

Report on the investigation of a fire
in the engine room on the
suction dredger

Arco Avon

12 miles off the coast of Great Yarmouth
resulting in one fatality
on 18 August 2015



Extract from
The United Kingdom Merchant Shipping
(Accident Reporting and Investigation)
Regulations 2012 – Regulation 5:

“The sole objective of the investigation of an accident under the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 shall be the prevention of future accidents through the ascertainment of its causes and circumstances. It shall not be the purpose of an investigation to determine liability nor, except so far as is necessary to achieve its objective, to apportion blame.”

NOTE

This report is not written with litigation in mind and, pursuant to Regulation 14(14) of the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012, shall be inadmissible in any judicial proceedings whose purpose, or one of whose purposes is to attribute or apportion liability or blame.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

AB	-	Able Seaman
ANSI	-	American National Standards Institute
AVR	-	Automatic Voltage Regulator
BA	-	Breathing apparatus
BST	-	British Summer Time
CAT Scan	-	Computerized axial tomography scanner
cm	-	centimetre
CO ₂	-	Carbon dioxide
COSWP	-	Code of Safe Working Practices for Merchant Seamen consolidated edition 2010 ¹
DoC	-	Document of Compliance
FR	-	Fire retardant
FRS	-	Fire and Rescue Service
HAML	-	Hanson Aggregates Marine Limited
HSE	-	Health and Safety Executive
IMO	-	International Maritime Organization
ISM	-	International Safety Management (Code)
kg	-	kilogramme
kW	-	kilowatt
“Mayday”	-	A word used internationally as a distress signal in voice radio communication meaning the prefix to “Grave and Imminent Danger to a Person, Ship, Aircraft or Other Vehicle Requiring Immediate Assistance”
MCA	-	Maritime and Coastguard Agency
MCR	-	Machinery control room
mg	-	milligramme
MGN	-	Marine Guidance Note
MGO	-	Marine gas oil
mm	-	millimetre
MSN	-	Merchant Shipping Notice

¹ Replaced with Code of Safe Working Practices for Merchant Seafarers 2015 edition in September 2015.

NCN	-	Non-conformance note
NFRS	-	Norfolk Fire and Rescue Service
OOW	-	Officer of the watch
PMS	-	Planned maintenance system
PPE	-	Personal protective equipment
PPE 99	-	The Merchant Shipping and Fishing Vessels (Personal Protective Equipment) Regulations 1999
PTO	-	Power take-off
PTW	-	Permit to Work
RNLI	-	Royal National Lifeboat Institution
s	-	second
SCMG	-	Ship Captain's Medical Guide
SMC	-	Safety Management Certificate
SMS	-	Safety management system
STCW	-	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended
UMS	-	Unmanned machinery space
UTC	-	Universal co-ordinated time
V	-	Volt
VDR	-	Voyage Data Recorder
VHF	-	Very high frequency

TIMES: all times used in this report are BST (UTC +1) unless otherwise stated

SYNOPSIS



At 2312 on 18 August 2015, a fire broke out in the engine room of the dredger *Arco Avon* while the vessel was loading a sand cargo approximately 12 miles off Great Yarmouth, UK. *Arco Avon*'s third engineer, Anthony Jones, was badly burned in the fire and later died as a result of his injuries. As a consequence of the fire, which was extinguished following activation of the CO₂ smothering system, the vessel lost all power and remained at anchor with its dredging equipment partially deployed for 9 days until it could be taken under tow and delivered to a repair facility.

The MAIB investigation concluded that:

- The third engineer was attempting to repair a failed fuel pipe when fuel, under pressure in the pipe, ignited.
- No one else on board was aware of a failed fuel pipe or that the third engineer had apparently decided to repair it.
- The third engineer was using a portable angle grinder to access the repair site, and had underestimated the risk of doing so.
- Possible contributing factors to the third engineer's underestimation of risk were that he had neither carried out a formal risk assessment nor sought a permit to work prior to commencing the repair.

The Maritime and Coastguard Agency has taken actions to review and update:

- The Code of Safe Working Practices for Merchant Seafarers to address the hot work hazard of sparks generated by the use of fixed and portable angle grinders.
- Merchant Shipping Notice 1870 (M+F) to introduce an appropriate standard for overalls for work in engine rooms or other area where there is a risk of fire.
- The Ship Captain's Medical Guide to provide clear guidance on the appropriate medical treatment for serious burns.

The Maritime and Coastguard Agency has been recommended to more widely promulgate the contents of IMO Circular MSC.1/Circ.1321 i.e. that owners and operators conduct periodic inspections of low pressure fuel system components. Bureau Veritas has been recommended to advise its surveyors of the contents of the circular.

Hanson Aggregates Marine Limited has been recommended to review and, as appropriate, amend its safety management system to ensure, inter alia, that manning levels, watchkeeping duties and communication procedures provide for safe engine room operations at all times.

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF ARCO AVON AND ACCIDENT

SHIP PARTICULARS	
Vessel's name	<i>Arco Avon</i>
Flag	United Kingdom
Classification society	Bureau Veritas
IMO number/fishing numbers	8508383
Type	Suction dredger
Registered owner	Hanson Aggregates Marine Limited
Manager(s)	Hanson Aggregates Marine Limited
Construction	Steel
Year of build	1986
Length overall	98.6m
Registered length	92.74m
Gross tonnage	3474
Minimum safe manning	8
Authorised cargo	Dredge spoil
VOYAGE PARTICULARS	
Port of departure	Dagenham
Port of arrival	Dagenham (planned)
Type of voyage	Commercial
Cargo information	Sand
Manning	10
MARINE CASUALTY INFORMATION	
Date and time	18 August 2015, 2312
Type of marine casualty or incident	Very Serious Marine Casualty
Location of incident	Approximately 12 miles off Great Yarmouth, UK
Place on board	Engine room
Injuries/fatalities	1 fatality
Damage/environmental impact	Fire damage to engine room power cabling and control systems. Smoke damage throughout engine room.
Ship operation	Loading (dredging)
Voyage segment	Mid-water
External & internal environment	Wind: F4, sea state: moderate
Persons on board	10



Arco Avon

1.2 NARRATIVE

1.2.1 Pre-accident events

At approximately 1200 on 18 August 2015, *Arco Avon* left Dagenham and proceeded along the east coast of the UK to its designated loading area. Loading involved dredging within a defined geographical box, designated '240' by The Crown Estate², located approximately 12 nautical miles off Great Yarmouth. The dredging operation usually took about 5 hours to complete. At 2000, approximately 1 hour before arrival at the loading area, the officer of the watch (OOW) called the third engineer to prepare the machinery for loading. The third engineer then proceeded to the engine room and changed the alarm and monitoring system from its remote, unmanned configuration, to local control for manned machinery space operations. He then started No.2 generator and transferred the vessel's electrical load from the shaft alternator on to No.2 generator and prepared the dredging pump which would be powered by the shaft alternator. The normal arrangement for power distribution during loading operations would have been for No.3 generator to provide power for the vessel's services with the shaft alternator supplying power for the dredging pump. Due to a defect on No.3 generator's voltage regulator this machine was unavailable for use. Loading commenced at approximately 2124, after which there was no further communication between the bridge team and the third engineer prior to the accident.

² The Crown Estate is a diverse portfolio of UK buildings, shoreline, seabed, forestry, agriculture and common land that generates revenue for the government each year.

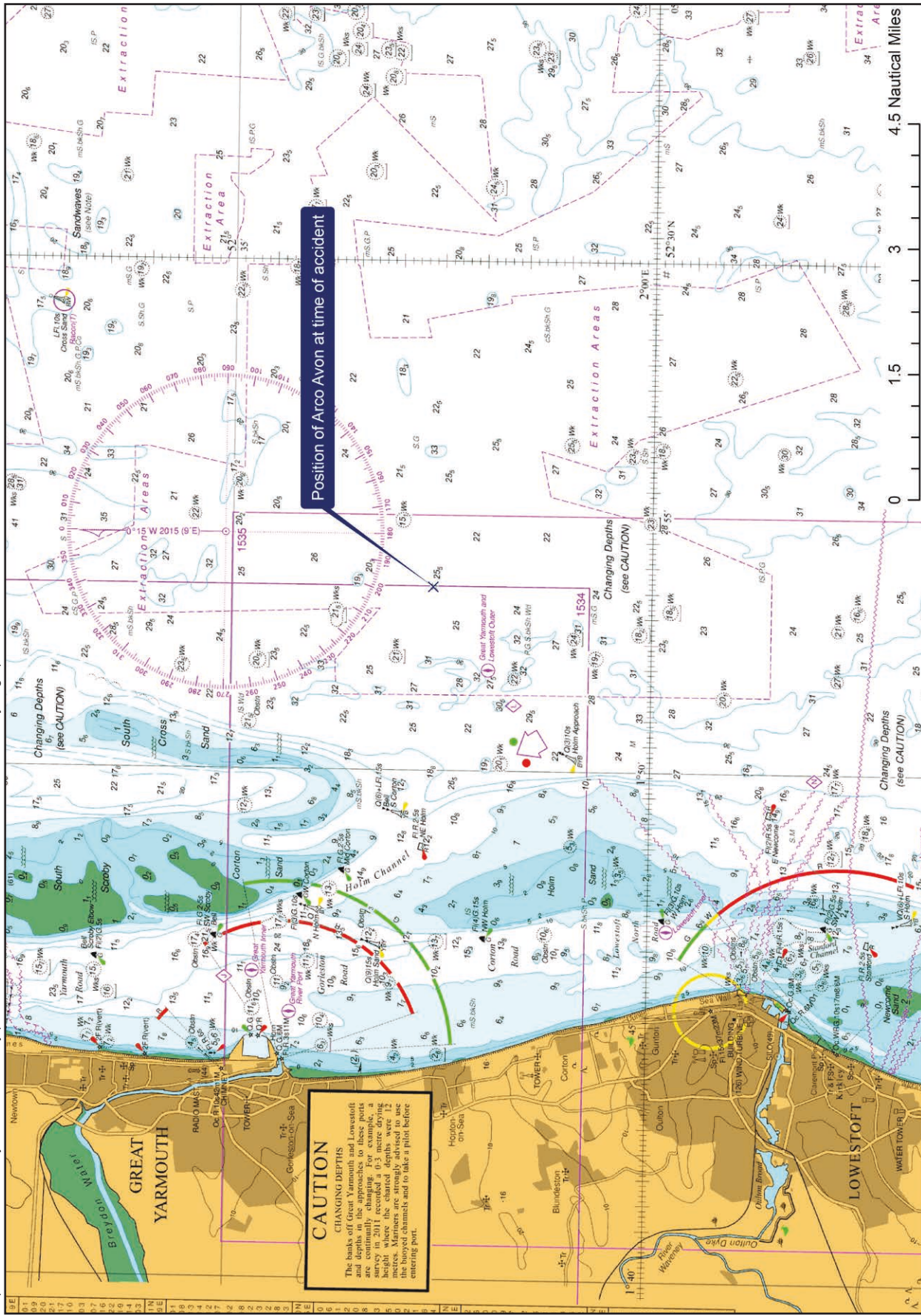


Figure 1: Chart showing location of accident

1.2.2 The accident

Loading proceeded as planned until 2312, when a fire detector activated. The fire detection panel on the bridge indicated that the fire was within the engine room. The alarm was reset on the fire detection panel, which was situated on the bridge, but it immediately reactivated, sounding throughout the accommodation on each occasion. The alarm was then reset again but it activated for a third time, alerting the rest of the crew, some of whom had already responded to the initial alarm and had proceeded to the bridge. The remaining crew then mustered rapidly on the bridge, which was the designated emergency station, with the exception of the third engineer, who was on watch alone in the engine room, and the chief officer, who was asleep following his period of duty.

The master looked aft as the crew were mustering and noted smoke coming from engine room vents (**Figure 2**). Having established that there was a fire in the engine room, the master immediately made two telephone calls to the engine room, both of which were unanswered. Following a discussion with the master, the chief engineer was about to leave for the engine room to investigate further when the third engineer telephoned the bridge. He told the chief engineer that there was a fire in the vicinity of No.2 generator and that he had been hurt. The chief engineer told him to evacuate the engine room. The call had been made from the machinery control room (MCR), which meant that the engineer had to re-enter the engine room and exit through the fire as there was no direct escape route from the MCR.



Figure 2: Port engine room vent

The master ordered the designated fire team to dress in fire suits and breathing apparatus (BA) in preparation to fight an engine room fire. The team consisted of the second engineer and an able seaman (AB). The chief engineer left the bridge and went aft to assume the role of on-scene commander. He was accompanied by the bosun, whose role was to shut the engine room ventilation flaps.

At approximately 2214 the master began to recover the dredging equipment as it was essential to raise the dredge pipe off the seabed while the vessel still had sufficient electrical power so as to prevent significant damage. Approximately 1 minute later, once the pipe was clear of the seabed, he stopped the dredging pump. These actions were carried out concurrently with fire-fighting preparations.

As the chief engineer and the bosun reached the aft end of the main deck, they met the third engineer, who had just exited the engine room through the doorway to the main deck (**Figure 3a**). His clothes appeared to have been burned off, and he was showing obvious signs of physical trauma, but he was able to walk unaided. He spoke briefly to the chief engineer, repeating the information relayed in his earlier telephone call. The chief engineer told the bosun to take the third engineer to the crew mess room and to summon first-aid assistance; he then relayed this information to the master via a portable very high frequency (VHF) radio. At approximately 2322, as the bosun and third engineer were crossing the main deck, the vessel's main power supply failed, leaving the deck in darkness. After a few seconds, power was briefly restored but then failed again. Several seconds later, the emergency generator started, restoring emergency lighting. The bosun and the third engineer were then able to continue to the mess room, where the third engineer was left in the care of the cook. The bosun then returned to the aft end of the main deck to continue closing the machinery space ventilation flaps. The chief engineer had remained at the aft end of the main deck and opened the engine room access door. He was met by dense smoke and heat, and concluded that the fire team would be unable to enter the engine room.

When the main electrical power failed at 2322, the voyage data recorder (VDR) ceased recording and power for recovery of the dredging equipment was lost.

The second engineer dressed in a fire suit and BA, which was located on the bridge, while the fire team AB went to the forward machinery access void space to collect an additional fire suit and BA. The AB then took his equipment to the crew mess room, where the cook and another AB helped him to dress. The plan was for the fire team to proceed along one of the two tank top void spaces and enter the engine room through the door at the aft end of the void (**Figure 3b**). The chief officer had assisted the second engineer to dress and had left the bridge with him to take control of the fire team. However, the second engineer went ahead and proceeded alone along the starboard void space.

The chief officer began preparations to rig a fire-fighting hose, for use by the fire team, from a hydrant at the forward end of the starboard void space.

