WATER MIST DEVELOPMENTS FOR THE ROYAL NAVY

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ABSTRACT

Water mist is being investigated by several navies as a replacement for Halon in warship machinery spaces. The Royal Navy's firefighting section, ME225, has a programme of work being undertaken at the Fire Research Station as our contribution in a co-operative effort with the US and Canadian navies. The first phase of trials[1&2] examined the interaction of water mist with flame. using mists generated by a low pressure hydraulic system (up to 10 bar). This demonstrated the feasibility of a low pressure system and showed that a combination of small and large droplets is required for effective extinguishment. The next phase' of work was on a larger test rig (5m x 5m x 6m) which can simulate various configurations, from a zone in a large machinery space to a small enclosed machinery space. For most of the trials to date, the rig has been used without walls to simulate a zone in a large space. The rig has moveable obstructions to allow the fire to be shielded and various fuels were tested Nozzles from several commercial systems were selected for comparison with the low pressure nozzles used for the earlier trials. The aim was to assess which is the most effective system whilst gaining an understanding of the factors which are important when designing a water mist system, such as operating pressure and water delivery rate.

Water mist is showing potential for use as a Halon alternative although, because it is not a gas, it is unlikely that it will ever be able to penetrate machinery spaces with the effectiveness of Halon. This means that if Water mist is introduced, a different philosophy may need to be adopted for fighting fires on warships.

INTRODUCTION

The Royal Navy is a major user of halon 1211 and 1301 fire extinguishing agents, with halon installations used to protect machinery spaces and other high risk compartments on over 100 vessels, including warships, Royal Fleet Auxiliaries and some submarines. Halon is no longer manufactured in the developed world, in accordance with the requirements of the Montreal Protocol on substances which deplete the ozone layer. Alternative agents are therefore required to replace halon in existing applications and to protect new ships.

There are a range of alternatives to halon on the market but all of them have drawbacks in terms of limited performance, environmental acceptability, toxicity, or ease of use. This means that none of the currently available alternatives is suitable to replace halon in existing ship applications, and even when considering their use in new installations there are significant concerns. Our policy is therefore to rely on banked supplies of halon to support existing vessels, and to use CO_2 for new designs and installations. CO_2 is lethal at extinguishing concentrations and so our intention is to adopt a better agent for use in new ship designs as soon we have sufficient confidence to do so.

The use of water mist has been under consideration for many years as a development of sprinkler technology but, with the advent of the Montreal Protocol, renewed interest in this subject has developed over the last few years. For a warship the advantage of water mist over conventional sprinkler systems is its ability to operate successfully with much reduced volumes of water, and to be **used** on liquid pool fires. The advantages of water mist over gaseous alternatives in terms of environmental acceptability and personnel safety are most attractive. Water mist is a technology that the Royal Navy, in common with other potential users, would like to use if it is proved to be sufficiently effective. In order to understand and develop water mist further for our needs, we have implemented a programme of research and this paper discusses the outcome of this work to date.

INVESTIGATION OF EXTINCTION MECHANISMS

The first phase of experimental work was an investigation of the mechanisms by which water mist extinguishes well ventilated liquid pool fires in confined spaces. This work would also provide a basis for selecting nozzles for full scale trials. The nozzles were chosen to provide a range of spray characteristics, but all were low pressure (below 10 bar). Low pressure water mist systems had not received much attention at the time, and were of particular interest to the Royal Navy because of the possibility of running systems directly off ships' fire mains (i.e. the high pressure sea water system), either as the primary mode of operation or, more likely, to provide a back-up following exhaustion of a primary fresh water supply. Low pressure systems also provide the opportunity for simpler engineering than high pressure installations.

The trials demonstrated that low pressure systems can be effective in providing control and extinguishment of small pool fires. Analysis of the interaction of water mist within the fire plume, using a Phase Doppler Analyser, indicated that the principle mode of interaction was flame cooling, possibly combined with some localised inerting, followed by fuel cooling. To achieve this most effectively, the spray needed to contain a mixture of fine and larger drops. Fine drops of **less** than 200 microns were found to be most effective in cooling the flame, because they provided a large surface area for evaporation. These fine drops could easily be carried away by the fire plume and hence it was also important to have larger drops, between 250 and 500 microns, that would carry the smaller drops into the flame, and penetrate the flame to cool the fuel. It was found that flame cooling alone was not sufficient to achieve extinguishment, fuel cooling was also required.

