Report on the investigation of

The machinery space fire on board

Oscar Wilde

In Falmouth Bay

2 February 2010

Marine Accident Investigation Branch
Mountbatten House
Grosvenor Square
Southampton
United Kingdom
SO15 2JU

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

2/E	-	Second engineer
AER	-	Auxiliary engine room
AFFF	-	Aqueous film forming foam
BA	-	Breathing apparatus
BMA	-	Bahamas Maritime Authority
C	-	Celsius
CCTV	-	Closed-circuit television
C/O	-	Chief officer
CoSWP	-	Code of Safe Working Practices for Merchant Seamen
DFM	-	Dobson Fleet Management
DNV	-	Det Norske Veritas
ECR	-	Engine control room
EEBD	-	Emergency escape breathing device
EOOW	-	Engineer officer of the watch
EPDM	-	Ethylene propylene diene monomer (synthetic rubber)
ETO	-	Electro-technical officer
EU	-	European Union
FP	-	Fire protection
FPM	-	A Fluorocarbon rubber (commonly referred to as ‘viton’)
FSS	-	Fire safety systems
GPU	-	Gas-driven pump unit
HFO	-	Heavy fuel oil
IMO	-	International Maritime Organization
kg	-	kilogram

Knots	-	Nautical miles per hour
kW	-	Kilowatt
LR	-	Lloyd’s Register
m	-	metre
MAU	-	Machinery accumulator unit
MCA	-	Maritime and Coastguard Agency
MGN	-	Marine guidance note
MGO	-	Marine gas oil
MIRG	-	Maritime Incident Response Group
mm	-	millimetre
MNTB	-	Merchant Navy Training Board
MSC/Circ	-	Maritime Safety Committee circular
OSC	-	On scene commander
PMS	-	Planned maintenance system
Ro-ro	-	Roll-on roll-off
SOLAS	-	International Convention for the Safety of Life at Sea
UHF	-	Ultra High Frequency (radio)
UTC	-	Universal co-ordinated time
V	-	Volts
WTD	-	Watertight door

Times: All times used in this report are UTC unless otherwise stated

Oscar Wilde

SYNOPSIS

At approximately 1913 on 2 February 2010, a fire broke out in the auxiliary engine room on board the Bahamas registered roll-on roll-off passenger ferry Oscar Wilde. The ferry had just sailed from Falmouth, UK, after completing her annual docking. The seat of the fire was in way of the auxiliary engines' fuel supply module and quickly spread across the compartment. The fire was eventually extinguished by the ship's crew at 2100. There were no passengers on board and none of the ship's crew were injured. However, the fire caused the vessel to lose electrical power, which ultimately required her to be towed back into Falmouth for repairs.

As part of the fire-fighting effort, the fixed local application (water-mist) fire suppression system, and the total flooding (high-expansion foam) and bilge (low-expansion foam) fire-extinguishing systems were activated, but did not extinguish the fire. A second fire broke out on the deck above the auxiliary engine room and smoke spread to adjacent compartments, including the engine control room, and remote passenger accommodation areas.

The fire occurred when a pressure regulating valve's actuator diaphragm ruptured and fuel oil sprayed onto an exposed high-temperature surface on an adjacent auxiliary engine. The diaphragm failed because it had been manufactured from rubber that was not resistant to oil. The fire was not extinguished by the high-expansion foam total flooding system because rust and scale within the dry pipe network had clogged the foam distribution nozzles and prevented the production of foam. The performance of the local application water-mist and bilge foam systems was adversely affected by inadequate maintenance. The fire spread to an adjacent compartment due to the absence of thermal insulation.

Following the fire, MAIB issued a Safety Bulletin which included a recommendation to the owners of ships fitted with high expansion foam systems utilising the atmosphere from within a protected space, aimed at ensuring similar corrosion issues were identified and rectified. In April 2010, the Bahamas Maritime Authority (BMA) brought to the attention of the International Maritime Organization (IMO) sub-committee on fire protection (FP), the need to urgently review current requirements for the installation and testing of the distribution piping of high expansion foam systems using inside air.

Further recommendations have been made to the BMA aimed at: increasing international awareness and recognition of the hazards posed to personnel by high-expansion foam; verifying Oscar Wilde's compliance with the SOLAS structural fire protection requirements, and; providing assurance that the vessel's fixed fire-extinguishing systems can be relied upon in an emergency. A recommendation has been made to Lloyd's Register to make its clients aware of the circumstances of the fuel system failure. Irish Ferries has been recommended to fully implement changes to its fixed fire-fighting systems as recommended by the system manufacturers.

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF *OSCAR WILDE* AND ACCIDENT

Vessel details

Registered owner	:	Irish Continental Line Ltd
Manager	:	Dobson Fleet Management Ltd
Port of registry	:	Nassau
Flag	:	Bahamas
Type	:	Ro-ro passenger ferry
Built	:	1987 by Wartsila in Turku, Finland
IMO number		8506311
Classification society	:	Lloyd's Register
Construction	:	Steel
Length overall	:	166.3m
Gross tonnage	:	31,914
Engine power and type	:	19,800kW / 2 x Wartsila Sulzer ZA 49V12 and 2 x Wartsila Sulzer ZA L6
Service speed	:	23 knots
Other relevant info	:	Machinery space fixed fire-extinguishing systems: • Inside air high-expansion foam total flooding system • high pressure water-mist local application system • low-expansion foam bilge spreading system

Accident details

Category	:	Serious marine casualty
Time and date	:	1913 on 2 February 2010
Location of incident	:	50º 04'0N 005º 00'0W, Falmouth Bay, England
Persons on board	:	113
Injuries/fatalities	:	Nil
Damage	:	Material damage within the auxiliary engine room and lobby area adjacent to the engine control room.

1.2 NARRATIVE

1.2.1 Initial fire

During the afternoon of 2 February 2010, the crew of the roll-on roll-off (ro-ro) passenger ferry *Oscar Wilde* prepared the vessel for sea, following completion of an annual docking period in Falmouth, England. The ship was due to sail at 1600, but problems clearing rust and debris from the vehicle decks' drencher system pipework delayed her departure. 'Stand-by engines' was eventually ordered at 1815 and the ferry sailed 15 minutes later bound for Rosslare, Ireland. It was dark, the visibility was good, the sea state was moderate and the wind was westerly force 4 to 5.

As the vessel left the berth, the engineer officer of the watch (EOOW) changed the main engine and auxiliary engine fuel oil systems from marine gas oil (MGO) to heavy fuel oil (HFO). A series of fuel pressure alarms followed, and the chief engineer instructed the EOOW to change the auxiliary engine fuel supply back to MGO.

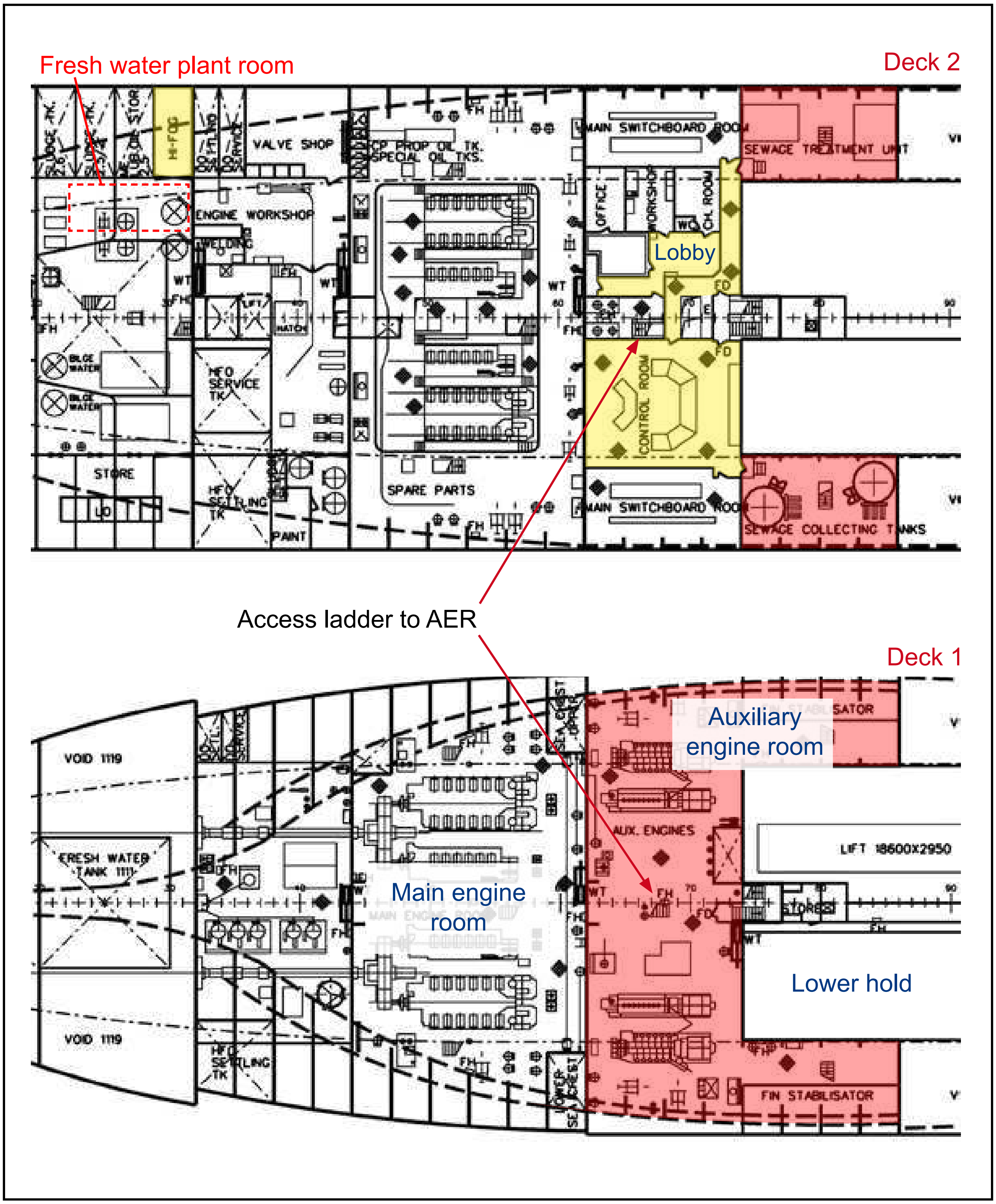
At 1900, the master rang 'full away on passage'. Shortly afterwards, the chief engineer again changed the auxiliary engine fuel supply to HFO, and monitored the system's pressures, temperatures and viscosity. At 1912, No.3 and No.4 auxiliary engines' low fuel oil pressure alarm sounded and a stand-by fuel booster pump cut-in. Approximately 1 minute later, a flame detector covering the auxiliary engine fuel booster module activated.

The flame detector initiated alarms on fire detection panels in the engine control room (ECR) and on the bridge. Almost simultaneously, an audible alarm sounded on the *Hi-fog*[1] system's remote release panel in the ECR. The bridge was informed that there might be a problem with No.3 auxiliary engine, and the chief engineer and EOOW went to the auxiliary engine room (AER) to investigate **(Figure 1)**. They entered the AER from the lobby area on deck 2. When half way down the machinery space ladder, the engineers saw flames above the fuel module close to No.3 auxiliary engine **(Figure 2)**. The space was filling rapidly with smoke and the chief engineer and EOOW had to return to the ECR.

Meanwhile, contract cleaners opened hydraulic watertight door number two (WTD2) between the main and auxiliary engine rooms **(Figure 3)** and saw thick black smoke. They closed the door and alerted the second engineer (2/E), who was inspecting the main engines on the deck plates above. He rushed to the door, opened it slightly, saw the smoke and closed it again. The 2/E told the cleaners to leave the engine room, and rigged a fire hose and a foam branch pipe.

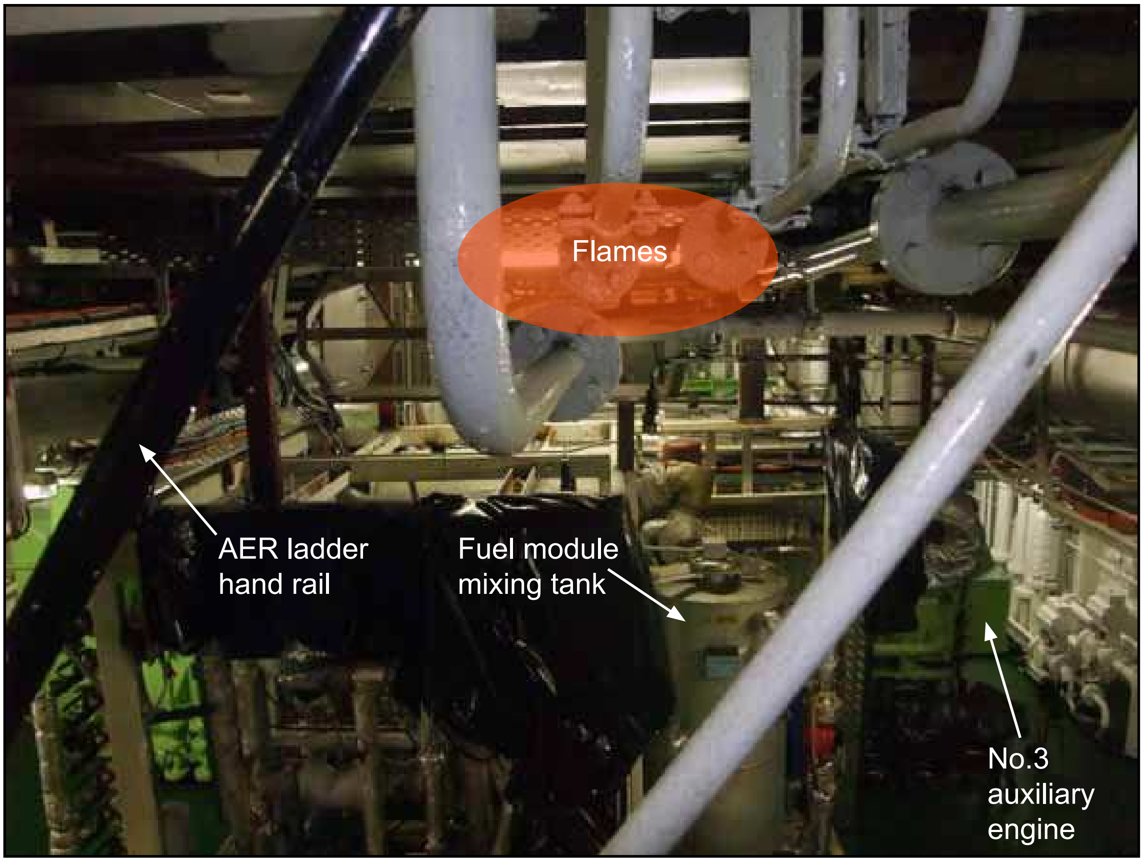
[1] *Hi-fog* – brand name of the local application fixed fire-extinguishing water mist system fitted in the ship's machinery spaces.

Figure 1



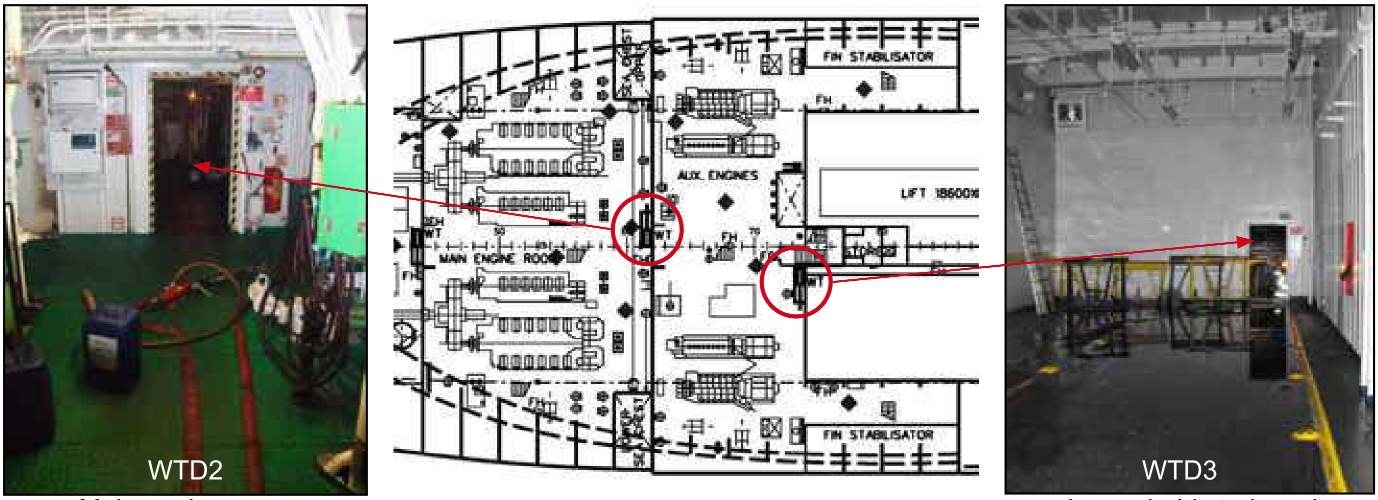
Machinery space layout

Figure 2



View of the fire from the auxiliary engine room ladder

Figure 3



Main engine room

Lower hold starboard

Number two and number three watertight doors

At 1915, the chief engineer informed the bridge that there was a fire in the AER and advised the master that the ship was going to black-out. The vessel was approximately 1.5 miles east of The Manacles and heading south at 15 knots **(Figure 4)**. The master reduced engine speed and called the ship's special mobile groups **(Figure 5)** to their stations.

Figure 4

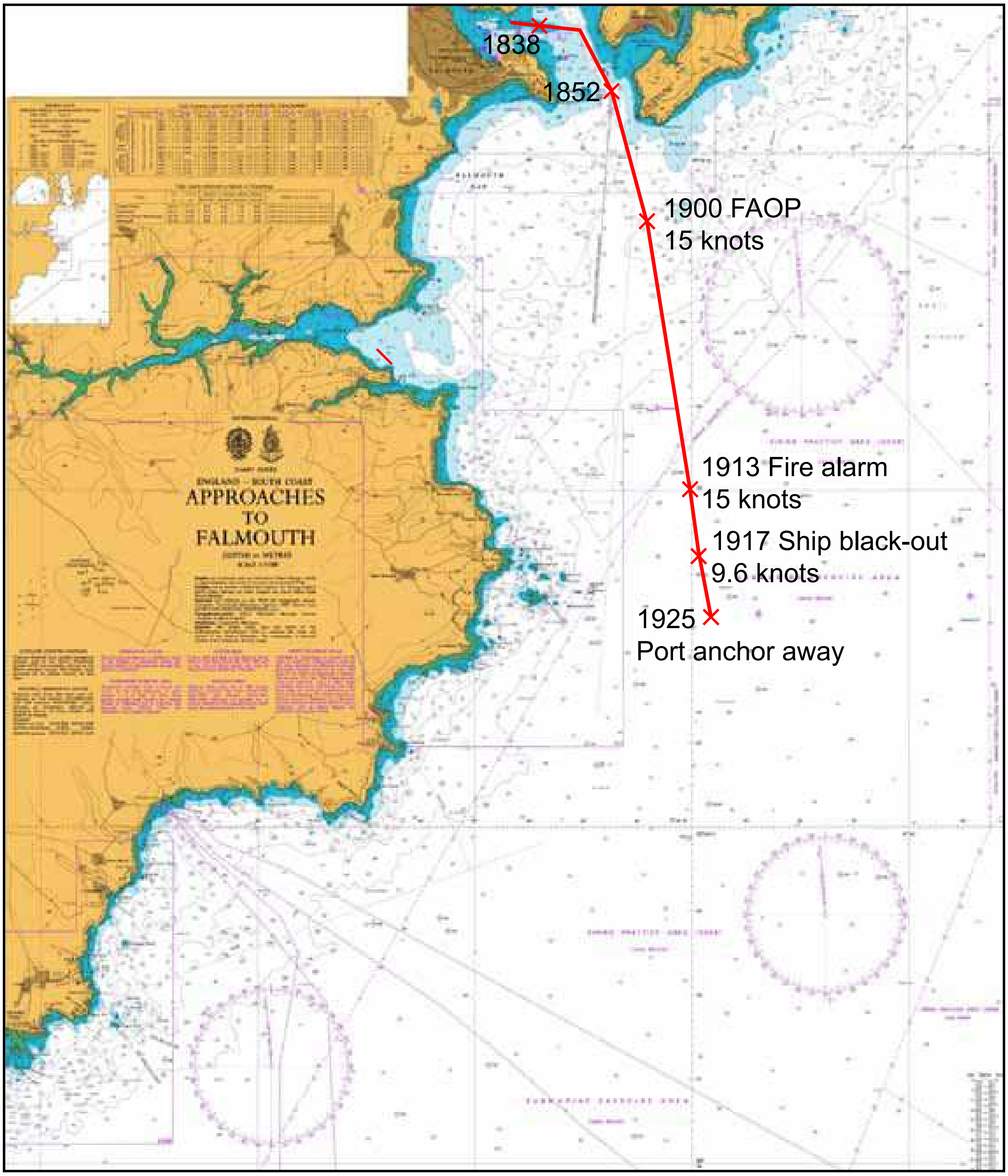
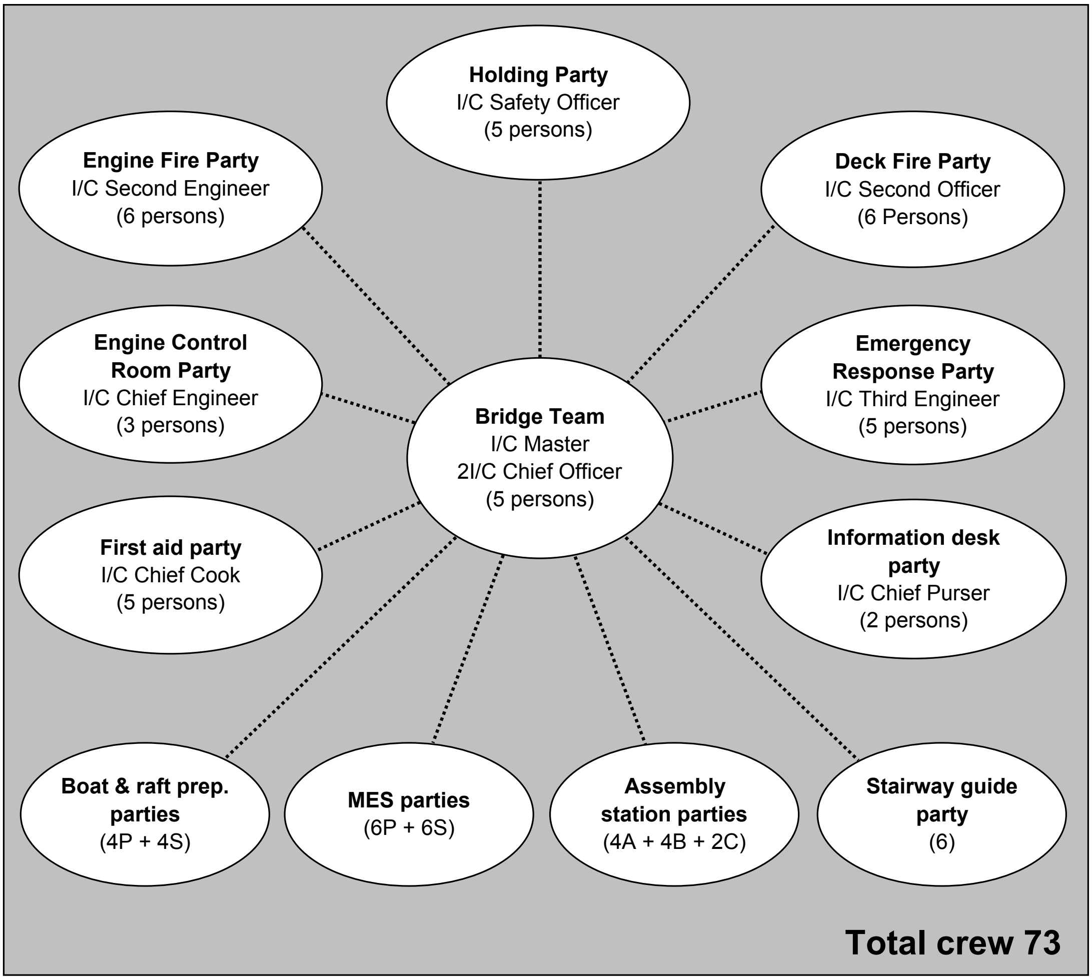


Chart of Falmouth Bay

Figure 5



Ship's special mobile groups

The chief engineer started the emergency fire pump and crash-stopped the machinery space ventilation fans. Unsure of the status of the *Hi-fog* system, he attempted to manually activate the section of the system covering the starboard side of the AER, using the remote release panel in the ECR. The chief engineer then instructed the EOOW to shut down the main and auxiliary engines.

The extra 2/E joined the 2/E in the engine room and manually activated the *Hi-fog* section covering the port side of the AER using the remote switch located next to WTD2 **(Figure 3)**. The extra 2/E and the 2/E then went to their emergency stations. On his way to his emergency station in the ECR, the extra 2/E saw water dripping down from the funnel casing, indicating that the *Hi-fog* was operating in that area.

At 1916, the master sounded the general emergency alarm, ordered the deck crew to prepare the anchors for letting go, and put the rudders hard-over to port. Approximately 30 seconds later, the ship blacked-out and the emergency generator started. The chief engineer activated the ECR remote fuel pump stops and tripped the machinery space ventilation fire dampers. The electrical supplies to the AER were isolated by the duty electro-technical officer (ETO).

When the extra 2/E arrived in the ECR he saw the funnel casing button on the *Hi-fog* release panel was illuminated, but the buttons for the port and starboard sections of the AER were not. The extra 2/E immediately pressed the buttons to activate the system on the port and starboard sides of the AER.

On the bridge, the chief officer (C/O) assumed his emergency stations role as second-in-command, and co-ordinated internal communications between the mobile parties and the bridge. He was assisted by the ship's marine manager and technical superintendent. The bridge team crash-stopped the accommodation ventilation fans, closed the accommodation fire doors and switched the watertight door control system to its emergency mode to ensure that all machinery space watertight doors were closed. The vehicle deck ventilation dampers were left open.