On arrival at the engine room entrance the second engineer opened the access door and quickly realised that the prevailing heat and smoke would prevent the fire team from entering the space. Aware that he was detached from the team and without means of communication, he closed the engine room door and began to retreat back along the starboard void. On reaching the forward end of the void, he met the fire team AB. The second engineer explained the situation to the AB,

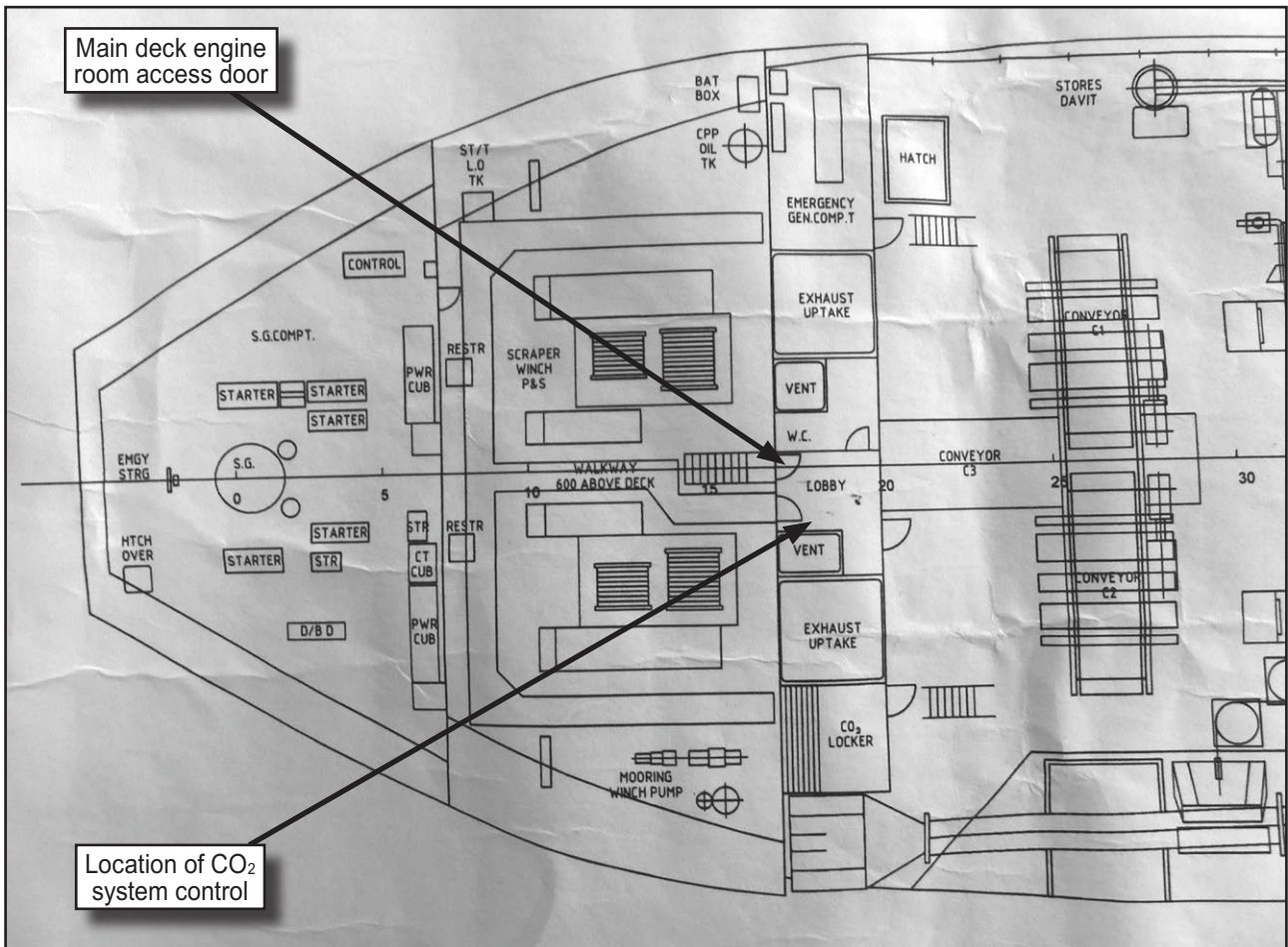


Figure 3a: Engine room main deck access

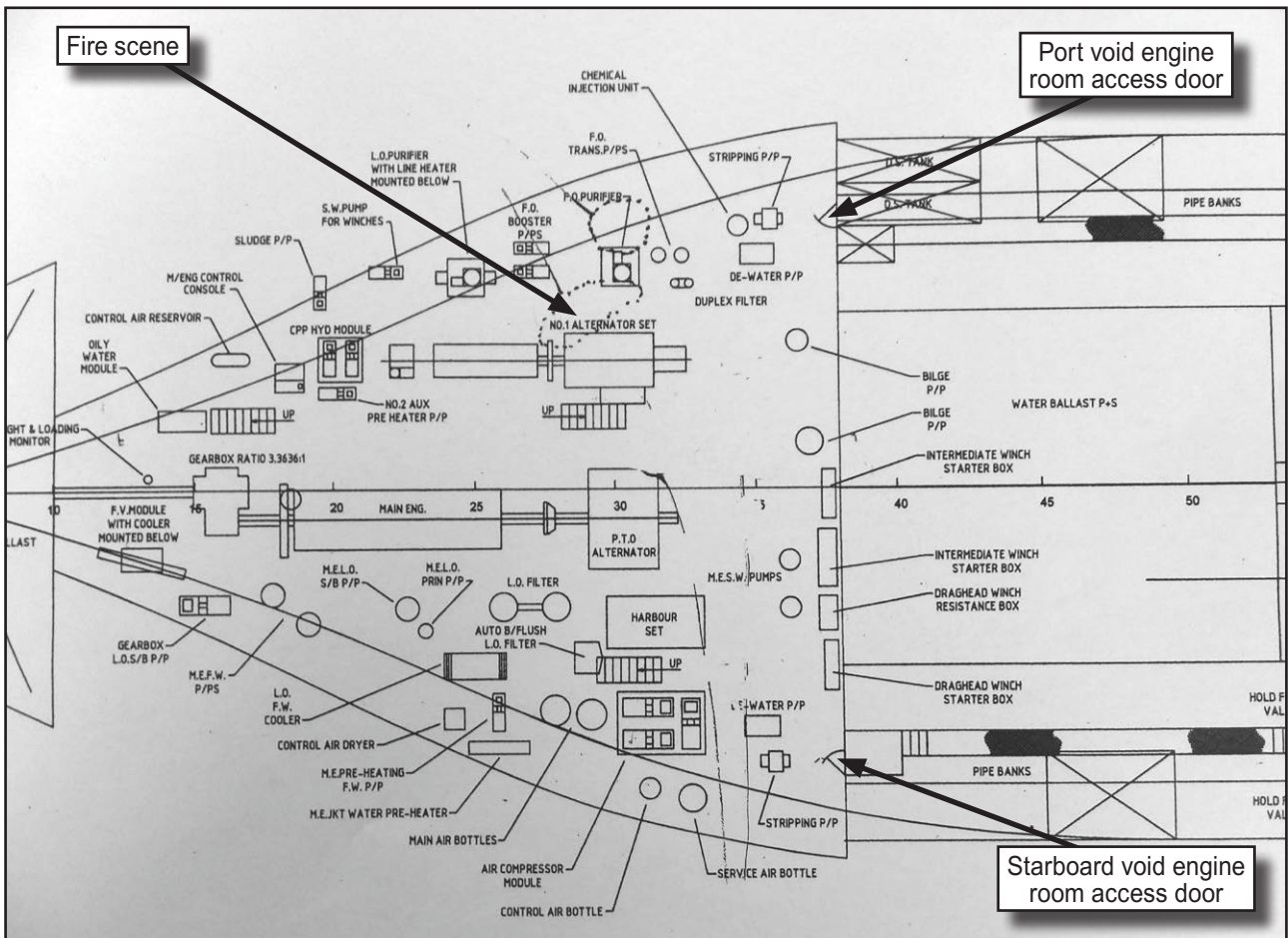


Figure 3b: Engine room tank top

following which the two firefighters reported their findings to the chief officer. The chief officer then contacted the master using VHF radio and passed the information that the fire team were unable to enter the engine room.

At 2325, the master broadcast a "Mayday". He followed this up at 2336 with a request for evacuation of an injured crew member. Humber Coastguard responded by tasking a rescue helicopter and a Royal National Lifeboat Institution (RNLI) all-weather lifeboat to stand by.

The chief engineer reported by VHF radio to the master and recommended that the engine room CO₂ fixed fire-extinguishing system be activated to extinguish the fire. The master required a personnel muster to be completed before he would give approval to activate the CO₂ system. Completion of the muster was delayed as a result of some confusion regarding the location of the second engineer. Once approval had been given, the chief engineer operated the CO₂ system from its remote operating position in the main deck engine room access lobby.

The chief engineer believed that the CO₂ system had functioned correctly; however he went to the CO₂ cylinder room to check. He found that approximately 50% of the cylinders had failed to operate, which he then manually activated. At 2338 the master reported to the Coastguard that CO₂ flooding of the engine room had been carried out.

Following operation of the CO₂ system, the crew focused their efforts on containment of the fire through engine room boundary cooling and temperature monitoring. The only cooling required was on the main deck, directly above the seat of the fire. Water for boundary cooling was supplied by the vessel's diesel-driven emergency fire pump that was located in the forward machinery space. During this period, the port anchor was deployed to ensure that the vessel remained in a navigationally safe position.

The third engineer remained in the crew mess room accompanied by the cook, who had been designated the first-aider. Although visited by several members of the crew, including the master, his medical care was left solely to the cook and this was limited to the provision of liquid refreshment in the form of fruit squash.

At 2352, the master reported to the Coastguard that the fire was under control, the engine room had been shut down and that the surrounding decks were cooling. The master reiterated concern over the serious condition of the third engineer and, at 2356, the Coastguard gave an estimated time of arrival of 15 minutes for an RNLI lifeboat and 35 minutes for a rescue helicopter.

At 0013 on 19 August, two crew from the Gorleston RNLI lifeboat, one of whom was a paramedic, boarded *Arco Avon*. The paramedics assessed the third engineer's condition and commenced medical treatment, which included administration of medical oxygen and pain relief medication.

Following the arrival on scene of rescue helicopter R912, discussions between the helicopter pilot and the master identified the stern of the vessel as the most appropriate area for winching operations. The third engineer was placed in a stretcher and, with some difficulty, he was manoeuvred along the deck to the agreed winching position. At 0137, R912 departed for the Norfolk and Norwich University Hospital with the third engineer embarked. However, despite further medical treatment, the third engineer died of his injuries later that day.

As a result of discussion between the Coastguard and Norfolk Fire and Rescue Service (NFRS), consideration was given to airlifting a fire-fighting team out to the vessel. However, at 0250, the master reported to the Coastguard that the fire had been extinguished and that the situation on board was under control. Following this, the Coastguard released all search and rescue units from the scene and the decision was made that the NFRS team would board the vessel as it arrived in port.

The vessel's owner, Hanson Aggregates Marine Limited (HAML) arranged for a tug, *Sea Beaver*, to stand by *Arco Avon* in case further assistance was required. *Arco Avon* remained at anchor overnight with all of its remaining crew on board.

1.2.3 Post-accident events

It was initially intended that *Arco Avon* would be towed into Great Yarmouth to allow an assessment of the damage and a forensic examination of the fire scene. However, owing to the vessel's increased draught as a result of its partially deployed dredging equipment, there was insufficient depth of water for it to enter Great Yarmouth. The dredging equipment could not be recovered due to a lack of electrical power and possible damage to the vessel's main switchboard, which was located in a compartment within the engine room and could not therefore be accessed. Despite an examination by a salvage team who had been appointed by the owners, an alternative method of recovering the equipment safely could not be identified.

On the evening of 19 August, some of *Arco Avon*'s crew departed the vessel, leaving the master, chief engineer, second engineer and chief officer on board with a tug standing by in attendance. The crew noted that water was entering the engine room bilges. It was concluded that a seawater-fed cooler in the vicinity of the seat of the fire was the most likely cause of sea water ingress. During the dredging operation the main sea water suction intakes had been changed over from the main engine room to the forward machinery space to reduce contamination caused by the dredging process. This meant that the crew were able to enter the forward machinery space and close the sea water isolation valves to stem the leak. A salvage pump was provided by the tug to allow removal of the flood water. On the evening of 20 August the master, chief engineer, second engineer and chief officer were replaced by a relief crew.

In view of a forecast of deteriorating weather and high winds for the area, a salvage operation was initiated by HAML and, on 22 August, the vessel was towed to a sheltered anchorage. *Arco Avon* was taken to a repair/layby berth in Hull on 27 August.

1.3 ENVIRONMENTAL CONDITIONS

At the time of the accident, weather conditions were good, with a moderate sea state and force 4 winds.

1.4 VESSEL, EQUIPMENT AND MANNING

1.4.1 Vessel background

Arco Avon was a suction dredger operated by HAML, the UK marine division of the Heidelberg Cement Group. The vessel was constructed in 1986 and was the first of four sister vessels built by Appledore Shipbuilders Limited.

The vessel was built to the requirements of The Merchant Shipping (Cargo Ship Safety Construction and Survey) Regulations 1984 and The Merchant Shipping (Fire Protection) Regulations 1984. Compliance with the regulations was verified under survey by Bureau Veritas (BV).

Arco Avon was classed by BV for dredging up to a distance of 15 miles offshore. The vessel's recent operations had involved loading sand and gravel off the coast of Great Yarmouth and discharging the cargo at Dagenham.

1.4.2 Machinery

Propulsion

Arco Avon's propulsion comprised a Mirrlees Blackstone KMR6 Mk3, 4 stroke, single acting, 6 cylinder in line diesel engine driving a controllable pitch propeller through a reduction gearbox. At the free end of the engine, was a power take-off (PTO) driving a shaft alternator (known on board as No.1 generator) through a flexible coupling. The shaft alternator supplied 1,800kW at 660V.

Auxiliary generators

Arco Avon was equipped with two auxiliary generators:

- A Mirrlees ESL 8 Mk II 8 cylinder engine rated at 1065kW (known on board as No.2 generator) that generated electricity at 660V.
- A Caterpillar 3408 DI-TA 8 cylinder engine (designated the harbour generator on the vessel's plans, although known on board as No.3 generator), that generated electricity at 415V.

Generator configuration

Arco Avon's electrical supply and distribution system could be configured in a number of different ways to suit particular operations. When in transit, all electrical power was provided by the shaft alternator through a step down transformer to 415V to supply the vessel's services. When loading, the shaft alternator provided power directly to the dredging pump, which required 660V, with all other services supplied by No.3 generator. When discharging, No.2 generator provided all required electrical power.

At the time of the accident, *Arco Avon's* No.3 generator was out of service due to a fault with its automatic voltage regulator (AVR) that limited the supply voltage to about 380V. This prevented it from being synchronised with the other generators. Although spare parts to rectify the defect had been delivered before the vessel's departure from Dagenham on 18 August, these were found to be incorrect and the fault was not repaired.

The chief engineer conducted an impact assessment and concluded that the vessel could continue to operate. The defect meant that loading operations would be carried out using the shaft alternator to supply power for the dredge pump and No.2 generator to supply the rest of the electrical load. However, the lack of redundancy meant that if any further electrical faults developed, dredging operations would have to be curtailed. The master concurred with the assessment but the operational

programme was amended to carry a sand load to Dagenham instead of a mixed load of sand and gravel to Belgium. This was to allow service engineers to meet the vessel at Dagenham and repair the defective AVR.

1.4.3 Fuel system

Arco Avon's main engine and auxiliary generators ran on marine gas oil (MGO), commonly referred to as diesel. Fuel was stored in two wing bunker tanks, treated directly through a centrifugal purifier, and transferred to two daily service tanks (**Figure 4**).

Fuel for the main engine was pumped from the service tanks via booster pumps to a main engine fuel supply rail, from which high pressure injection pumps took their suction. Surplus fuel was returned to the suction side of the booster pumps via a pressure regulating valve designed to maintain the return side of the system at a minimum pressure of approximately 1.8 bar.