FULL SCALE EXTINGUISHING TRIALS

The aim of these trials was to evaluate the extinguishing capabilities of different nozzles on a full scale rig, which would simulate a shipboard machinery space[3]. The concept was to consider general protection of a zone within a machinery space, rather than protection of specific components. The nozzles were therefore positioned at the ceiling, ***6*** metres from the fire, and the rig was used without walls for the majority of tests. The idea behind zoning is to operate the water mist system only in the area where there is a fire. To apply mist to an entire machinery space means that water consumption **is** higher, reducing the potential for water mist systems to minimise water usage. The protection of zones would also allow systems to be designed and sized to cope with smaller **flow** rates than would be required for an entire machinery space.

Mawhinney[4], during IMAS 94', concluded that the maximum compartment size for a total flooding water mist system was 200m^3, due to system engineering and water utilisation considerations. Typically UK warship machinery spaces range from 100 to 7500 m^3.

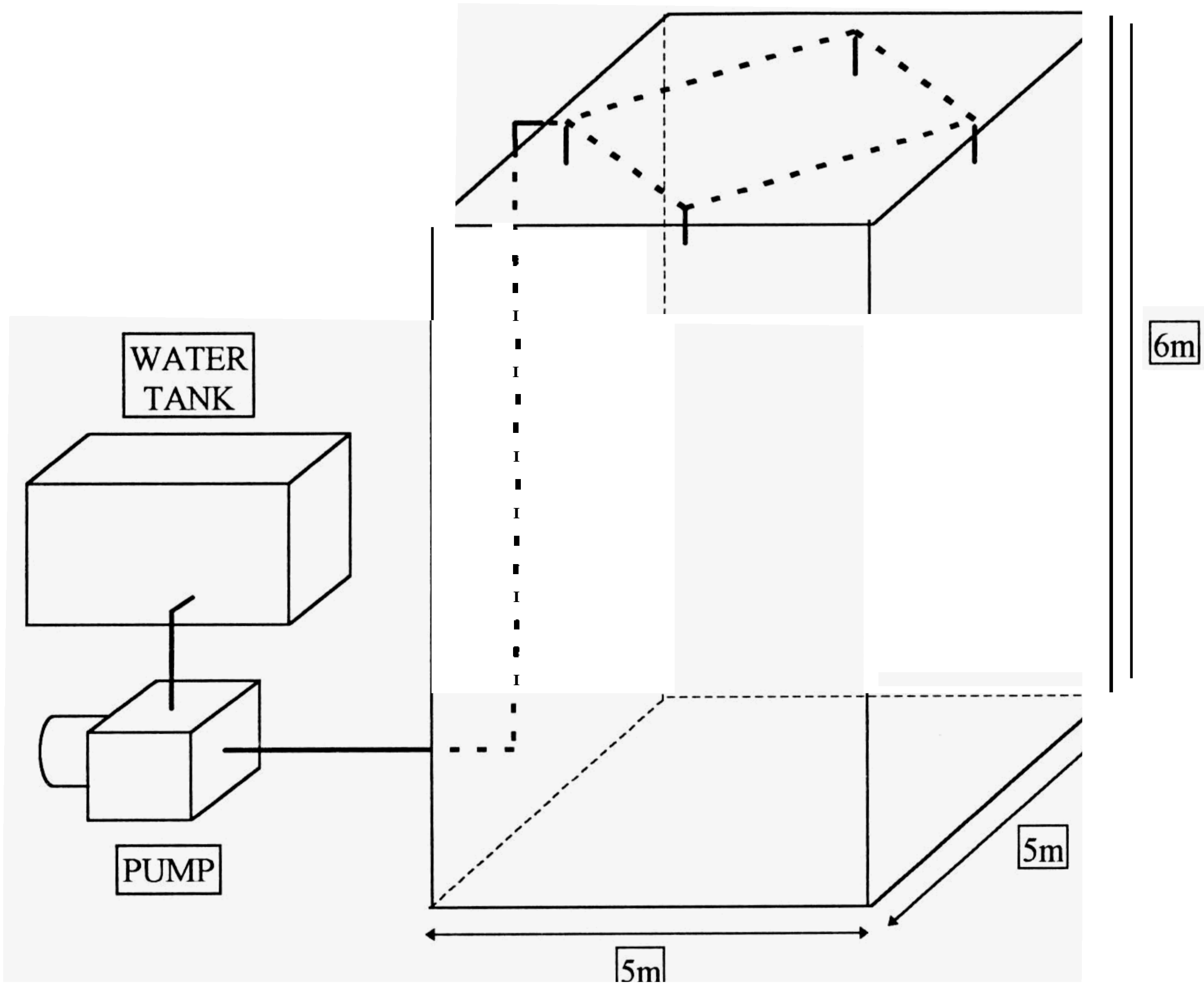

Figure 1 - Water mist Test Rig. (shown in configuration used for high pressure testing with NRL modified multi-orifice nozzles).