At 1918, the C/O instructed the safety officer to proceed to the starboard aft side of the lower hold **(Figure 3)**. Approximately 1 minute later, the safety officer relayed to the bridge that the 2/E had attempted to operate the *Hotfoam*[2] system, but it was not working. The C/O told the safety officer to rig hoses and prepare to fight the fire from watertight door number 3 (WTD3). He then sent the engine and deck fire parties to the lower hold. The anchors were reported to be ready for letting go at 1921.

About this time, the chief engineer informed the C/O that the fire might be out. The C/O instructed the safety officer to open WTD3 and look inside the AER. When the safety officer opened the door he saw smoke but no flames; the smoke did not enter the lower hold. Shortly after, the safety officer was joined in the lower hold by the engine and deck fire parties, and he assumed the role of on-scene commander (OSC).

On instruction from the C/O, the 2/E handed control of the engine fire party to the OSC and went to the domestic fresh water plant room on deck 2 **(Figure 1)** to check the status of the *Hi-fog* system. The 2/E confirmed that the *Hi-fog* system appeared to be working correctly and then went to check the condition of the spaces adjacent to the AER.

The ferry anchored at 1924. Shortly after, the C/O sent the emergency response party to monitor and cool the bulkhead between the main engine room and the AER on deck 1. The third engineer in charge of the party misunderstood this instruction and took his team to the engineers' workshop area and monitored the aft main engine room bulkhead on the deck above **(Figure 1)**.

At 1927, the chief engineer reported hot spots on the deck of the lobby area outside the ECR. Two minutes later, the 2/E reported hot spots on the forward main engine room bulkhead next to WTD2 **(Figure 6)**. The C/O interpreted this message to mean hot spots had been reported in the fire control station. This caused some confusion on the bridge as the control station was 2 decks above the AER **(Figure 7)**.

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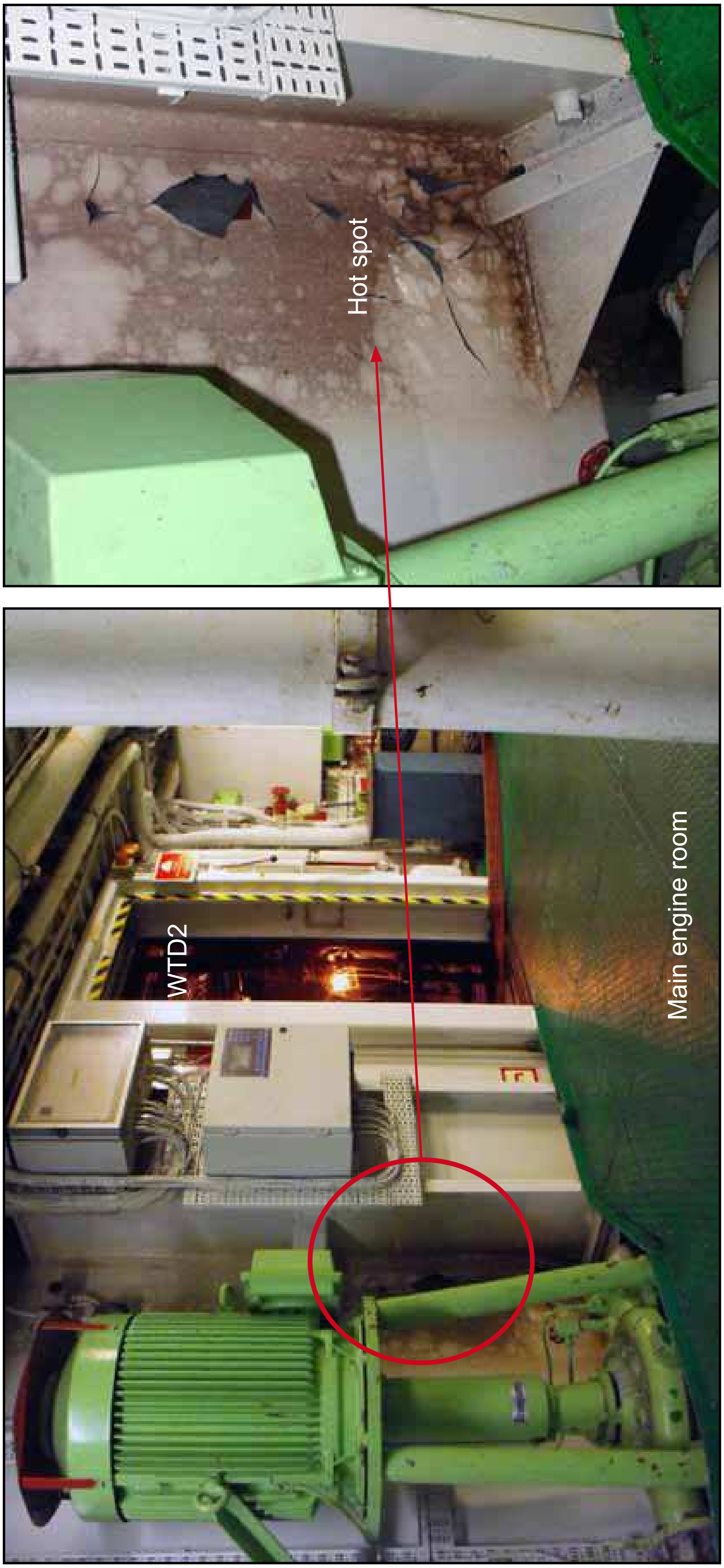
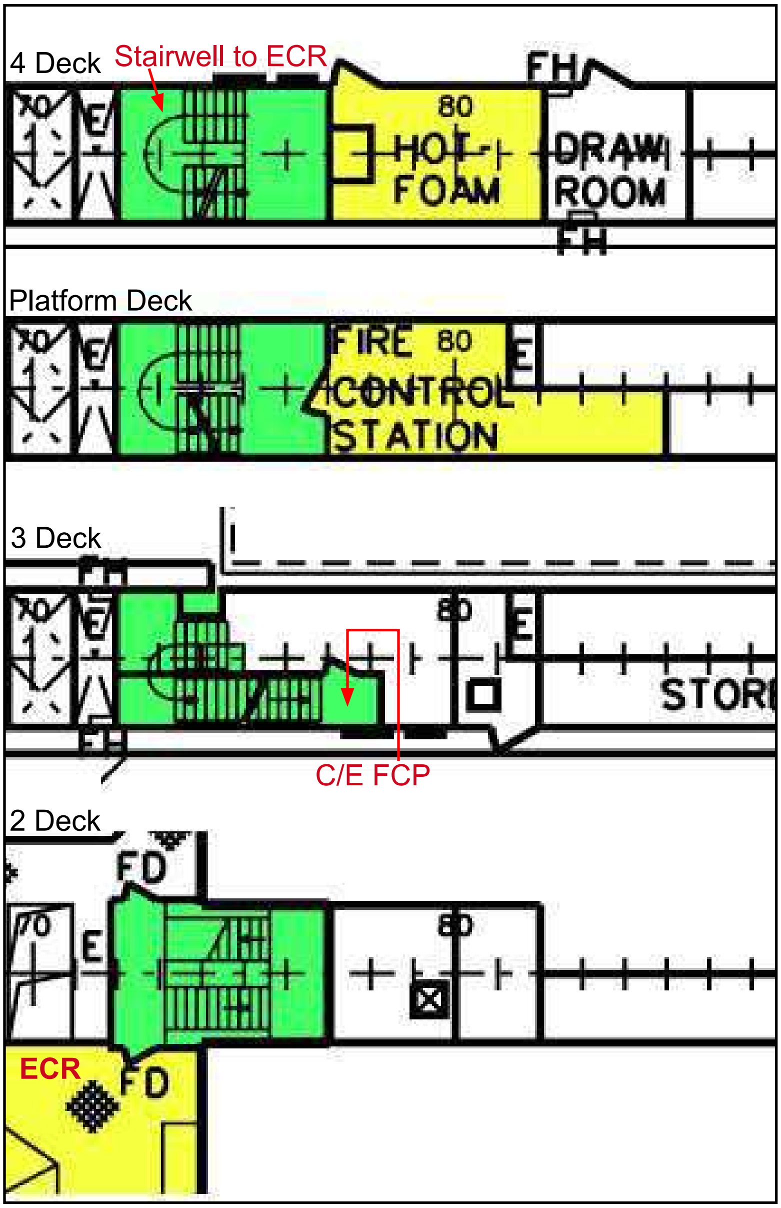
2 *Hotfoam* – brand name for the total flooding high-expansion foam fixed fire-extinguishing system fitted to the ship's machinery spaces.

Figure 6



Hot spots on main engine room bulkhead

Figure 7



Fire control station and *Hotfoam* room

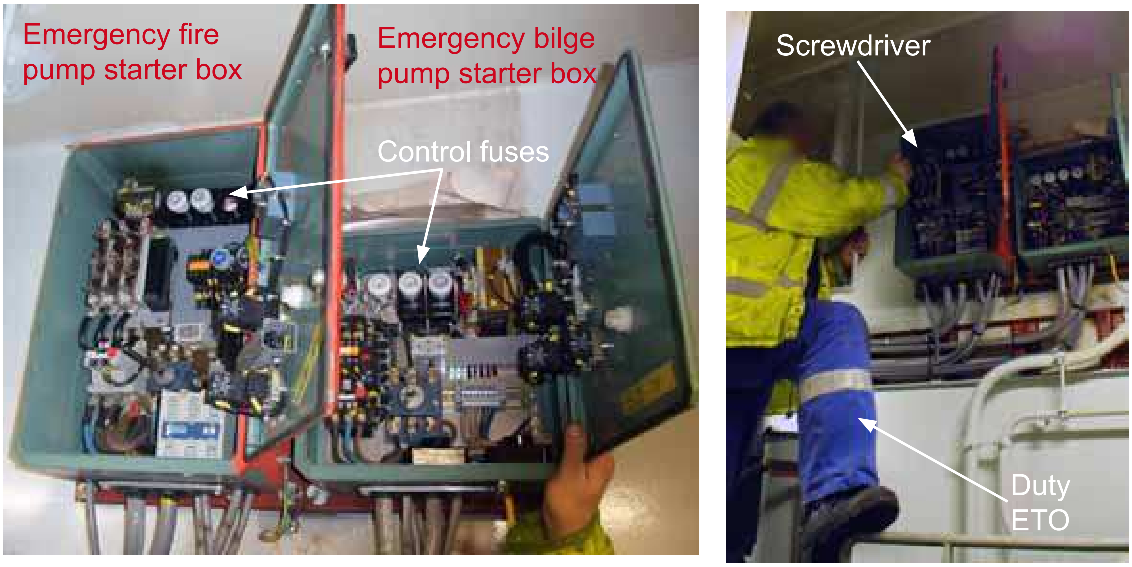
By 1930, the ECR, switchboard rooms and adjacent lobby area were smoke-logged. The ECR was evacuated; the EOOW went to the lower hold while the chief engineer, extra 2/E and duty ETO went to the fire control station where they tripped the fuel oil quick-closing valves. On instruction from the C/O, the chief engineer also opened the vehicle deck drencher valve for zones 3 and 4. Independently the 2/E decided to go to the *Hotfoam* room on deck 4 **(Figure 7)**, where he attempted to activate the fixed high-expansion foam system.

Meanwhile, the OSC had seen flames in the AER and had tasked a fire team wearing breathing apparatus (BA) to fight the fire from WTD3 using both water and foam.

At 1932, water pressure in the fire main was lost. The OSC withdrew the firefighters and closed WTD3. The vehicle deck drencher valve was closed, and the chief engineer, 2/E, extra 2/E, duty ETO and EOOW rushed to the emergency fire pump in the bow thruster compartment.

The emergency fire pump was not running. The 2/E opened its starter box and replaced a blown control fuse with a fuse taken from the adjacent emergency bilge pump starter box. This also blew when he attempted to restart the fire pump. The duty ETO climbed onto a set of guardrails next to the starter box, and used his screwdriver to push in the start control contactor **(Figure 8)**. The pump started and fire main pressure was re-established. The EOOW was sent to close the engine room fire main isolation valve while the chief engineer went to the *Hotfoam* room, and the 2/E checked the *Hi-fog* system. The extra 2/E and the duty ETO remained in the bow thruster space.

Figure 8



Emergency fire pump starter box and actions of the duty ETO

While the emergency fire pump was out of action, the OSC arranged for extra drums of foam concentrate to be delivered to the lower hold, and organised air bottle changes for his BA teams. Once the emergency fire pump had been restarted and water pressure restored to the fire main, WTD3 was re-opened and a BA team recommenced the attack on the fire from the lower hold.

At 1943, the chief engineer attempted to activate the *Hotfoam* system. He confirmed the system was running and that foam was entering the space. However, the OSC did not see foam entering the AER.

In the bow thruster space, the duty ETO continued to hold in the emergency fire pump contactor which was sparking and generating smoke within the starter box. The extra 2/E advised the C/O that the pump might only last a further 5 minutes. A second ETO was dispatched to the bow thruster space with an emergency repair bag to assist his colleague.

At 1949, a BA team advanced on the fire from WTD3. Approximately 3 minutes later, the 2/E reported the *Hi-fog* bottles were empty and was instructed by the C/O to return to the lower hold.

At 1958, power was lost to the emergency fire pump and an ETO, stationed in the emergency switchboard room, found that the pump's circuit breaker had tripped, and immediately reset it. The pump was restarted and fire main water pressure was restored. At this point, the master asked the coastguard to make a fire tug available and requested the assistance of the Maritime Incident Response Group (MIRG)[3]. He also ordered the vessel's port lifeboats to be lowered to the embarkation deck.

At 2004, the chief engineer reported the *Hotfoam* system had run out of foam. The OSC reported the fire appeared to be out, but there were signs it had travelled at deckhead level and spread to the funnel uptake area. Approximately 1 minute later, smoke detectors were activated in several passenger cabins in zone 2 on deck 8. The assembly station parties investigated and found smoke but no fires in the cabins.

At 2015, the OSC advised the C/O that the fire might have spread to the ECR and switchboard rooms on deck 2 above the seat of the fire. The chief engineer went to the ECR via the accommodation stairwell **(Figure 7)** to investigate. Four minutes later, he reported that there was no sign of fire. At 2024, the OSC also reported that there was no sign of fire in the AER.

As the fire appeared to be out, the accommodation fire doors were reset to allow smoke to clear from the cabin areas on deck 8. The smoke in the AER began to clear, but the C/O decided not to allow the fire dampers for the engine room to be opened because of the risk of the fire re-igniting.

The MCA's emergency towing vessel, *Anglian Princess*, arrived on the scene at 2031.

1.2.2 Fire spread and re-ignition

The chief engineer took two firefighters wearing BA from the lower hold and instructed them to search the switchboard rooms, lobby area and compartments above the AER on deck 2. At about 2037, they found a fire in the corridor

[3] The Maritime and Coastguard Agency's Maritime Incident Response Group (MIRG) consists of specially trained firefighters from 15 Fire and Rescue Services around the UK's coast. It provides assistance with fires, chemical spillages and industrial accidents to ships and structures at sea.

outside the ECR's port aft door. The chief engineer set up a control point on deck 3 next to the stairwell door **(Figure 7)** and rigged hoses. Firefighters with BA were sent to assist from the emergency response party.

At 2048, sparks were seen falling from the funnel casing area in the AER. One minute later, a fire in the AER re-ignited about 5m from WTD3 and was immediately engaged by a BA team. The fire outside the ECR was also attacked.

At 2052, the emergency fire pump stopped again. It was soon restarted, but its unreliability resulted in the bridge team considering whether to request the transfer of a portable fire pump from *Anglian Princess*. The master consulted with the ship's designated person in Dublin before deciding against this option. By 2100, the fires in the AER and outside the ECR had been extinguished.

1.2.3 Arrival of the MIRG

At 2132, a 6-man reconnaissance team from the MIRG was winched onto *Oscar Wilde* from a search and rescue helicopter. The helicopter then returned to shore to collect equipment and additional firefighters. The MIRG team prepared its equipment on the open deck and undertook an initial incident assessment.

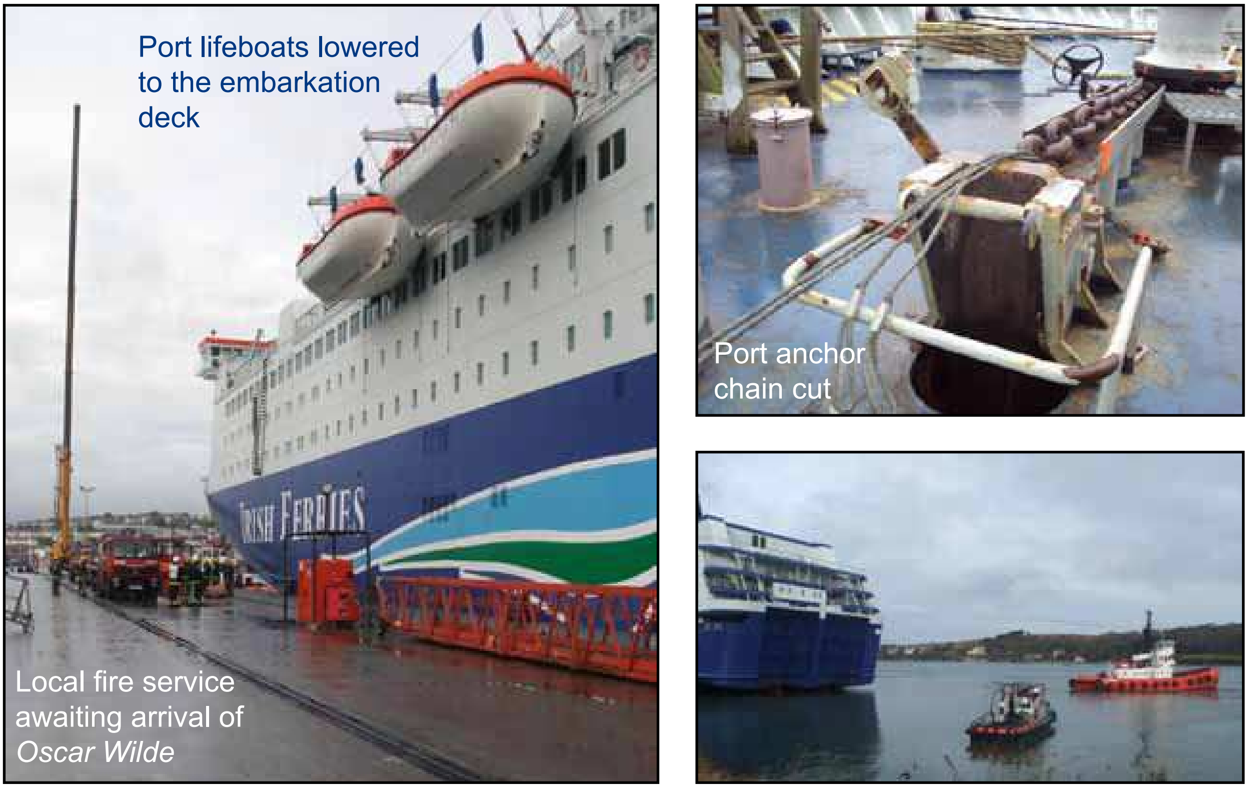
The smoke in the AER and ECR had started to clear, but the C/O ordered that nobody was to enter the AER without wearing BA and told the chief engineer to carry an emergency escape breathing device (EEBD) when inspecting the fire boundaries. At 2138, the chief engineer reported 'all fires are out' and the master ordered the bridge team to re-group and discuss all options before taking any further actions. He re-iterated that non-BA wearers were not to enter the AER until the MIRG team had inspected the space and had confirmed that there was no risk of re-ignition.

At 2202, the MIRG team leader arrived on the bridge and was briefed on the circumstances of the fire. He explained that his firefighters would be arriving on the next helicopter and that his priority was to carry out a thorough assessment of the current situation and monitor the fire boundaries. When the MIRG team arrived in the lower hold, several of the ship's crew and the technical superintendent were already inside the AER but were not wearing BA. The compartment contained light smoke and the MIRG team assessed it was safe for them to also enter without BA to conduct a thermal survey. Approximately 15 minutes later, the second MIRG team arrived on board.

At about 2250, the machinery spaces' fire dampers were opened to assist the removal of smoke from the funnel uptake areas. At 2257 the MIRG team leader confirmed that the fires were out, and recommended the AER be returned to the engineers for damage assessment. The ship's crew were stood down from their general emergency stations and a fire watch was maintained overnight in the machinery spaces.

Due to the extent of the fire damage it was not possible to restore main electrical power to the vessel. Therefore, the anchor could not be recovered. At 0555 the following morning, the port anchor chain was cut to allow the vessel to be towed back to Falmouth **(Figure 9)**.

Figure 9



Oscar Wilde towed back to the Falmouth ship repair yard

1.3 BACKGROUND INFORMATION

1.3.1 Ownership and operation

Oscar Wilde was one of four passenger ships owned by Irish Continental Line (Irish Ferries) and managed by Dobson Fleet Management Ltd. (DFM). The ferry had been operating between Ireland, the UK, and France since 2008, when the vessel was bought from its original owners by Irish Ferries. The DFM operations manager, and designated person, was located in Irish Ferries' head office in Dublin, Ireland.

1.3.2 Persons on board

On board *Oscar Wilde* were 94 crew, 15 commercial contractors and 4 shore-based operations staff. The master was Irish, the chief engineer, C/O and 3 pursers were British and the remainder of the crew were made up of Polish, Estonian, Latvian, Lithuanian and Romanian nationals.

1.3.3 Docking period

Oscar Wilde had been in the Falmouth Ship Repair yard for her annual dry-docking, and passenger certificate renewals. In addition to the normal survey and certification requirements, the vessel also changed classification societies from Det Norske Veritas (DNV) to Lloyd's Register (LR). The docking period was originally scheduled to last 10 days but, due to the size of the work package, it was shortened by 2 days and an additional crossing between Rosslare and Cherbourg was programmed for 3 February 2010.

1.4 THE AUXILIARY ENGINE ROOM

The AER was a category A machinery space[4] and was located forward of the main engine room. It contained four diesel-powered alternators (auxiliary engines) which produced the vessel's 440V electrical power supply. No.1 and No.2 auxiliary engines were located on the port side of deck 1, and No.3 and No.4 auxiliary engines were on the starboard side **(Figure 1)**. The auxiliary engine fuel oil supply module was positioned inboard of No.3 auxiliary engine directly below the ECR. The sewage collection and treatment compartments on the port and starboard sides of deck 2 formed part of the AER space.

1.5 POST-FIRE EXAMINATION

Post-fire examinations identified three seats of fire. These were:

- on the outboard side of the auxiliary engine fuel module **(Figure 10)**
- in the AER bilge adjacent to WTD2 **(Figure 10)**
- in the corridor between the port aft ECR door and deck 2 lobby area **(Figure 11)**.

The heat damage and burn patterns on the outboard side of the fuel module indicated that the seat of the fire was low down but had spread to the electrical cables above. Damaged cables included the start/stop control cables for the emergency fire pump. No.3 auxiliary engine was not significantly affected by the heat radiated from the fuel module fire. The greatest damage at deckhead level was evident between the fuel module and the AER ventilation duct openings and starboard forward casing uptake area **(Figure 12)**.

The heat from the bilge fires close to the aft AER bulkhead caused the casing of the manual break-glass fire alarm call point next to WTD2 to melt and the paint on the bulkhead in the main engine room to blister **(Figure 13)**. The manual call point alarmed about 5 minutes after the initial flame sensor had activated.

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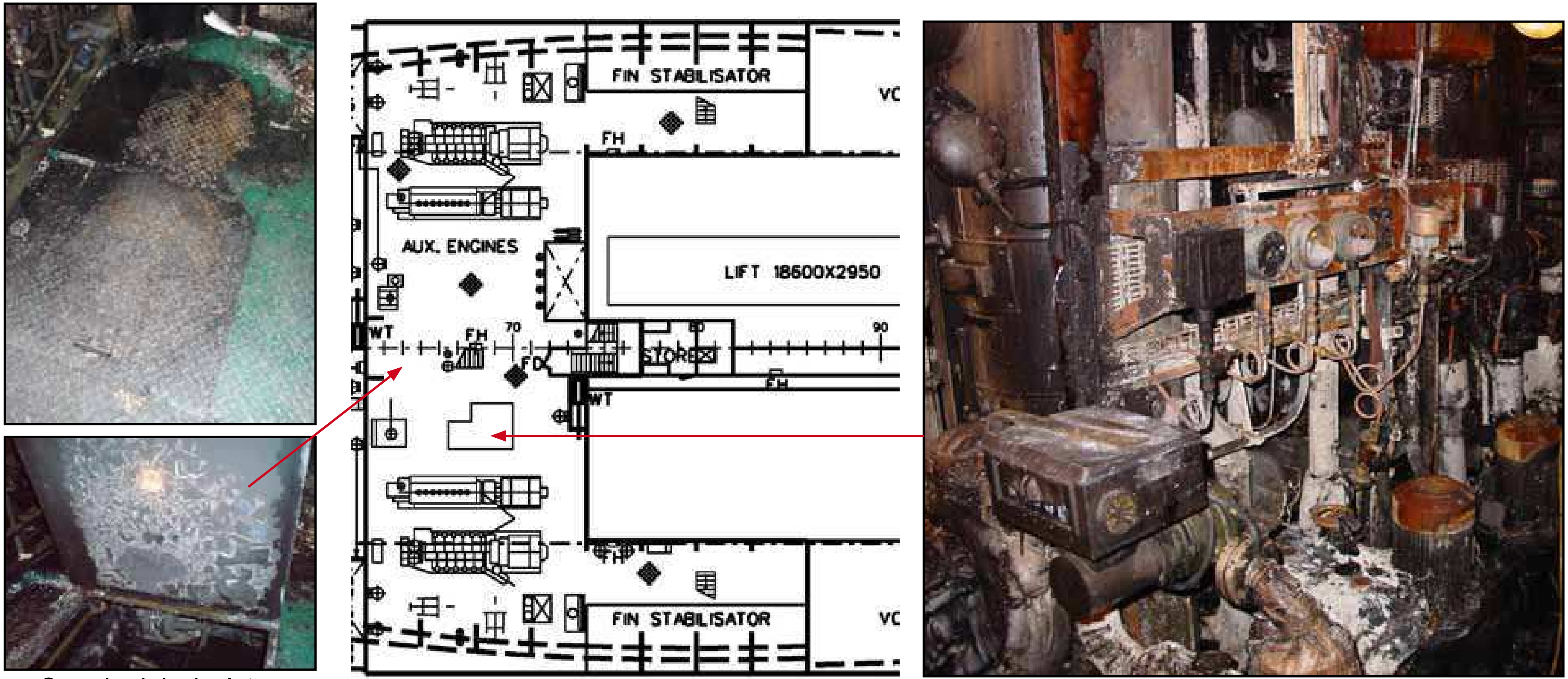
4 Category A machinery space – a machinery space which contains (a) internal combustion type machinery used either for main propulsion purposes, or for other purposes where such machinery has in the aggregate a total power output of not less than 375kW, or (b) any oil-fired boiler or oil-fired unit; and any trunk to such a space.