The auxiliary generator engines' fuel supplies were gravity-fed directly from the service tanks with returns directed back to these tanks.

The fuel system pipework was manufactured from steel and complied with ANSI³ schedule 40, which classified it as a 1½ inch (38mm) pipe, with an outside diameter of 1.90 inches (48mm) and a wall thickness of 0.15 inch (4mm). The pipe ran beneath the engine room floor plates on the outboard side of No.2 generator. It was supported along its length by steel hoop brackets, clamping it against support stanchions.

1.4.4 Engine room CO₂ fixed fire-extinguishing system

The engine room fixed fire-extinguishing arrangements were provided by a Kidde CO₂ smothering system. The system comprised 23 x 45kg CO₂ cylinders arranged for simultaneous release that was designed to achieve a ≥40% by volume concentration of CO₂ in the space. The CO₂ cylinders were located in a dedicated storage room on the starboard side at the aft end of the main deck (**Figure 5**).

The amount of CO₂ needed to reduce the oxygen level to a point at which fuels are prevented from burning varies depending upon the properties of individual fuels. To ensure that smothering systems are effective, the concentration of CO₂ required is relatively high (40% in a marine environment) and this therefore results in an atmosphere which cannot sustain human life.

The CO₂ system was activated from an operating cabinet located in the access lobby to the engine room at the aft end of the main deck (**Figure 6**). The cabinet door was kept locked with a key available in a 'break glass' box on the front of the cabinet. Opening the cabinet automatically sounded an alarm and stopped the engine room ventilation fans. Inside the cabinet were two pilot cylinders, each with its own isolation valve, and two main system valves. Valve A was operated to open the discharge manifold to the engine room distribution pipework. Valve B was then opened to allow gas pressure from the pilot cylinders to operate a piston in the discharge valve fitted to each of the main cylinders (**Figure 7a**) which, in turn, allowed gas from the main cylinders into the discharge manifold. If the remote operation failed, the discharge manifold valve could be opened locally in the CO₂ cylinder room (**Figure 7b**) and the main CO₂ cylinders could be opened manually.

³ American National Standards Institute.

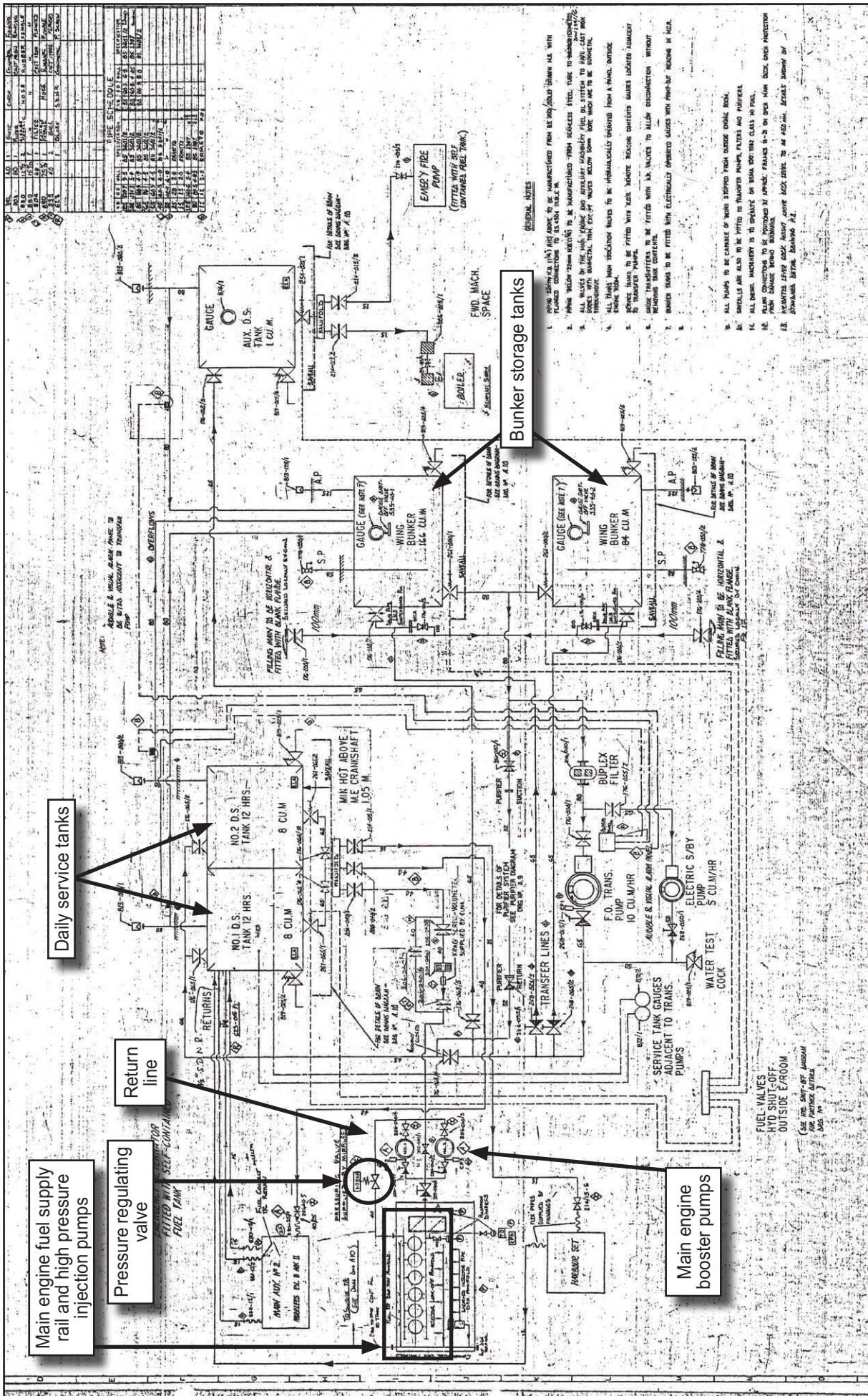


Figure 4: Fuel system

Main engine fuel supply rail and high pressure injection pumps

Pressure regulating valve

Return line

Daily service tanks

Bunker storage tanks

Main engine booster pumps

GENERAL NOTES

1. PIPE SCHEDULE (NOT LISTED ABOVE) TO BE MANUFACTURED FROM HEAVY DUTY STEEL WITH FLANGED CONNECTIONS TO EXCEPT THIS IS.
2. WHEN "BLOW THROUGH VALVES" IS MANUFACTURED FROM STEEL, FITTED TUBE TO MANUFACTURE.
3. ALL VALVES IN THE MAIN ENGINE AND AUXILIARY MACHINERY FUEL SYSTEM TO BE CAST IRON THROUGHOUT. SUBJECT TO THE EXCEPT NOTES BELOW SOME VALVES MAY BE OF STEEL.
4. ALL BLOW THROUGH VALVES TO BE HYDRAULICALLY TESTED FROM A WIND TUNNEL.
5. SERVICE VALVES TO BE FITTED WITH KEYS. SERVICE VALVE KEYS TO BE KEYS LOCATED ADJACENT TO SERVICE VALVES.
6. SERVICE VALVES TO BE FITTED WITH KEYS TO ALLOW DISCONNECTION WITHOUT SERVICE VALVES.
7. BUNKER TANKS TO BE FITTED WITH ELECTRICALLY OPERATED VALVES WITH PUMP BY ROOMS IN EACH.
8. ALL PUMPS TO BE CAPABLE OF WITH STANDING FROM OUTSIDE ENGINE ROOM.
9. BATTERIES ARE ALSO TO BE FITTED TO TRANSFER PUMPS, FILTERS AND PURIFIERS.
10. ALL DECK MACHINERY IS TO OPERATE ON BUNKER TANK CLASS IN FUEL.
11. FUEL CONDUITS TO BE PROVIDED BY APPROX. 150mm DIA. IN EACH MAIN DECK WITH PROTECTION FROM DAMAGE BY SHARP OBJECTS.
12. FUEL CONDUITS TO BE PROVIDED BY APPROX. 150mm DIA. IN EACH MAIN DECK WITH PROTECTION FROM DAMAGE BY SHARP OBJECTS.
13. FUEL CONDUITS TO BE PROVIDED BY APPROX. 150mm DIA. IN EACH MAIN DECK WITH PROTECTION FROM DAMAGE BY SHARP OBJECTS.
14. FUEL CONDUITS TO BE PROVIDED BY APPROX. 150mm DIA. IN EACH MAIN DECK WITH PROTECTION FROM DAMAGE BY SHARP OBJECTS.
15. FUEL CONDUITS TO BE PROVIDED BY APPROX. 150mm DIA. IN EACH MAIN DECK WITH PROTECTION FROM DAMAGE BY SHARP OBJECTS.

FUEL VALVES HYD SHUT-OFF OUTSIDE ENGINE ROOM (SEE THE SERVICE VALVE KEYS FOR APPROX. DETAILS)



Figure 5: CO₂ cylinder room

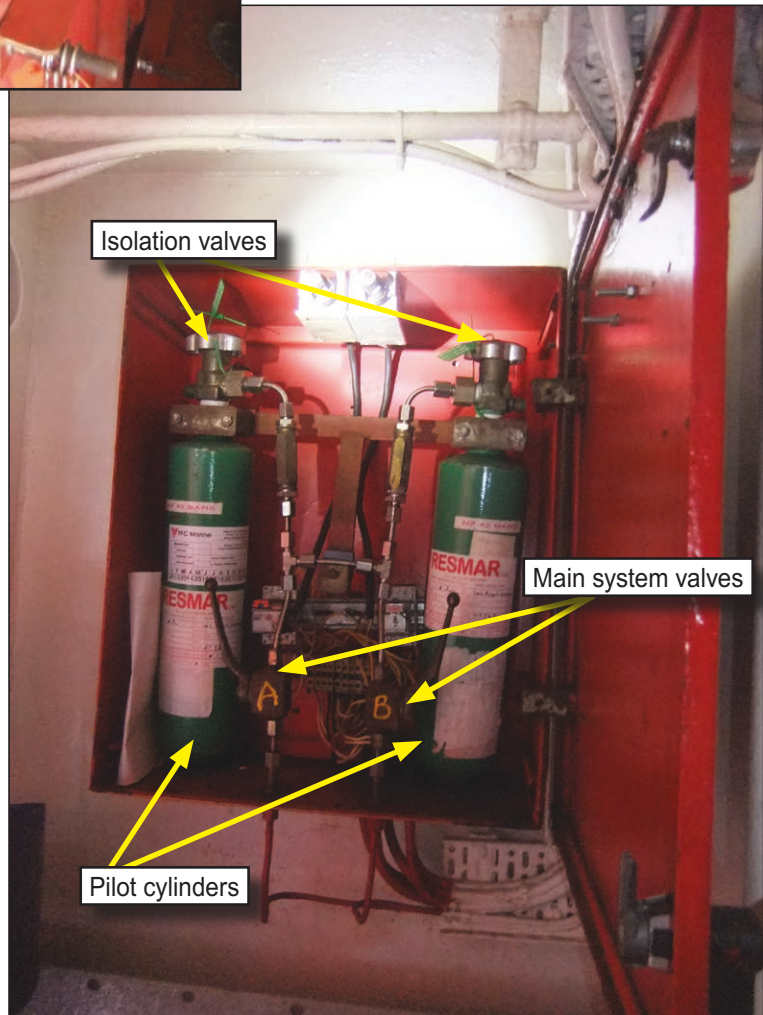


Figure 6: CO₂ system operating control cabinet

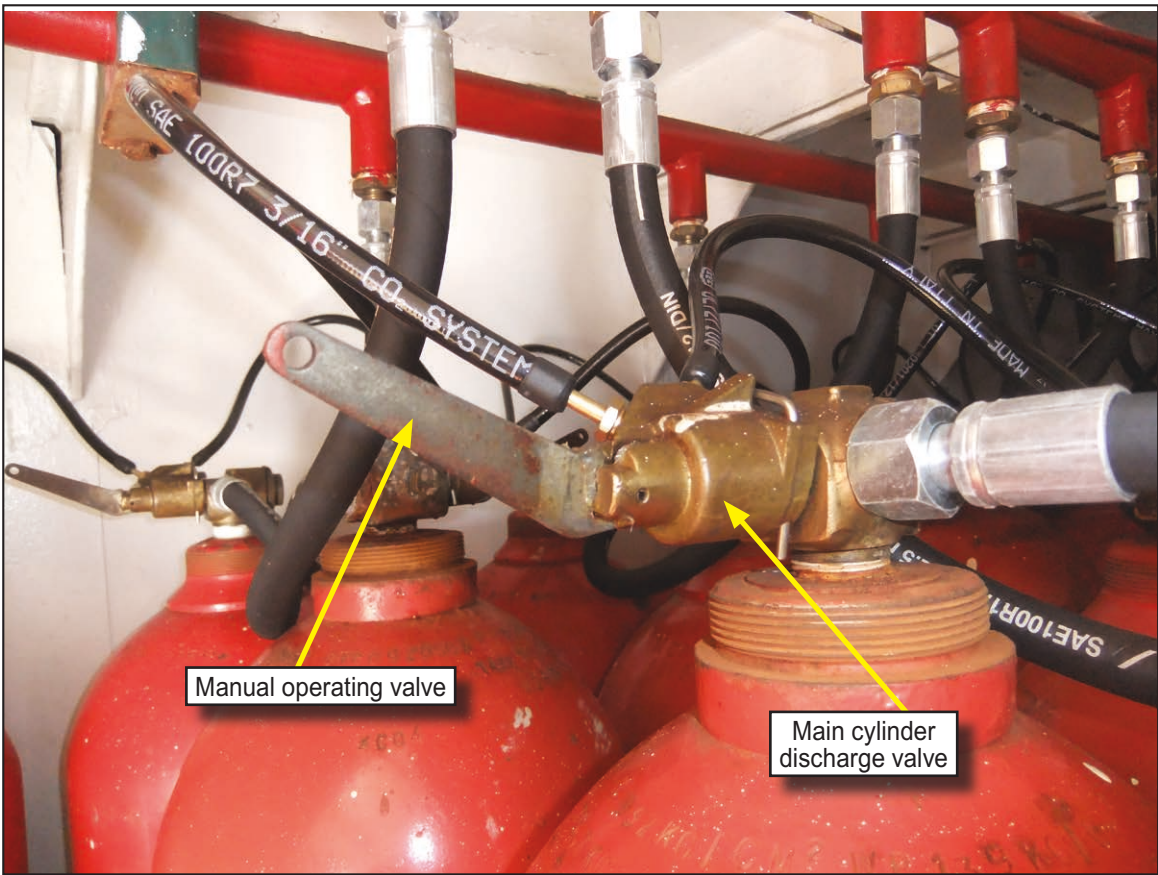


Figure 7a: CO₂ cylinder valve



Figure 7b: CO₂ manifold valve

1.4.5 Manning

Arco Avon had been issued with a safe manning document requiring a minimum of eight crew, including a chief engineer, a second engineer and one additional watchkeeping engineer. There was no requirement for any engine room ratings. The document was endorsed for Unmanned Machinery Space (UMS) operations stating: '*a lone watchkeeper must not attend the machinery spaces unless a suitable watch alarm is fitted and operational or an alternative system is in place.*'⁴ At the time of the accident, there were 10 crew on board, with the engineering department's manpower at the minimum level required by the safe manning document.