Design of the water mist test rig

The test rig was designed and built by the Fire Research Station at their Cardington Laboratory on behalf of the Ministry of Defence. This test rig, depicted in Figure 1, is not designed to simulate any particular machinery space, however the ceiling height set at 6m represents the largest shipboard machinery spaces in Royal Navy and Royal Fleet Auxiliary vessels and hence represented the most challenging situation likely to be encountered. The ceiling and floor are manufactured from steel as are the support frames holding up the ceiling. Initially the structure was left open, hence simulating a 5m x 5m x 6m zone within **a** large, well ventilated space.

For obstruction simulation, two overhead pipes 4m long and 0.4m diameter were installed 2.5m above the floor, their position relative to the fire is shown in Figure 2. Two moveable obstructions were also used, one mesh and one solid, these are also shown in Figure **2. A** 1.13m diameter fire pan was placed in the centre of the test rig floor. For Avtur, an aviation fuel, this gave a fire of approximately 2MW. The test rig was instrumented for temperature and gas analysis

FUEL	NATO REF	USE	FLASH POINT	VISCOSITY
DIESO F-76	F-76	Fuel, naval distillate (petroleum)	61°C	1.7-4.3mm^2/s (cSt) @ 40°C
OM-100	0-240	Light service lubricating oil	165°C	72-81mm^2/s (cSt) @ 40°C
OM-33	H-576	Mineral hydraulic oil	160°C	26-33mm^2/S (cSt) @ 40°C
OX-30	-	Mineral hydraulic oil	165°C	26-33mm^2/s (cSt) @ 40°C
AVTUR/FSII	F-34	Fuel, aviation (kerosene)	38°C	8.0mm^2/s (cSt) @ -20°C
CLASS A SIMULATION	Polycarbonate pipe insulation wrapped in mineral fibre navy board soaked in 8 litres of Dieso F-76			

Table 1 - Range of Fuels Used in testing.

Fuels tested

A range of fuels were chosen based on their applicability to use in machinery spaces onboard Royal Naval vessels. The choice consisted of; ship propulsion fuel, lubricating oil, two hydraulic fluids, an aviation fuel and a Class A simulation. The first four of these fuels are commonly found in machinery spaces. The aviation fuel was chosen as a worst case scenario, although unlikely to be in use in the machinery spaces it is possible that it could have drained down into the space from the hanger/flight deck areas. The Class A fire consisted of insulation and fibre soaked Dieso F-76, since this was considered to be representative of the Class A fire threat in a machinery space. Some properties of the chosen fuels are shown in Table 1.