Figure 10



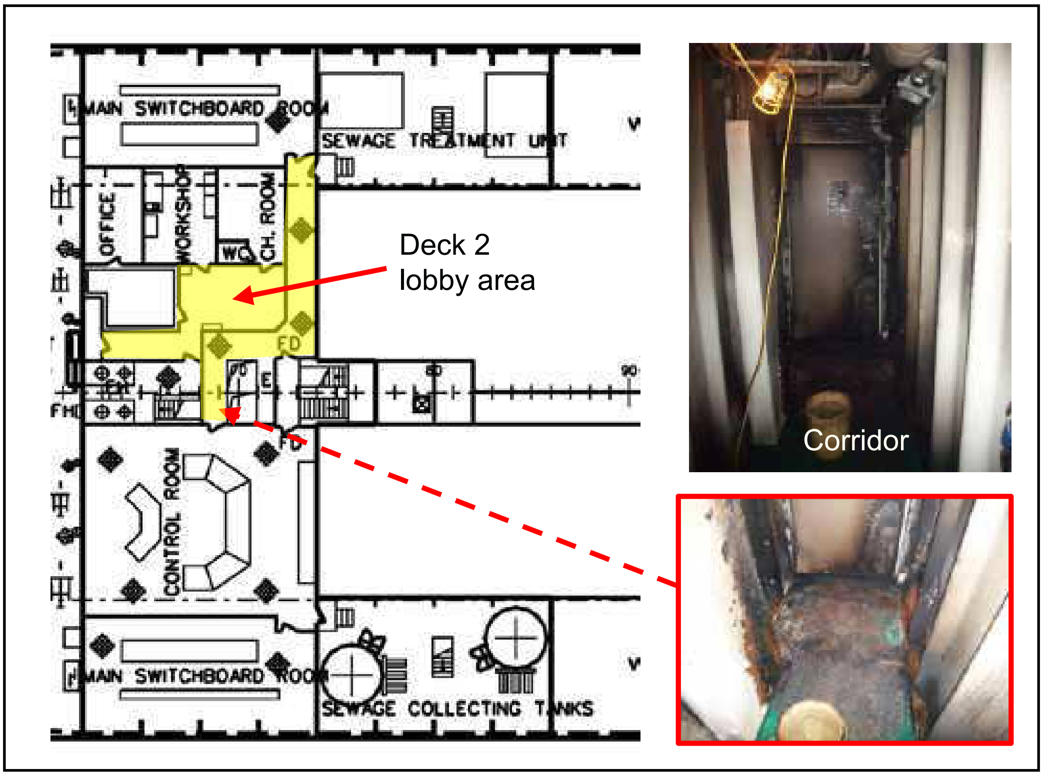
Scorched deck plates from localised bilge fires

Auxiliary engine room deck 1 layout

Outboard side of the auxiliary engines' fuel oil module

Seats of fires in the auxiliary engine room

Figure 11

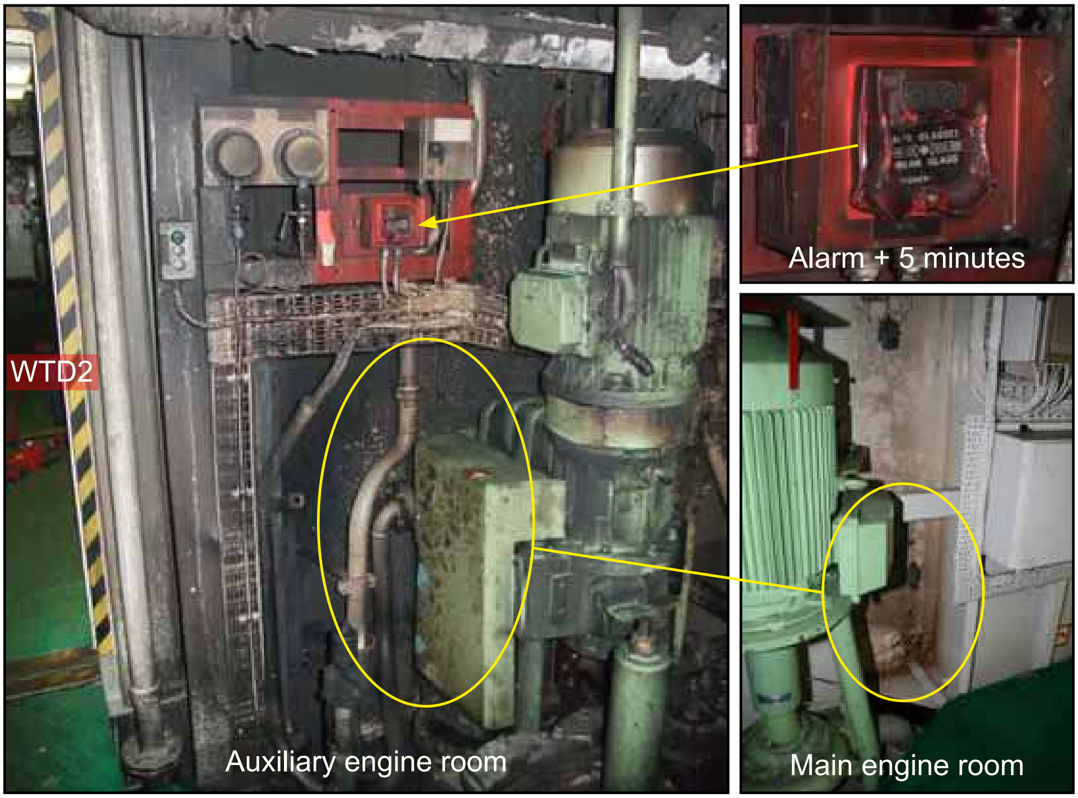


Seat of fire in corridor leading to the engine control room

Figure 12

Fire damage to deckhead cables in the auxiliary engine room

Figure 13



Damage caused by bilge fire

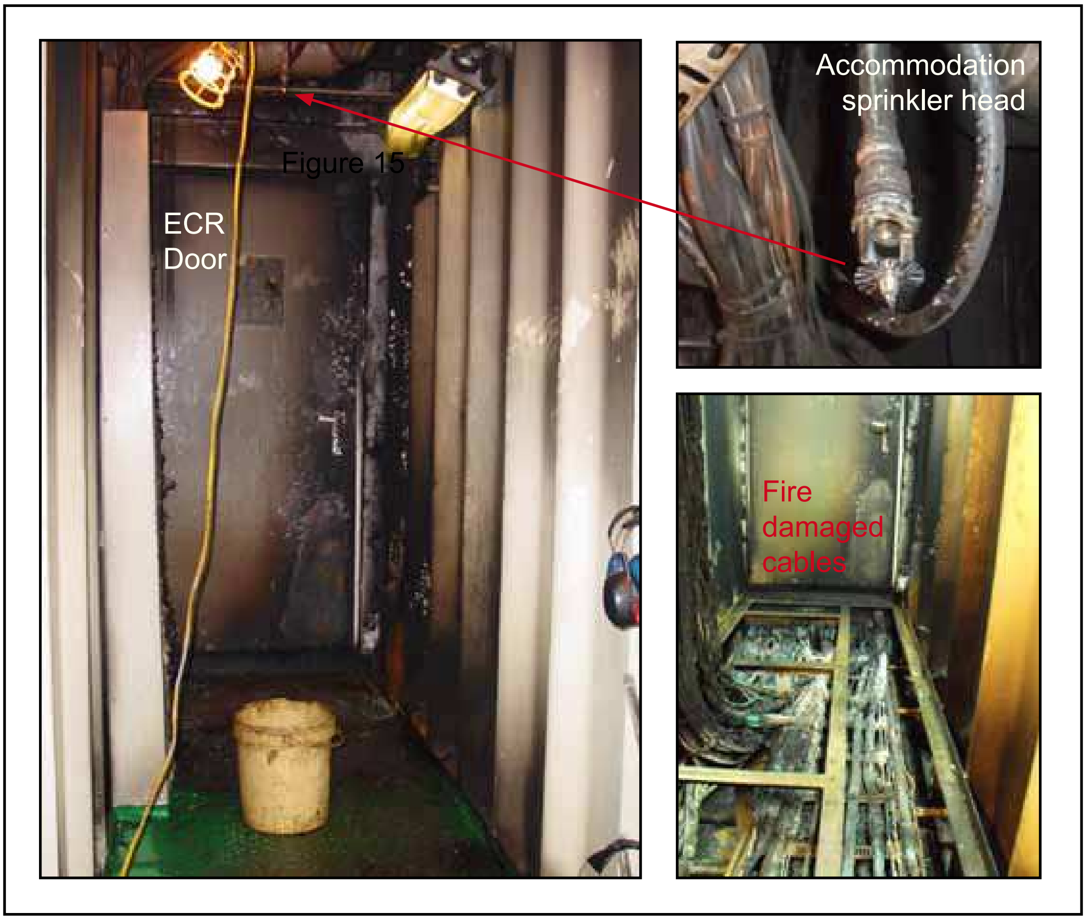
The seat of the fire in the corridor outside the ECR was located at deck level on a cable tray that ran under a section of raised floor plates. The heat from the flames burnt paint on the bulkhead and ECR door, melted a light fitting and burst a sprinkler head bulb **(Figure 14)**.

Heat damage was limited to the AER and the lobby and corridor area outside the ECR on deck 2. Smoke damage was found in the main engine room, the AER funnel casing, the ECR, the workshop and office areas outside the ECR, the main switchboard rooms, the boiler room, and zone 2 passenger accommodation areas on deck 8.

The AER ventilation dampers were found to be in the closed position **(Figure 15)**. However, the exhaust louvres on the back of the funnel did not form a gas-tight seal when closed.

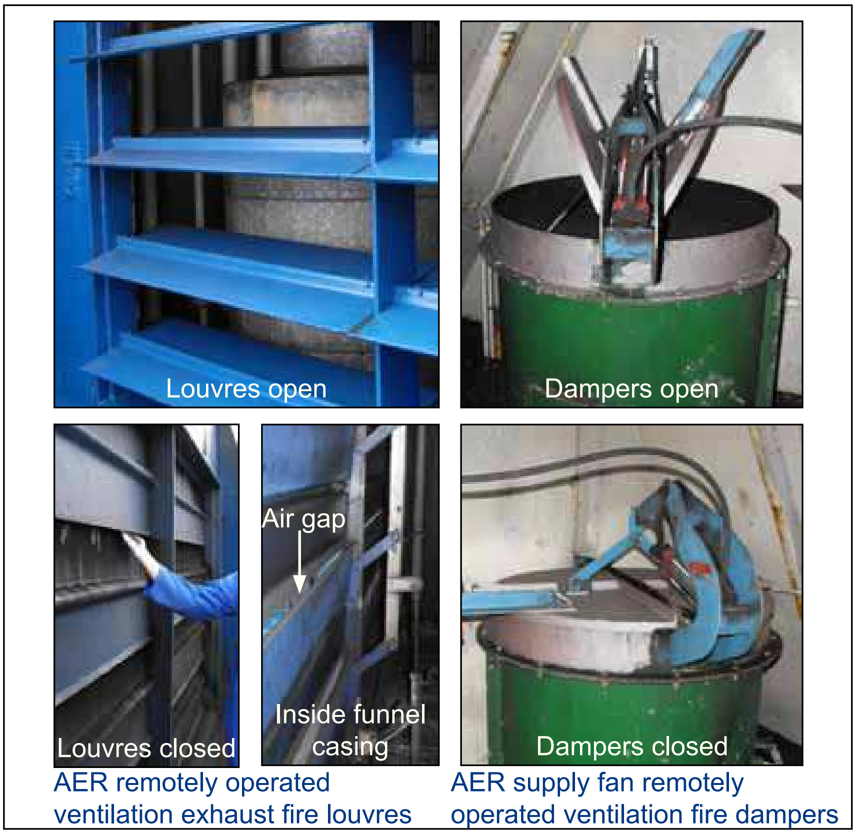
Several deck penetrations between the AER and ECR had not been properly packed and did not provide a gas-tight seal **(Figure 16)**. The ventilation supply and exhaust system for the ECR and adjacent compartments was common to the zone 2 passenger accommodation spaces on deck 8. The crew was unfamiliar with the ventilation system, and the vent trunk fire dampers between these areas had not been closed. The doors to the switchboard rooms and other compartments on deck 2 were secured in the open position.

Figure 14



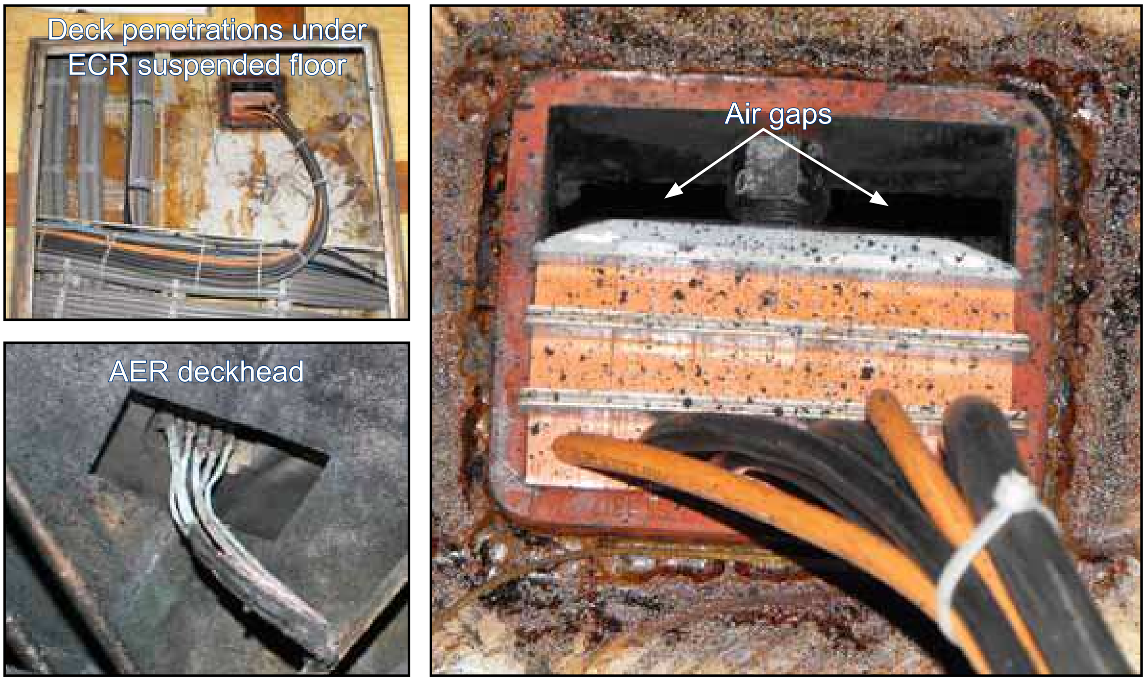
Fire damage on deck 2 outside the engine control room

Figure 15



AER ventilation system fire dampers

Figure 16



Engine control room deck penetrations

1.6 AUXILIARY ENGINE FUEL OIL SYSTEM

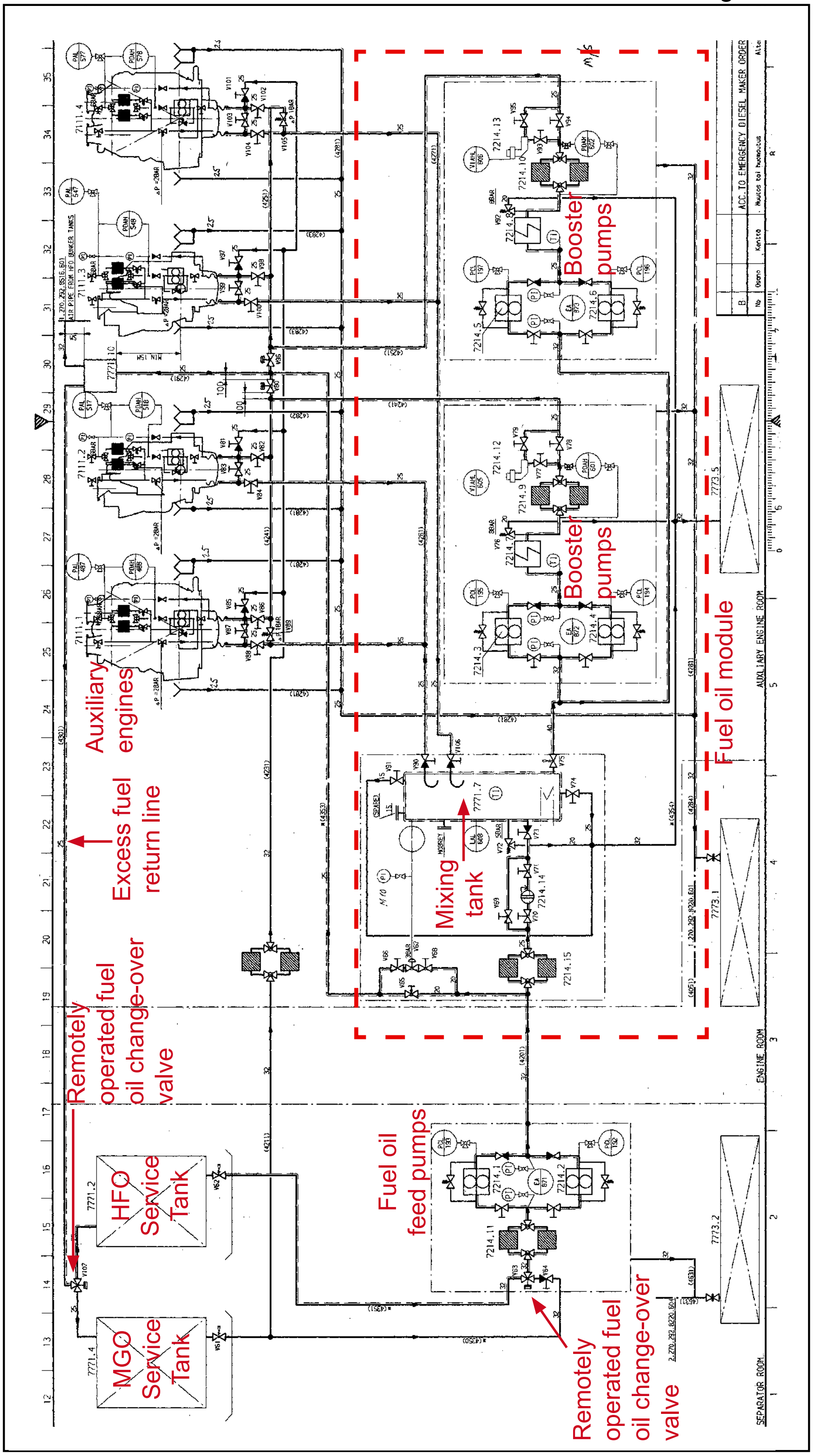
The fuel system was designed and manufactured by Wartsila at its Turku shipyard in Finland. It consisted of an HFO service tank, an MGO service tank, two feed pumps, a fuel module, and two remotely operated change-over valves **(Figure 17)**. The module housed a 100 litre fuel oil mixing tank, a flow meter, an excess pressure regulating valve, four booster pumps, two pre-heaters, two viscometers and six filters. After the mixing tank, the system split into two sections; the port section served No.1 and No.2 auxiliary engines and the starboard section served No.3 and No.4 auxiliary engines.

The feed pumps transferred the oil from the service tanks, through the flowmeter, to the mixing tank. The booster pumps transferred oil from the mixing tank to the engines via the pre-heaters and viscometers. Engine-driven fuel pumps boosted the individual engines' fuel supply pressure to between 6 and 7bar. The excess fuel from the engines was returned to the mixing tank. The excess pressure regulating valve was designed to operate at a pressure range between 2 and 5bar. It maintained the pressure in the mixing tank at 3bar by returning any excess fuel supplied by the feed pumps to the service tanks.

A 50 litre black-out tank, fitted in the service tank return line, was designed to provide a head of fuel sufficient to restart an auxiliary engine following the total loss of electrical power. The system could also be configured to bypass the fuel module and run the engines on MGO fed directly from the service tank under gravity.

The HFO used on board *Oscar Wilde* had a viscosity of 10 – 55mm²/s at 100ºC and a flashpoint of 62ºC. The MGO had a viscosity of 2.9mm²/s at 40ºC, a flashpoint of 64ºC and a sulphur content of 0.078%. In order to maintain the HFO at the required viscosity it was heated by steam to a temperature of 150ºC.

Figure 17



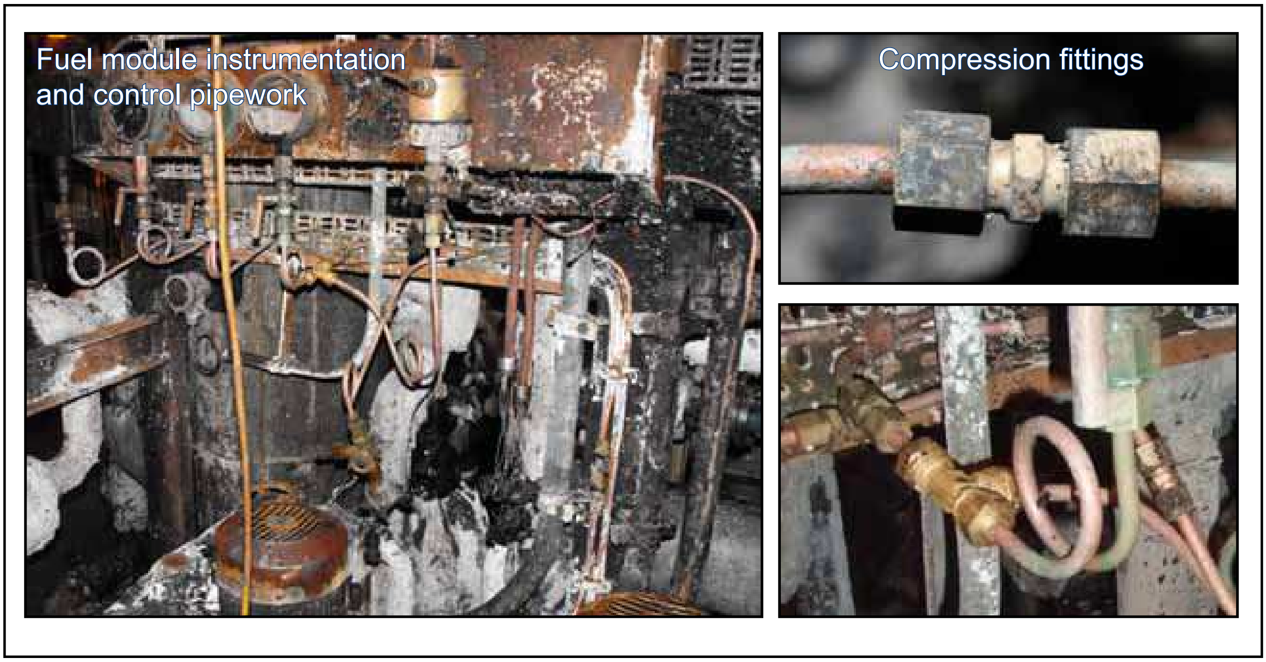
Auxiliary engine fuel oil system

1.7 POST-FIRE EXAMINATION OF THE AUXILIARY ENGINE FUEL MODULE

Examination of the fuel module, after its lagging had been removed and the affected area had been cleaned, failed to identify a definite fuel oil leakage point. However, despite the integrity of the pressurised system initially appearing to be intact, three potential points of failure were identified and examined; the module's instrumentation and control pipework and associated compression fittings; a severely heat damaged pressure switch; and the excess pressure regulating valve.

Copper pipework was used extensively on both the auxiliary engine and main engine fuel modules to connect the pressure gauges and sensors to the main fuel oil circuit **(Figure 18)**. The copper pipes were interconnected by compression fittings and, although many of the fittings were found to be loose, none of the connections appeared to have failed and no breaks or fractures were identified.

Figure 18

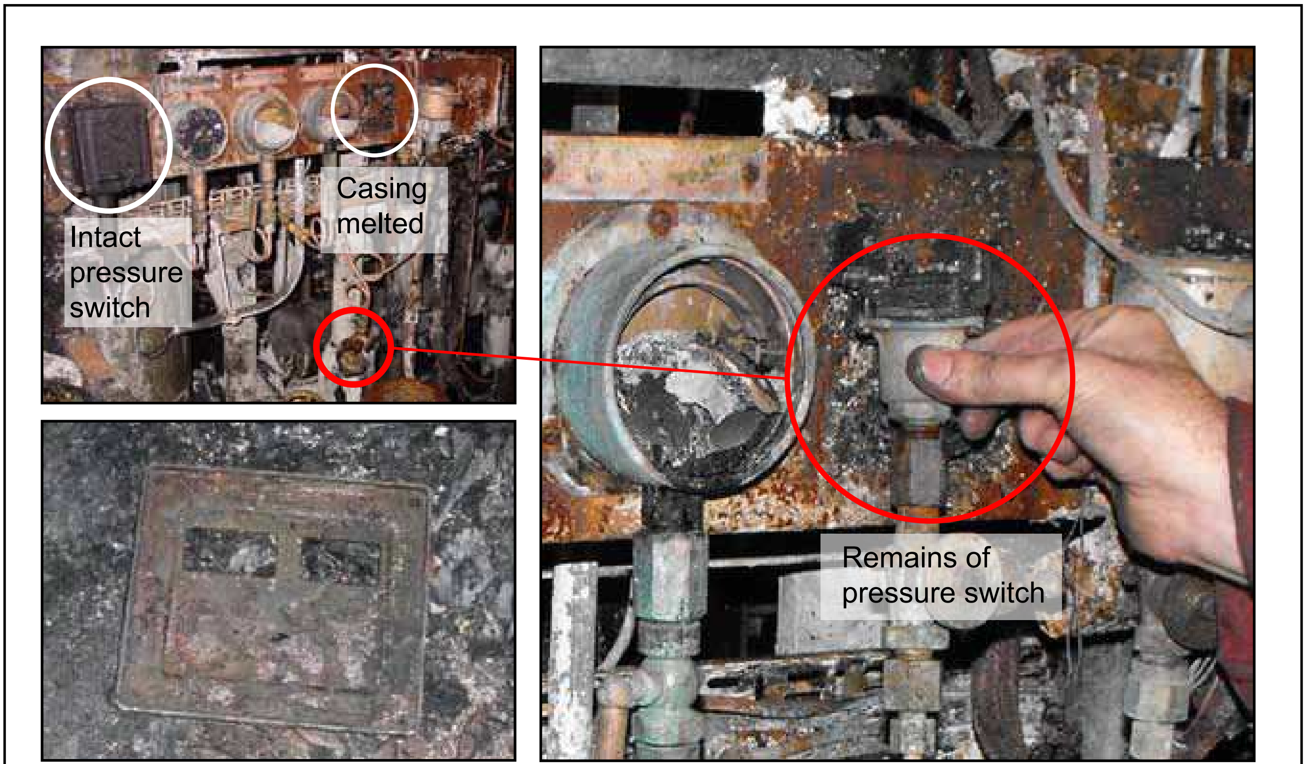


Fuel module copper pipework and compression fittings

One of the module's pressure switches had been exposed to intense localised heat. Its metal alloy casing had completely melted and its steel casing cover was found on the deck plates close to No.3 auxiliary engine **(Figure 19)**. The remains of the pressure switch were removed and closer examination revealed its pressure bellows to be intact.