Arco Avon was manned with a crew of UK nationals. During transits to the loading area, they operated with a deck officer and lookout on the bridge and the engine room in the UMS mode. When dredging, the bridge manning was supplemented by the master, who controlled the dredging operation, and the engine room reverted to a manned condition with a single engineer officer as watchkeeper.

All crew members were employed through Hanson Ship Management Limited, a crewing agency dedicated to providing manpower for HAML vessels.

Master

The master was an experienced seafarer and had worked within the dredging industry for more than 20 years. He held an STCW II/2 qualification and had been master on *Arco Avon* since 2011.

Chief engineer

The chief engineer had started his career in the Royal Navy and, after serving approximately 8 years, left to join the Merchant Navy. His civilian seafaring was predominantly within the dredging industry, where he had fulfilled the roles of both chief engineer and technical superintendent. He held an STCW III/2 qualification and had been chief engineer of *Arco Avon* since 2013.

Third engineer

Anthony (Tony) Jones had served for 26 years in the Royal Navy. On leaving in 1994, he had an interest in a motorcycle repair business and then relocated from Devon to Kent, where he worked in the ship repair industry before joining the Merchant Navy. He spent 2 years working on ferries before moving to the dredging industry. He joined Hanson Ship Management Limited in 2013 and was appointed to *Arco Avon* as third engineer. He held an STCW III/1 qualification.

Tony was well regarded on board *Arco Avon* and within the company. He was noted for being extremely ordered, and for identifying issues that needed attention and completing tasks as soon as practicable.

Tony died as a consequence of severe burns he received in the fire. Postmortem examination results gave the cause of death as multiple organ failure. Subsequent toxicology results indicated that he had consumed no alcohol.

⁴ Section 15.9.1 of the Code of Safe Working Practices for Merchant Seamen (COSWP) 2010 edition, which was the current version at the time of the accident, states that seafarers should only enter or remain in an unmanned machinery space alone to carry out a specific task that they may be expected to complete in a comparatively short time. Furthermore, before entering, leaving and at regular intervals while within the space, they must report by telephone or other means provided to the duty deck officer. Similar guidance is now provided in the Code of Safe Working Practices for Merchant Seafarers 2015 edition.

1.5 SAFETY MANAGEMENT, SURVEY AND INSPECTION

Safety Management System (SMS)

HAML operated a fleet of eight dredgers (seven in service and one in long-term lay-up). Seven vessels were managed under a Document of Compliance (DoC) issued to the company by the MCA on 15 November 2010 and individual Safety Management Certificates (SMC) issued to each ship. The DoC had been subject to annual verification by the issuing authority, the last audit having been carried out on 11 February 2015.

Arco Avon's SMC was issued on 27 May 2015. The attending MCA auditor noted that:

- There was a comprehensive system in place for risk assessments and permits to work.
- The maintenance of the deck and engine room departments was of a high standard.
- Engine room maintenance and cleanliness were of a high standard.
- The SMS contained a list of potential shipboard emergencies, which formed part of the vessel's regular emergency drill programme.
- During the fire drill the ability and knowledge of the two BA wearers were particularly good.

The auditor issued two non-conformance notes (NCN), one related to crew familiarisation with SMS updates and the other to evidence of annual document review.

Permits to work

Within the master's standing orders, which applied to all crew, there was reference to the permit to work (PTW) system and risk assessments. The following statement appeared under the heading of risk assessments:

'The vessel operates its own risk assessment procedure. The ships staff are to generate a risk assessment for all tasks carried out onboard prior to any job being undertaken. All personnel onboard should be involved in risk assessment. All risk assessments should be used in conjunction with the company permit to work system. All risk Assessments should be reviewed every 12 months.' [sic]

No evidence was found to indicate that a documented risk assessment had been conducted or a PTW had been raised in respect of the attempted fuel pipe repair that is concluded to have resulted in the fire.

Lone working

The SMS contained instruction relating to lone working in the engine room:

'Engine Room Procedures AE09

Lone Working in the Engine Room

Ref – CoSWP 15.9 – Unmanned Machinery Space

This procedure applies to both Engineer Officer of the Watch and any other member of the crew entering the engine room at any time.

- 1. The term 'Engine Room' applies to all machinery spaces*
- 2. The use of machinery spaces as a means of access to other areas of the ship should be avoided*
- 3. Whenever anyone enters a machinery space, whether alone or with a co-worker, the bridge Officer of the Watch must be informed*
- 4. Whenever anyone enters a machinery space they should be equipped with a hand held radio which is in contact with the bridge OOW*
- 5. It is accepted that there may be areas of the engine room where there is no, or poor, radio reception. These areas should be identified and additional safeguards put in place, eg inform the bridge OOW and increase frequency of telephone contact*
- 6. Whenever a lone worker or watchkeeper is in the engine room, the Patrol (or Watchkeeping) Alarm must be activated*
- 7. If the Patrol Alarm is out of service then an alternative robust procedure must be put in place, eg regular phone or radio contact at intervals of no more than 15 minutes or increase the manning of the watch*
- 8. Whenever work is carried out in the engine room or machinery spaces, especially by a lone worker, particular attention should be paid to safe working practices as laid down in the CoSWP, in particular (but not exclusively) with regard to –*
 - Manual handling*
 - Machinery guarding*
 - Personal Protective Equipment – especially hearing protection*
 - The handling of dangerous substances*
 - The use of hand tools*
 - The use of portable electrical equipment'*

Loading operations

The chief engineer's standing orders also formed part of the SMS and contained a specific section relating to loading operations:

'LOADING OF SHIP

- 1. The Bridge will notify the Duty Engineer before loading is due to commence.*
- 2. De-ballasting can commence on instruction from the Bridge OOW.*
- 3. Ensure sufficient power is available and systems ready for loading.*

4. *Change over SW suction from Aft to Forward. The Forward SW suction only is to be used whilst dredging.*
5. *Before starting check IHC power pack and Dredge pump L.O. tank levels. Check Auto-greaser level. Ensure flushing pumps are running.*
6. *During load the Duty Engineer will progress routine duties and planned maintenance as required.*
7. *Duty Engineer is to inform the Bridge of his whereabouts should he need to leave the machinery space.*
8. *On completion of loading the Bridge will normal inform the Engine Room that loading is completed.*
9. *SW suction can now be changed from Forward to Aft.*
10. *The bridge will inform the Engine Room de-watering may commence.*
11. *Inform the Chief Engineer of any problems immediately.’ [sic]*

Maintenance

Coupled with the SMS was a computer-based planned maintenance system (PMS). The PMS was used for both routine tasks based on a formal planned maintenance strategy, and for the recording of ad hoc tasks generated manually to record breakdowns and repairs.

Classification society surveys

Arco Avon’s certificate of class was issued by BV on 10 November 2011. A range of class surveys had been carried out by BV in February 2015. These included annual, continuous and occasional machinery surveys. The following is an extract from Bureau Veritas Rules for the Classification of Ships:

‘Chapter 3 - ‘Scope of Surveys’ (All Ships)

3.5 Systems in machinery spaces

3.5.2 The fuel oil, lubricating oil, hydraulic oil, thermal oil, and feed and cooling water systems, together with pressure filters, heaters and coolers used for essential services, are to be opened up and examined or tested, as considered necessary by the Surveyor. Safety devices for the foregoing items are to be examined.’

In respect of the class surveys conducted on board Arco Avon, there had been no concerns raised relating to the low pressure fuel pipework or the fuel system in general.

1.6 INTERNATIONAL MARITIME ORGANIZATION INITIATIVES

IMO circular MSC.1/Circ.1321 – Guidelines for Measures to Prevent Fires in Engine-Rooms and Cargo Pump-Rooms was issued on 11 June 2009. The circular contained annexed guidelines detailing the prevention measures.

Part III Chapter 1 of the Annex concerns the control of flammable oils within engine rooms. It covers issues with design and installation, maintenance, system pressure pulses and vibration. The following is an extract:

'1.5 Inspection and maintenance

1.5.1 The ship safety management system should contain procedures to identify vibration, fatigue, defects, poor components and poor fitting of the fuel system and ensure that proper attention to protecting hot surfaces is maintained. Means, such as check lists should be prepared to ensure that all procedures are followed at major overhauls and that all components, supports, restraints, etc., are refitted on completion of such work. The installed system should be routinely inspected for:

- .1 verification of the adequacy of its supports and the condition of its fittings;*
- .2 evidence of fatigue stresses to welded or brazed pipes and connections;*
- .3 assessment of the level of vibration present; and*
- .4 condition of the lagging or shielding of hot surfaces.*

1.5.2 Components of the fuel system should be comprehensively examined, particularly threaded connections, at each dismantling.

1.5.3 Injection pump holding-down bolts should be proved tight by testing with a torque spanner at frequent intervals (not to exceed 3 months).

1.5.4 The supports and retaining devices of the low pressure fuel system should be checked at regular intervals (not to exceed 6 months), to be proved tight and to provide adequate restraint. The lining of such devices should be examined for wear and renewed if they provide insufficient support.'

The circular invited Member Governments to bring the annexed guidelines to the attention of ship designers, owners, operators, shipbuilders and other parties concerned. This had not been formally actioned in the UK.

1.7 ACCIDENT SITE EXAMINATION

An examination of the accident site was conducted by MAIB inspectors from 28 August 2015.

There was evidence of heat and flame damage on the outboard side of No.2 generator which extended around the area local to the fire scene. The contents of a mezzanine deck used for storage directly above the fire scene were burned, and plastic fittings and containers had melted with debris from the deck falling down onto the accident site. There was severe smoke damage throughout the engine room.

Smoke patterns and heat damage generally radiated away from the deck adjacent to the bedplate of No.2 generator. Electrical power cables and control wiring in the vicinity of No.2 generator had suffered extensively from heat damage.

Floor plates adjacent to No.2 generator were missing, giving access to a defective fuel pipe located beneath the floor plates. An angle grinder, a spanner, and a ratchet with an attached socket were located on the floor plates adjacent to the access opening (**Figure 8a**). A cable reel to provide power to the angle grinder was plugged into a nearby power socket (**Figure 8b**). A number of hose clips and pieces of rubber jointing material were found on the workshop bench along with spare angle grinder discs and, in the vicinity, an operators' handbook.

The hoop bracket supporting the fuel pipe at the position of the leak was hanging below the pipe with one retaining nut still in place (**Figures 9 and 10**). The other end of the bracket was sheared off and the remaining nut was seized onto the bracket. The bracket had significant material wastage and was twisted along its length (**Figures 11a and 11b**).

Along the length of the defective fuel pipe there was evidence of fretting in way of the support brackets and from contact with other pipes where flanged pipe joints rested against the fuel line (**Figures 12a and 12b**).

The pipe supporting stanchion in way of the hanging hoop bracket displayed evidence of a cut, the width of which matched the thickness of the angle grinder disc (**Figure 13**).

1.8 ABRASIVE WHEELS

Safe use of, and the associated hazards relating to abrasive wheels is referred to both in COSWP and by the Health and Safety Executive (HSE) in its publication HSG17 (third edition published 2000) 'Safety in the use of abrasive wheels'.

COSWP section 20.4 gives guidance on the use of portable power-operated tools but does not specifically refer to angle grinders. Section 20.6 is titled abrasive wheels and contains information relating to fixed bench grinders and their abrasive wheels but makes no reference to the use of portable grinders.

HSG17 is a comprehensive document which recognises that portable and hand-held grinding machines form the largest number of abrasive wheels in use and details checks, tests and standards relating to the equipment. Neither the guidance in COSWP nor that within HSG17 makes any reference to the hazards created by the sparks generated during grinder operation.

Although not referred to in its guidance (HSG17), in 2004 the HSE produced a research report (HSE Research Report 222⁵), which studied the ignition and flame spread of clothing fabrics subjected to angle grinder sparks (**Annex A**). The findings of this project are discussed at Section 1.10.

COSWP chapter 24 identifies that risk assessments and appropriate control measures are required to protect personnel affected by hot work. It states that welding and flame-cutting activities in places other than the workshop should generally be the subject of a PTW. While acknowledging welding and flame-cutting as hot work activities, the chapter makes no mention of cutting and grinding using abrasive wheels.

⁵ Research Report 222 – Tests for the ignition of flame spread of clothing fabrics subjected to angle grinder sparks – prepared by Building Research Establishment Ltd for the HSE 2004.