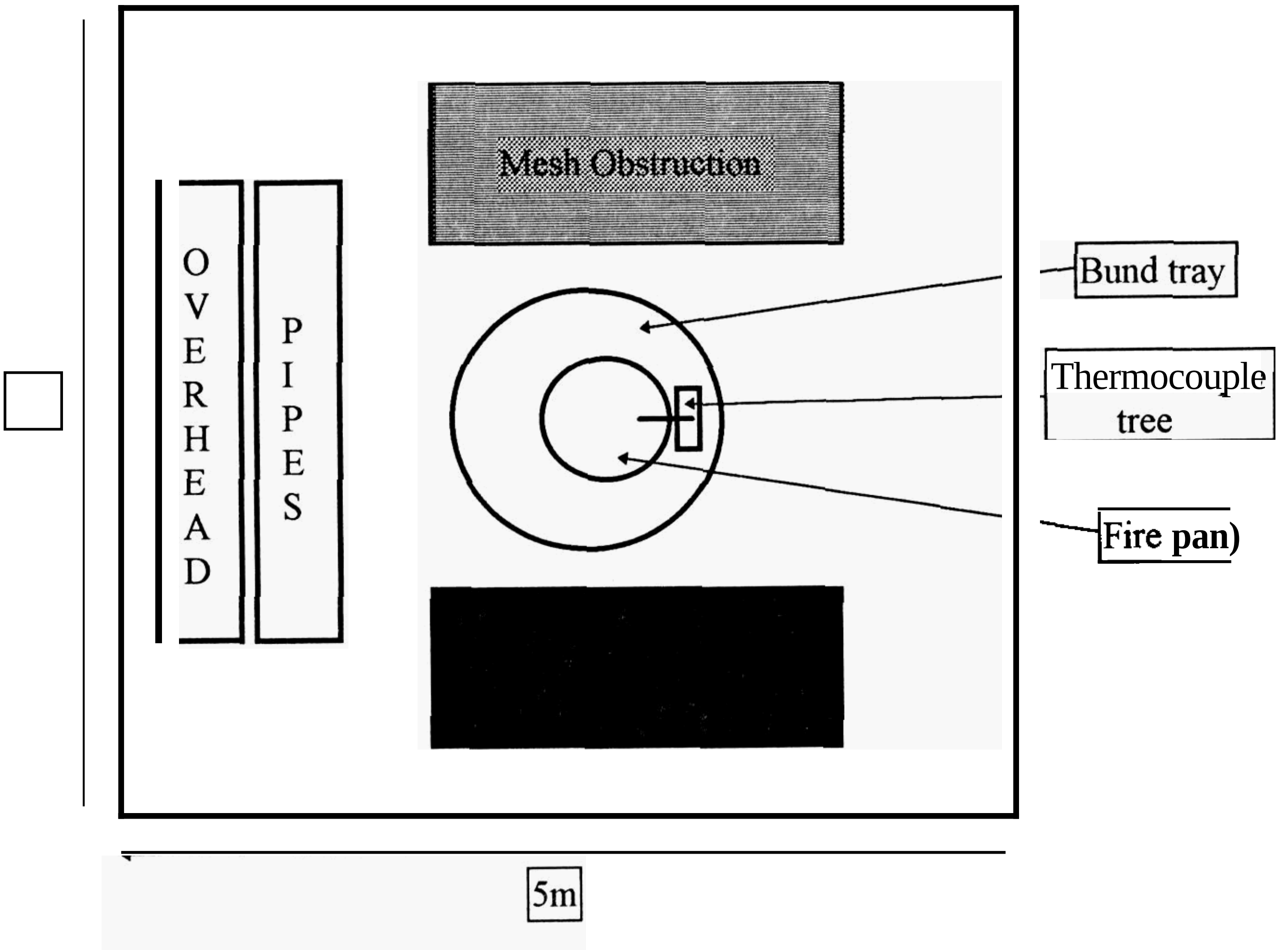

Figure 2 - Plan view of test rig. (Moveable obstructions shown for information)

Nozzles tested

The trials used a range of nozzles:

- the most effective nozzles from the earlier trials (Lechler 460-648 and Lechler 402-644)
- commercial low and medium pressure nozzles offered by manufacturers (Spraying Systems Inc ¾-7G-1 and Grinnell AM10 *AquaMist*)
- the most successful nozzles from **US** Navy trials on the ex-USS SHADWELL' (NRL modified Spraying Systems 7G, higher pressure - 70 bar)

Nozzles were selected with a view to achieving an application rate of **3.5**$l/m^2/min$, although the Grinnell nozzle exceeded this. This rate was chosen because it is about one-third of the application rate currently used for machinery space AFFF spray systems. The low and medium pressure nozzles were installed in a grid of 9 nozzles at 1.5m spacing, the grid being positioned 1m in from each side of the test rig ceiling. The high pressure nozzles were installed in a grid of 4 nozzles as shown in Figure 1, 1m in from the side of the test rig ceiling at the mid point of each side. Manufacturers data for the nozzles tested are shown at Table 2.

DISCUSSION OF RESULTS

The results are summarised for each of the nozzles tested.

When considering the results it needs to be re-iterated that this series of tests were simulating general profection of a zone within a large well ventilated machinery space and that this is not necessarily the design intent of the individual nozzles.

Lechler 460-648

This was a single orifice low pressure nozzle with a spray angle of 120°. Eighty percent of the spray volume was in drops of between 80 and **330** microns diameter. This nozzle extinguished all fuels except **Avtur** and Dieso F-76 soaked fibres, with OX30 fires being rapidly extinguished.

Lechler 402-644

This nozzle has a narrower spray angle (60") than the 460-648, giving drops of a higher mean velocity and with eighty percent of the spray volume between 90 and 800 microns. This nozzle performed slightly better than the 460-648 in that it extinguished the same range of fuels, but generally in shorter times. Again Avtur and **DSF** were not extinguished.