The excess pressure regulating valve's actuator was positioned close to the seat of the fire. The valve was removed and its actuator inspected **(Figure 20)**. The rubber diaphragm was in poor condition and had suffered heat damage.

Figure 19



Pressure switch casing cover found on deck plates

Fire damaged pressure switch

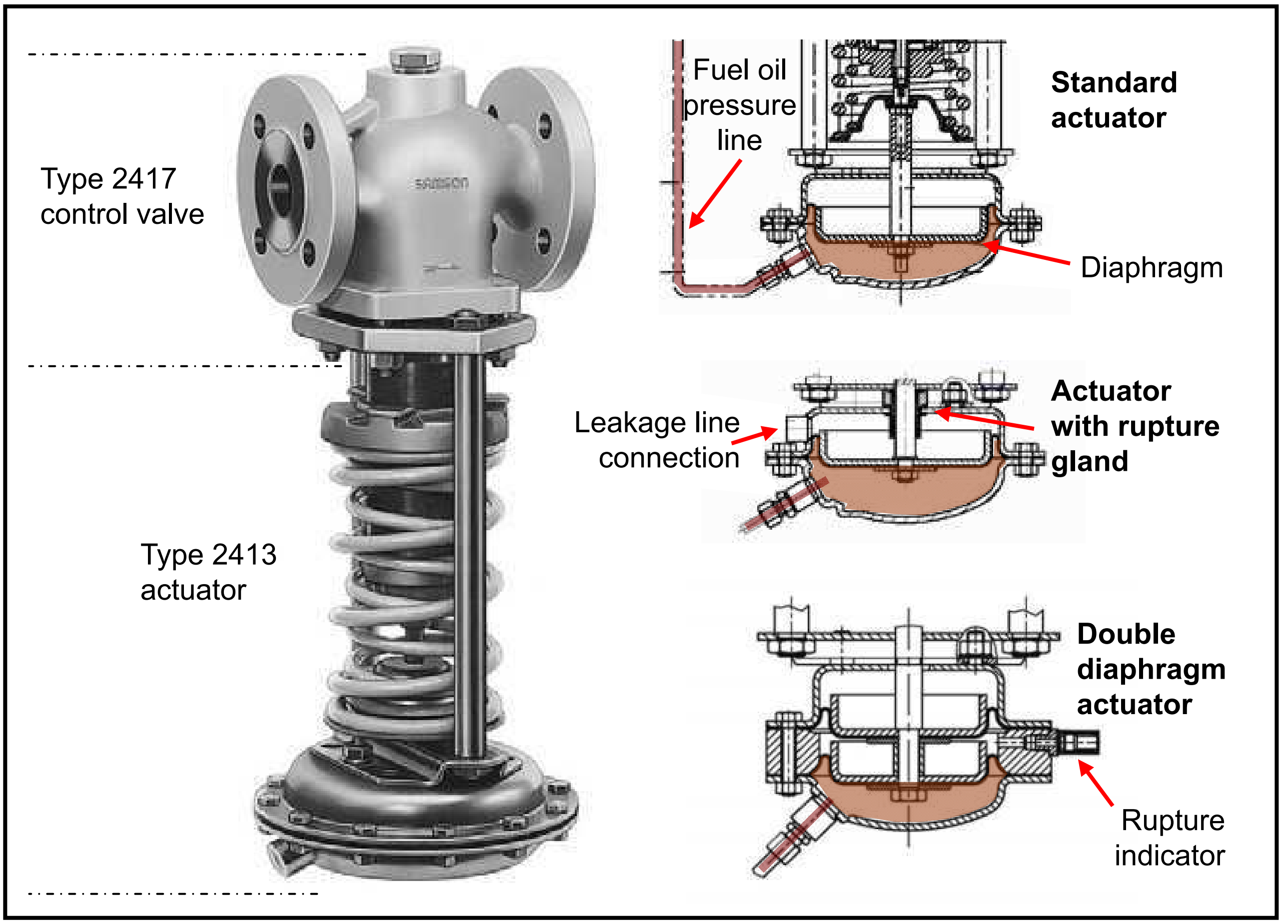
Figure 20

Location of the fuel system's excess pressure regulating valve

1.8 EXCESS PRESSURE REGULATING VALVE

The excess pressure regulating valve fitted to the auxiliary engines' fuel module was a type 41-73 self-operated back pressure regulating valve manufactured by Samson Controls Ltd **(Annex A)**. The regulating valve comprised two main components: a type 2417 control valve and a type 2413 actuator **(Figure 21)**.

Figure 21



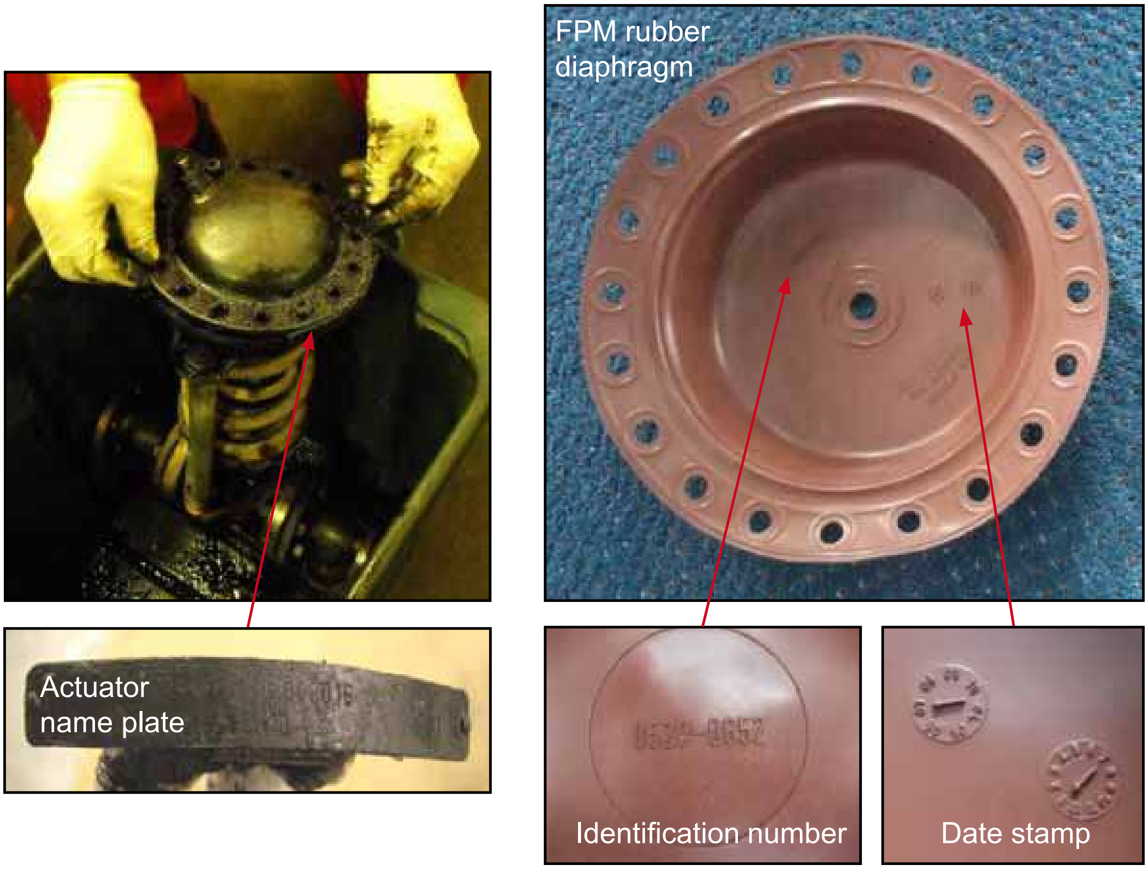
Samson Type 41-73 self-operated back pressure regulating valve

The type 41-73 regulating valve is commonly used to control pressures in systems containing water, steam, oils and gases. The valve can be used to operate over many pressure ranges. Samson produces several actuator sizes and optional safety features, including actuator diaphragm leakage glands, leakage lines, rupture indicators and double diaphragm systems **(Figure 21)**. The standard type 2413 actuator has a single EPDM[5] rubber diaphragm and no rupture protection. Samson also provides an FPM[6] rubber diaphragm for use with oils. Details relating to the valve actuator design specification are provided on a brass tally plate and the diaphragm's date of manufacture can normally be found moulded on its surface **(Figure 22)**.

5 EPDM rubber (ethylene propylene diene monimer (M type)) is a type of synthetic rubber.

6 FPM rubber is a fluorocarbon rubber commonly referred to by the brand name *viton*.

Figure 22



Actuator name plate and diaphragm markings

The test report on the diaphragm removed from the valve actuator identified deterioration of the rubber and a tear in its main flex region **(Annex B)**. This damage was remote from the fire damage evident at its outer edge. The diaphragm was made from EPDM rubber and was therefore not suitable for use in fuel oil systems. The actuator had a diaphragm area reducing plate which increased the valves' operating pressure range to 4.5 to 10bar **(Figure 23)**. The actuators fitted to the fuel modules on board *Oscar Wilde* were not fitted with any optional safety features.

Following the examination of damage to the diaphragm from the excess pressure regulating valve, similar valves fitted to the vessel's two main engine fuel modules were replaced. The diaphragms in the main engine valves were also made from EPDM rubber and found to be severely degraded in the main flex area **(Figure 24)**. The replacement valves were fitted with FPM diaphragms, diaphragm leakage glands and rupture indicators.

Figure 23

Condition of the auxiliary engines' excess fuel pressure regulating valve diaphragm

Figure 24

Diaphragm removed from the port main engine fuel system

Diaphragm removed from the starboard main engine fuel system

Main engine actuator diaphragms

The information on the actuator tally plates corresponded with that given for EPDM diaphragms and, in the case of the auxiliary engine system, the higher pressure range. No date stamps were found on any of the diaphragms. Neither Irish Ferries, nor the vessel's previous owners, had any record of the actuators being replaced or overhauled. Samson advised that the absence of date stamps on the diaphragms indicated that they were likely to be about 10 years old.

Although the Samson type 41-73 regulating valve was included in the original fuel module design, Wartsila was unable to establish the original actuator specification or determine the number of similar fuel modules manufactured at its shipyard. Furthermore, Samson was unable to ascertain how many of its valves had been supplied to Wartsila, or estimate how many are currently in use on board ships.

1.9 FUEL OIL CHANGE-OVER PROCEDURE

To comply with the European Union's (EU) directive[7] on low sulphur fuel, *Oscar Wilde* had to run her auxiliary engines and boilers on fuel oil with a maximum sulphur content of 0.1% (by mass) while *at berth*[8] in EU ports. The directive, which came into force on 1 January 2010, required the ship to change over from HFO (residual fuel) to low sulphur MGO (distillate fuel) as soon as possible after arrival *at berth,* and change back as late as possible prior to departure. The vessel's procedures **(Annex C)** required the engineers to change to MGO when the master had finished with the engines after berthing, and return to HFO 90 minutes before the scheduled departure time.

The fuel oil change-over procedure developed by Wartsila required the operator to switch the three-way fuel oil supply and return valves to the appropriate service tanks, and to closely control and monitor the rate of fuel oil temperature and viscosity change to avoid thermal shock. When changing from a residual fuel to a distillate fuel, it is common industry practice to switch the system supply to the higher grade fuel and then allow sufficient time for the residual fuel in the return line(s) to be flushed through before changing over the return valve(s). This prevents the low sulphur fuel service tank being contaminated by any residual HFO. When changing back to HFO there is no need to flush the return line and therefore both the supply and return line valves can be switched at the same time.

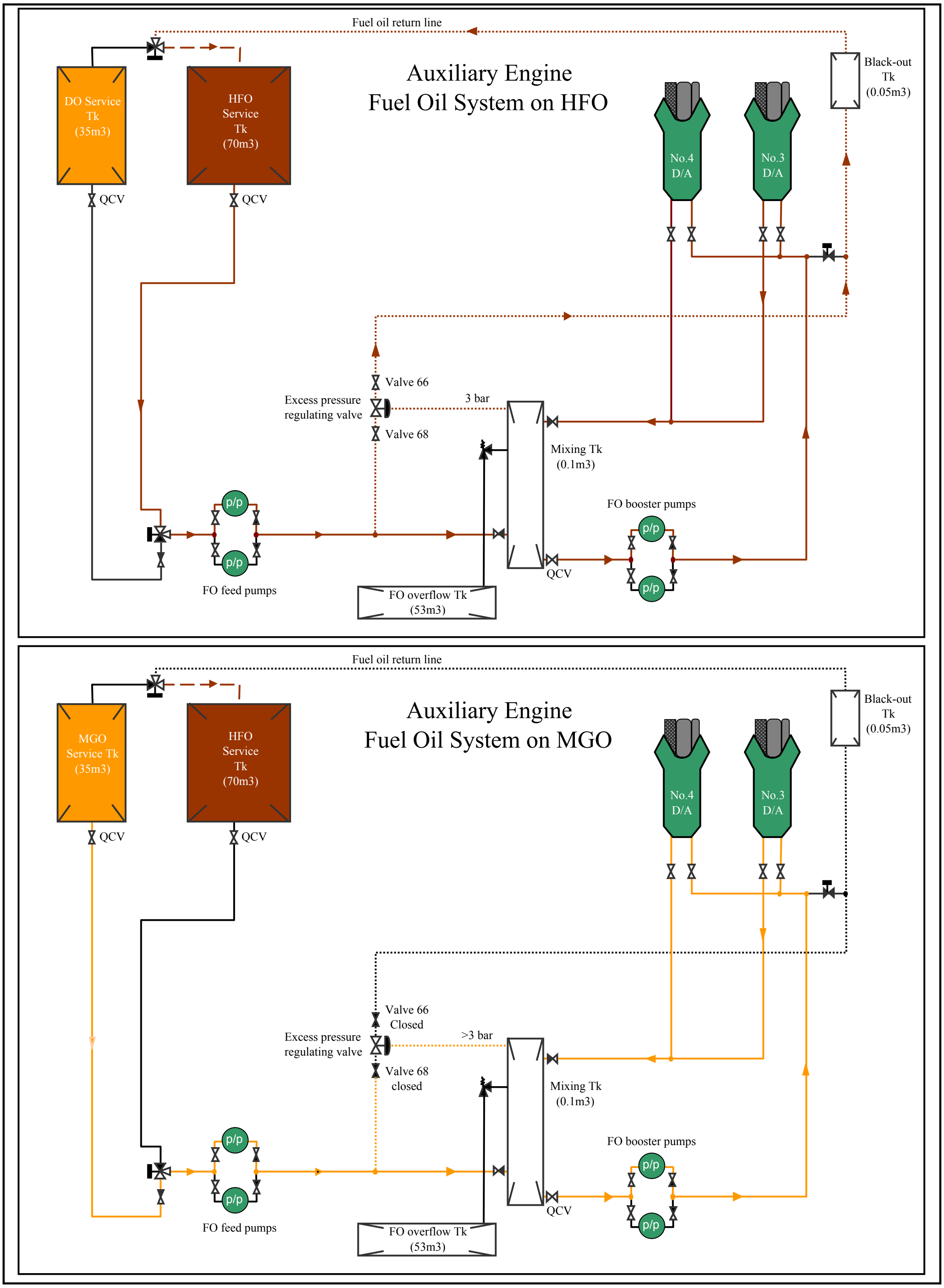
The change-over procedure adopted by DFM differed to the procedure developed by Wartsila. When using MGO, the DFM procedure required the crew to close valves V66 and V68 **(Figure 25)** in the AER in order to isolate the excess pressure regulating valve and prevent fuel returning to the service tanks. The regulating valve control line was not isolated and its actuator remained

[7] EU Directive 2005/33/EC, Amendment to the EU Low Sulphur Directive, Article 4b maximum sulphur content of marine fuels used by inland waterway vessels and ships at berth in community ports.

[8] "at berth" – this covers ships in EU ports which are secured at anchor, on moorings or alongside irrespective of whether they are working cargo or not.

open to the mixing tank. When the procedure was first introduced the system pressure increased sufficiently to cause the mixing tank relief valve to lift. To prevent this occurrence, the ship's engineers reduced the feed pumps' relief valve pressure settings.

Figure 25



Simplified illustration of the auxiliary engines' fuel oil system

Throughout the day prior to sailing from Falmouth, the ship's engineers had experienced problems maintaining the required pressure in the auxiliary engine fuel system. The succession of low pressure alarms led the chief engineer to start the second fuel oil feed pump and instruct the EOOW to abort the initial attempt to change over to HFO as the vessel was manoeuvring out of Falmouth harbour. Once the master had ordered "full away on passage", the chief engineer changed over to HFO by operating the three-way supply and return valves remotely in the ECR; he was unaware that the EOOW had closed the manually-operated valves V66 and V68, and therefore did not open them in accordance with the vessel's operating procedure.

Low sulphur marine distillates do not require to be heated, and therefore the system temperature alters significantly during each change-over. If this process is not monitored and controlled effectively, mechanical damage due to thermal shock can result. Other potential problems with low sulphur fuels include:

- poor lubricating characteristics
- undesirable additives or blend components
- a cleaning action or searching nature which can lead to clogging and increased leakage.

Certain additives found in low viscosity marine fuels can aggressively attack and break down rubber-based products.

Sulphur emissions requirements similar to those introduced in the EU came into force in California, USA, in July 2009. Anecdotal evidence provided by the San Francisco Bar Pilots indicates its implementation led to a marked increase in engine failures. LR has issued a technical bulletin[9] advising of the technical issues associated with the use of low sulphur fuels.

1.10 HEAT SOURCE

Following the fire, fuel oil residue was found on the outboard side of No.3 auxiliary engine **(Figure 26)**. SOLAS[10] requires surfaces with temperatures above 220ºC that might come into contact with fuel oil as a result of a system failure, to be properly insulated. Inspection of the auxiliary engine identified missing sections of exhaust lagging, a loose exhaust manifold heat shield and several missing indicator cock heat shields.

9 FOBAS Bulletin No.05/2009 – Use of low (0.10% m/m max) sulphur marine fuel oils.

10 SOLAS chapter II-2, part B, regulation 4, 2.2.6 Protection of high-temperature surfaces.

Figure 26

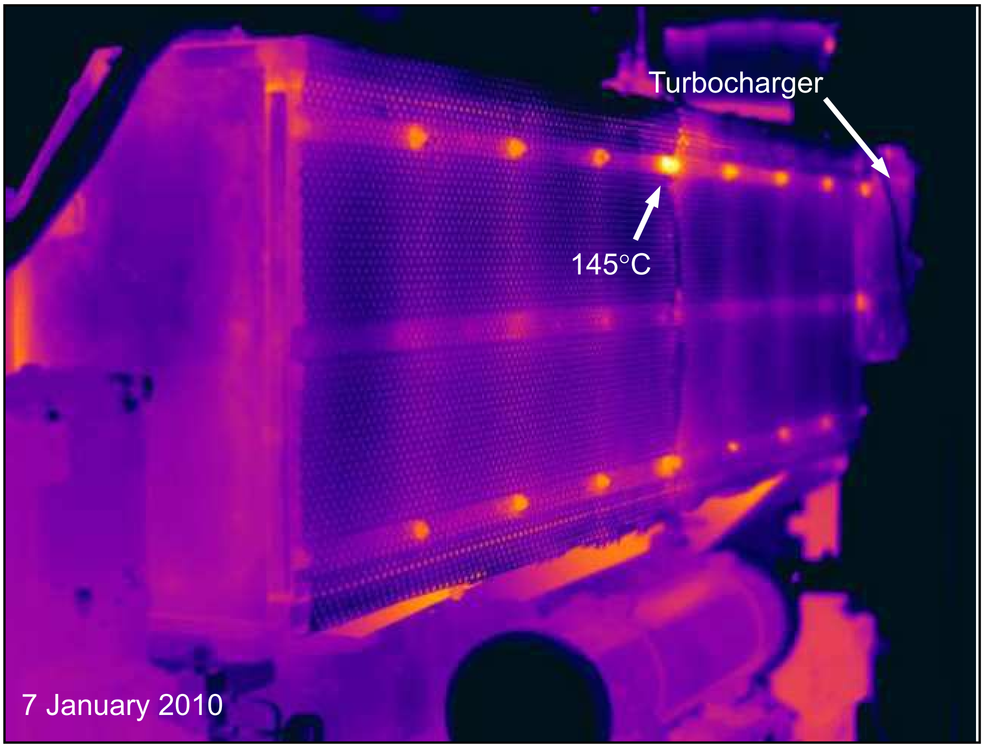
Exhaust manifold shielding and turbocharger lagging

Fuel oil residue on cylinder head casing

Fuel oil residue on number three auxiliary engine

A thermal survey of the ship's electrical distribution system was carried out by a specialist contractor prior to the docking period. The main and auxiliary engines were not included in the work package but, at the request of the chief engineer, thermal images were taken of the auxiliary engine exhaust shields **(Figure 27)**. These images identified hot spots, but information relating to the loading on the engines at the time of the survey was not available and no images were taken of the turbocharger or the outboard side of the engine. Work was carried out on the main and auxiliary engines during the docking period that would have required the removal of lagging and heat shields. However, a thermal survey was not carried out prior to the ship returning into service.

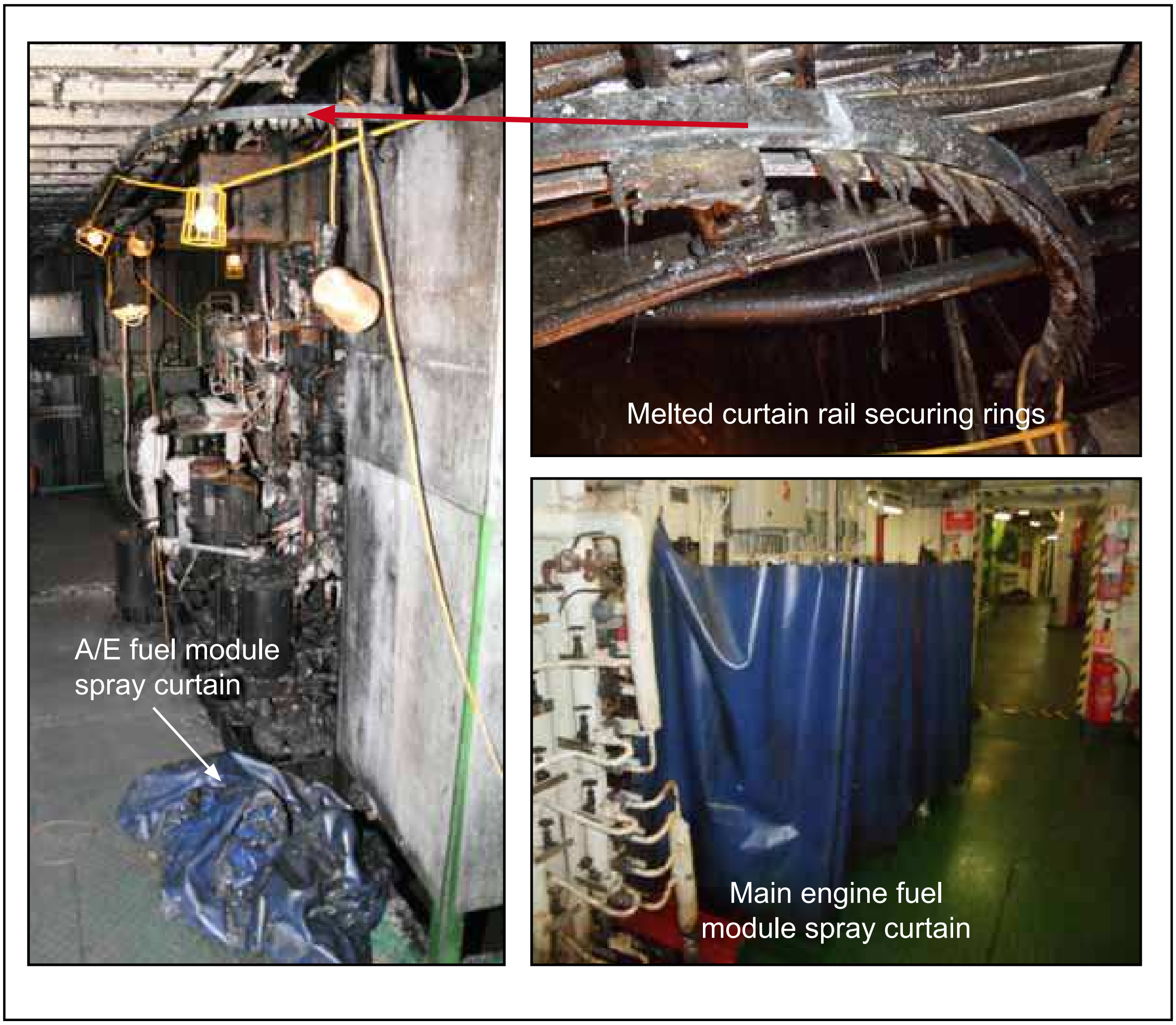
Figure 27



Thermal image taken of number three auxiliary engine exhaust manifold shielding prior to docking period

SOLAS also requires precautions to be taken to prevent any oil that escapes under pressure from any pump, filter or heater from coming into contact with heated surfaces. To help meet this requirement the vessel's previous owners had installed fuel spray curtains around the main and auxiliary engine fuel modules. The auxiliary engine fuel module's spray curtain securing rings had melted during the fire, and the curtain was found on the deck at the forward end of the module **(Figure 28)**.