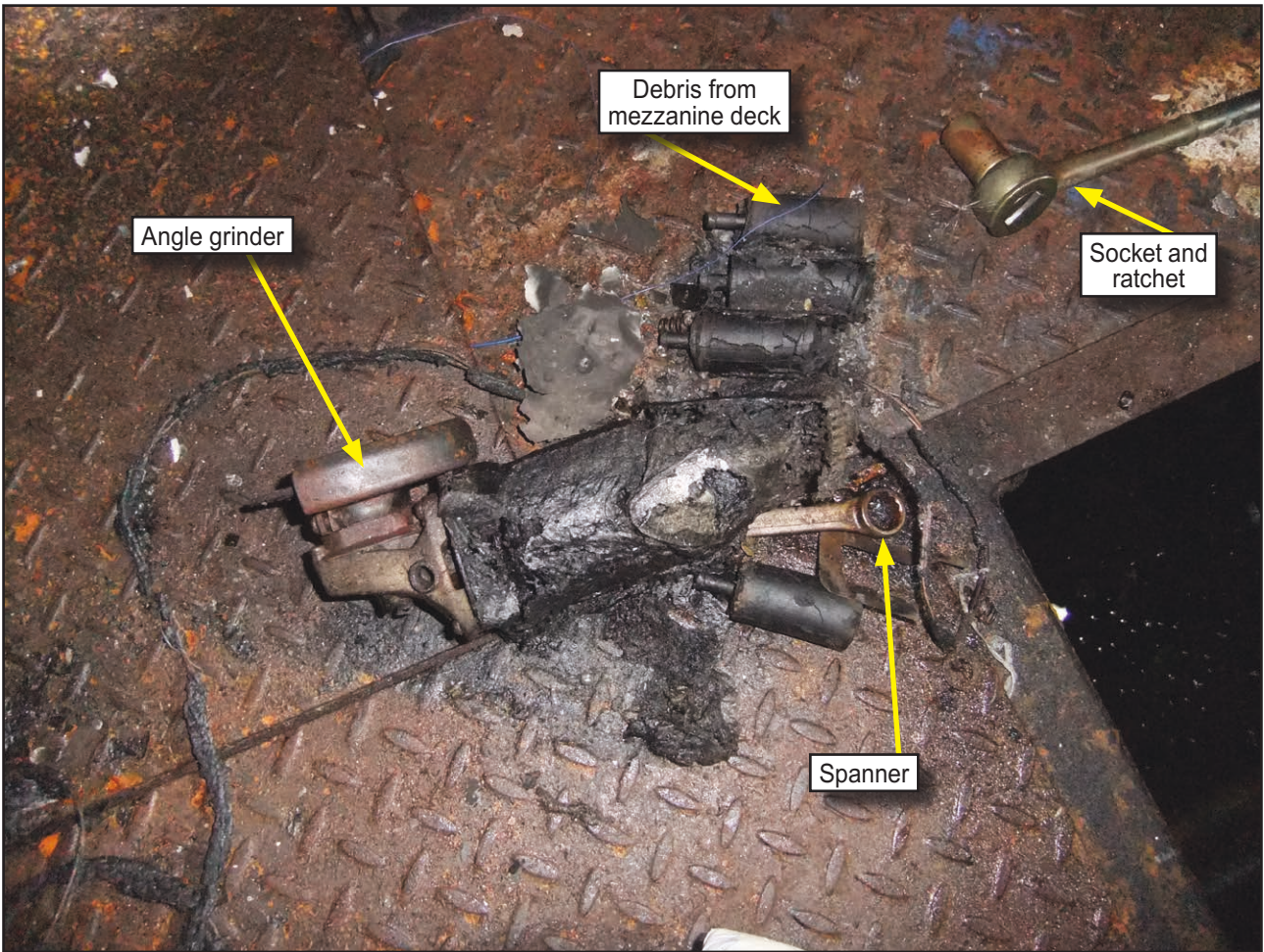


Figure 8a: Tools and angle grinder as found

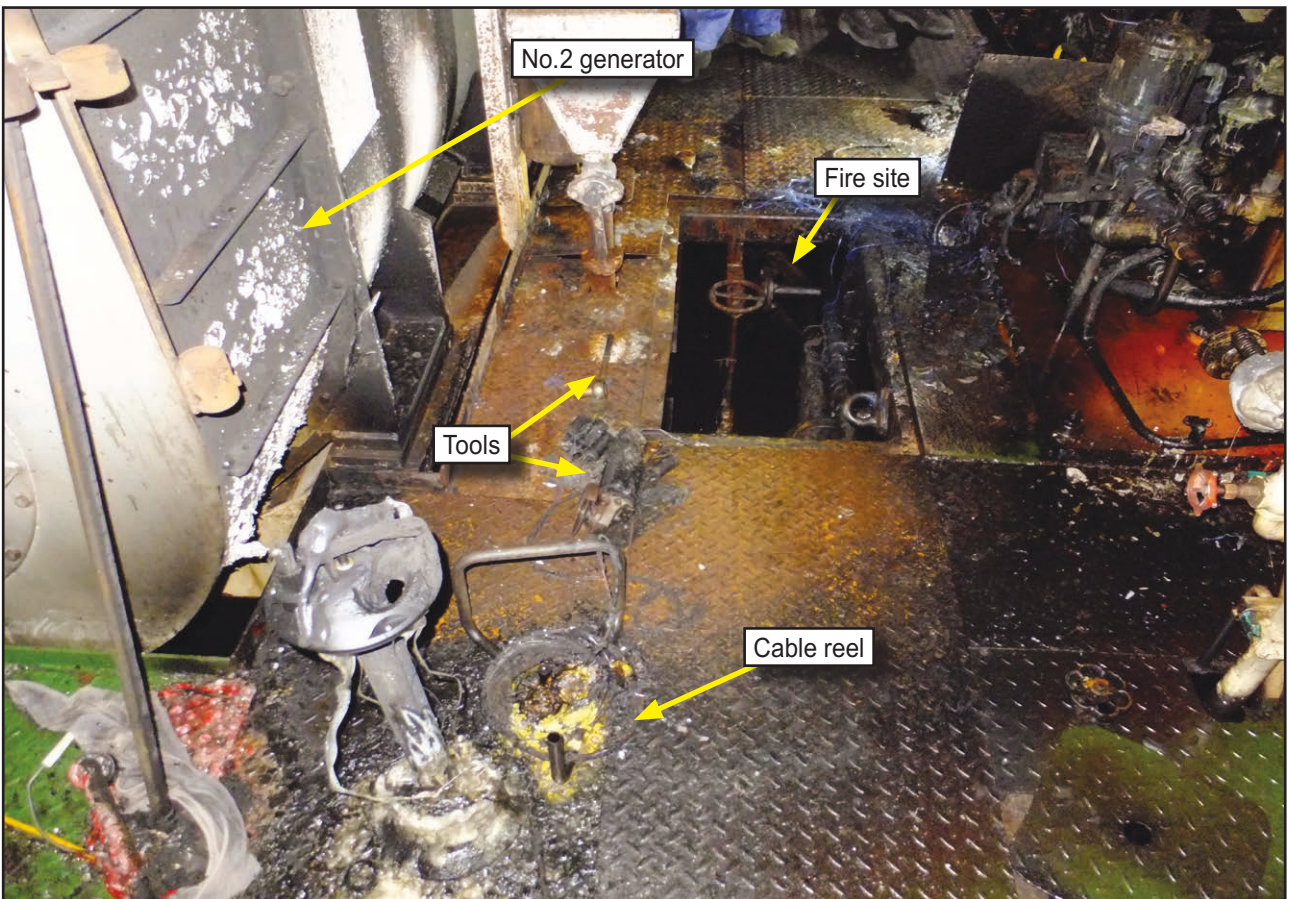


Figure 8b: Accident scene with tools and cable reel

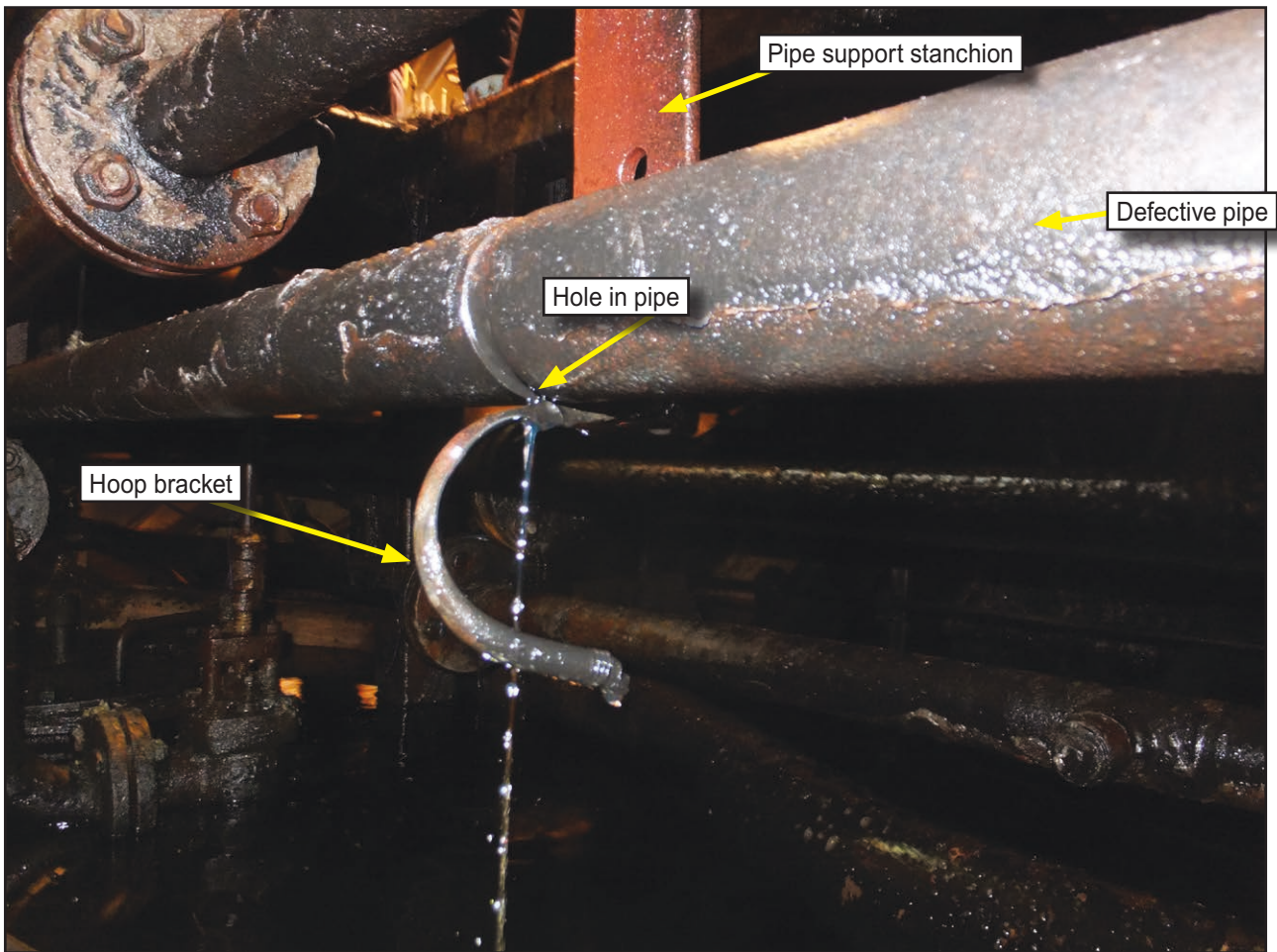


Figure 9: Pipe showing leak and partially detached hoop bracket

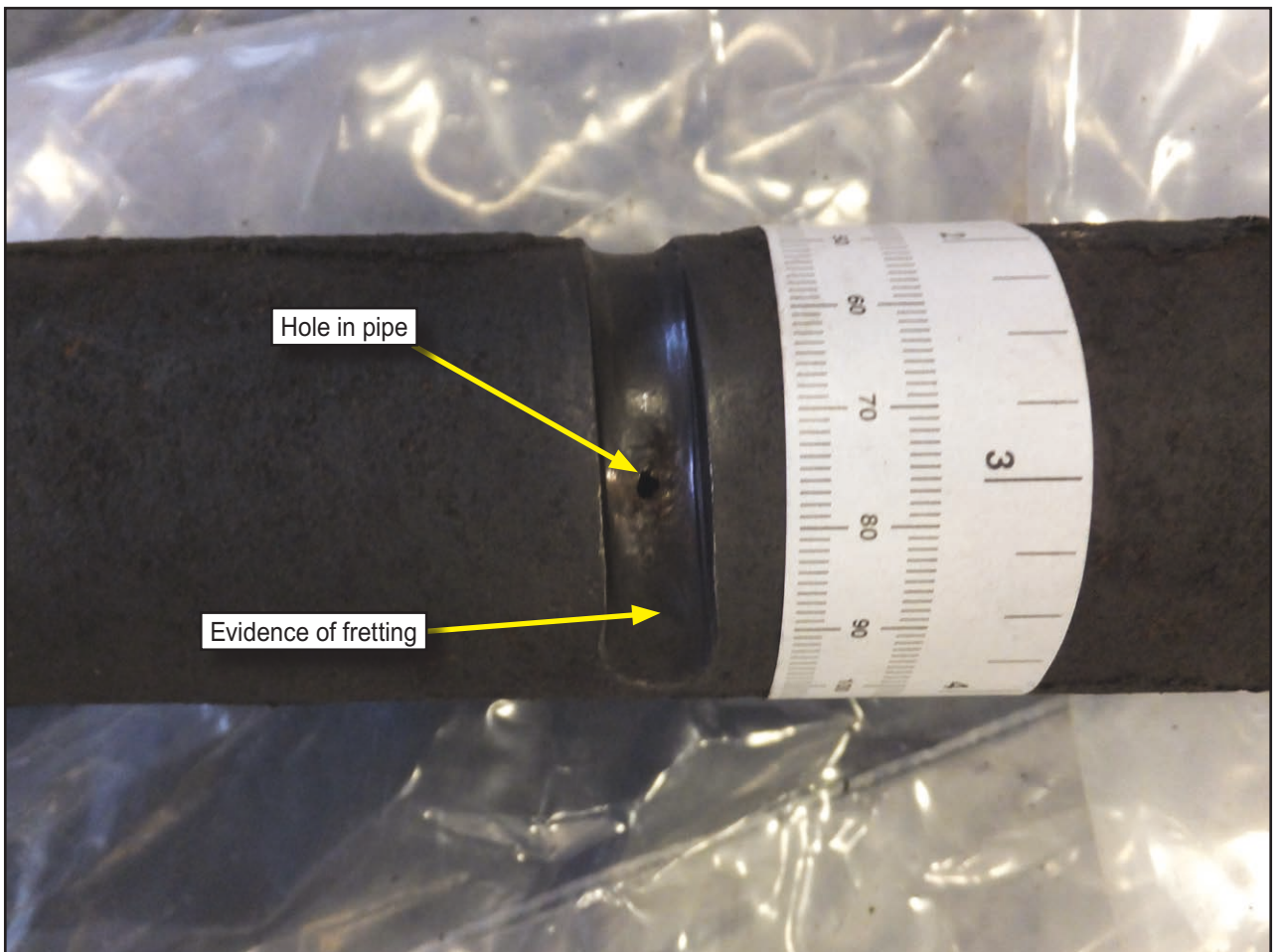


Figure 10: Defective fuel pipe



Figure 11a: Hoop bracket

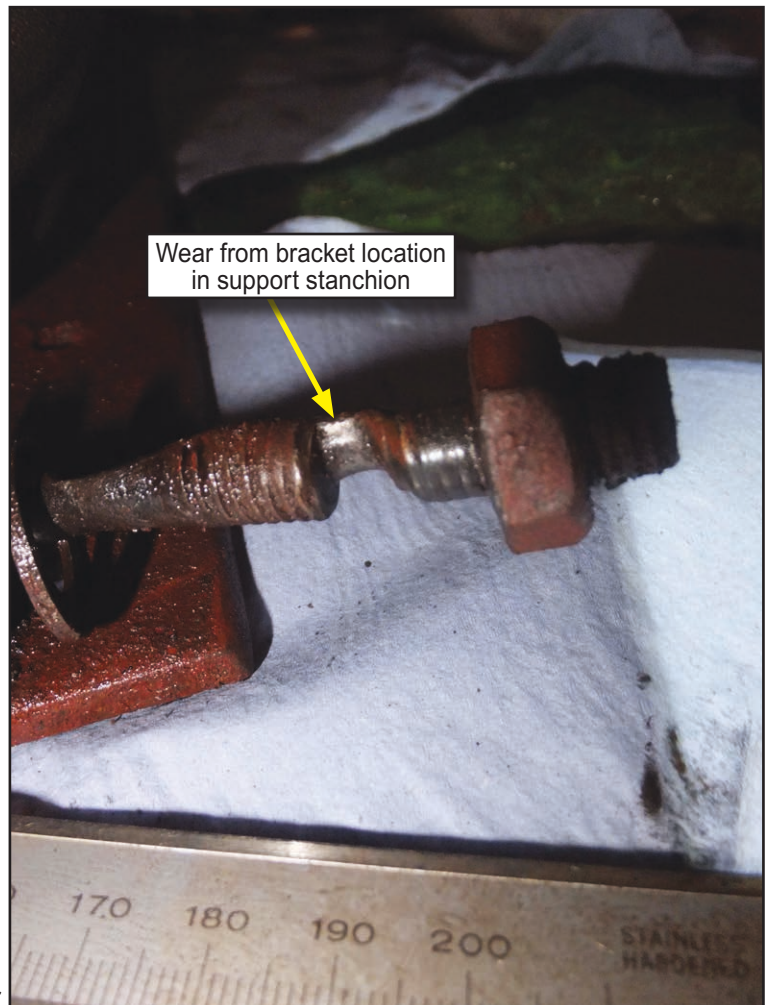


Figure 11b: Hoop bracket wear

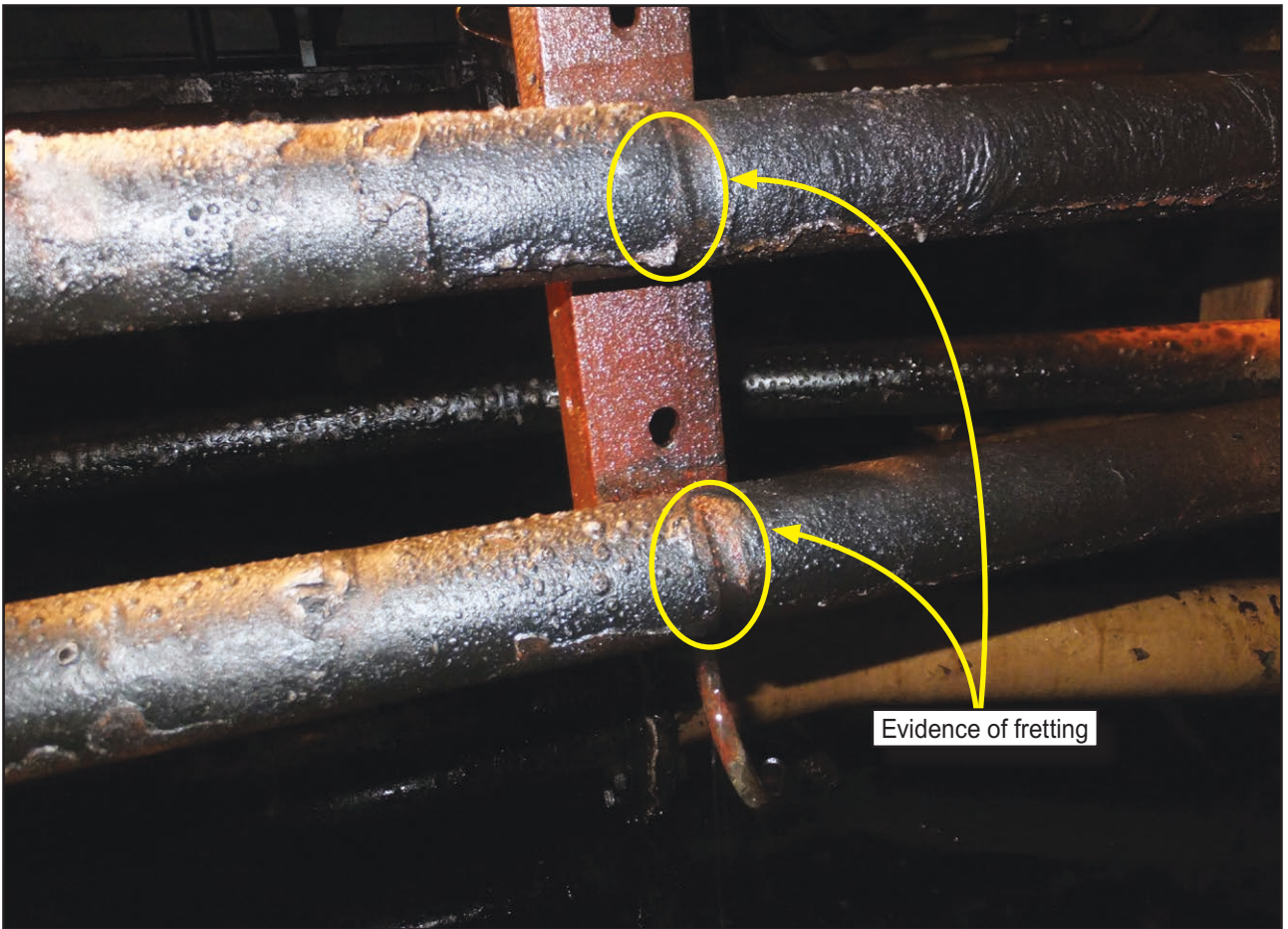


Figure 12a: Evidence of additional fretting



Figure 12b: Evidence of pipe interference

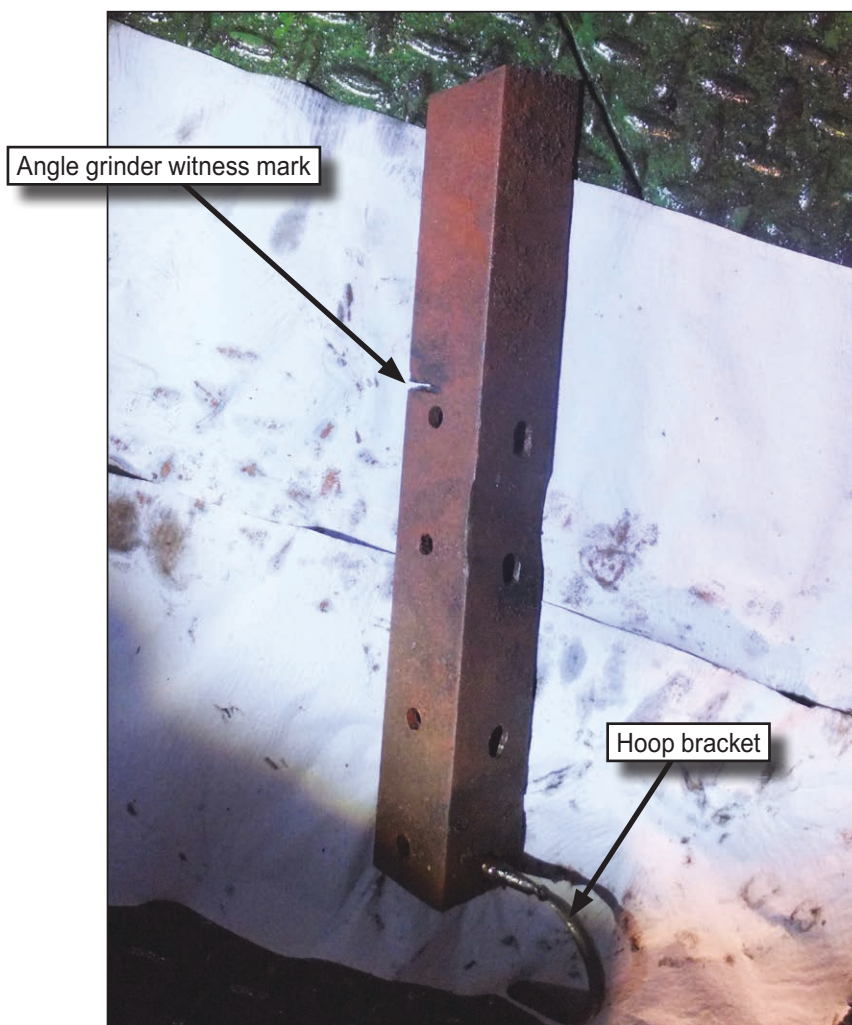


Figure 13: Pipe support stanchion

The Code of Safe Working Practices for Merchant Seafarers 2015 edition provides similar guidance to that referred to above in respect of COSWP consolidated edition 2010, which it replaced in September 2015.

One of the risk assessments (Engine Room Work Shop Activities) in *Arco Avon's* SMS, noted the need to keep flammable material away from the bench grinder in the workshop. However, use of the bench grinder was listed as a non-hot work activity and the instruction was not extended to the use of portable grinders. The operators' handbook for the portable angle grinder found at the accident site stated, in two separate sections, that the tool should not be operated near flammable materials as sparks could ignite them.

While *Arco Avon's* crew generally acknowledged that use of an angle grinder constituted a hot work activity, a PTW was often not implemented, particularly in respect of work carried out within the machinery spaces.

1.9 PERSONAL PROTECTIVE EQUIPMENT

The Merchant Shipping and Fishing Vessels (Personal Protective Equipment) Regulations 1999 (PPE 99) require ship owners and employers to ensure that personal protective equipment (PPE) is provided for seafarers engaged in, or at risk

from hazardous work activities on board UK registered ships. MSN 1731 (M+F)⁶ (**Annex B**) details standards of PPE and states that work in engine rooms or any area where there is a risk of fire requires overalls made of fabric of low flammability.

To enhance safety, HAML policy had been for all crew to wear high-visibility coveralls when on the outside deck of their vessels and, with time, this practice had extended to the engine room. During an onboard safety committee meeting on 5 May 2014, crew members on a sister vessel had raised concerns that the high-visibility coveralls, which were only supplied as a polyester/cotton garment, may not afford the level of low flammability required under PPE 99.

