with further development this approach has high potential to meet the needs of the Royal Navy's halon alternative programme as *a* primary compartment drench firefighting system with excellent all-round capabilities and, in particular. a high degree of personnel safety during and after a fire.

FUTURE WORK PROGRAMME

Phase 5 is now under review for extension to include the further work required on additive concentration with Fine Water Spray systems. This will examine the effect of varying the additive concentration on the ability of a FWS nozzle to produce a mist fraction of good quality and its effect on extinguishing performance and post-fire security. It is envisaged that this work may also test the ability of different nozzles to lay an effective blanket of additive on the fuel surface from the overhead position. Looking further ahead, Phase 6 is planned to test the FWS nozzle philosophy against fuel spray fires with and without additives. Phase 7 will take the systems into a real-scale compartment test rig for a comprehensive test programme. Phase 8 is planned to complete the programme, when it is hoped that installation guidelines for RN platforms can be written. All remaining work is planned to be completed in about 3 years time.

ACKNOWLEDGMENTS

Thanks are extended for the efforts of the following people during the planning and execution of the work described in this paper: Dr. J. L. D Glockling and his staff at the Loss Prevention Council's Special Projects Group in Borehamwood, Hertfordshire, England.

REFERENCES

1. C. Buckley, D. Rush, *Development of Water Mist for the Royal Navy*, published MoD paper, 1996.
2. M. Edwards, S. Watkins, *Further Development of Water Mist for the Royal Navy*, published MoD paper 1997.
3. Dr. J. L. D. Glockling, M. Edwards, S. Watkins. *Development of a Water Based Fire Suppression System for Naval Fighting Ships*, published MoD paper 1999.
4. Loss Prevention Council/Chartered Insurers Institute report LPR6, *A Report on the Fire Extinguishing Performance Charurteristics of Some Gaseous Alternatives to Halon 1301*, published report 1996.
5. Dr. J. L. D. Glockling, K. Annable, "Water Mist Development Phase 1 Results" unpublished MoD report 1998.
6. Naval Engineering Standard 357, "Requirements for Gaseous Firefighting Systems for Main Machinery Spaces and Compartments of Surface Ships - Part 1 - Carbon Dioxide Systems" MoD standard.
7. Naval Engineering Standard 357, "Requirements for Gaseous Firefighting Systems for Main Machinery Spaces and Compartments of Surface Ships - Part 2 - Halon 1301 Systems" MoD standard.
8. Dr. J. L. D. Glockling, K. Annable, "Comparative Performance Testing of Water mist Systems" unpublished MoD report, 1997.
9. Dr. J. L. D. Glockling, K. Annable, "Water Mist Development Phase 2 Results" unpublished MoD report, 1998.
10. Dr. J. L. D. Glockling, K. Annable, "Water Mist Development Phase 3 Results" unpublished MoD report, 1998.
11. Dr. J. L. D. Glockling, K. Annable, "Water Mist Development Phase 4 Results" unpublished MoD report, 1999.
12. Dr. J. L. D. Glockling, K. Annable, "Water Mist Development Phase 5 Results" unpublished MoD report, 1999.