Figure 28



Fuel spray curtain

1.11 CONTAINMENT OF FIRE

In order to contain a fire in its space of origin, SOLAS[11] states the following functional requirements shall be met:

- *the ship shall be subdivided by thermal and structural boundaries;*
- *thermal insulation of boundaries shall have due regard for the fire risk of the space and adjacent spaces; and*
- *the fire integrity of the divisions shall be maintained at openings and penetrations.*

Spaces are classified according to their fire risk in order to determine the appropriate fire integrity standards to be applied to the boundaries between adjacent spaces. *'A'* class divisions are formed by suitably stiffened steel (or equivalent material) bulkheads and decks that are capable of preventing the passage of smoke and flame to the end of a 1 hour standard fire test. They are also insulated such that the average temperature of the unexposed side will not increase more than 140ºC above the original temperature, and that the temperature at any one point will not increase more than 180ºC above the original temperature within the times listed below:

- class A-60 - 60 minutes
- class A-30 - 30 minutes
- class A-15 - 15 minutes
- class A-0 - 0 minutes

On passenger vessels that carry more than 36 passengers, the fire integrity of the decks of machinery control rooms, corridors, lobbies, and offices located above auxiliary machinery spaces containing internal combustion engines should be class A-60. In addition, the bulkheads between corridors/lobbies and these machinery spaces should be Class A-30. The spaces on board *Oscar Wilde* were classified in 1985 during the design and build process, and a set of plans was drawn up detailing the main fire zones, A and B class divisions and their insulation values **(Figure 29)**.

The deck between the ECR and the AER was provided with A-60 structural fire protection. The ECR was positioned directly above the seat of the fuel module fire, but minimal heat transfer was evident on its deck.

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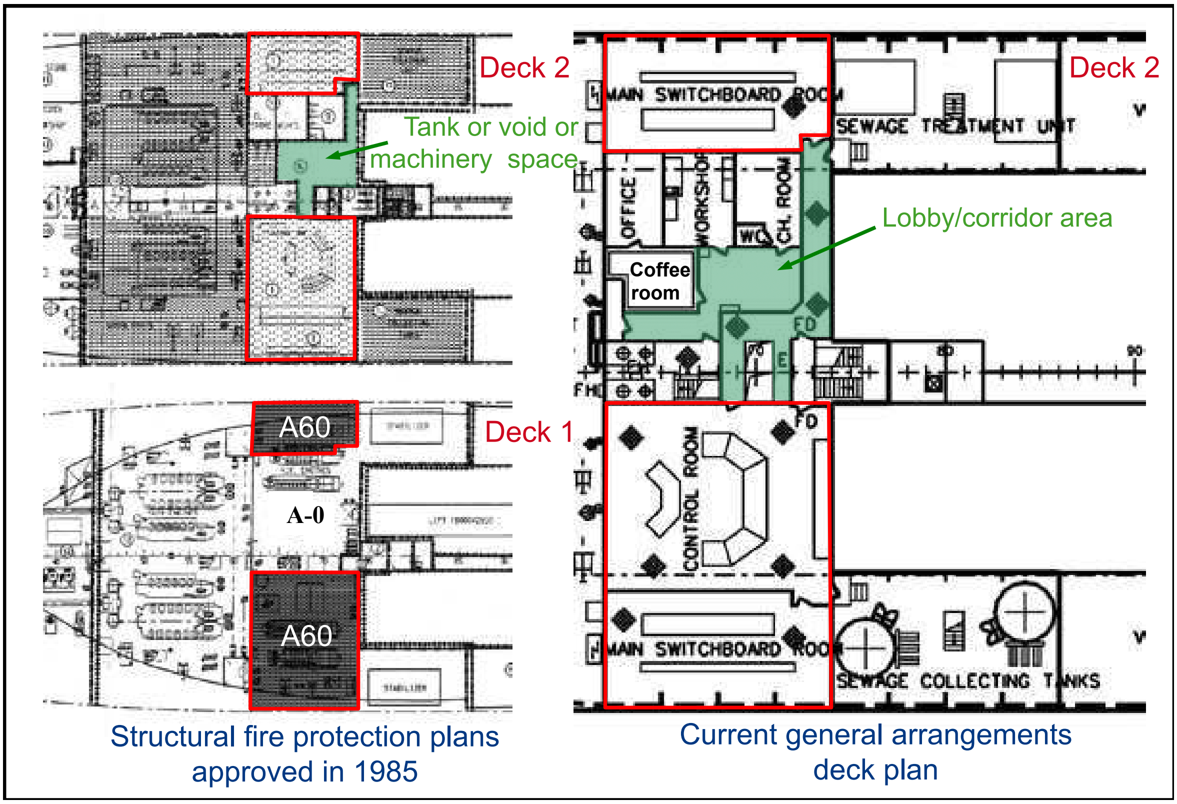
[11] SOLAS chapter II-2; part C – Construction: fire protection, fire detection and fire extinction; regulation 9 – Containment of fire.

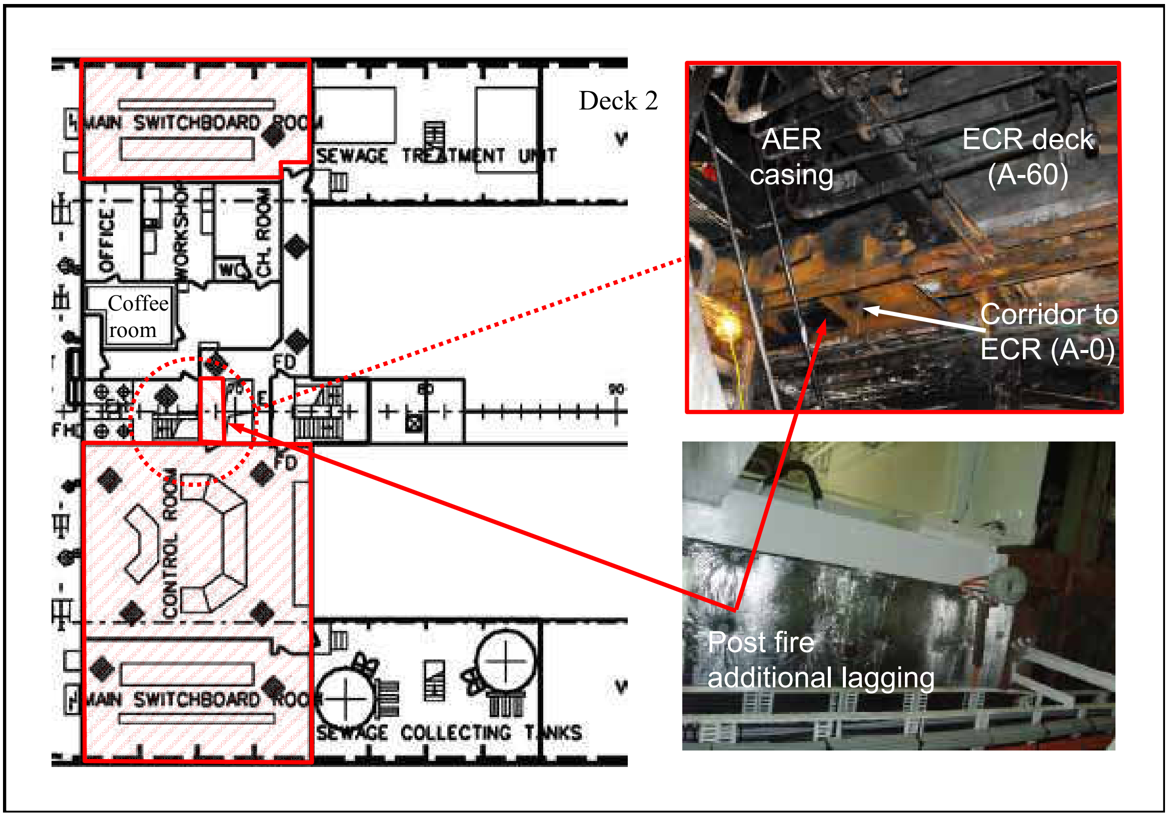
Figure 29



Structural fire protection plan

The lobby and corridor area on the port side of the ECR was classified as a *tank, void or auxiliary machinery space having little or no fire risk*. As such, the deck and bulkhead boundaries between it and the AER required A-0 structural fire protection. Therefore, no thermal insulation was provided. Some of the compartments had changed use over time; an electrical store had been converted to an office and a coffee room had been provided for the engineers **(Figure 29)**. The deck between these areas and the AER also had no thermal insulation. Following the fire, and prior to *Oscar Wilde* returning into service, Irish Ferries fitted an additional section of A60 insulation to the deck between the AER and the corridor area next to the ECR **(Figure 30)**. This additional insulation has subsequently been extended to cover the whole of the AER boundary.

Figure 30



Additional thermal protection fitted prior to the vessel returning to service

1.12 FIXED FIRE-EXTINGUISHING SYSTEMS

SOLAS[12] requires category A machinery spaces to be protected by fixed fire-extinguishing systems capable of suppressing and swiftly extinguishing a fire. To comply with SOLAS, the AER on board *Oscar Wilde* was protected by a high pressure water-mist local application fire-suppression system and a high-expansion foam total flooding fire-extinguishing system. The crew referred to the systems by their brand names, *Hi-fog* and *Hotfoam* respectively. In addition, the AER bilge was protected by a fixed low-expansion foam spreading system which had been supplied by the *Hi-fog* manufacturer and was inter-linked with the local application system. All three systems provided protection to several machinery compartments.

1.13 *HI-FOG* SYSTEM

1.13.1 Design

The *Hi-fog* local application fire-suppression system was manufactured by Marioff Oy. and was installed by the vessel's previous owners in 2000. It was type approved by DNV and was considered to comply with the principal requirements set out in Maritime Safety Committee circular (MSC/Circ) 913[13].

12 SOLAS chapter II-2; part C – Suppression of fire; regulation 10 – Fire-fighting.

13 MSC/Circ.913 – Guidelines for the approval of fixed water-based local application fire-fighting systems for use in category A machinery spaces.

The system was designed to suppress and contain fires on high risk, critical machinery, such as main and auxiliary engines, boiler fronts and pressurised fuel oil systems, without the need to shut down engines, evacuate personnel or seal the protected spaces.

Many of the crew on board *Oscar Wilde* thought that the system was designed to extinguish fires. However, the manufacturer's operating manual advised that the system should allow the crew time to prepare the compartment prior to operating the fixed total flooding system.

1.13.2 General description

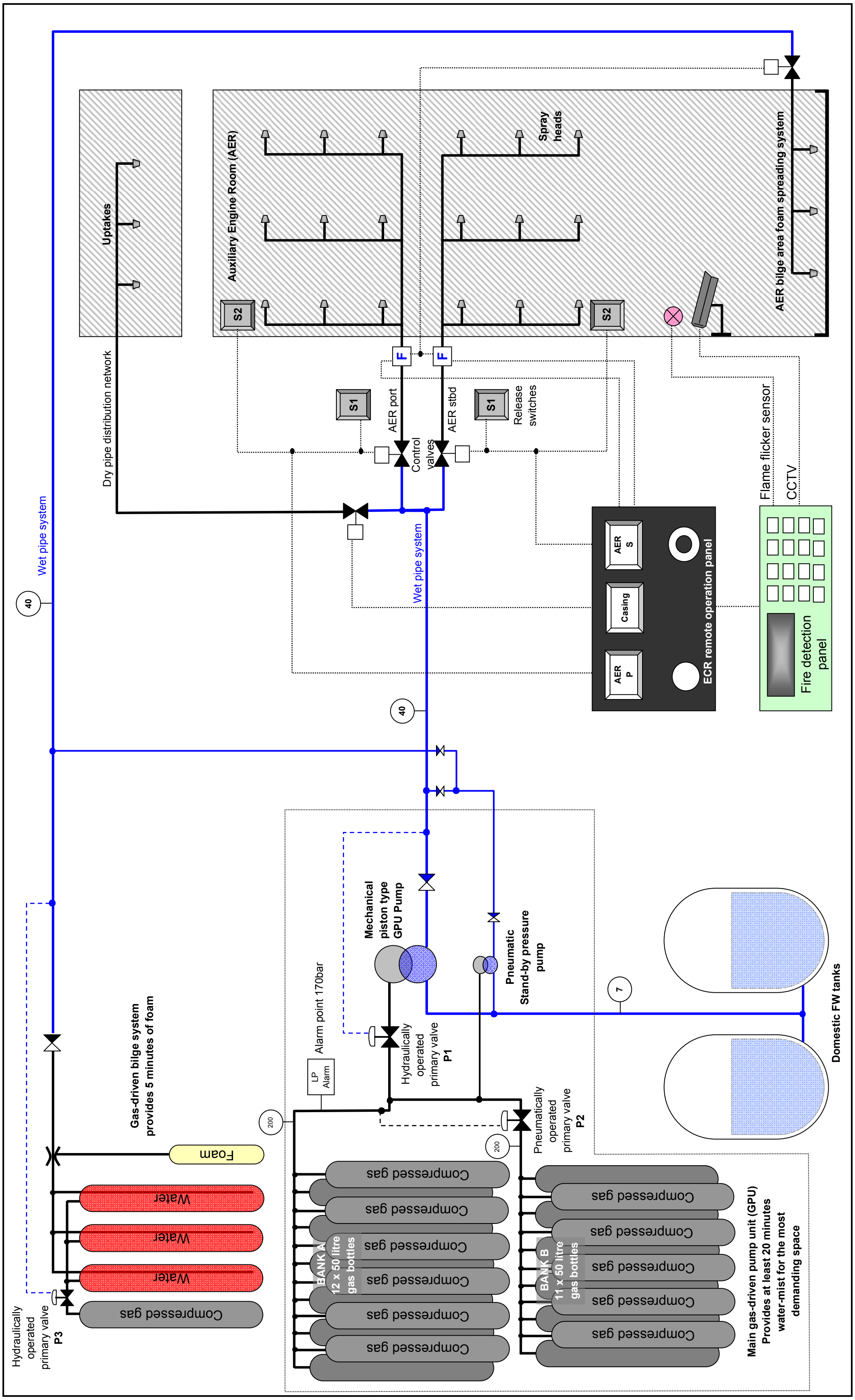
The system consisted of three main elements: a gas-driven pump unit (GPU), a wet pipe section, and a dry pipe distribution network. The GPU had two high pressure piston-type reciprocating pumps (one pump was specifically for the upper levels of the main engine room), a stand-by pressure pump, and two gas cylinder banks, A and B **(Figure 31)**. The protected areas were the port and starboard sections of the main and auxiliary engine rooms, the separator room, the engineer's workshop area, the boiler room, and the funnel casings. The system was configured to provide at least 20 minutes supply of water-mist to the largest area. Four extra gas cylinders were provided to give the option of an additional 10 minute discharge into the funnel casing.

The gas cylinders were required to be charged with either nitrogen or compressed air to a pressure of between 170 and 200bar. An alarm was intended to sound if the gas pressure in either of the cylinder banks dropped below 170bar. A dedicated high pressure air compressor was provided to allow the ship's crew to top-up the cylinder pressures after tests and maintenance.

The wet pipework between the GPU and the section control valves was filled with water from the ship's domestic fresh water system and was maintained at 40bar by a stand-by pump. The dry pipework ran from the section control valves, positioned outside the protected spaces, to the water-mist spray heads. The starboard AER was protected by nine spray heads, three of which were positioned above the auxiliary engine fuel module. The port section of the AER was also fitted with nine spray heads, and the funnel casing with eight.

The section control valves were electrically operated but could also be opened manually if the control circuit or solenoid failed to function. In the event of a loss of power to the operating solenoid, the control valves were designed to close. The control circuit had a 24V battery back-up power supply.

Figure 31

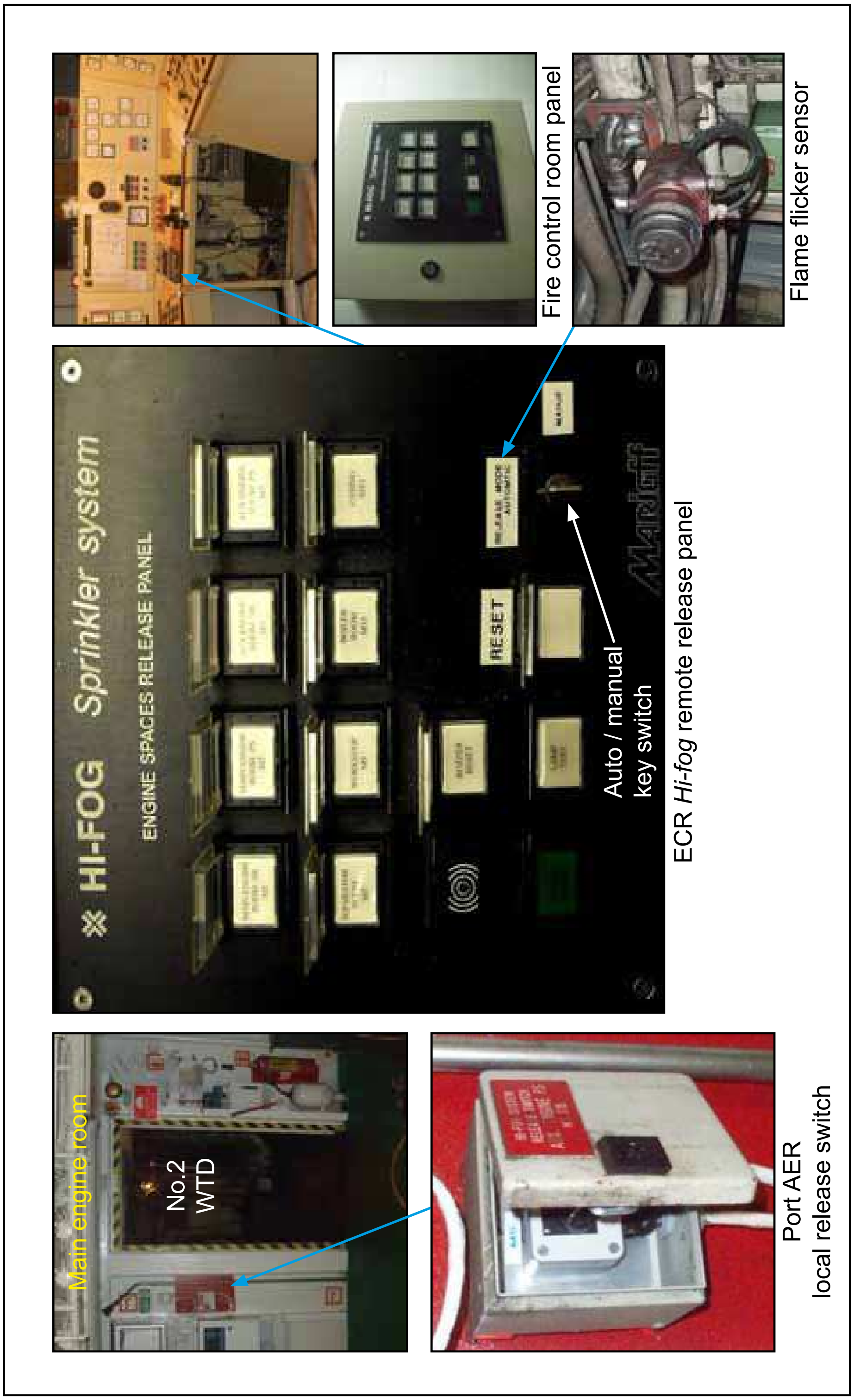


Simplified illustration of the *Hi-fog* and bilge foam flooding system

1.13.3 System activation and modifications

When originally installed, the *Hi-fog* system was activated by either operating a release switch or by pressing a button on one of the vessel's two remote release panels **(Figure 32)**. Local release switches were provided within each of the protected spaces, and remote release switches were positioned in adjacent compartments. The master release panel was located in the ECR and a back-up panel was provided in the fire control station.

Figure 32



Hi-fog system activation points

The AER release switch activated by the extra 2/E was in the main engine room on the port side of WTD2 **(Figure 32)**. He was unaware that the switch activated only the port section control valve and did not see the release switch for the starboard section, which was located several metres away on the same bulkhead.

In 2006, following lessons learned from other fires, the control system was upgraded to provide automatic activation by linking the fire detection system to the *Hi-fog* master release panel. The *Hi-fog* control circuits were also modified to automatically open the funnel casing section valve when any of the main or auxiliary engine room sections were activated. In addition, a control link to the machinery space closed-circuit television (CCTV) system was provided. A key-operated switch fitted to the master release panel was used to enable the automatic functions. The system was normally left in its automatic mode but was switched to manual for maintenance and testing, or when hot work was carried out in one of the protected spaces. The system upgrade was not carried out by Marioff, and a description of the automatic functions had not been added to the system's operating manual.

1.13.4 Operating sequence

The activation of the auxiliary engine fuel module's flame sensor **(Figure 32)** should have triggered alarms on both the fire detection and *Hi-fog* remote release panels, and the automatic operation of the starboard AER and casing section valves. The CCTV camera for the starboard side of the AER should also have been automatically selected and displayed on the ECR monitor.

The system was designed so that when a protected area control valve was opened, the stand-by pressure in the wet pipe section dropped due to the flow of water through the open valve. The reduction in pressure caused the hydraulically-operated gas primary valve (P1) to open, and allowed the gas in cylinder bank A to drive the GPU high pressure reciprocating pump **(Figure 31)**. The pump delivered water to the spray heads at a sufficient pressure (typically between 70 and 80bar) to produce water-mist. Flow monitoring switches sensed the flow of water and sent a signal to illuminate the relevant protected area buttons on the remote release panels and activated the bilge flooding system. Once the gas pressure in cylinder bank A dropped to 15bar the pneumatically-operated gas primary valve (P2) opened to release the gas from cylinder bank B.

The section control valve could be closed by returning the release switch back to its original position, or by pressing the release panel button for a second time. When activated automatically, the *Hi-fog* release panel reset button needed to be pressed before the section valve could be closed.

1.13.5 Post-fire inspection and tests

The *Hi-fog* system was inspected the day after the fire, and all the gas bottles were found to be empty. One of the cylinders had been isolated prior to sailing because its bursting disc[14] had failed.

On 7 February 2010, a manufacturer's service engineer examined the system. His observations included:

- the system had been put back into service by the ship's crew who had recharged the gas cylinders to 145bar
- the gas cylinder low pressure alarm had not activated
- the system had been serviced by Marioff in August 2009 but no certificate was issued because the gas bottles were out of date for test.

On 1 March 2010, the service engineer returned to the ship to re-commission the system. He found the pneumatic primary valve was passing air, causing the stand-by pressure to rise and equalise with the pressure in the gas cylinders. He also found a constant *'open'* signal was being sent to the starboard AER and workshop area section control valves. During the initial system function checks, the starboard AER control valve failed to open because its solenoid had burnt out.

The system was prepared for discharge into the workshop area using one gas bottle. In consultation with the ship's technical superintendent, the service engineer adjusted the control settings outside the normal operating parameters in order to increase the likelihood of the GPU's high pressure pump starting. The test was initiated from the remote release panel in the ECR and was witnessed by an LR surveyor and MAIB inspector. The high pressure pump did not start and the test failed **(Figure 33)**. The service engineer initially attributed the failure to a lack of gas, and repeated the test using 6 cylinders. During the second test, the high pressure pump started and the system appeared to function correctly. The service engineer had little experience of working on Marioff's gas powered units, and attributed the initial system failure to the partial isolation of a pressure regulating valve.

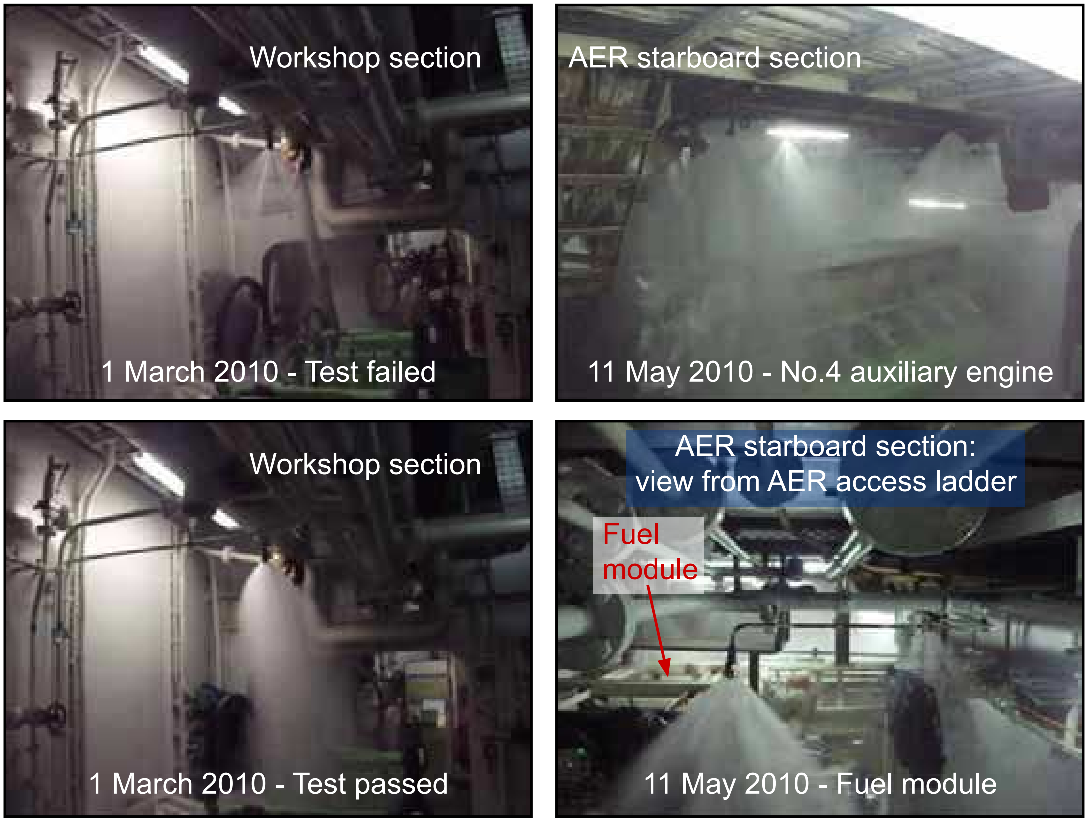
On 11 May 2010, a series of *Hi-fog* trials was carried out on board *Oscar Wilde* in Cherbourg. The starboard AER section of the system was tested in accordance with the manufacturer's instructions and the ship's planned maintenance system (PMS) schedules, using one gas cylinder from each cylinder bank. The first test was initiated by triggering the fuel module flame detector. On activation, the section valves for the starboard AER and funnel casing opened, the GPU high pressure pump started and water-mist was

14 Bursting disc – a non-reclosing pressure relief device which protects pressure vessels, equipment or systems from over pressurisation or potentially damaging vacuum conditions.

generated **(Figure 33)**. When the gas pressure in cylinder bank A dropped to 15bar the pneumatic primary valve opened to provide gas from bank B. Observations made during the trial included:

- the initial stand-by pressure was equal to the gas bottle pressure of 195bar
- the gas bottle low pressure alarm was set at 100bar
- the automatic CCTV function did not work
- the water-mist coverage appeared to be less substantial over the fuel module compared to the auxiliary engines **(Figure 33)**
- one gas cylinder was sufficient to conduct the test.