Subsequently, HAML revised its policy and issued a Fleet Directive (E356) dated 18 December 2014, detailing the PPE that each employee was entitled to have, and the process for ordering and obtaining it. Engineers were allowed three white cotton coveralls and one high-visibility polyester/cotton coverall. The revised PPE policy also stated that engineers should wear a high-visibility vest over their cotton coveralls when on the outside deck.

1.10 OTHER TECHNICAL INVESTIGATIONS

Angle grinder

The angle grinder found on the engine room floor plates adjacent to the failed fuel pipe was examined using a computerized axial tomography scanner (CAT scan) to determine its operating condition (**Figure 14a**). The scan identified that the operating switch contacts were open, indicating that the grinder had been switched off (**Figure 14b**).

Fuel pipe testing

Flow and spray tests on the defective fuel pipe were conducted by the MAIB in conjunction with Burgoynes, Consulting Scientists and Engineers, who were acting on behalf of HAML. Tests were carried out using water at a range of pressures from 1 through to 5 bar, with 2 bar being deemed most representative of the likely pressure in the pipe at the time of the accident. The tests showed a powerful jet of fluid spraying from the hole in the defective pipe. The flow and pressure were sufficient for the fluid to atomise as it hit the ground beneath the test rig (**Figure 15a**). When a screwdriver was introduced into the jet to simulate the position of the hoop bracket, the degree of atomisation increased significantly (**Figure 15b**).

PPE flammability testing

Flammability testing of coveralls available to the third engineer (67% polyester 33% cotton and 100% cotton) along with a control sample from a new 67% polyester 33% cotton coverall were carried out at a UK test facility. Limited flame spread testing according to the provisions of EN ISO 15025:2002 of three fabric samples was carried out:

Sample 1 - 100% cotton – used but laundered.

Sample 2 - 67% polyester 33% cotton – used but laundered.

Sample 3 - 67% polyester 33% cotton – new and unused.

⁶ Replaced with MSN 1870 (M+F) in January 2016. The details relating to engine room PPE (overalls) remain unchanged.

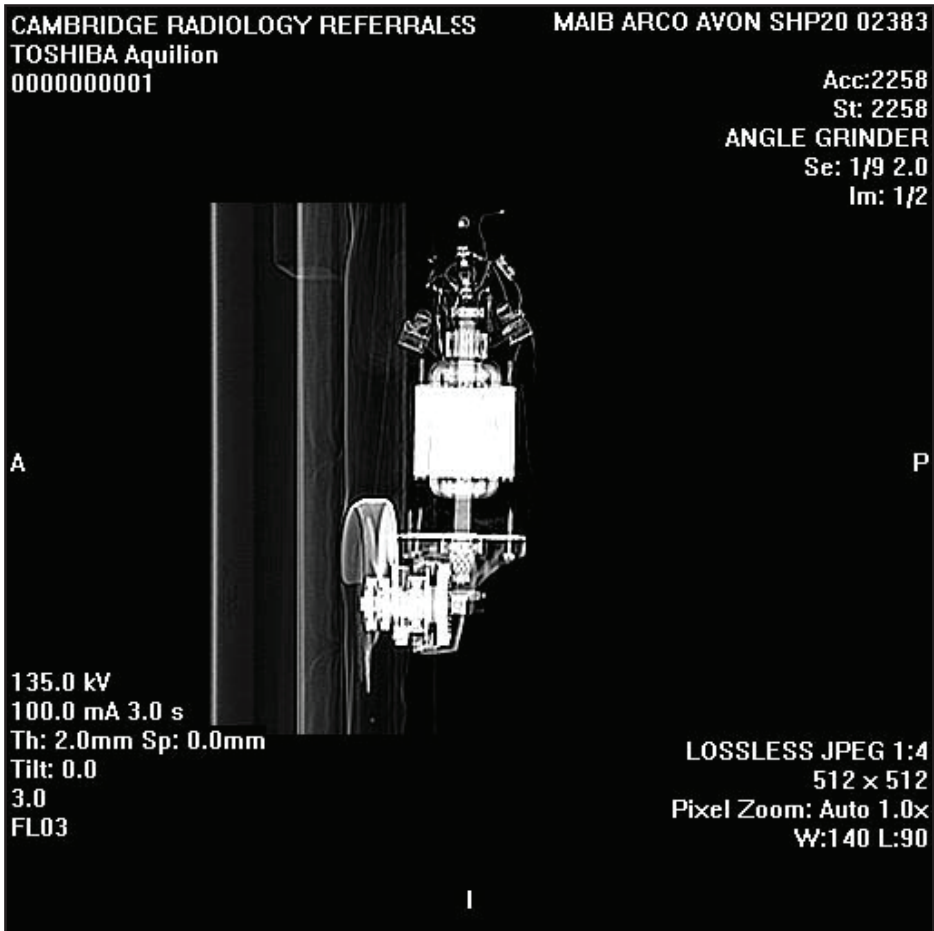


Figure 14a: CAT scan of angle grinder

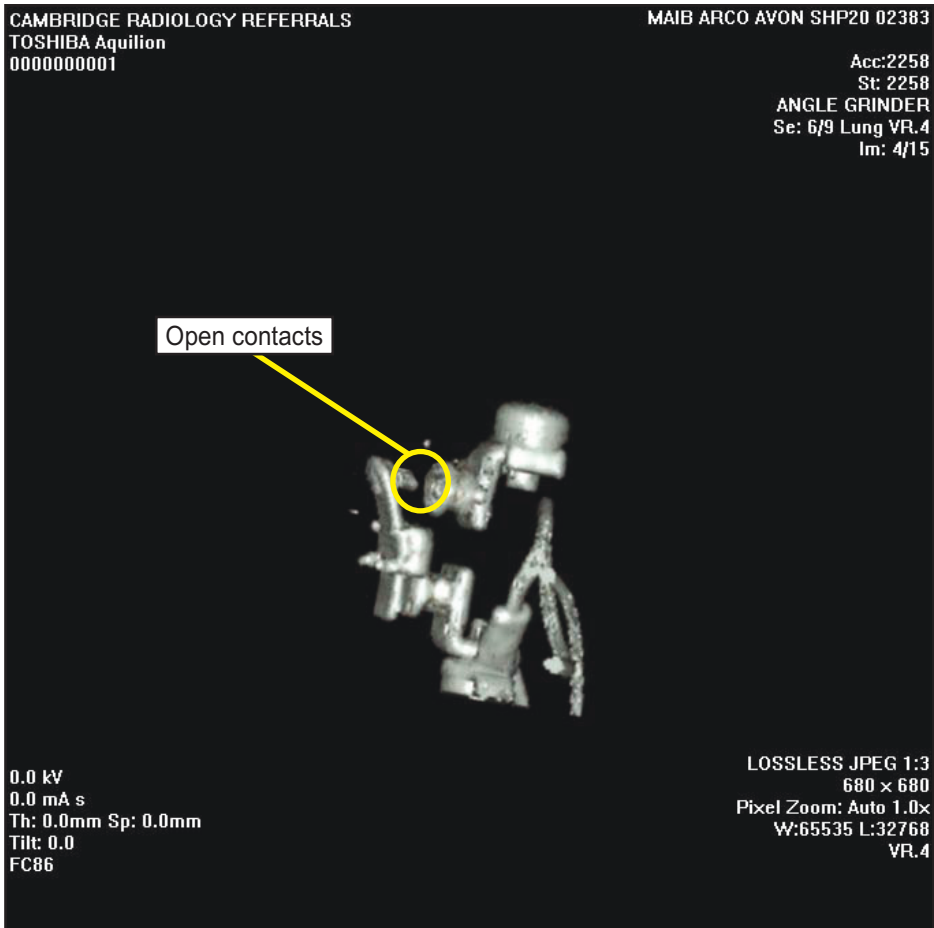


Figure 14b: CAT scan of angle grinder switch



Figure 15a: Spray test



Figure 15b: Spray test

The tests showed that each of the samples was made from a fabric that supported combustion after removal of the ignition source. These results demonstrated that neither of the coverall types available to the third engineer would have given any flame or heat protection. Following the initial tests, a further sample of each garment was soaked in diesel to determine the likely effects of ignited diesel on each fabric type. Adding diesel significantly increased the burning rate of all the samples.