Spraying Systems Ine ¾-7G-1

This was also a low pressure nozzle, with each head having seven separate orifices. This nozzle was less successful than the earlier nozzles in that it also failed to extinguish the OM33 fire.

Grinnell **AM10** ***AquaMist***

This nozzle is similar in appearance to a conventional sprinkler, but with a spherical deflector. It had an 80% volume distribution of drops between 100 - 230 microns, and operated at a slightly higher pressure **(12** bar) than the Lechler and Spraying Systems nozzles. It also delivered water at **a** higher application rate of 4.3 $l/m^2/min$. This nozzle was the most successful during our trials, extinguishing all fuels except Avtur and **Dieso F-76** soaked fibres and generally with faster extinction times than the Lechler nozzles. Although flow rates were higher, less water was used to achieve extinction because **of** the shorter times. The mesh obstruction did not adversely affect the ability of the mist to achieve extinguishment but no extinctions were achieved with the solid obstruction.

NRL Modified **Spraying Systems 7G**

This nozzle head is based upon the Spraying Systems ***7G*** head, but with extension pipes between the head and the individual nozzles, to allow better formation of spray cones, without interfering with each other. Three versions of this nozzle were trialed, having different sized central and peripheral orifices and referred to as NRL **1,** NRL **2** and NRL **3** in this paper. These nozzles operated at **a** higher pressure of 70 bar. The nature **of** the high pressure pumping system meant that tests were started at 15 bar, with **full** pressure being reached after 30-40 seconds. This delay was reduced to around ***5*** seconds for the NRL **3** nozzle trials. The **NRL** nozzles were the least successful during our trials, with all three versions failing to extinguish any of the fires with any of the fuels.

The measured droplet characteristics for all the nozzles tested are detailed in Table ***2*** and a summary of the fire test results are shown in Table **3.**

Nozzle	Description	Flow (l/min)	Pressure (bar)	Spray Angle (degrees)	$D_{V0.1}$ micron	$D_{V0.5}$ micron	$D_{V0.9}$ micron	Mean velocity (m/s)	Delivery per head (l/min)
Lechler 460648	Single orifice	6.6	7	120	81	182	334	3.7	8
Lechler 402644	Single orifice	7.5	7	60	91	226	823	8.7	8.5
Spraying Systems ¼7G1	Multiple orifice	8.2	8	45 (est)	127	188	312	2.2	8.5
Grinnell AM10 AquaMist	Misting sprinkler	Not known	12	Not known	99	155	229	3.1	12
NRL 1	Modified multiple orifice	8.2	70	Not known	103	163	242	2.4	-
NRL 2	Modified multiple orifice	15.2	70	Not known	113	174	265	5.1	-
NRL 3	Modified multiple orifice	19.7	70	Not known	76	115	184	7.1	19

Notes: 1. Flow, Pressure and Spray angle data are as supplied by manufacturer. 2. Drop size distribution and mean velocity have been measured 1m directly below nozzle centre. 3. Flow rate is nominal per head as installed in the test rig.

Table 2 - Manufacturers data for nozzles and measured droplet characteristics

Nozzle	DIESO F-76		OM-100		OM-33		OX-30		AVTUR/FSII		CLASS A SIM	
	No obstruction	Mesh obstruction	No obstruction	Mesh obstruction	No obstruction	Mesh obstruction	No obstruction	Mesh obstruction	No obstruction	Mesh obstruction	No obstruction	Mesh obstruction
Lechler 460648	✓560	✓543	✓400	✓112	×	✓472	✓31	✓ 29	×	×	×	×
Lechler 402644	✓520	✓480		✓20		✓33	✓ 405	✓ 20	×	×	×	×
Spraying Systems ¼7G1	✓440	×			×	×		✓37	×	×	×	
Grinnell AM10 *AquaMist*	✓161	✓235	✓46	✓32	✓43	✓80	✓11	✓32	×	×	×	×
NRL 1	×				×				×		×	
NRL 2	×	×			×				×	×	×	
NRL 3 (2 walls fitted)	×	×			×	×				×		

Key: ✓ denotes successful extinction followed by extinction time in seconds. × denotes unsuccessful extinction.

Table 3 - Summary of fire test results

OBSERVATIONS

As was expected, the lower flash point fuels were found to be the most difficult to extinguish. **Avtur,** the lowest flash point fuel, was not extinguished by any of the mists. This underlines the importance of considering the fuels likely to be encountered when specifying a water mist system. All the mists also failed to extinguish any of the Dieso **F-76** soaked fibre fires. This was a three-dimensional fire of wrapped insulation and fibre board in the form of a hollow cylinder and to achieve extinguishment, the mist needed to penetrate internal as well as external surfaces. The failure to put out these fires indicated the limited ability of mists to flow round and penetrate obstructions in the way that gaseous agents can, and the problem of dealing with deep-seated and hidden fires.