Figure 33



Hi-fog system discharge tests

1.14 *HOTFOAM* SYSTEM

1.14.1 General description

The *Hotfoam* fire-extinguishing system was manufactured by Unitor Marine Systems Ltd. (now Wilhelmsen Ships Equipment Ltd.) and was installed in 2001 as a replacement for the vessel's Halon gas total flooding system. Unitor supplied the main plant but the pipework was supplied and installed by a ship repair contractor. The system was type approved by DNV against its classification rules and its interpretation of the relevant SOLAS requirements.

The multi-stage system was designed to cool a protected space by providing a 2 minute supply of water spray before filling the space with high-expansion foam. The foam extinguishes a fire by starving it of oxygen. In addition, the foam's contact with hot surfaces generates steam and provides a cooling effect.

The *Hotfoam* system protected the main engine room, AER, separator room and compressor room. The foam generators were located inside the protected spaces and used the atmosphere inside the compartment to aspirate the finished foam. The AER had 13 foam generators, which were capable of filling the space within 3.2 minutes at a rate of 2m/min. The system was designed to be activated remotely from a dedicated compartment on deck 4 where the control cabinet and main plant were located. The compartment contained a 600 litre foam concentrate storage tank, a foam concentrate pump, a foam solution proportioner, a sea water supply valve and four foam solution distribution valves **(Figure 34)**.

Figure 34

Hotfoam compartment

1.14.2 Operating procedure

A set of basic operating instructions provided by the equipment manufacturer was attached to the inside of the operating cabinet door **(Figure 34)**. The instructions explained how to operate the system in its automatic and manual modes. To operate the system from the control cabinet, the instructions given were:

*Push the **"alarm"** button for the space on fire. The alarms will sound.*

*Push the **"on"** button. The system will run with only water for 2 minutes then fill the room(s) on fire with foam.*

*Let the system run until fire is out. Then stop foam/water supply with the **"stop"** button. Restart foam production if necessary.*

The instructions also stated:

The system has capacity to provide foam to fill up all the protected spaces 5 – 6 times with foam.

Additional guidance provided in the manufacturer's manual emphasised the importance of starting the water spray application immediately after a fire occurs **(Annex D)**. It also explained that, during the initial 2 minute period prior to foam being produced, the affected space should be evacuated and a decision made regarding whether to stop the system and fight the fire with portable equipment, or to continue to flood the space with foam.

High-expansion foam and water-mist are not compatible if used at the same time because the mist or spray will knock down the foam. Some modern high-expansion foam flooding systems have interlocks that, when activated, automatically stop the local application water-mist system. This information was not included in the manufacturer's manual, or taken into account in its operating procedure.

The chief engineer operated the system in its automatic mode from the control cabinet in the *Hotfoam* room. He followed the manufacturer's operating procedure and was unaware of the need to stop the *Hi-fog* system prior to flooding the AER with foam. The instructions and guidance provided by the manufacturer were not expanded upon in the vessel's onboard procedures.

1.14.3 IMO guidance

SOLAS requires fixed fire-extinguishing systems to comply with the provisions of the Fire Safety Systems (FSS) code. At the time of the accident the FSS code did not provide guidance on high-expansion foam systems using inside air. However, in May 2008 the International Maritime Organization (IMO) issued guidelines for such systems in its MSC.1/Circ.1271[15] which is applicable to ships with build contracts placed after 1 July 2009. The guidelines include requirements for system design, performance, testing and onboard procedures, and states:

> *'the system and its components should be suitably designed to withstand ambient temperature changes, vibration, humidity, shock, clogging and corrosion normally found in machinery spaces'.*

The circular requires system pipework and components that come into contact with foam concentrate to be constructed from corrosion resistant materials such as stainless steel or equivalent. All other system pipework and the foam generators should be made from galvanised steel or equivalent. It also requires all sections of pipework to be provided with connections for flushing, draining and purging. To prove the distribution pipes are clear, the circular recommends the system is blown through with air. The *Hotfoam* system and its successor *Hifoam*, complied with most of the requirements set out in MSC.1/Circ.1271. However, Wilhelmsen did not stipulate a corrosion resistance criterion for the system's distribution pipes and its guidance stated *'there is no special requirement for the piping installation'*.

The quantity of foam concentrate should be sufficient to produce a volume of finished foam equal to five times that of the largest protected space, which the system must be capable of filling in less than 10 minutes. Procedures are required to be in place to ensure a suitable ventilation opening is kept open when the system is activated in spaces of greater volume than $500m^3$. This is to prevent the space pressurising and therefore adversely affecting the generation of the foam. This information was not included in the manufacturer's manual or operating instructions, and the crew were unaware of this requirement.

The IMO guidelines also require procedures to be in place to ensure that personnel re-entering a protected space after a system discharge wear BA.

1.14.4 Post-fire inspection and tests – *Oscar Wilde*

Following the fire, the system's control valves were found to be in the correct position for a discharge into the AER. The foam storage tank was empty but no high-expansion foam was found in the AER. There was evidence that foam solution had entered the compartment via the foam generators. Liquid was dripping from some of the generator nozzles, areas of soot had been washed from the bulkheads immediately behind some of the generators, and soapy liquid was found in several machinery save-alls remote from any of the *Hi-fog* spray heads and fire-fighting efforts **(Figure 35)**. Samples collected from the sewage treatment and collecting tank save-alls contained approximately 98% sea water and 2% *Hotfoam* concentrate.

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[15] MSC.1/Circ.1271 – Guidelines for the approval of high-expansion foam systems using inside air for the protection of machinery spaces and cargo pump-rooms.

Figure 35

Hotfoam solution delivered to the AER

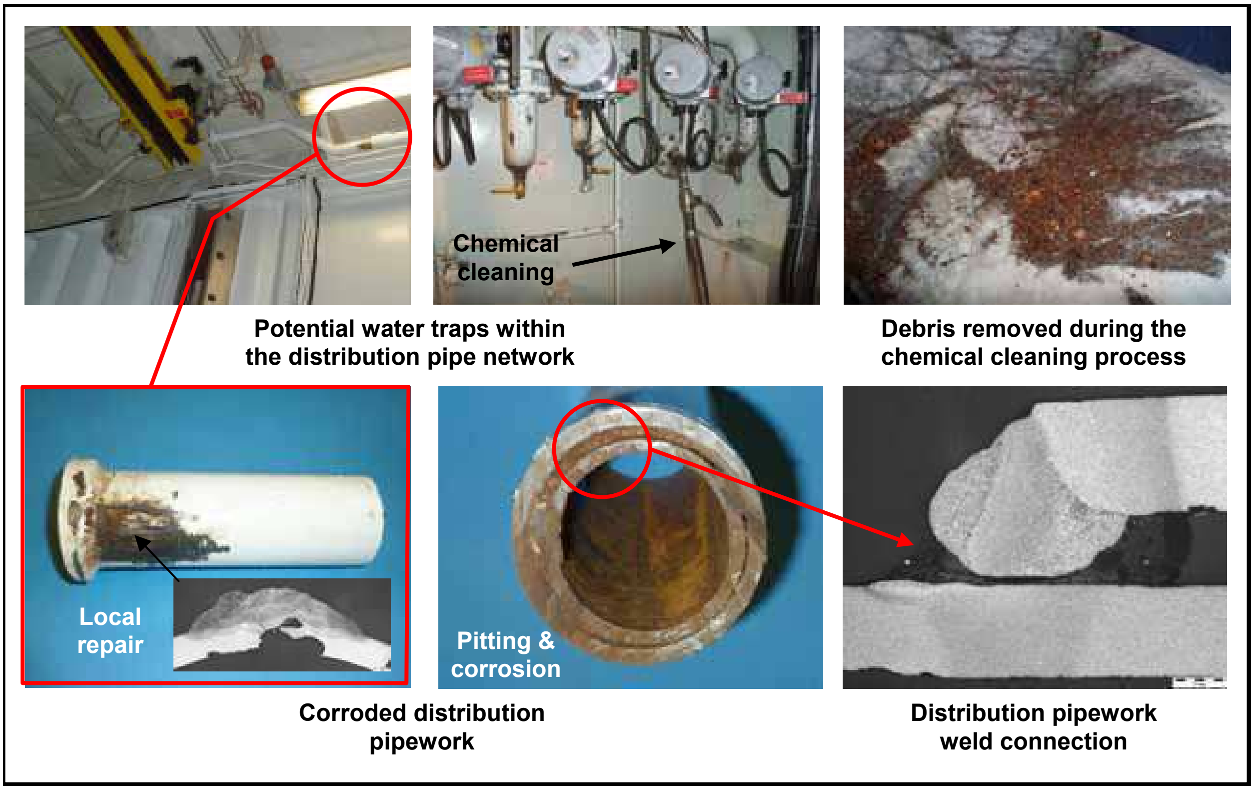
On 5 March 2010, manufacturer's representatives conducted a thorough examination of the system. The foam concentrate pump was found to be fully operational and the sea water strainer was clear. The foam proportioner was in good condition, set at the required 2%, and was functioning correctly. Thirty-one of the 39 AER foam generator nozzles were found to be completely blocked with rust and scale **(Figure 36)**. The nozzles from the other protected spaces were removed for inspection, and approximately 50% were found to be blocked.

The distribution pipes were heavily corroded and contained debris, particularly in sections where liquid could become trapped **(Figure 37)**. Analysis of a removed section of distribution pipe showed that it was made from mild steel and had not been galvanised or zinc coated. It was heavily corroded, had suffered a localised pinhole failure, and had not been effectively welded to its adjacent pipe **(Annex E)**.

Figure 36

Blocked *Hotfoam* generator nozzles

Figure 37



Hotfoam system distribution pipework

The distribution pipework was chemically cleaned and was proved clear of debris before being tested to the satisfaction of the class and flag surveyor. The manufacturer's investigation report included the following recommendations:

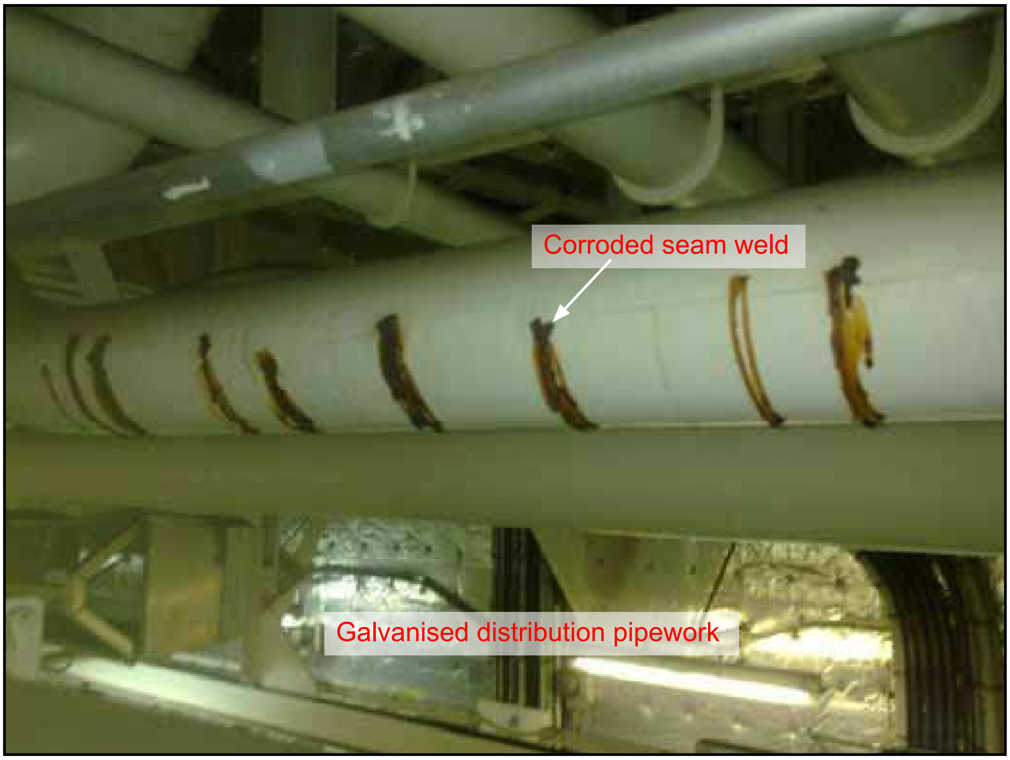
- *Installation of drainage valves at lowest points in distribution piping (already done on distribution manifold only)*
- *Reinstall new distribution piping to avoid water traps as mentioned in 6 and to guarantee corrosion resistance of piping*

Wilhelmsen's report also recommended action to improve the design criteria, maintenance schedules and test procedures for its high-expansion foam fire-extinguishing systems.

1.14.5 Post-fire inspection and tests – other vessels

As a result of its findings on board *Oscar Wilde,* Wilhelmsen carried out several enhanced surveys of *Hotfoam* systems fitted to other vessels. Its service engineers closely inspected the distribution pipework and foam generator nozzles and identified that water traps were common, and that corrosion was prevalent within the dry pipe systems. They also found that welded seams within galvanised systems were particularly prone to corrosion **(Figure 38)**. In addition, many foam generators could not be accessed to allow nozzles to be inspected, particularly on the larger tankers.

Figure 38



Hotfoam system survey on other vessels

1.15 BILGE FOAM SYSTEM

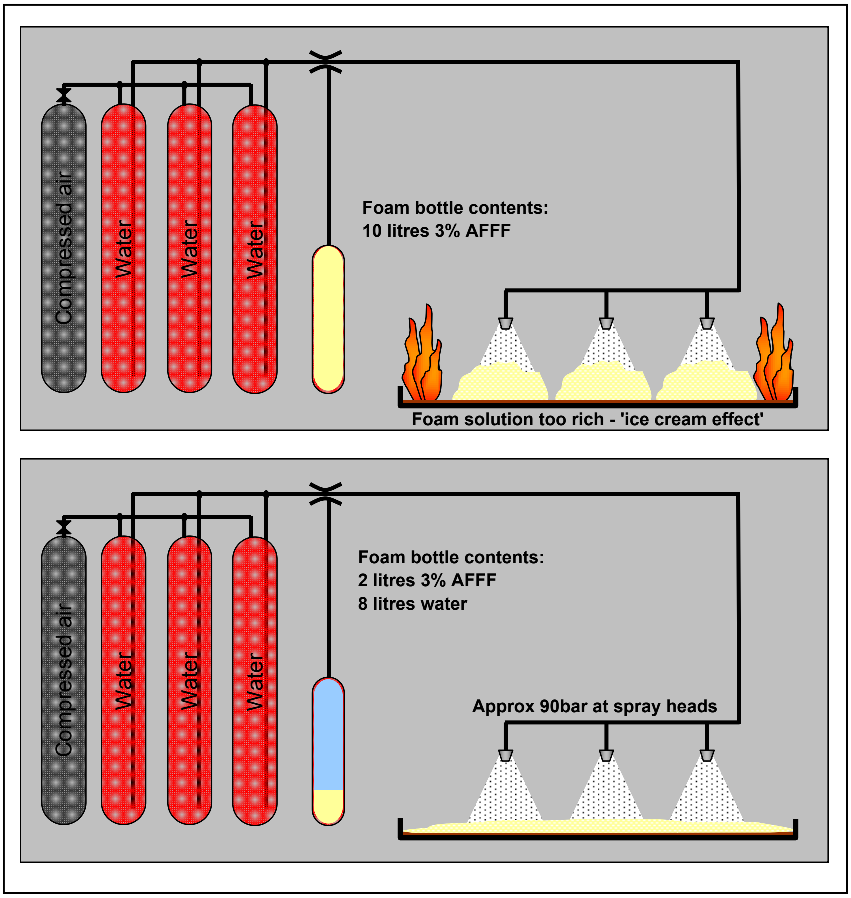
1.15.1 General description

The machinery space bilge foam fire-extinguishing system, also manufactured by Marioff, protected the bilge areas in the engine room, AER and separator room. It was installed at the same time as the *Hi-fog* system, and was one of only seven similar installations developed to meet the requirements of the vessel's previous owners. A 150 litre gas powered machinery accumulator unit (MAU150), originally designed to deliver water-mist to small enclosed spaces, was adapted to provide a 5 minute supply of low expansion foam.

The system comprised three 50 litre water cylinders, one 50 litre gas cylinder, a 10 litre foam cylinder, an inline inductor, and wet and dry pipework similar to that fitted to the *Hi-fog* system **(Figure 31)**. The wet pipework was maintained at 40bar by the *Hi-fog* system's stand-by pressure pump.

The system was not type approved but, in 2000, Marioff conducted a series of trials to satisfy itself and DNV that the system produced the required quality and quantity of finished foam. During the tests, the foam cylinder was initially filled with a 3% aqueous film forming foam (AFFF) concentrate, but the finished foam was too stiff to spread, and resulted in an 'ice cream' effect **(Figure 39)**. The foam concentrate was progressively diluted and the optimum performance occurred when the foam cylinder was filled with 2 litres of 3% AFFF concentrate and 8 litres of water. This information was included in the manufacturer's operating and maintenance manual.

Figure 39



Foam concentrate

1.15.2 Operating sequence

The bilge system section control valves were configured to open automatically when the *Hi-fog* was activated within the relevant protected spaces. When a bilge system section control valve opens, the stand-by pressure in the wet pipe system creates a flow through the dry pipe network. The drop in the stand-by pressure causes the hydraulic gas cylinder primary valve (P3) to open **(Figure 31)**. The gas charge forces the water from the three 50 litre cylinders to the spray heads. The water flow draws foam concentrate from the foam cylinder into the distribution pipework. The resulting foam solution is aspirated as it exits the spray heads, and low-expansion finished foam is produced which should spread evenly across the bilge to smother the fire.

1.15.3 Post-fire inspection

After the fire, the MAU150 gas, water and foam cylinders were empty. The system was refilled and put back into service by the ship's crew prior to the Marioff service engineer attending the vessel on 1 March 2010. Although not familiar with the system, the service engineer noted that the water cylinders were not full and the crew were unaware of the correct filling method. The crew had attempted to fill the cylinders through the gas lines, and did not remove the cylinder vent plugs.

1.16 FIRE PROTECTION AND FIRE-FIGHTING SYSTEMS MAINTENANCE

SOLAS[16] requires all fire protection and fire-fighting systems and appliances to be properly tested, inspected, and maintained ready for use. *Oscar Wilde*'s crew carried out the lower level routine planned maintenance and defect repairs to the vessel's fixed fire-extinguishing systems. More complex periodic maintenance, inspections and repairs were carried out by nominated approved fire-fighting equipment service providers and/or manufacturers' representatives. DFM's main service provider was Resmar Ltd. based in the UK. It was approved by DNV to *carry out surveys and maintenance on fire-extinguishing equipment, systems and self-contained breathing apparatus on board ships classed by the society*.

The planned maintenance tasks and inspection routines for fixed fire-extinguishing systems were prompted by, and recorded on, the ship's computerised PMS database. Details of unplanned maintenance and defect repairs were also recorded on the database.

The work package for the docking period did not contain any maintenance tasks for the fixed fire-extinguishing systems. Therefore, the attendance of the equipment manufacturers' representatives was not arranged.

[16] SOLAS chapter II-2, part E – Operational requirements, regulation 14 – Operational readiness and maintenance.

1.16.1 *Hi-fog*

The IMO[17] requires all water-spray fixed fire-extinguishing systems to be tested for operation annually. Marrioff recommends a function discharge test be conducted at 6-monthly intervals, and that its customers produce a test plan to ensure the test releases are carried out from different release locations.

The ship's PMS included weekly, 4-monthly, 6-monthly and annual tasks for the *Hi-fog* system. The PMS required discharge tests of each protected section at 4-monthly intervals by operating the system from the ECR, fire control station, local control positions, and by activating the appropriate flame detectors **(Annex F)**. According to the PMS database, all sections had been tested in the 4 month period prior to the fire, and the port and starboard sections of the AER were last tested on 23 January 2010. However, the actual routine adopted on board was to test only one section at each 4-monthly interval with the aim of covering all sections within a 2 year period. The revised test plan had not been formalised and its methodology was not documented.

The system's annual service was due on 30 January 2010 and was recorded as being completed on the day of the fire. An annual service certificate was last issued by Marioff on 30 October 2008 when the engineer's report noted that the:

- gas bottles were below the minimum pressure of 170bar (120bar)
- gas bottles were due a 10-yearly pressure test and inspection within 6 months
- MAU150 water cylinders were not full.

A Marioff service engineer attended the vessel again in August 2009 to carry out defect repairs. The work carried out included the:

- overhaul of the hydraulic primary gas valve
- overhaul of all section valves
- replacement of three faulty flow switches
- replacement of a faulty section valve solenoid.

The engineer noted that the gas and water cylinders were overdue for their 10-yearly pressure test and inspection, and he recommended the renewal of the cylinders' pressure hoses. This work was not carried out and was highlighted during the vessel's transfer to LR. As a result, Resmar was contracted to pressure test and refill the *Hi-fog* gas cylinders during the docking period. This was considered an urgent requirement and, due to time constraints, a written work specification was not issued.

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17 MSC/Circ.850 – Guidelines for the maintenance and inspection of fire-protection systems and appliances.

At the start of the docking period, a system discharge test was carried out in the main engine room at the request of the LR surveyor. When the system was activated by the ship's crew, the section valve opened and water-spray entered the compartment. However, the GPU high pressure pump failed to start and mist was not generated.

The ship's engineers and the technical superintendent worked on the system during the docking period. They had little or no experience of working on *Hi-fog* systems and had a limited knowledge of the GPU's control system. With the aid of the manufacturer's manual, they attempted to rectify the problems identified. The hydraulic primary gas valve, a pressure regulator and a gas pipe were replaced before the system was again presented for survey. A second test was carried out in the separator room on 1 February 2010 to the satisfaction of the LR surveyor. The system was activated manually and allowed to run for 25 seconds.

At 1614 on 2 February 2010, the *Hi-fog* gas cylinder manifold low pressure alarm cleared. Four minutes later, the 2/E isolated the cylinders and the alarm activated again. The 2/E carried out work on the system's hydraulic and pneumatic primary gas valves. The work was completed shortly after the ship sailed from Falmouth and the gas cylinders were re-opened. The low pressure alarm cleared at 1838.

1.16.2 *Hotfoam*

Oscar Wilde's PMS included 2-weekly, monthly, 3-monthly and 6-monthly tasks for the ship's crew to carry out on the *Hotfoam* system. These included a monthly requirement to check and record the foam concentrate level in the storage tank, and a 6-monthly requirement to produce high-expansion foam on the vehicle deck using a portable foam generator. The PMS records show the monthly routine was carried out 9 times in the 12-month period prior to the fire. The function test was carried out to the satisfaction of the class surveyor at the beginning of the docking period **(Figure 40)**. Following the test, the class surveyor identified that the foam concentrate tank was only half full. An order was immediately placed for 330 litres of foam concentrate, but the concentrate did not arrive prior to the vessel sailing.

The PMS also included two annual tasks to be carried out by an approved service engineer. The first task was to conduct an annual service in accordance with the manufacturer's requirements; the second was to send a sample taken from the foam concentrate tank for laboratory analysis. These tasks were carried out by a Resmar service engineer on 12 May 2009. His report identified no shortfalls and, following a blow through with compressed air, the distribution lines were declared clear **(Annex G)**.

A Wilhelmsen service engineer last conducted the annual maintenance on 15 May 2008; again no defects or shortfalls were identified **(Annex H)**. The foam concentrate test certificate stated that the foam tank had been filled in March 2002. The manufacturer recommended that the concentrate be renewed every 5 years.

Figure 40

Hotfoam system discharge test

1.16.3 Bilge foam system

The ship's PMS did not include specific tasks for the maintenance of the bilge foam system, which was carried out as part of the *Hi-fog* schedules. The system's gas, water and foam cylinders were taken ashore with the *Hi-fog* gas cylinders for pressure test and inspection by Resmar's sub-contractor during the docking period. On completion of the test the sub-contractor refilled the gas cylinders with nitrogen to 200bar. It also refilled the water cylinders and the foam cylinder. The foam cylinder was filled with 10 litres of 6% AFFF foam concentrate. The ship's crew reinstalled the cylinders, but the bilge foam system and its control circuit were not tested or proven during the docking period.

1.17 HAZARDS ASSOCIATED WITH HIGH-EXPANSION FOAM

Wilhelmsen advertised its high-expansion foam systems as environmentally friendly, non-toxic and harmless to people **(Annex I)**. The material safety data sheet for the synthetic 2% high-expansion foam concentrate lists the chemical hazards associated with the liquid, but does not address the hazards of the finished foam within a protected space.