None of the coveralls from which the samples were taken were labelled to indicate that they were designed or supplied to give heat or flame protection.

The following standards are recognised as applicable to PPE tested against EN ISO 15025:2002 to meet limited flame spread claims:

EN ISO 14116:2015: Protective clothing. Protection against flame. Limited flame spread materials, material assemblies and clothing.

EN ISO 11611:2015: Protective clothing for use in welding and allied processes.

EN ISO 11612:2015: Protective clothing. Clothing to protect against heat and flame.

HSE Research Report 222 (**Annex A**) tested a number of fabrics for ignition and flame spread when they were subjected to angle grinder sparks. The report studied natural and synthetic fabrics and both untreated and fire retardant (FR) garments. The report's conclusions include the following:

- 'The range of synthetic and natural fibres tested showed ignition times and flame-spread rates covering a wide range but there was no particular distinction between values obtained for the two types.
- Synthetic fibres tended to melt and natural fibres tended to form a surface char, both effects having a strong influence on performance in the ignition and flame spread tests.
- Natural/synthetic fibre mixes were not particularly distinguishable from their "pure" counterparts.
- A cotton fabric marked as "FR interliner" ignited readily.
- A cotton fabric purchased as "FR" and checked for acceptable FR content by elemental analysis did exhibit very limited ignition and flame spread behaviour, both before and after being subject to a single standard laundry cycle.
- Tests on a full sized manikin clothed in separate tests with an FR and non FR "coverall" demonstrated the value of FR treated materials when subjected to sparks from an angle grinder. The FR coverall did not ignite after 5 minutes of sustained spark impingement whereas the non FR coverall ignited after approximately 20 seconds and burnt to completion.' (**Figure 16**)

Courtesy of HSE



Figure 16: Coverall ignition and flame spread test after approximately 45 seconds (ignition occurred at approximately 20 seconds)

1.11 MEDICAL CARE

Requirements for the provision of onboard medical care are defined in The Merchant Shipping (Maritime Labour Convention) (Minimum Requirements for Seafarers etc.) Regulations 2014, which are promulgated through MGN 482 (M) Maritime Labour Convention, 2006: Medical Care. Under these regulations, ship owners are required to provide seafarers with medical care on board ship. This is achieved through a combination of the provision of medical stores and training of personnel.

The Merchant Shipping Act 1995 Part III Chapter 53 states that where a ship does not carry a doctor, the master is responsible for ensuring that any necessary medical attention is given by him or under his supervision by a duly appointed person.

On *Arco Avon*, the master's standing orders stated that the OOW was to administer first-aid treatment and that the master was to be informed. The master was also to be informed immediately of any major injury occurrences, and was to be consulted if there were any doubts concerning treatment.

The Ship Captain's Medical Guide (SCMG) is published by the MCA for use on ships not carrying a doctor. The guide gives the following advice in respect of burns:

'Burns and scalds, clothing on fire

- *by far the best way to put out a fire on a person is to use a dry powder fire extinguisher at once;*
- *if a dry powder extinguisher is not available, then lay the person down and smother the flames by wrapping him in any available material (not made of man-made fibre), or throw buckets of water over him, or use a hose;*
- *make sure all smouldering clothing is extinguished. NOTE: The powder from a fire extinguisher will not cause much, if any, eye damage. Most people shut their eyes tightly if sprayed with powder. Any powder which gets in the eye should be washed out immediately after the fire has been extinguished and while cooling is being undertaken.*

Heat burns and scalds

- *all heat burns should be cooled as quickly as possible with running cold water (sea or fresh) for at least ten minutes, or by immersing in cold water and keeping the injured part in motion; cooling of extensive burns (>15%) should be avoided as hypothermia will result;*
- *if it is not possible to cool the burn on the spot, the casualty should be taken to where cooling can be carried out;*
- *try to remove clothing gently but do not tear off any which adheres to the skin;*
- *then cover the burned areas with a dry, non-fluffy, dressing which is larger than the burns and bandage in place;*
- *further treatment as in Chapter 4.*

Chapter 4

■ *burns of over 18% of the body surface in adults or 10% in children or older persons ... Until removed to hospital put the patient to bed and seek to restore the fluid balance by encouraging the patient to drink as much as possible. Put rehydration powder into the drink according to the instructions; (if not available dissolve 1 teaspoonful of salt in 1/2 litre of water). If vomiting occurs and persists, fluid per rectum may be necessary. Relieve pain and start antibiotic treatment. Remove rings, jewellery or constricting items of clothing. Anxiety may be relieved by giving diazepam 5 mg, repeated every 4 hours. Cling film makes a good temporary dressing for large burns.'*

The SCMG was not referred to on board *Arco Avon* following the accident and prior to the third engineer's evacuation by helicopter.

1.12 PREVIOUS / SIMILAR ACCIDENTS

The MAIB and other authorities have investigated a number of fires and incidents relating to failures in low pressure fuel systems. These have largely been the result of flange/joint failures rather than pipe failures, but have resulted in similar atomised fuel leaks.

Norsea

On 2 September 2002, the passenger/ro-ro cargo ferry *Norsea* suffered an engine room fire while on passage in the North Sea. A low pressure fuel pipe had fretted against its clamp and housing, causing a small hole in the pipe's wall. Following its own investigation of the accident, the management company introduced a monthly procedure for checking the security of fuel pipes, clamps and mounting bolts, and inspection of pipework for chafing. It also fitted additional clamps to the pipework.

At the time of the accident, *Norsea's* engine room was manned by a lone engineer. The MAIB investigation report No.16/2003 states:

'It might be argued that machinery spaces which are manned are likely to provide an enhanced level of vessel safety. However, when attended by a lone watchkeeper, who is protected only by a watch alarm designed for short inspection visits, any improvement in vessel safety might be at the price of placing that watchkeeper at an elevated level of risk'.

1.13 VOYAGE DATA RECORDING

The information from the VDR was downloaded on 21 August 2015 while the vessel was still at anchor off Great Yarmouth. The information had been correctly saved by the crew. However, contrary to VDR performance standards and for reasons that have not been established, the unit did not continue to record using its own uninterruptible power supply when the vessel lost its main power supply.

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 OVERVIEW

Arco Avon suffered an engine room fire that resulted in the death of the third engineer.

Physical evidence from the fire scene indicates that the third engineer was attempting to remove a securing bracket so he could make a temporary repair to a leaking low pressure fuel return pipe on the main engine fuel system. The main engine remained running throughout the repair attempt. During the process his overalls became soaked in fuel and, when he used a portable angle grinder to remove the bracket, high energy sparks from the grinding disc ignited the atomised fuel from the leak and his diesel soaked clothing. This resulted in the fire in the engine room. He was able to exit the engine room and reach medical assistance, but not before he had sustained burns that ultimately proved fatal.

It is not known why the third engineer attempted such a hazardous repair on his own and without informing the bridge watchkeeper or the chief engineer of either the problem or his intentions. However, the onboard routines for lone working in the engine room specifically allowed maintenance to be carried out during the watch. While there was a documented requirement to complete a PTW this was often waived for work in the machinery spaces. Further, reports of the third engineer's character indicate that once he had started the repair task he would likely have persevered to complete it on his own despite it becoming increasingly challenging.

2.3 THIRD ENGINEER'S ACTIONS

It is likely that the third engineer became aware of a fuel leak through the smell of diesel in the engine room as there was no evidence of any fuel system or bilge alarms on the engine room data logger. Access covers in the engine room floor plates had been lifted, which suggests that he conducted a search of the area to find a diesel leak. It is apparent that he found the defective fuel pipe beneath the floor plates adjacent to No.2 generator.

Tools and equipment had been systematically prepared to carry out a repair from which it is concluded that he had decided to take autonomous action to repair the failed fuel pipe.

Although it was both required (chief engineer's standing orders and SMS Engine Room Procedure AE09 Lone Working in the Engine Room) and expected as good practice, on this occasion the third engineer informed neither the chief engineer nor the bridge OOW of a problem. The master's standing orders also stated a requirement for risk assessments and permits to work to be completed. By acting alone, without any other members of the crew being aware of his intentions, the third engineer compromised both his own and the rest of the crew's safety.

Had the third engineer informed the chief engineer and/or bridge OOW of the situation and his intended action, or had there been another watchkeeper in the engine room, it is probable that a discussion and some form of dynamic risk assessment would have been conducted. His omission in not informing the chief engineer or bridge OOW is likely to have been influenced by the onboard culture of routine lone working and absence of regular and frequent communication.

The apparent initial repair attempt may be rationalised through the third engineer's experience and positive attitude to prompt remedial action. At first glance, it could have appeared to be a relatively quick and straightforward task to release the hoop bracket and to slide a hose clip along the pipe to cover the hole.

However, to access the hoop bracket retaining nuts, the third engineer would have needed to stand in the bilge adjacent to the pipe run. He would have been in very close proximity to the leak and would almost certainly have been soaked in fuel from the spray created by the leak.

Notwithstanding this, once the extent of fretting had been uncovered, the realisation that a hose clip and rubber jointing would not suffice should have been apparent and ought to have prompted a review of his intentions. His apparent decision to use an angle grinder to cut the pipe support stanchion is therefore more difficult to rationalise as once the securing bracket had been freed it would have been relatively easy to pull the pipe away from the stanchion in order to fit a hose clip.

Despite the lack of direct guidance in respect of angle grinders and hot work, given his experience, the third engineer ought to have recognised the extreme risk of using any tool capable of generating sparks in close vicinity to atomising fuel, causing him to review his intended actions. During the fuel pipe testing following the accident, using a screwdriver to simulate the position of the hoop bracket indicated that the diesel spray leaving the hole in the pipe and impacting on the defective hoop bracket and surrounding structure would have atomised to a degree likely to have resulted in a readily ignitable fuel source.

The examination of the angle grinder showed that the operating switch contacts were open. This finding, along with the positioning of the grinder, suggest that it is likely to have been placed in its resting position as a deliberate act by the third engineer. The witness mark on the pipe support bracket matched the width of the angle grinder disc, indicating that the tool had been used as part of the third engineer's apparent repair attempt.

In reviewing the task, the third engineer would have been aware that isolating the fuel system would have involved stopping the main engine which, in turn, would have interrupted the loading programme. Once he had reached this critical point in the event, it might have been his professional pride and confidence in his ability to successfully complete the repair that drove him to carry on with the task.

2.4 LONE WATCHKEEPING

Arco Avon was certified for UMS operations, but at the time of the accident the engine room was in a manned condition with a single engineer in attendance. SMS Engine Room Procedure AE09 Lone Working in the Engine Room mandated the use of the UMS patrol alarm whenever a lone worker or watchkeeper was in the engine room. These instructions were compliant with the vessel's safe manning document and with the guidance available in COSWP (section 15.9.1).

The requirement to use the patrol alarm was acknowledged by the vessel's crew. However, it was deemed an impractical tool to cover the periods when the engine room was manned by a lone watchkeeper. The use of telephone or radio to keep the bridge OOW informed of the watchkeeper's location was a more normal procedure. This system was recognised within the SMS but only for periods when the patrol alarm was out of service. Given the routine, rather than exceptional, practice of not using the patrol alarm, the requirement to communicate with the bridge OOW at not more than 15-minute intervals had been allowed to lapse, as evidenced by the lack of communication on this occasion from 2124, nearly 2 hours prior to the accident.

As noted during the *Norsea* investigation (section 1.12), the practice of operating machinery spaces with a lone watchkeeper not only risks a loss of contact in a potentially hazardous environment, but it also encourages an individual to act autonomously. With no local co-worker to challenge an individual's actions, the risks of commencing and subsequently compounding hazardous activities are exacerbated.

In the case of *Arco Avon*, there was a specific requirement, mandated through the chief engineer's standing orders, that during loading operations the duty engineer was to progress routine duties and conduct planned maintenance while on watch. This instruction effectively condoned lone working and was not consistent with the guidance contained in section 15.9.1 of COSWP or with similar guidance now provided in the Code of Safe Working Practices for Merchant Seafarers 2015 edition.

The patrol alarm was designed specifically for unmanned operations. It allowed the on-call engineer to investigate alarms or conduct machinery space inspections while maintaining a form of contact. However, it is not a suitable system to allow a watchkeeper to perform maintenance tasks during their period of duty.

2.5 SOURCE OF IGNITION

The fire scene investigation revealed extensive heat and smoke damage in the vicinity of the failed fuel pipe.

Two potential sources of ignition were considered: the running No.2 generator, which was adjacent to the defective fuel pipe, and sparks generated through use of the portable angle grinder.

The exhaust pipe on No.2 generator was at the top of the engine and ran along its outboard side. This was the component on the generator most likely to have been a source of sufficient heat to ignite a diesel spray. However, the flame spread pattern on the side of the generator indicated that the fire had started at the base of the engine and had spread up its side towards the exhaust system. Furthermore, the fuel pipe testing following the accident indicated that the diesel spray from the defective pipe would have been directed away from the generator and into the engine room bilge. Therefore it was concluded that the generator was unlikely to have provided the ignition source.

The location of the angle grinder and the witness mark on the fuel pipe support stanchion provided strong evidence that the angle grinder had been used during the third engineer's apparent repair attempt. The fuel pipe testing demonstrated that an atomising spray of fuel would have resulted as the fuel impinged on the hanging hoop bracket and adjacent engine room structure. This, coupled with the findings of

HSE's Research Report 222 (**Annex A**), led to the conclusion that the high energy sparks from the portable angle grinder were the probable source of ignition for the fire.

2.6 ABRASIVE WHEELS AND HOT WORK

The use of angle grinders for both cutting and grinding is commonplace on board ships. They are exceptionally versatile tools, well suited to general repair work both within and outside of an engine room.

It is widely accepted that the sparks generated by abrasive wheels during grinding and cutting operations contain sufficient energy to ignite flammable substances. Therefore, both grinding and cutting processes constitute hot work and should be treated as such. Furthermore, there are a number of documented fires in shore-based industries that have been caused as a result of using angle grinders.

Guidance relating to hot work and use of abrasive wheels on board UK registered ships is readily available in COSWP. However, in its current form, the Code could be misinterpreted as not recognising grinding as a hot work activity. COSWP defines hot work as welding and flame cutting, but makes no specific mention of cutting and grinding using abrasive wheels. Conversely, the section relating to abrasive wheels concentrates on the hazards associated with disc and wheel failures, but does not identify flammability hazards related to the generation of sparks.

The evidence from this and other accidents, coupled with research findings, clearly indicate that the sparks generated by using fixed and portable angle grinders produce a hot work hazard. However this is not currently acknowledged in marine industry guidance.