Even the most successful nozzle failed to extinguish the fire when the solid obstruction was in place. In contrast the mesh obstruction was not found to adversely affect the performance of the mists, and in some cases performance actually improved with faster extinction times being obtained. In these cases it was considered that the mesh had interfered with the fire plume, thus making it easier for the mist to penetrate. These results are encouraging in terms of water mist's ability to extinguish fires under walkways in machinery spaces, although the results with the solid obstruction indicate that water mist is poor at extinguishing fires under solid obstructions.

Observation of the fire during mist application showed that there was no significant entrainment of the mist into the flame. The open nature of the rig meant that there was no containment of the mist and hence it did not build up and recirculate. Where in our trials extinguishment was achieved it was by direct action of the mist on the fire, with secondary action by entrainment not being a significant factor. A striking feature of the results is the wide variation in performance for mists with similar drop distributions. In particular the best performing nozzle, the AM10, had a similar drop distribution and drop velocity to the NRL 1 head, which failed to extinguish any fires.

This indicates that drop size data alone is insufficient for specification of a system and indeed these nozzles performed very differently when viewed on the rig. The AM10 created a mist which seemed to have the ability to penetrate the fire plume and directly act upon the fire to achieve

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extinguishment. In contrast, the wide effective spray angle of the NRL nozzles created a mist which tended to get carried away in the smoke layer; it did not seem able to penetrate the fire plume to attack the fire. Had the rig been enclosed, the story could have been different in that the mist carried in the smoke layer could have recirculated within the space and, possibly, have been more effective in interacting with the fire. Our trials suggest that high pressure nozzles of the NRL type rely on containment to operate in a 'total flooding' mode, and that without this they are ineffective. Therefore they are unsuitable for protection of a zone within a well ventilated machinery space.

FACTORS TO CONSIDER WHEN SELECTING A WATER MIST SYSTEM

From our tests we can summarise the main factors that require to be considered when selecting a water mist system:

Type of fuels in space to be protected,

Nozzle characteristics (i.e. drop size, drop velocity, pressure, spray angle)

Configuration of space to be protected (i.e. level of obstruction, ventilation)

CONCLUSIONS

These trials were conducted in very challenging conditions, representative of the most demanding situation likely to be encountered on a warship. We conclude that a zoned design of water mist system, mounted at high ceiling level, cannot be recommended to provide complete protection of a machinery space, since it may be ineffective against some types of fuel and hidden fires. Nonetheless it is encouraging to find that the best systems would be able to provide general protection of the space against liquid pool fires for fuels with flash points over 60°C. Although the **Avtur** fires could not be extinguished by any of the systems tested, it is important to note that this fuel was selected to provide a worse case fire and it would not normally be found onboard. The Dieso **F-76** soaked fibres represented a common fire threat which none of the systems could put out, but in this case a great measure of control was obtained by the best systems and hence fire spread would have been contained.

It was interesting to find that during our study, in an unenclosed space, low and medium pressure systems performed much better than the high pressure system we tested. This has important implications for ship installation in that low pressure systems are easier to engineer, and hence cheaper to install and maintain. The low pressure nozzles we trialed had larger orifices than the high pressure variant and should be less prone to blockages. For these reasons, and because of the possibility of running the system from the ships fire main, our preference would be to use low pressure, unless there are clear advantages in favour of high pressure systems. During our trials we found no such advantages.

FUTURE RESEARCH/WAY FORWARD

We believe that water mist requires further development before it can be considered suitable for machinery space protection in the Royal Navy. Water mist refuses to behave in a way which gives confidence in its ability to be applied in untested situations and system performance can vary significantly in different applications. This is dramatically illustrated by the fact that the nozzles found to be the most effective in US trials were the least effective during ours.

To complete this series of trials it is proposed to fully enclose the test rig for a further comparison between the best performing low pressure nozzles and the high pressure NRL nozzles. In this configuration the rig will simulate a small machinery space or pump room of $150m^3$ volume. We expect that the performance characteristics of the NRL nozzles will be better suited to a 'total flood' situation where the mist is physically retained within the volume.

Other aspects which could be considered are variations in nozzle height, the effects of additives and different fire types, such as spray fires.

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