The UK's Fire Service personnel are instructed to wear BA and use guide lines whenever they enter a high-expansion foam-filled compartment. Its operations manual[18] explains that:

> *High-expansion foam, even in a relatively well-known environment, has a very claustrophobic effect, and in an unknown environment this effect can be heightened. Other hazards encountered include:*
>
> - *there is a general loss in effectiveness of vision, hearing and sense of direction, i.e. disorientation;*
> - *penetration of light from torches and equipment is severely affected;*
> - *audibility of speech, evacuation signals, low-pressure warning whistles and distress signal units is also severely restricted;*
> - *transmission of heat is reduced and the location and travel of fire are therefore harder to determine. Thermal image cameras are also ineffective.*
> - *damage to structural features above and around may not be visible, with the danger of ceilings etc. collapsing onto firefighters;*
> - *the compartment may contain trapped gases which, with the introduction of fresh oxygen, could result in backdraught conditions.*

Additional hazards include:

- it would be extremely difficult to locate casualties within a foam-filled space and unconscious casualties are likely to suffocate
- high-expansion foam conducts electricity.

The ship's crew appeared to be unaware of these hazards. IMO guidance[19] for practical fire-fighting training recommends trainees to:

> *Enter and pass through, with lifeline but without breathing apparatus, a compartment into which high-expansion foam has been injected*.

Within the UK, fire training schools implement the Merchant Navy Training Board's (MNTB) course criteria. This does not include the practical exercise recommended by the IMO. The MNTB criteria requires the hazards presented by the foam, and techniques for re-entering a space containing foam, to be taught in the theoretical part of the basic and advanced fire-fighting courses. The UK's fire training schools have adopted different methods to meet the requirements set out by the MNTB and IMO. These range from the use of information booklets and verbal instruction to practical drills where trainees wearing BA enter spaces filled with high-expansion foam.

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18 Fire Service Manual; Volume 2 – Fire Service Operations; Firefighting Foam.

19 STCW, chapter VI, Section B-VI/1: Guidance regarding familiarisation and basic safety training and instruction for all seafarers – Fire prevention and fire fighting.

1.18 FIRE-FIGHTING EQUIPMENT

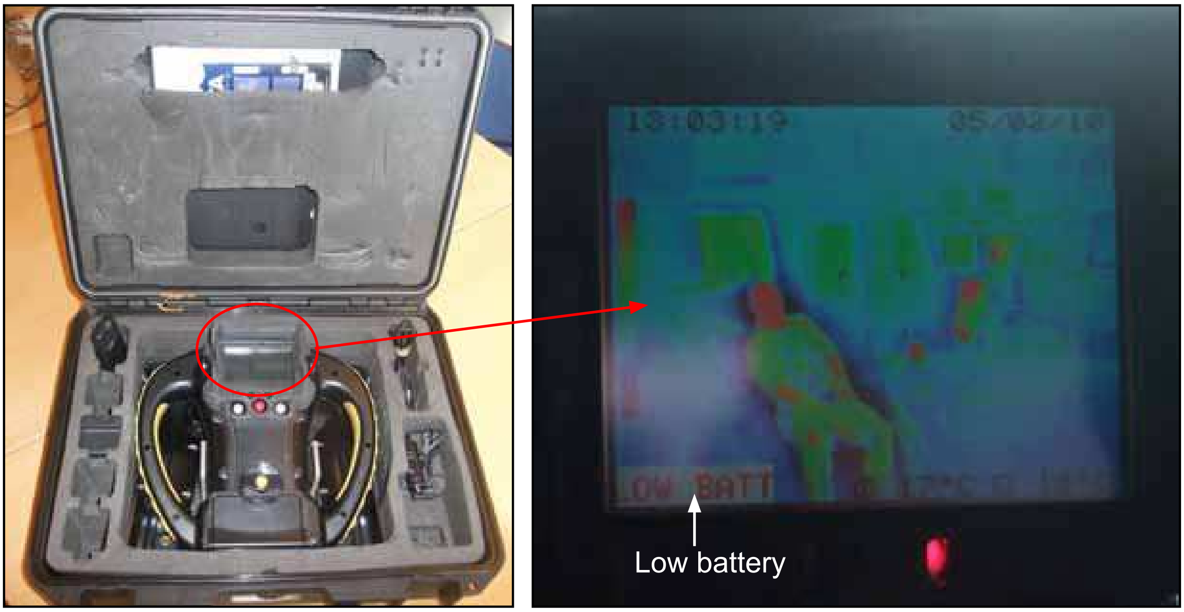
1.18.1 Radios

Hand-held, ultra high frequency (UHF) radios were used as the primary means of communication during the fire. Formal voice procedures were not used and messages were not repeated. About 1 hour into the incident, the radios began to fail as their batteries ran out of charge.

1.18.2 Thermal imaging camera

The ship held a thermal imaging camera which was located at the deck fire party's muster point. It was standard practice to take the camera to a scene of a fire. On this occasion, the fire party forgot to take the camera to the lower hold and it remained unused in the fire store throughout the incident. After the fire, it was found that the camera's battery had not been charged prior to sailing and only had sufficient charge to power the camera for 1 to 2 minutes **(Figure 41)**.

Figure 41



Thermal-imaging camera

1.18.3 Emergency escape breathing devices

EEBDs are designed to provide a minimum 10 minute supply of air to allow persons time to escape from compartments containing smoke or toxic gases. The ship held 27 EEBDs, 5 of which were located in the machinery spaces, 1 in the ECR and 1 in the fire control station. None of the engineers carried an EEBD during the evacuation from the ECR, or when entering or monitoring potentially smoke-logged compartments.

1.19 FIRE-FIGHTING TRAINING, DRILLS AND KNOWLEDGE

DFM had worked with Warsash Maritime Academy since 2006 to develop a bespoke command and control training course. The C/O had attended the course, but the chief engineer and safety officer had not. The chief engineer had attended a 4 day advanced fire-fighting refresher course in 2008.

The ship's crew had carried out regular fire drills and a major machinery space fire exercise had been conducted on board *Oscar Wilde* in Cherbourg 2 months before this accident. The local French fire service participated in the exercise, and the scenario included the use and failure of the *Hi-fog* and *Hotfoam* systems **(Annex J)**. During the drill, the 2/E was the OSC and his control point was located in the ECR. The only weaknesses identified during the exercise were: command and control difficulties as a result of language differences between the crew and the French fire service; and the poor reception experienced on the hand-held radios.

1.20 SIMILAR ACCIDENTS AND INCIDENTS

1.20.1 Machinery space fires

The MAIB marine incident database includes 34 fires since 2005 in which pressurised oil has come into contact with hot surfaces due to mechanical failure.

1.20.2 *Hotfoam* systems

In October 2005, corrosion was found in the distribution pipework of the *Hotfoam* system on board a 36,398 GRT Swedish registered cruise ferry during its annual service. The system had been installed as a replacement for Halon in 1998. Unitor had supplied the main plant but the pipework was supplied and installed by a ship repair contractor. The distribution network was chemically cleaned, flushed and surveyed before being put back into service. Unitor concluded that the functionality of the system had merely been prolonged, but the long term problem had not been resolved, and strongly recommended that the owners replace the corroded distribution pipework with new galvanised piping as soon as possible.

1.20.3 Water-mist systems

On the evening of 18 June 2009, a fire broke out on a diesel generator on board the cruise ship *Royal Princess* as she departed Port Said, Egypt. The machinery space was protected by three fixed fire-extinguishing systems; a local application water-mist system (not manufactured or provided by Marioff), a CO_2 total flooding system and a low expansion foam bilge flooding system. The water-mist system was activated as soon as the fire was detected, but witnesses stated that "*it was either having little effect*" or "*it was possibly slowing* *the expansion of the fire but no more"*. The compartment was shut down and the fire was extinguished when the CO_2 was injected. The investigation report[20] published by the Bermuda Department of Maritime Administration concluded that:

> *While the system was activated in the first few seconds of this fire, from the descriptions given by eyewitnesses it does not appear that it was as effective as staff had anticipated in suppressing the fire.*

In addition, the supply of water-mist was interrupted on two occasions during the fire, and the system had to be manually restarted by the ship's crew. The investigation identified that the power supply to the protected area section control valve solenoids was lost when a low-level water tank alarm activated, and when the ship was blacked-out. These interruptions caused the valves to close, and the system had to be manually restarted when power was restored. The investigation report concluded that:

> *The water-mist system worked but did not prove as effective as anticipated and that the ship's crew were not entirely aware of its limitations in terms of how many sectors can be operated at one time and of the need to restart the system after any power interruption [sic].*

20 Investigation report issued by the Bermuda Department of Maritime Administration (DMA), into a fire on the cruise ship Royal Princess off Port Said, Egypt on 18 June 2009.

SECTION 2 - ANALYSIS

2.1 AIM

The purpose of the analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendations to prevent similar accidents occurring in the future.

2.2 CAUSE OF THE FIRE

There is little doubt that the initial fire broke out when fuel oil escaped under pressure from the auxiliary engine fuel module's pressure regulating valve actuator and came into contact with an exposed high-temperature surface on the adjacent auxiliary engine.

The bilge fires adjacent to WTD2 and the fire in the corridor outside the ECR were secondary. These fires almost certainly resulted from oil entering the bilge from the fuel module, and heat transfer from the AER, through the steel deck, to the electric cables on deck 2 above.

2.3 FAILURE OF THE EXCESS PRESSURE REGULATING VALVE ACTUATOR DIAPHRAGM

The actuator diaphragm in the excess pressure regulating valve perished and ruptured as a result of its prolonged exposure to marine fuel oils. The fuel oils had attacked the outer surface of the rubber causing it to swell and delaminate, prior to the inner woven layer tearing and the diaphragm rupturing. This occurred because the diaphragm was made from EPDM rubber and was not resistant to oils. Therefore, the diaphragm was unsuitable for use in the fuel system.

It is unlikely that the ruptured diaphragm, and the diaphragms removed from the main engine's fuel modules which were also made from EPDM, were the same type as the diaphragms fitted at build. Although the original actuator specification is unknown, the operating range of the actuator fitted to the auxiliary engine fuel module was too high to effectively maintain the desired fuel system pressure. It is likely that the wrong type of actuators, rather than just the diaphragms, had been fitted during maintenance or overhaul since the vessel had been in service.

It was not possible to ascertain the age of the actuators fitted to the auxiliary and main engine fuel module's pressure regulating valves, but the lack of date stamps on the diaphragms indicate they were at least 10 years old. The poor condition of the diaphragms recovered from the main engine regulating valve actuators indicate that it was only a matter of time before they too would have ruptured.

Depending on the type of oil EPDM rubber comes into contact with, failure can occur within hours rather than years. In this case, it is possible that the degradation of the diaphragm had been accelerated by its recent increased exposure to the potentially more aggressive additives typically found in low sulphur fuels, together with more frequent changes in operating temperatures.

The anecdotal evidence discussed in paragraph 1.9 indicates that fuel oil system and machinery component failures have increased following the introduction of the new low sulphur regulations. Any rise in the failure rate of fuel oil systems' components or seals will almost certainly result in an increased risk of fire.

2.4 FUEL OIL CHANGE-OVER PROCEDURE

When running on MGO, the configuration of the auxiliary engine fuel oil system on board *Oscar Wilde* was not in accordance with the system manufacturer's operating procedure and was unsafe. The isolation of the service tank return line resulted in the loss of automatic pressure regulation. Instead, system pressure was governed by the auxiliary engines' fuel demand. When demand for power was high, the fuel pressure in the mixing tank fell. Conversely, as the power demand decreased, the fuel pressure increased. In order to reduce the risk of over-pressurising the system, the crew adjusted the feed pump relief valve setting away from the manufacturer's recommended level. Although this action prevented the fuel system from over-pressurising when the electrical demand was relatively constant alongside, it would not have prevented the system over-pressurising during periods of fluctuating electrical demand, or when experiencing fuel oil temperature increases when changing to HFO.

When the ship left the berth, the demand for electrical power was high. This caused the auxiliary engine fuel system pressure to drop, the low pressure alarms to sound, and the stand-by booster pump to cut-in. In order to raise the system pressure, the chief engineer started the second fuel oil feed pump. However, once on passage, the ship's electrical load reduced, causing the pressure in the mixing tank to increase. As valves V66 and V68 were closed when the fuel was changed from MGO to HFO, the excess pressure regulating valve could not prevent the pressure in the mixing tank from rising. Furthermore, as the temperature in the mixing tank would have risen as the HFO entered the system, this would also have resulted in a corresponding increase in pressure. It is likely that the resulting elevated system pressure contributed to the diaphragm's failure.

The fuel change-over procedure developed by DFM required *Oscar Wilde* to be running on HFO prior to sailing. However, the vessel had remained on MGO due to the uncertainty of her sailing time. When 'stand-by engines' was called, there was not sufficient time to change on to HFO before the vessel left the berth. Instead, the first attempt to change to HFO was made as *Oscar Wilde* manoeuvred from the berth; a critical period in which the potential consequences of mechanical failure were significantly increased. In such circumstances, it would have been prudent to delay the change-over until the vessel was in more open water.

The excess pressure return line to the MGO service tank was isolated in order to prevent HFO from contaminating and adversely affecting the properties of the low sulphur distillate fuel when changing between the two fuel types. The contamination of the MGO service tank could also have been prevented by allowing a quantity of MGO to return to the HFO service tank after each change-over. However, it is highly likely that the latter option, which was much safer than isolating the service tank return line, was not used because of the need to flush through the 50 litre black-out tank and the relatively high cost of MGO, which was about 50% more expensive than HFO at the time of the accident.

2.5 PROTECTION OF HIGH-TEMPERATURE SURFACES

There was a significant risk that fuel could leak from the fuel module. The valve actuators fitted to the fuel module pressure regulating valves did not have rupture safety devices. Therefore, as on this occasion, failure would always result in fuel oil escaping under pressure. It was also apparent that the fuel module had many other potential leak sources such as small bore copper pipework, compression fittings, filters, pump seals and heaters. Copper pipe is susceptible to work hardening and subsequent failure if it is exposed to vibration. Its use on pressurised fuel systems should be carefully considered and its condition continuously monitored.

The high-temperature surfaces on No.3 auxiliary engine were not fully insulated or shielded. The exhaust system lagging had not been fully re-instated and the exhaust manifold heat shield had not been properly secured. In addition, several indicator cock heat shields had not been fitted prior to sailing.

The curtain fitted around the auxiliary fuel module to prevent oil spray coming into contact with heated surfaces was not in place when the diaphragm failed. It is likely it had been left open to facilitate the inspection of the fuel module and allow easy access to valves V66 and V68 during the fuel change-over process. However, the fuel module curtain was not full height, and even if the curtain had been in place when the diaphragm ruptured, it is unlikely it would have prevented the fuel spray from coming into contact with the adjacent high-temperature surfaces **(Figure 28)**.

2.6 FIRE SUPRESSION

2.6.1 Fire starvation

A fire can be suppressed and ultimately extinguished by starving it of either the fuel or air required for combustion. A Category A machinery space is intended to be closed down remotely so that a gas tight seal is formed around its boundaries and potential fuel sources are isolated.

SOLAS[21] requires a means of isolating the fuel supply and return pipework to individual engines to be provided for multi-engine installations which are supplied from the same fuel source. However, because of her age, *Oscar Wilde*

[21] SOLAS chapter II-2, part B, regulation 4, 2.2.5 Oil fuel piping.

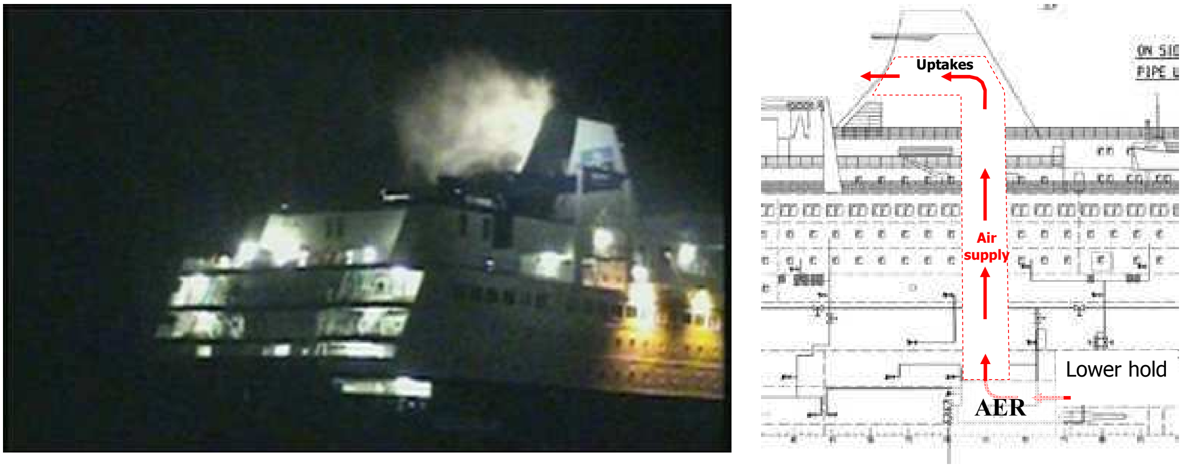
did not have to meet this requirement. Therefore, in order to isolate the fuel supply to the auxiliary engines and fuel module during the fire, it was necessary to black-out the ship.

The auxiliary engines were stopped at 1917. Consequently, fuel oil was fed to the fire under pressure for approximately 4 minutes. A further 13 minutes elapsed before the quick-closing valves were tripped to isolate the HFO service tank from the fuel module. However, as the excess pressure regulating valve actuator remained open to the mixing tank, any fuel remaining in, or returning to, the tank from the system pipework or black-out tank would have continued to feed the fire. As a result, fuel was probably still being fed from the mixing tank to the fire after the *Hi-fog* system had been exhausted.

The machinery space ventilation fans were stopped immediately after the flame detector alarm sounded, and the AER ventilation fire dampers were tripped about 2 minutes later. Although the condition of the ventilation exhaust louvres on the stern of the funnel, and lack of packing in the deck penetrations meant that the boundaries of the AER were not gas-tight, the supply of oxygen to the fire was still significantly restricted within minutes of the fire starting.

However, when the OSC opened WTD3 a draught was induced from the vehicle deck, through the AER, as the hot combustion gases rose up the funnel casing and escaped through the exhaust louvres. In addition, as the vehicle deck ventilation dampers had not been closed, the 25 knot winds over the deck of the anchored vessel served to create a forced draught through the compartment **(Figure 42)**. The OSC was aware that the draught was keeping the smoke out of the lower hold, but the implications of fanning the fire were not considered. Consequently, the air flow from the lower hold ventilated the compartment before it had been adequately cooled, and contributed to the fire's re-ignition.

Figure 42



Air supply from the lower hold to the AER

2.6.2 Control of smoke spread

Following ignition, smoke quickly spread to the compartments on deck 2 directly above the fire through open doors and ventilation dampers, and unsealed deck penetrations. Smoke was also allowed to travel up through fire zone 2 into the passenger accommodation spaces on deck 8 because the relevant ventilation fire dampers had not been closed. SOLAS[22] states that:

> *Practicable measures shall be taken for control stations outside machinery spaces in order to ensure ventilation, visibility and freedom from smoke are maintained so that, in the event of fire, the machinery and equipment contained therein may be supervised and continue to function.*

The evacuation of the smoke-filled ECR and adjacent spaces adversely affected the command and control efforts and prevented the crew from monitoring and cooling the fire boundaries above the AER. This ultimately resulted in the fire spreading outside the AER.

Monitoring smoke boundaries and controlling the spread of smoke is as important as monitoring and cooling the fire boundaries. Otherwise, access to large sections of the vessel can be very quickly lost. It is difficult to simulate the effects of smoke during fire drills and exercises, and the issue is often overlooked. The crew did not know the locations of the ship's ventilation duct fire dampers and no guidance regarding the shutdown of ventilation was held on board. In this respect, compartment *shut-down* or *fire control* cards for high risk spaces are used by some shipping companies, and these can greatly increase the crew's ability to fight and contain fire and smoke.

2.6.3 Containment of fire

The fire was not contained within the AER because heat from the fire was conducted through an un-insulated section of the fire boundary to electric cables on the deck above. According to the ship's original structural fire protection plans, thermal insulation was not required for the boundaries between the AER and the corridor and lobby area outside the ECR. However, these plans were produced and approved before the ship was built, and did not accurately reflect the actual deck layout or the use of some of the compartments in the area. Consequently, several of the spaces had been incorrectly classified at build and no thermal protection from the AER had been provided.

The secondary fire outside the ECR would undoubtedly have been prevented if A-60 thermal insulation had been provided at the boundary with the AER. Therefore, regardless of the current classification of the compartments on board *Oscar Wilde,* and requirements set out in SOLAS, the benefits of providing thermal insulation between the AER and all the compartments above the space are clear.

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[22] SOLAS chapter II-2; part C – Suppression of fire; regulation 8 – Control of smoke spread.

2.7 FIXED FIRE-EXTINGUISHING SYSTEMS' PERFORMANCE

2.7.1 *Hi-fog* system

When the fire detection system alarmed, the starboard AER and uptake sections of the *Hi-fog* system should have activated automatically to provide a supply of water-mist for a minimum of 20 minutes. Although none of the crew recalled seeing water-mist entering the AER, the exhaustion of the *Hi-fog* gas cylinders and the relatively low level damage caused to No.3 auxiliary engine indicates that water-mist was produced to some degree.

However, it was evident that the system's performance was not optimal as it did not effectively suppress or contain the initial fire. This was probably due to several factors.

First, it is possible that the system did not activate automatically when the fuel module flame sensor alarmed. The 2/E had been working on the *Hi-fog* system just prior to departure, and the possibility that it had not been returned to its automatic mode cannot be ruled out. As the chief engineer and EOOW did not see any water-mist in the smoke-filled AER when they first investigated the fire alarm, it is possible that the system was operated only when the chief engineer took the precautionary measure of attempting to operate the system manually on his return to the ECR. Any delay in the activation of the *Hi-fog* system would have allowed the fire to quickly spread to the electric cables located directly above the fuel module.

Second, it is also possible that the *Hi-fog* system didn't produce the intended quality of water-mist. During the initial *Hi-fog* test presented to the LR surveyor during the vessel's change of class, the GPU's high pressure pump failed to start and, despite the stand-by pressure priming pump delivering water to the nozzles, an effective water-mist was not produced. If the repairs carried out by the ship's crew were not fully effective, it is possible that a similar failure might have delayed the production of water-mist. This possibility is supported by the 2/E's requirement to undertake additional maintenance after the system had been surveyed by LR, and the similar system failure witnessed after the accident.

Third, the evidence strongly indicates that the flow of water-mist to the AER was interrupted during the initial stages of the fire. The starboard AER and funnel casing sections should have activated automatically, and the port AER section valve was operated manually using the local release switch in the main engine room. However, when the extra 2/E returned to the ECR, he found the remote release panel was indicating that only the funnel casing section control valve was open. This was possibly due to the: temporary loss of power to the section valve solenoids during black-out, despite the provision of a 24V battery back-up supply; inadvertent manual closure of valves when attempting to ensure the system had activated; and/or adverse effects of fire damage on control circuits. In addition, the manufacturer's post-fire survey identified that the starboard AER section valve's solenoid had burnt out but did not establish when this had occurred.

Fourth, the operating period of the system was less than originally designed, and was likely to have been below the minimum 20 minutes required by SOLAS. The gas bottles had been filled with nitrogen to 200bar during the docking period, but discharge tests and maintenance had been carried out prior to the vessel sailing. In addition, it is likely that the isolated cylinder with the failed bursting disc had been over-pressurised during re-charging operations. Had the remaining 22 gas cylinders been fully re-charged to 200bar when the ship sailed, the system would have been capable of providing simultaneous protection to the port and starboard AER and casing sections for about 19 minutes and 20 seconds.

However, it is unknown what the gas cylinder pressures were when the 2/E finished working on the GPU. Although the gas manifold low pressure alarm cleared when the system was reset, because the alarm had been adjusted to 100bar, it is not possible to determine if the cylinder pressures were above the minimum of 170bar.

The system upgrade carried out in 2006 allowed the automatic simultaneous activation of the casing section with the main and auxiliary engine room sections. However, the gas cylinder banks were sized to provide a minimum 20 minute supply of water mist to the most demanding space, the main engine room, and an additional 10 minute supply to the casing. The automation of the system has resulted in a maximum 14 minutes and 30 seconds supply of water-mist being available to suppress fires in the main engine room.

Finally, the trials conducted on 11 May 2010 clearly demonstrated that the water-mist coverage above the fuel module was not as extensive as that provided for the auxiliary engines, and it appeared that there was a blind spot directly above the seat of the fire **(Figure 33)**. This is supported by the extent of the damage to the electric cables running at deckhead level above the water-mist nozzles.

As with the similar accident on board *Royal Princess* (paragraph 1.20.3) on 18 June 2009, the performance of the local application water-mist system was not as effective as anticipated by the ship's crew. Many of the crew expected the system to extinguish the fire, and were unaware of its intended purpose and limitations. Furthermore, it is likely that the problems experienced with the system during the docking period affected the crew's confidence in its reliability, and led to the 2/E being despatched to check its operation during the fire.

2.7.2 *Hotfoam* system

The *Hotfoam* system was fully discharged into the AER, but it failed to produce any foam and, therefore, did not extinguish the fire. The initial attempts to operate the system failed due to the loss of fire main pressure when the power supply to the emergency fire pump was interrupted. When the system was eventually activated 30 minutes after the fire had started, no foam was produced because the generator nozzles were blocked with debris. This caused the foam solution to dribble through the nozzles without reaching the velocity required for aspiration. The chief engineer was unaware that foam was not being produced in the AER because the control panel and gauges in the *Hotfoam* room indicated that the system was functioning correctly.

The debris in the nozzles was flakes of rust generated by the internal corrosion of the distribution pipes. It is almost certain that foam solution had become entrapped during periodic function tests and then forced around the distribution pipes when the system was blown through with compressed air. The foam solution is likely to have sat in the recesses of the dry pipe distribution network and attacked the steel. The resultant corrosion products would have been dislodged by the compressed air and blown into the nozzles. As the nozzles were not routinely inspected, the presence of debris and potential for failure was not identified.