2.7 PERSONAL PROTECTIVE EQUIPMENT

During the evidence gathering phase of the investigation it was noted that, despite the change in company policy relating to the provision of cotton coveralls, the majority of engineers on HAML vessels continued to wear polyester/cotton high-visibility coveralls.

MSN 1731 (M+F) (**Annex B**) stated that for *Work in engine rooms or any area where there is a risk of fire* the PPE provided should be *Overalls made of fabric of low flammability*. The MSN gave the examples of *natural fibre, high cotton content and non-flammable clothing*. However, it did not quote a standard to indicate suitability and fitness for purpose. The limited flame spread test carried out on sample garments during this investigation and the HSE study into ignition and flame spread of fabrics subject to angle grinder sparks demonstrated that cotton coveralls, on their own, do not offer suitable protection against ignition and flame spread. The fact that coveralls of 'high cotton content' were listed in MSN 1731 (M+F) as suitable for use in engine rooms as a protection against fire is a significant concern. This might have led to an unfounded confidence that a cotton garment would provide a recognised level of fire protection.

Notwithstanding the findings in relation to the properties of cotton coveralls, even fabric with an FR finish is likely to ignite and continue to burn after being soaked with diesel. The presence of atomised fuel coupled with the wicking effect of a diesel-saturated coverall resulted in an extremely flammable garment that could be readily ignited by the introduction of sparks generated from the use of an angle grinder.

2.8 EMERGENCY RESPONSE

Following activation of the fire alarm, *Arco Avon's* crew mustered quickly and the decision-making process was generally well considered and appropriate.

However, the uncoordinated approach to the engine room by the members of the fire team led to the second engineer becoming separated from the fire team AB. The lack of co-ordination was the direct result of the two firefighters dressing in widely separated locations and no re-muster and briefing from the fire team controller (chief officer) before deployment. A further concern was that both the chief engineer and the second engineer opened different access doors to the engine room while alone and without any fire-fighting medium for protection. Had the two doors been opened simultaneously, a through draught could have introduced additional oxygen, causing the fire to burn more intensely.

The second engineer was new to the vessel and his lack of familiarity with its layout might explain why he became separated from the fire team AB. However, neither he nor the chief engineer should have attempted to open an engine room access door until the fire team were assembled with the appropriate equipment and had been fully briefed on their required actions. Re-entry of a closed compartment containing a confirmed or suspected fire is an extremely hazardous activity that requires comprehensive planning and a co-ordinated approach. Current entry protocols for a machinery space fire are for the BA team to be 'on air' and equipped with a charged fire hose, and for them to initially crack open the door approximately 10cm for 10s to ascertain the conditions within the compartment before proceeding. In his role of on-scene commander, the chief engineer should have taken control at the scene and directed the fire team to attempt the investigation following a thorough assessment of boundary conditions.

Once the decision to use the CO₂ fixed fire-extinguishing system had been made it was important to activate the system rapidly. The sooner the system could be operated, the more effective it was likely to be. That the second engineer had become separated from the fire team AB delayed a full headcount from being achieved, which consequently delayed the master's approval to activate the system.

Having operated the CO₂ system from the control cabinet, the chief engineer's decision to confirm the successful activation of the system from the cylinder room, was entirely appropriate. On entering the room, he discovered that 50% of the cylinders had failed to operate, and so manually opened the remaining cylinders to complete the system discharge. The reason why many of the cylinders had not operated remotely could not be established.

Once the CO₂ system had been operated, checking the cylinder room should have been a controlled operation with the room being treated as an enclosed space. There was a significant risk that CO₂ would have escaped into the cylinder room and thus depleted the oxygen content of the atmosphere. Unless the atmosphere inside a CO₂ cylinder room can be confirmed as safe, BA must be used when entering the room or the initial emergency could be compounded with additional casualties.

Following operation of the CO₂ system, containment through boundary cooling using the emergency fire pump and temperature monitoring was competently implemented and maintained.

2.9 MEDICAL TREATMENT

The first-aid treatment given to the third engineer immediately following his evacuation from the engine room was rudimentary. It was not until an RNLI paramedic arrived that care, commensurate with the extent of his injuries, was instigated.

Although *Arco Avon's* master's standing orders required the OOW to administer first-aid treatment, care of the third engineer was left to the cook. While the cook had undertaken elementary first-aid training, it would not have prepared him to deal with a casualty in such a serious condition. MGN 482 (M) Maritime Labour Convention, 2006: Medical Care reiterates that The Merchant Shipping (Training and Certification) Regulations 1997 require all deck officers to be trained in medical first-aid or medical care. Furthermore, as confirmed in *Arco Avon's* master's standing orders, the Merchant Shipping Act 1995 gives the master responsibility for ensuring that medical treatment is given either by him or under his supervision.

All of the crew were shocked by the extent of the injuries to the third engineer, and it is concluded that this contributed significantly to the low level of medical care administered by them. The published guidance available on board was not referred to as treatment was left entirely to the cook, who did not have ready access to the SCMG. Given the current SCMG guidance that cooling of extensive burns (>15%) should be avoided as hypothermia will result, reference to it might not have prompted any cooling of the third engineer's burns. Without cooling, the extent and consequent effect of the burns would have continued to increase for a significant time.

Independent medical advice suggests that cooling is effective for up to 3 hours but most effective in the first 30 minutes. While cooling of extensive burns may risk inducing hypothermia, this could be managed by selectively cooling individual areas while maintaining body temperature through the use of clean dry blankets or clothing and, where possible, operating in a heated compartment.

In this case, the severity of the injuries was such that any action by the crew was unlikely to have saved the third engineer.

2.10 MAINTENANCE AND SURVEY

Inspection of the fuel system pipework following the accident revealed that the fuel leak had been the result of fretting caused by relative movement between the pipe and one of the hoop brackets. The fretting had resulted in a deep groove around approximately 50% of the pipe's circumference and a 2mm diameter hole at the bottom of the pipe. The condition of the defective pipe was consistent with other pipes located beneath the engine room floorplates.

HAML's PMS recorded both planned and breakdown maintenance. However, there were no specific tasks within the system for inspection of the low pressure fuel system. The vessel was classed with BV and had been subject to surveys every year since build. While BV's guidance to surveyors included notes relating to the fuel system, no defects or anomalies had been noted in respect of *Arco Avon*. The IMO had recognised that inspection of the fuel system was an important element of fire prevention. IMO circular MSC.1/Circ. 1321, dated 11 June 2009, was issued to provide guidelines for measures to prevent fires in engine rooms and cargo pump

rooms. This circular, the contents of which had not been promulgated by the MCA to the shipping industry, recommends a 6-monthly inspection of all low pressure fuel system components to be included in the vessel's SMS.

The majority of the pipe runs forming the main engine low pressure fuel system were located beneath the floor plates in *Arco Avon's* engine room and were not readily accessible for inspection or survey. The layout of the pipework allowed flanges from one pipe to come into contact with another, resulting in wear due to fretting. More damaging were the system's steel hoop brackets used to clamp the pipes against their support posts. These brackets were not fitted with any form of packing between the pipe and bracket. Vibration associated with the normal operation of the vessel and possible vibration induced by pressure pulses within the system allowed the brackets to loosen. The combination of vibration and material loss through corrosion resulted in loosening of the brackets in service, with some failing completely. The loose brackets then allowed relative movement between the materials, resulting in fretting of the pipework. On examination following the accident, the condition of the low pressure fuel system pipes was generally found to be poor and not commensurate with the overall material condition of the engine room.

The lack of a requirement in HAML's PMS for fuel system pipework inspections to form part of the vessel's routine maintenance was compounded by the discretionary nature of BV's survey of fuel system pipework, and this allowed defective pipework below the engine room floor plates to go undetected.

2.11 SAFETY MANAGEMENT SYSTEM

The auditor who issued *Arco Avon's* SMC on 27 May 2015 noted that there was a comprehensive system in place for risk assessments and PTWs.

However, the SMS did not contain any risk assessments relating to hot work procedures involving grinding or cutting activities using abrasive wheels. While there were extensive records of completed PTWs, none of them referred to a risk assessment, either generic or task specific, contrary to the master's standing orders that a risk assessment was to be generated prior to any job being carried out.

While HAML's SMS provided a tool to support its vessels in operating in a safe and consistent manner, operational inconsistencies on board *Arco Avon* were not detected by the vessel's shore management team. There appears to have been no challenge during internal audits in relation to particular anomalies between direct instruction (standing orders) and safe systems of work (e.g. regularity and frequency of communications with engine room staff, and the use and coupling of risk assessments and PTWs). This suggests that while HAML operated an SMS that was compliant with the ISM Code, the practical application of the SMS was deficient in some areas.

SECTION 3 - CONCLUSIONS

3.1 SAFETY ISSUES RELATING TO THE ACCIDENT THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. Although required by *Arco Avon*'s chief engineer's standing orders and elsewhere in the vessel's SMS, the third engineer informed neither the chief engineer nor the bridge OOW of a fuel leak and his apparent intended action to repair it. His reason for not doing so is likely to have been influenced by the onboard culture of routine lone working and absence of regular and frequent communication. [2.3]
2. The UMS patrol alarm was deemed on board *Arco Avon* to be an impractical tool to cover the periods when the engine room was manned by a lone watchkeeper. [2.4]
3. Given the routine, rather than exceptional, practice of not using the patrol alarm, the vessel's SMS requirement to communicate with the bridge OOW at not more than 15-minute intervals had been allowed to lapse. [2.4]
4. *Arco Avon*'s chief engineer's standing orders requiring the duty engineer to progress routine duties and conduct planned maintenance while on watch, effectively condoned lone working and was not consistent with the guidance provided in section 15.9.1 of COSWP or with similar guidance now provided in the Code of Safe Working Practices for Merchant Seafarers 2015 edition. [2.4]
5. From the results of fuel pipe testing following the accident and the findings of HSE Research Report 222, it is concluded that high energy sparks from the portable angle grinder were the probable source of ignition for the fire. [2.5]
6. The fact that sparks generated by using fixed and portable angle grinders produce a hot work hazard is not currently acknowledged in marine industry guidance. [2.6]
7. The presence of atomised fuel coupled with the wicking effect of a diesel-saturated coverall, regardless of the fact that the third engineer was not wearing a coverall of 100% cotton, resulted in an extremely flammable garment that could be readily ignited. [2.7]
8. A combination of vibration and fuel pipe support bracket material loss through corrosion had resulted in loosening of the brackets in service and consequent fretting of the pipework. The fretting had resulted in a hole in a low pressure fuel pipe located below the engine room floor plates. [2.10]
9. The contents of IMO circular MSC.1/Circ.1321, which recommends a 6-monthly inspection of all low pressure fuel system components to be included in the vessel's SMS, had not been promulgated by the MCA to the shipping industry. [2.10]
10. The lack of a requirement in HAML's PMS for fuel system pipework inspections to form part of the vessel's routine maintenance was compounded by the discretionary nature of BV's survey of fuel system pipework, and allowed defective pipework below the engine room floor plates to go undetected. [2.10]
11. While HAML's SMS provided a tool to support vessels in operating in a safe and consistent manner, operational inconsistencies on board *Arco Avon* were not detected by the vessel's shore management team. [2.11]

3.2 OTHER SAFETY ISSUES RELATING TO THE ACCIDENT⁷

1. The third engineer's apparent initial repair attempt may be rationalised through his experience and positive attitude to prompt remedial action. However, his apparent decision to then use an angle grinder to cut the pipe support stanchion is more difficult to rationalise. [2.3]
2. The third engineer would have been aware that isolating the fuel system would have involved stopping the main engine which, in turn, would have interrupted the loading programme. It might have been his professional pride and confidence in his ability to successfully complete the repair that drove him to carry on with the task. [2.3]

3.3 OTHER SAFETY ISSUES THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. The fact that coveralls of 'high cotton content' were listed in MSN 1731 (M+F) might have led to an unfounded confidence that a cotton garment would provide a recognised level of fire protection. [2.7]
2. An uncoordinated approach to the engine room led to the fire team being separated and was a direct result of the two firefighters dressing in widely separated locations with no re-muster and briefing from the fire team controller before deployment. [2.8]
3. The chief engineer and second engineer opened different access doors to the engine room while alone and without any fire-fighting medium for protection. Had the two doors been opened simultaneously, a through draught could have introduced additional oxygen causing the fire to burn more intensely. [2.8]
4. Following activation of the CO₂ fixed fire-extinguishing system, the chief engineer entered the CO₂ cylinder room without wearing BA and without first checking and confirming the atmosphere inside the room as safe. [2.8]
5. Contrary to *Arco Avon's* master's standing orders, medical care of the third engineer was left to the cook, who had not received the level of training to prepare him to deal with a casualty in such a serious condition. However, the severity of injuries was such that any action taken by the crew was unlikely to have saved the third engineer. [2.9]
6. Current SCMG guidance that cooling of extensive burns (>15%) should be avoided as hypothermia will result, is not consistent with independent medical advice received by the MAIB following the accident. [2.9]

3.4 OTHER SAFETY ISSUES⁷

1. The practice of operating machinery spaces with a lone watchkeeper not only risks a loss of contact in a potentially hazardous environment, but it also encourages an individual to act autonomously. With no local co-worker to challenge an individual's actions, the risks of commencing and subsequently compounding hazardous activities are exacerbated. [2.4]

⁷ These safety issues identify lessons to be learned. They do not merit a safety recommendation based on this investigation alone. However, they may be used for analysing trends in marine accidents or in support of a future safety recommendation

SECTION 4 - ACTIONS TAKEN

The **Maritime and Coastguard Agency** has taken actions to review and update:

- The Code of Safe Working Practices for Merchant Seafarers to address the hot work hazard of sparks generated by the use of fixed and portable angle grinders.
- Merchant Shipping Notice 1870 (M+F) to introduce an appropriate standard for overalls for work in engine rooms or any area where there is a risk of fire.
- The Ship Captain's Medical Guide to provide clear guidance on the appropriate medical treatment for serious burns.

Hanson Aggregates Marine Limited has issued:

- Fleet Directive E363 detailing amendments to personal protective equipment requirements on its vessels.
- Fleet Directive M33 requiring fleet-wide inspection of fuel systems.
- Fleet Directive M34 requiring fleet-wide inspection of high temperature surface insulation and spray shields.

SECTION 5 - RECOMMENDATIONS

The **Maritime and Coastguard Agency** is recommended to:

2016/136 Review International Maritime Organization circular MSC.1/Circ.1321 – Guidelines for measures to prevent fires in engine-rooms and cargo pump-rooms, and, as appropriate, promulgate its contents to the shipping industry.

Hanson Aggregates Marine Limited is recommended to:

2016/137 Review and, as appropriate, amend its safety management system to ensure:

- Its planned maintenance system includes a 6-monthly inspection of all low pressure fuel system components, as recommended in IMO circular MSC.1/Circ.1321.
- Manning levels, watchkeeping duties and communication procedures provide for safe engine room operations at all times.
- Portable angle grinding is included and addressed as a hot work activity.
- Fire-fighting training is enhanced to address and correct re-entry techniques.
- A procedure is included for entering the CO₂ cylinder room following system activation.
- Improved oversight by shore management to identify operational inconsistencies, particularly with regard to the use of risk assessments and permits to work.
- The master's role and responsibilities, when dealing with medical casualties, is reinforced.

Bureau Veritas is recommended to:

2016/138 Advise its surveyors of the contents of IMO circular MSC.1/Circ.1321 – Guidelines for measures to prevent fires in engine-rooms and cargo pump-rooms.