When the system was installed, there were no IMO requirements or guidance regarding the design and installation of high-expansion foam systems using inside air. Furthermore, the manufacturer had no specific installation requirements for the distribution pipework. The system fitted on board *Oscar Wilde* was not self-draining, and the most severe areas of corrosion were in the sections of pipe where water or foam solution could become trapped. In addition, the pipes fitted were manufactured from mild steel and had not been galvanised or protected internally against corrosion in any way.

Nevertheless, the system had been serviced, inspected and tested in accordance with the manufacturer's requirements and current IMO guidance. Consequently, the issues identified during this investigation and the subsequent problems identified during the targeted inspections conducted by Wilhelmsen are of serious concern. It is apparent that full compliance with the current IMO requirements will not guarantee the reliability of these safety critical systems.

Dry pipe systems are prone to corrosion in a marine environment, and foam concentrates and solutions are particularly corrosive and aggressively attack steel. It is clear from the manufacturer's investigation of a similar incident (paragraph 1.20.2), that chemical cleaning of the distribution pipework merely prolongs the functionality of the system but does not resolve the long term problem. Therefore, the case for a review of the current design, construction, test and maintenance requirements is compelling.

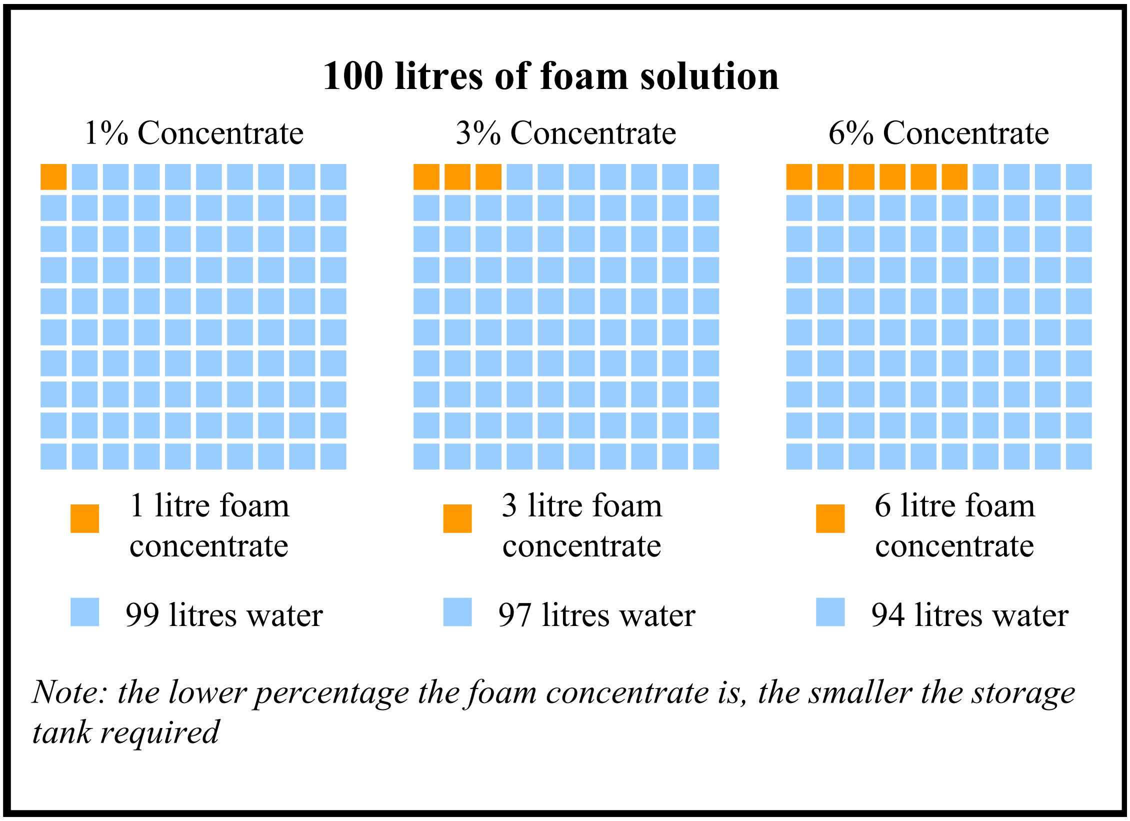
2.7.3 MAU150 bilge foam spreading system

It is apparent that fuel oil had collected in the aft section of the AER bilge, close to WTD2 and the bulkhead adjacent to the main engine room, and had ignited. As these fires burned for some time after the MAU150 system had fully discharged, it is evident the fixed bilge foam spreading system was not effective.

Finished foam is produced from three main ingredients: foam concentrate, water and air. The foam concentrate is mixed with water to produce a foam solution. Air is added to the foam solution to make bubbles (aspiration) and produce finished foam.

Foam concentrates must be mixed with water in the correct proportions to ensure optimum fire-fighting performance. They are generally supplied by manufacturers as 1%, 3% or 6% concentrates. The percentage refers to the quantity of concentrate required to be mixed with water to produce the foam solution. The lower the percentage concentration, the less concentrate needed to produce the required quantity of finished foam. Basically, 1% AFFF is six times stronger than 6% AFFF, and 3% is twice as strong as 6%. However, the fire-fighting characteristics of finished foam produced from 1%, 3% and 6% concentrates should be virtually identical **(Figure 43)**.

Figure 43



Foam solution concentrate and water ratios

Fire-fighting systems are designed to be used with different foam concentrates and it is extremely important that the correct concentrate is used. If a 3% concentrate is used in a system designed for 6% then there will be twice the desired amount of concentrate in the foam solution. This can result in the finished foam being too stiff to flow adequately. Alternatively, the use of 6% concentrate in a 3% system will result in a lean foam solution that provides finished foam with a reduced level of fire-fighting performance.

The machinery space bilge fire-fighting system was designed to use a foam concentrate that had been pre-diluted at a ratio of four parts water to one part 3% AFFF concentrate. However, during the docking period, the foam cylinder was filled with 10 litres of 6% AFFF concentrate. This would have produced a foam solution that was too rich. Therefore, it is likely that the finished foam was too stiff and didn't spread effectively over the whole area of the AER bilge.

2.8 OPERATIONAL READINESS AND MAINTENANCE OF FIRE-EXTINGUISHING SYSTEMS

2.8.1 Operational readiness

It is apparent that the machinery space fixed fire-extinguishing systems were not ready for effective use when the vessel sailed from Falmouth. This was primarily due to the ineffectiveness of the management of the systems' maintenance, and the availability of persons with sufficient equipment-specific competency to carry out the level of work undertaken during the docking period.

Oscar Wilde's fixed fire-extinguishing systems were complex and required regular planned maintenance. In order to ensure these critical emergency systems worked as designed, it was essential that they were maintained, inspected, and tested in accordance with the manufacturers' recommendations by nominated competent persons; be they manufacturers' representatives, accredited service engineers or adequately trained and experienced ship's crews.

2.8.2 Maintenance management

The fixed fire-extinguishing systems were presented for survey and tested to the satisfaction of LR surveyors in the week preceding the fire. However, they had not been maintained, tested and inspected in accordance with the manufacturers' requirements or the ship's PMS schedules, notably:

- The *Hi-fog* systems had not been tested in accordance with the PMS schedules.
- The *Hi-fog* gas cylinders had not been maintained at the required pressure.
- The *Hi-fog* and bilge flooding systems' gas, water and foam cylinders had not been pressure tested at the required intervals.

- The level in the *Hotfoam* concentrate tank had not been maintained or recorded, and the concentrate was possibly out of date.

- The bilge flooding system had not been charged with the correct type of foam concentrate.

It is the responsibility of a ship's owner and master to ensure that safety-critical systems comply with SOLAS and are maintained ready for use at all times while the ship is in service. Many fixed fire-extinguishing systems lie dormant between services and discharge tests, and are often overlooked. In this case, it is evident that the upkeep of the fixed fire-fighting equipment was not given sufficient priority. This is supported by the longevity and low level nature of the shortfalls identified by the LR surveyors during the change of class process. These deficiencies should have been identified during routine inspections and addressed prior to the systems being presented for survey.

The service engineers' inspection reports showed that the crew had repeatedly failed to maintain the *Hi-fog* gas cylinder pressures and fluid levels recommended by the manufacturers. Moreover, the failure to: pressure-test the gas cylinders as recommended by the Marioff service engineer; the lowering of the gas cylinder manifold low pressure alarm set point; the adjustment of the pneumatic control settings prior to presenting the *Hi-fog* system to the LR surveyor; and the failure to immediately repair or replace the defective pneumatic primary valve before the vessel re-entered service after the fire, demonstrate a complacent approach to the operational readiness of these systems.

As the fixed fire-extinguishing systems' annual maintenance schedules were not aligned with the passenger ship's survey cycle, the attendance of accredited service engineers was not considered necessary during the docking period. Therefore, when the *Hi-fog* system failed its test at the start of the docking period, the crew and technical superintendent had to attempt to identify and rectify the problems. However, they had not received equipment-specific training, had limited system knowledge, and little or no experience of overhauling the system.

Effective maintenance management and the alignment of annual maintenance schedules with safety equipment surveys can provide increased assurance that the fixed fire-extinguishing systems are ready for use when a ship is in service. The attendance of nominated competent persons during the docking periods should help provide expert knowledge if required, and ensure that any unforeseen emergent work is carried out effectively prior to the vessel returning to service.

However, it is of concern that the Marioff service engineer, contracted by DFM to re-commission the *Hi-fog* and bilge foam systems following the fire, demonstrated a limited knowledge of the systems. It is important that equipment manufacturers and accredited service providers ensure that their technicians are competent and deliver the level of service expected of them by ship owners, managers and crew.

2.8.3 Discharge tests and safety equipment surveys

The periodicity of the *Hi-fog* discharge tests prescribed in the PMS was in excess of that recommended by the equipment manufacturer and was considered, by the ship's engineers, too onerous and impractical. The alternative schedule adopted on board had not been formalised and the engineers had continued to close out the 4-monthly routines as if they had been completed. Consequently, although the PMS records indicate that the AER sections were tested during the docking period, this was not the case.

The successful tests presented to the LR surveyors before and after the fire, were carried out in the separator room and workshop sections. These spaces had the fewest number of heads, and were therefore considered the most convenient to carry out the tests. None of the tests witnessed by the LR surveyors were triggered by activating a flame sensor, and the bilge flooding system was isolated. Therefore, the automatic functions, the bilge foam system, and the GPU's main engine room upper level high pressure pump were not tested prior to the vessel returning into service.

The discharge tests presented to the LR surveyor on 1 March 2010 **(Figure 33)** were not carried out in accordance with the manufacturer's recommended procedure. The Marioff service engineer, in consultation with the ship's technical superintendent, had made adjustments to the normal operating parameters of the system in order to increase the likelihood of the GPU high pressure pump starting and the system being accepted by the surveyor. Such adjustments may mask critical system defects.

2.9 HAZARDS ASSOCIATED WITH HIGH-EXPANSION FOAM SYSTEMS

The *Hotfoam* system was activated before the AER had been shut down and while crew were in the space fighting the fire. The ship did not have a procedure or policy for activating the system, and command approval was not sought, or the chief engineer consulted, prior to the initial attempts by the 2/E to fill the AER with high-expansion foam. Had the system functioned correctly, the firefighters within the AER would have been placed at significant risk. They would have been unable to see physical hazards and/or communicate effectively, and might have become severely disorientated. The toxic combustion gases entrapped within the foam bubbles would have presented a lethal hazard to anyone not wearing BA. High-expansion foam total flooding systems using inside air should be treated with a similar level of caution to gaseous systems. The compartments should be shut down, all personnel accounted for and command approval sought before they are operated.

The crew had a very limited knowledge of the ship's high-expansion foam system and were unaware of the hazards associated with its use. There is no IMO guidance on the hazards associated with high-expansion foam systems, and the claim in the *Hotfoam* manufacturer's advertising literature, that the foam was harmless to people, was misleading.

It is of concern that the training requirement listed in STCW indicates that it is safe to walk through a foam-filled compartment without wearing BA. In the UK, the MNTB recommends that fire schools teach students about the hazards presented by compartments filled with high-expansion foam, and safe methods for re-entry. However, this is delivered in a variety of ways, and it is apparent that a review of the current situation is required to identify the most effective way of informing seafarers on how to safely use these systems.

2.10 FIRE-FIGHTING

2.10.1 Command and control

Following the initial alarm, the actions taken by the crew to combat the fire were swift and positive. The master immediately mustered the ship's special mobile groups and, when the chief engineer confirmed the location of the fire and advised of the need to black-out the ship, the crew were called to their general emergency stations. In the early stages of the fire the master concentrated on the navigational safety of his ship and organised external communications, while the C/O co-ordinated the fire-fighting effort.

The C/O had recently completed a command and control training course and this was reflected in his performance during the fire. He retained a calm and controlled demeanour throughout and gave clear instructions to the mobile party leaders. However, despite this, the fire-fighting command and control effort was impeded by several factors.

First, top level command aims were not clearly established, and a formal strategy regarding the use of the *Hotfoam* system was not communicated to the chief engineer or the OSC. A fire-fighting strategy should be set as early as possible, and a decision made whether to continue an aggressive attack on a fire or contain it within the space and activate the fixed total flooding fire-extinguishing system. Furthermore, if a continual aggressive attack on a fire cannot be maintained, and the compartment has had to be evacuated and closed down, any subsequent re-entry should be carried out with command approval, in a controlled manner.

Second, the spread of smoke led to the evacuation of the ECR. This was a key strategic command and control location and, once evacuated, communication with the chief engineer and his ECR party became more difficult.

Third, when the decision was made to instruct the OSC to open WTD3, the fire had been contained within the AER, despite the condition of the machinery space openings. The opening of the door provided a continuous supply of air to the fire, and undermined the performance of the *Hi-fog* system.

Fourth, the primary means of communication was via hand-held UHF radios, but communications were hampered by poor radio voice procedures. Command instructions and situation reports were not repeated. Therefore, it was not surprising that several key instructions and reports were not followed, or were misinterpreted. This was evident when the emergency response party monitored and cooled the wrong fire boundary, and the bridge team assumed that smoke had been reported in the fire control station. Communications were further hampered when the radios' batteries began to run out of charge.

Finally, although the master decided not to allow his crew to enter the AER, unless they were wearing BA, until the MIRG team had surveyed the fire damaged spaces and confirmed it was safe to do so, this instruction was not followed. The ship's engineers and technical superintendent were already in the AER, without BA, when the MIRG team arrived in the lower hold. Having extinguished the fires without suffering any casualties, and with the ship in no immediate danger, access to the AER should have been subject to careful preparation, detailed planning and risk assessment.

This was a major machinery space fire in which the fixed fire-extinguishing systems failed to perform as expected. Nonetheless, due to the effectiveness of the shore-based training arranged by Irish Ferries, realistic onboard drills, and the determination and efforts of the ship's crew, the fires were extinguished without injury. The actions and improvisation of the duty ETO to maintain firemain pressure required a degree of bravery, and are commendable.

2.10.2 Emergency fire pump

The emergency fire pump control cables between the ECR panel and the local starter box in the bow thruster space were among those damaged by the fire in the AER. The resulting short-circuit caused the control fuses in the local starter box to blow, causing the total loss of fire main pressure.

This accident shows that *Oscar Wilde* is particularly vulnerable to a fire in the AER. In the first instance, this will result in a loss of electrical power, with the consequent loss of propulsion and power to the main fire pumps. Furthermore, because the electrical control cables for the emergency fire pump are routed across the AER deckhead, a fire in the space is likely to result in a failure of the emergency fire pump. The case to re-route or protect the emergency fire pump control cables is therefore compelling.

2.10.3 Use of ancillary equipment

Thick black smoke within the AER prevented the OSC and the BA teams from initially locating the seat of the fire. Although a thermal imaging camera was available to assist in this task and was used during drills, it was not taken to the scene of the fire on this occasion. However, as its battery was virtually flat, the camera would have been of very limited value.

EEBDs were also available, but were not carried until prompted by the C/O when he realised the extent to which the chief engineer had been exposed to potentially toxic atmospheres. None of the evacuees from the ECR considered taking the compartment's EEBD before leaving the space, and neither the chief engineer nor the 2/E carried EEBDs when they entered smoke-logged spaces to monitor the fire boundaries. EEBDs should never be worn for fire-fighting purposes, but personnel who are particularly at risk of becoming trapped by smoke should consider carrying one as a precautionary measure.

SECTION 3 - CONCLUSIONS

3.1 SAFETY ISSUES DIRECTLY CONTRIBUTING TO THE ACCIDENT WHICH HAVE RESULTED IN RECOMMENDATIONS

1. The fire broke out when fuel oil escaped under pressure from the auxiliary engine fuel module's pressure regulating valve actuator and came into contact with an exposed high-temperature surface on the adjacent auxiliary engine. [2.2]

2. The auxiliary engine fuel oil module excess pressure regulating valve actuator diaphragm perished and ruptured because it had been manufactured from a non-oil resistant rubber, and therefore was not fit for purpose. [2.3]

3. The fire was not contained within the AER because heat from the fire was conducted through an un-insulated section of the fire boundary to electric cables on the deck above. [2.6.3]

4. Several spaces above the AER were incorrectly classified at build and were not protected by thermal insulation in accordance with SOLAS requirements. [2.6.3]

5. The performance of the local application water-mist system was probably adversely affected by a delay in activating the system, the inadequate production of water-mist, interruptions to the supply of water-mist, a reduced duration of operation and/or the lack of system water-mist coverage above the seat of the fire. [2.7.1]

6. The machinery space high-expansion foam fixed fire-extinguishing system was fully discharged into the AER, but failed to produce any foam because its discharge nozzles were clogged with rust from the internal corrosion of the dry pipe distribution network. [2.7.2]

7. The high-expansion foam system distribution pipe network was fabricated from mild steel and was not self-draining, therefore it was extremely susceptible to corrosion. [2.7.2]

8. The fire-fighting effort was impeded by the intermittent loss of fire main pressure due to the emergency pump control cables within the AER being damaged by the fire. [2.10.2]

3.2 OTHER SAFETY ISSUES IDENTIFIED DURING THE INVESTIGATION ALSO LEADING TO RECOMMENDATIONS

1. The crew were unaware of the hazards to personnel in compartments containing high-expansion foam. There is no IMO guidance on the hazards associated with the use of high expansion foam systems, and current STCW training requirements regarding their use are potentially unsafe. [2.9]

3.3 SAFETY ISSUES IDENTIFIED DURING THE INVESTIGATION WHICH HAVE NOT RESULTED IN RECOMMENDATIONS BUT HAVE BEEN ADDRESSED

1. When running on MGO, the configuration of the auxiliary engine fuel oil system on board *Oscar Wilde* was unsafe. The isolation of the service tank return line resulted in the loss of automatic pressure regulation. [2.4]

2. The valve actuators fitted to the fuel module pressure regulating valves did not have rupture safety devices, and therefore failure would always result in fuel oil escaping under pressure into the machinery spaces. [2.5]

3. The high-temperature surfaces on No.3 auxiliary engine were not fully insulated or shielded. [2.5]

4. The curtain fitted around the auxiliary fuel module to prevent oil spray coming into contact with heated surfaces was not in place when the diaphragm failed. [2.5]

5. Smoke spread rapidly from the AER to the ECR and adjacent compartments on deck 2 because the machinery space deck penetrations had not been packed correctly. [2.6.2]

6. Smoke spread to the passenger accommodation areas because the crew were unaware of the location of the ventilation system fire dampers and had no onboard guidance to assist them. [2.6.2]

7. The high-expansion foam system had been surveyed and tested in accordance with the manufacturer's instructions and current IMO guidelines. However, it is apparent that full compliance with these requirements, which includes blowing through with compressed air, will not guarantee the reliability of these safety critical systems. [2.7.2]

8. The bilge foam flooding system failed to extinguish the fires in the bilge because the system had been charged with the wrong type and quantity of foam concentrate prior to the ship sailing. [2.7.3]

9. The fixed fire-extinguishing systems had not been maintained in accordance with the manufacturers' instructions and the ship's PMS schedules. [2.8.2]

10. The ship did not have an operating procedure or policy for its high-expansion foam fire-extinguishing system. [2.9]

11. The fire-fighting command and control efforts were adversely affected by the absence of top level command aims, the loss of the ECR to smoke, a lack of knowledge of the fixed fire-extinguishing systems, and poor radio communication voice procedures. [2.10.1]

SECTION 4 - ACTION TAKEN

The **Marine Accident Investigation Branch** has:

- Issued Safety Bulletin 2/2010 **(Annex K)** to inform the shipping industry of the failure of the high-expansion foam fixed fire-extinguishing system and raise awareness of the potential for, and consequences of, corrosion within the system pipework. The bulletin included recommendation **S109/2010**:

  Owners of ships fitted with high expansion foam systems utilising the atmosphere from within a protected space are recommended to urgently:
  - Remove and inspect all foam generator nozzles to ensure they are free from debris.
  - Inspect sections of distribution pipework in which water or foam solution might collect and to fit drains where appropriate.

The **Bahamas Maritime Authority** has:

- Brought to the attention of the International Maritime Organization (IMO) Sub-committee on Fire Protection, in April 2010, the need to urgently review current requirements for the installation and testing of the distribution pipework of high expansion foam systems using inside air, with regard to:
  - The inspection of nozzles following blow through tests
  - The elimination of potential liquid traps
  - Consideration of the need to flush systems with fresh water periodically.

The **IMO's Sub-committee on Fire Protection** has:

- Amended proposed changes to the FSS Code to reflect the issues raised by the BMA. Revised amendments to chapter 6 of the FFS Code include:
  - Distribution pipework shall have a self-draining capability, and
  - Nozzles shall be able to be removed for inspection.

The **Maritime and Coastguard Agency** has:

- Reviewed the training delivered by the UK's fire-fighting schools to ensure they meet the requirements for high-expansion foam systems set out in the MNTB's course criteria.

Wilhelmsen Ships Equipment Ltd. has:

- Issued pipe installation procedures for high-expansion systems to:
  - Meet the requirements laid down in MSC.1/Circ.1271.
  - Eliminate potential water traps.

- Modified and reissued its commissioning and operating procedures to reflect the need to:
    - Check the material grade of the distribution pipe network.
    - Flush the system with fresh water and dry with compressed air after initial installation, activation or test.
- Modified and reissued its service procedures to reflect the need to:
    - Flush the system with fresh water and dry with compressed air periodically (5 yearly or during docking periods)
    - Remove and inspect ⅓ to ½ of the nozzles from each separate distribution line leading to protected space(s) following the annual blow through of the distribution network with compressed air (the nozzles should be removed at several different positions so as to give representative feedback of all nozzle conditions).
- Compiled a list of *Hotfoam* installations fitted to vessels and has undertaken to carry out a program of random inspections on selected vessels to:
    - Check that foam generator nozzles are not blocked
    - Identify potential water traps and appropriate locations to fit drain valves.
- Undertaken to include guidance in its operations manuals on the hazards to personnel in compartments containing high-expansion foam.
- Recommended Irish Ferries to:
    - Install drainage valves at the lowest points in the distribution pipe network.
    - Re-install the distribution pipework to avoid water traps.

Marioff Oy has:

- Recommended Irish Ferries install additional gas bottles to *Oscar Wilde*'s *Hi-fog* system.
- Re-instated the *Hi-fog* and bilge foam systems and returned the control and alarm points to their original design settings.
- Has undertaken to:
    - Issue a service bulletin to make *Hi-fog* operators aware of the importance of ensuring regulator isolation valves, control valves, stop valves and switches are kept in the correct position.
    - Improve its operating instructions.
    - Investigate the root cause of heat damage to the port AER section control valve solenoid.
    - Improve services offered to its customers during changes in vessel ownership.

Dobson Fleet Management on behalf of **Irish Ferries** has:

- Replaced the auxiliary engine fuel module and removed the black-out tank.
- Replaced the main engine fuel modules' excess pressure regulating valves with valves fitted with oil resistant diaphragms, leakage glands and leak indicators.
- Replaced the main engine fuel modules' copper pipework with steel pipework.
- Renewed the fuel module pressure switches.
- Installed a steel fuel spray shield between the fuel module and No.3 auxiliary engine.
- Reconditioned the auxiliary engines' exhaust shields and renewed their turbo-charger lagging pads.
- Extended the A-60 thermal insulation to cover all AER boundaries.
- Provided an alternative means of starting the emergency fire pump in circumstances when its control circuit is compromised.
- Undertaken to re-route the control cable between the ECR and the emergency fire pump to outside the AER during *Oscar Wilde*'s next docking period.
- Surveyed the cable glands and deck penetrations between the AER and ECR and made good the deficiencies identified.
- Chemically cleaned the *Hotfoam* distribution network and fitted additional drainage and flushing valves.
- Produced a detailed operating procedure for the *Hotfoam* system.
- Delivered additional training to the ship's crew in order to increase awareness of the fixed fire-extinguishing systems.
- Reviewed and amended the ship's PMS schedules for the fixed fire-extinguishing systems.
- Reviewed and amended the bridge team's decision support card system.

It has also undertaken to:

- Investigate the options of either replacing the *Hotfoam* distribution pipework, or replacing the *Hotfoam* system with an alternative total flooding system.
- Develop a high risk compartment fire control card system which will include critical information about fire-fighting equipment, ventilation shut down and electrical isolation.
- Provide additional bespoke fire-fighting command and control training for all key personnel on board its ships.

SECTION 5 - RECOMMENDATIONS

The **Bahamas Maritime Authority** is recommended to:

2011/105 Make a submission to the IMO proposing appropriate amendments to the STCW to ensure training syllabi covering fire fighting procedures identify the hazards posed by all types of high-expansion foam fire-extinguishing systems.

2011/106 Verify that *Oscar Wilde* complies with SOLAS requirements with regard to:

- The control of smoke spread and ventilation, and
- Thermal and structural boundaries,

and satisfy itself that the vessel's *Hotfoam* distribution network can be relied upon in an emergency situation, taking into account the changes to the service procedures implemented by the system's manufacturer.

Lloyd's Register is recommended to:

2011/107 Issue a classification newsletter to its clients advising of the circumstances of the fuel system failure on *Oscar Wilde* and providing guidance on how to establish if the correct type of diaphragm has been fitted to Samson type 41-73 back pressure regulating valves.

Irish Ferries is recommended to:

2011/108 Fully implement the recommendations made by the manufacturers of the fixed fire-extinguishing systems on board *Oscar Wilde*.

March 2011
Marine Accident Investigation Branch

Safety recommendations shall in no case create a presumption of blame or liability